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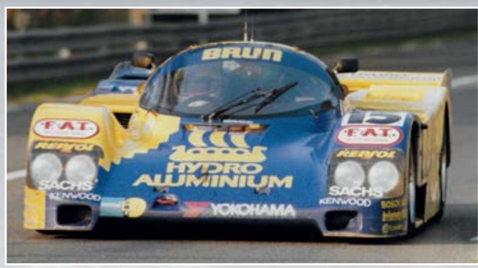
Toyota TS050

The *real* reason why this car should win Le Mans



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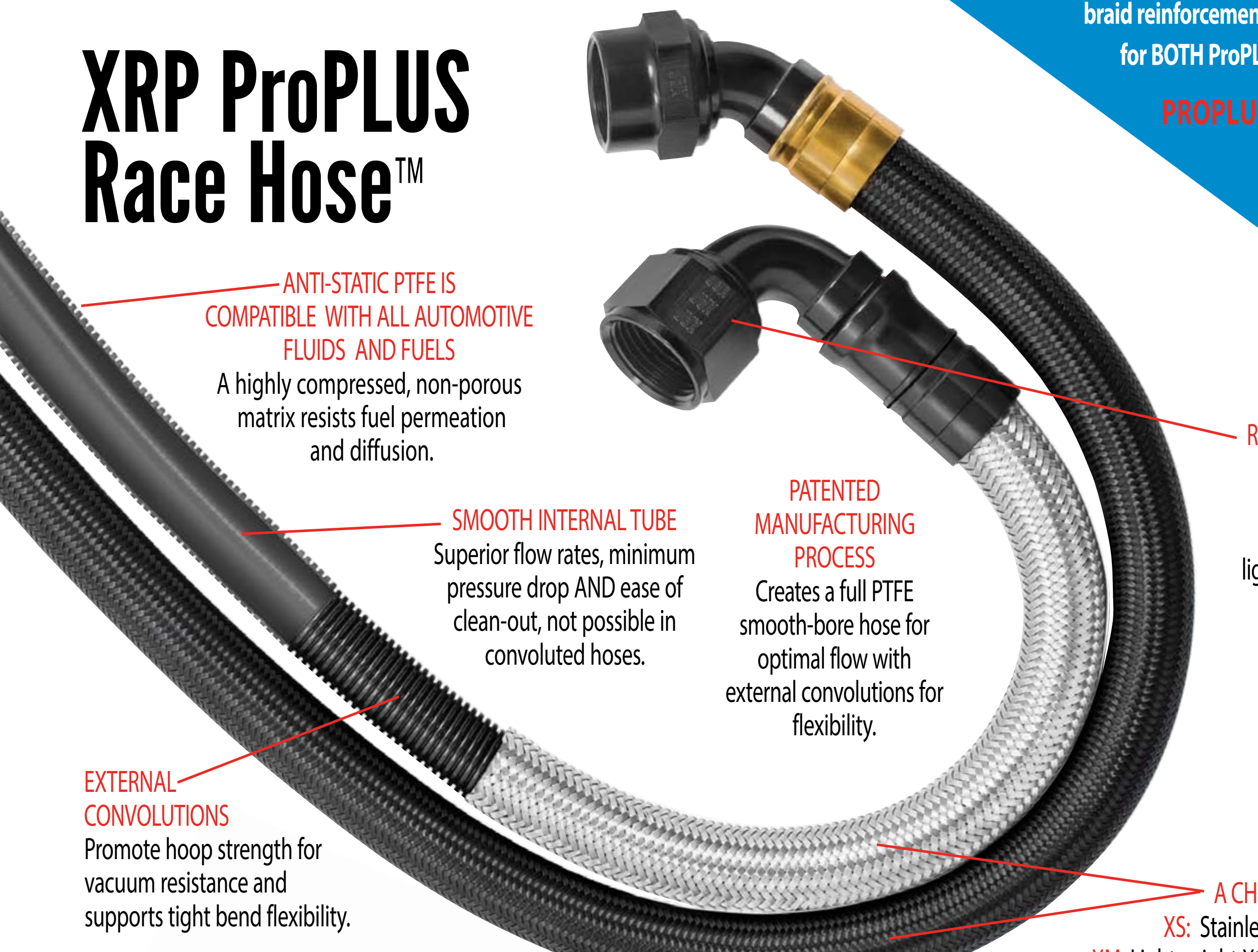

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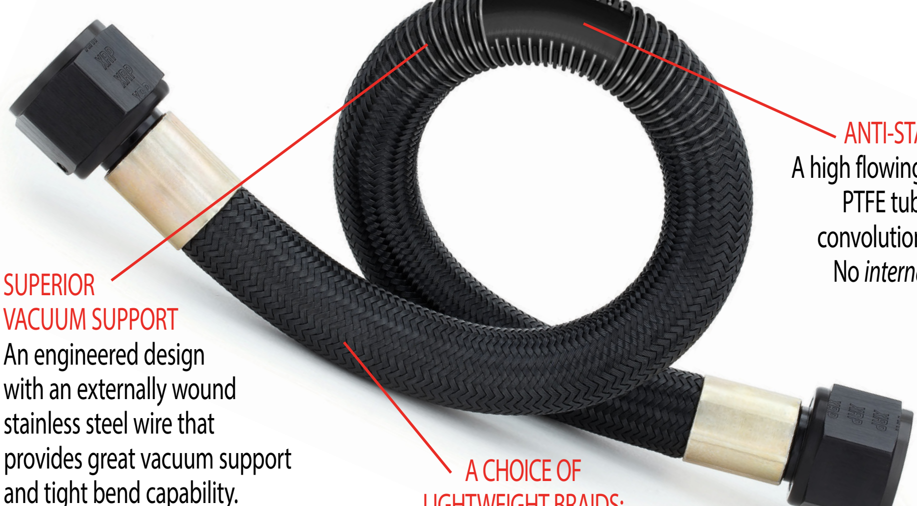

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THE XTREME IN RACECAR PLUMBING

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F1 owner Liberty has been sparking debate with its new proposals for F1's future – turn to the Peter Wright and Chris Aylett columns for two conflicting opinions

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Pro Stock drag race engines are the pinnacle of engineering for normally aspirated engines. The best air flow through the ports and manifold is critical. A perfect seal between the rings and the cylinder wall is critical. Hear what the experts say about their Rottler machines:

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Petrol heads

Why nothing in motorsport is quite as dangerous as a racing driver's brain

How we think, and how profoundly irrational we can be, actually comes from the way our brain is laid out and how it evolved. You have an area of your brain called the prefrontal cortex (PFC) and your baseline software is the limbic system. The limbic system is operational when you are born but the PFC will slowly mature up to your mid-20s, normally. So, for your first years you are more reliant on the limbic system. The limbic system will flood you with dopamine when taking risks or being impulsive, which was presumably a good trait when we were in the Stone Age.

The corollary is that as you mature the prefrontal cortex starts making you more responsible and will help you make more rational decisions and the really silly, stupid or outright self-destructive stuff becomes less fun than it used to be.

Grey matters

But in some people the PFC never matures. And there are a lot of these people in racing, driving very fast cars. It seems to come with the territory.

So far, so good; you don't want a slow racing driver in your car, and most veterans will subscribe to the theory that it is more effective to slow down a fast, reckless driver to the ideal pace than to try to whip speed into a slow one. But the downside becomes apparent when they are out of the racecar and you are out in a group with them.

Having two or more drivers in the group is the definition of impending chaos. This was recognised in the past at the car rental desks at Frankfurt airport. Turning up in team gear and having a great deal of trouble getting cars delivered was par for the course, even if pre-booked, for their experience was of cars previously being returned with the white car having green and red stripes, the red having green and white stripes and the green car joining in.

One of the more hazardous runs was the Paul Ricard to Nice airport Rentacar GP. Racing down the Promenade des Anglais has left an enduring memory of being three abreast, at warp speed, coming up to a pedestrian crossing, a little old lady stepping off the kerb behind her three poodles, the screeching of tyres and the lady's reflex of pulling hard on the leashes making the dogs somersault backwards out of the way. The ensuing tank slapper was caused by the mirth of all aboard, but we all survived unscathed, including the poodles …

… Until we dived down the tunnel into the airport and remembered too late that there was a 90-degree corner in it, not conducive to three-abreast flat out trajectories.

Then there were the flights, particularly charter flights to the inter-continental races. During one of said trips, a pillow fight ended up clogging the air-conditioning system with the foam rubber cascading from the ripped pillows. Sticks and stones may break my bones and all that, but the sanction that hurt was sending the bill for the repair and aeroplane downtime to the teams. This was Bernie Ecclestone's doing; he knew that the way to get people to behave was to hurt them in the wallet.

XPB

Bernie Ecclestone knew how to put a stop to bad behaviour on flights; the teams picked up the bill

Graham Hill was a legend on flights, once getting the whole passenger list to stand up and walk in unison to the front, then the rear of the plane, making for a roller coaster of a flight.

Arrested development

But back on the roads, and it was every man for himself. A trip from Pau to Barcelona over the Pyrenees was a good example of prefrontal lack. What was an already adrenaline fuelled game of 'Let's see what is at the other side of the double white line through a blind corner' turned quite serious after tripping over a road block set up by two Spanish motorcycle cops. But they made the huge tactical error of leaving a gap between the two bikes diagonally parked in the middle of a corner, and being the filling in the gap. The lack of PFC maturity was then exemplified by the driver going unhesitatingly for the gap, resulting in the unusual sight of cops cart-wheeling out of the way, but also setting off a red alert for the entire law enforcement community of the department.

There were then moments of sheer terror as the white line question became even more serious as it was being done inside tunnels while overtaking trucks in top gear, pedal to the metal. We then turned off the main road and hid under trees as the helicopters scoured the countryside for cars with French plates. We ended up arriving around five hours late due to all the skulking and hiding.

Dual control

Two drivers in the front seat of the car always meant there was a sharing of the controls, the passenger judiciously trying to pull the handbrake at the most inconvenient moment, say in the middle of a high speed corner, or failing that, if in a town, to bring the car to a screeching halt. The noise strangely seemed to attract cop cars. Having the driver in the back seat meant that it was either the trick of covering the eyes of whoever was driving (no need for white lines here) or the tossing of the headrests and the seat squabs out on the road.

But it was not only limited to the drivers. As a non-drinker my main role in all this was either sweet talking the cops in the local language or going to the town jail to extract whoever had been netted that night. An ex-motoring scribe turned team manager was a tough case to sort out, after the trolley that had been wheeled up from room service ended up falling from the eighth floor of a Sao Paulo hotel and landing on a Ferrari Dino parked out front. Trying to confuse the police superintendent about whether it had been pushed or just fell did not succeed; the car belonged to his son.

The use of fire hoses to surprise other room tenants was *de rigueur* and swimming pools where there to toss people in, that goes without saying.

We will not get into nightclubs, as it's definitely a subject for another column, given the number of offences racked up there between the marauding hordes and the inevitable overcharging by unscrupulous club owners, which would erupt into some shouting at the best, or getting free accommodation for the night at worst.

I blame the prefrontal cortex …

The limbic system will flood you with dopamine when taking risks, which was presumably a good trait when we were in the Stone Age

Identity crisis

What effect will Liberty's new proposals have on technology development in F1?

Out of desperation to make Formula 1 more exciting and attractive to fans – or to be more precise to attract new fans – and to reinvent the business model for competing teams such that non-manufacturer outfits are sustainable, Liberty Media launched a set of proposals in Bahrain. These covered: power units, costs, revenues, sporting and technical rules and regulations, and governance. No details were provided to the public, teams being sworn to secrecy until they had been thrashed out. Interestingly, they were billed as 'take it or leave it'.

We are not concerned with the commercial and financial, or the governance issues here, however important they may be. The key proposal objectives that concern a reader of *Racecar Engineering* are the following: 'The PU must be cheaper, simpler, louder, have more power. It must remain road relevant, hybrid and allow manufacturers to build a unique and original PU. New PU rules must be attractive for new entrants and customer teams must have access to equivalent performance.

'While there will be some standardised elements, car differentiation must remain a core value. We must make cars more raceable to increase overtaking opportunities. Engineering technology must remain a cornerstone but driver's skill must be the predominant factor in the performance of the car. The cars must and will remain different from each other and maintain performance differentiators like aerodynamics, suspensions and PU performance. However, we believe areas not relevant to fans need to be standardised.'

It is clear that the small team sustainability concern is to be addressed by reducing costs and increasing their share of the revenues, and this is also being used as an excuse to equalise the performance of the car – the chassis and the PU. What concerns me is whether this is a good direction, long-term, for the future of F1.

Top marques

F1 has always been about car manufacturers being able to demonstrate technical superiority in order to create a brand image for their production cars. Ferrari, Mercedes, Renault, Honda, McLaren, Alfa Romeo, Aston Martin, Porsche, Cooper, Maserati, Lotus, Lamborghini, Matra, Simca-Gordini, Talbot, Toyota, Lancia, Ford, BMW, Peugeot and so on. Before Formula 1, when top level motor racing was grand prix, many of the names were the same, and many others were there, too, such as Fiat, Sunbeam, Bugatti, Delage, Auto Union etc. The sponsored racing businesses are the supporting cast.

Liberty Media's proposals have the potential to turn F1 into a purely entertainment spectacle, rendering it unsuitable for demonstrating technical superiority. Grand prix racing has always given potential customers for the manufacturers' road products something to marvel at.

Currently there are three business models at large in Formula 1. Firstly, big auto – Mercedes *v* Renault *v* Honda. Secondly, specialist auto – Ferrari *v* McLaren. Thirdly, the independents, the racing businesses – Red Bull, Force India, Williams, Toro Rosso, Sauber and Haas

It is interesting to look at the annual revenue from car sales of the players in Formula 1: Mercedes: €95bn; Renault: €59bn; Honda: €106bn; Ferrari: €3.4bn; McLaren: €0.65bn, while the independents rake in anything from €0.1 to €0.3bn, their income derived from the racing itself.

Class war

Perhaps it is simply the natural order of things that Formula 1 is currently forming into three classes: 1, Mercedes *v* Ferrari – top PU, top chassis; 2, Red Bull *v* McLaren – top chassis, not top PU; 3, the rest – neither top PU nor top chassis.

How can Ferrari compete with Mercedes, with just 3.5 per cent of the revenue? The answer is

F1 has always been about manufacturers being able to show technical superiority in order to create a brand image for their production cars

Mercedes and Ferrari see F1 as a showcase for hi-tech kit, so Liberty's plan to focus more on entertainment might not be popular with these front-running teams

To achieve really competitively equal cars in Formula 1 requires not only PU equalisation, but also severe restrictions on aerodynamics

that while Mercedes generates just over six per cent profit on cars, Ferrari generates over 30 per cent on its products. Motor racing is just one of many marketing expenditures for Mercedes, while it is the only one for Ferrari. Once Honda focuses its financial superiority on making its power unit perform, one might also expect it to once again present a formidable challenge.

The result in 2017 was that the two top teams won 17 out of 20 races, and the two top drivers won 14 out of 20. This is considered boring.

Equality control

The proposed solution is to make the cars – PU and chassis – more equal and at the same time enable overtaking. It is not yet clear whether part of the solution to the latter will involve the major reduction in downforce that is necessary to achieve overtaking, which would result in a significant increase in lap time just as F1 has completed the process of going in the opposite direction.

The proposed PU objectives – cheaper, simpler, louder, and more powerful – means, if the future PUs are to be derived from the existing ones, some combination of larger capacity, higher revs, higher boost pressure, and the probable ditching of the MGU-H. This equates to a turbo V6, with MGU-K system, and something over 100bhp to find in the ICE due to the loss of the MGU-H. F2 and IndyCar have turbo V6s, and the MGU-K system is likely to be based on standard components now most of the development is done. MGUs, batteries, and inverters are becoming a commodity to the motor industry. The PUs would be less efficient, meaning heavier/slower cars in the race.

The desire for more power and noise somewhat baffles me as neither is apparent nor contributes to the entertainment of Formula 1 as viewed on a television screen. Maybe they do to someone who has paid £450 to watch the British Grand Prix weekend from a grandstand. Maybe not.

Do more equal cars guarantee better racing and hence entertainment? F2 has very equal racecars, but still the best drivers end up in the best teams with the best set up cars. In 2017, the F2 championship was between two drivers, one with seven wins, and one with five wins in 22 races. The qualifying and sprint race mixing of the grid did yield eight other race winners, the most any of these achieved was two wins.

Formula 1 was also a two horse race in 2017 with one driver winning nine of the races against the second on five wins in 20 races. There were three- , two- and one-race winning drivers as well. So which was more entertaining, F1 or F2?

If Formula 1 has much more equal cars, it is inevitable that the best drivers will still be in the best cars run by the best and richest teams. There will also still be drivers, even possibly the best in the world, who will be unable to take significant wins if they have bungled their contract negotiations and not ended up in one of the best teams. Would success ballast be the next step?

Balanced view

To achieve really competitively equal cars in F1 requires not only PU equalisation, but also severe equalising restrictions on aerodynamics. Why has there been no call for this? Red Bull, you want fairer, more equalised technical performance, do you not?

Equalisation, by any other name, is Balance of Performance, and can be applied, carefully, to solve motorsport's two most pressing problems: cost and entertainment value. It comes in three forms: spec cars for as near as possible driver skill-dominating motorsport, for example F2 and F4; highly prescriptive technical regulations (IndyCar, F3, LMP2); and true BoP cars that can never be matched perfectly (GT, touring cars, LMP1).

F1 is the formula with the most technical freedom, which is why Mercedes, Ferrari, Honda, Renault etc. compete and hopefully will continue to do so. They want this brand image.

As an aside I'd like to make one thing clear here. F1 does not have DNA, which is defined as: 'genetic instructions used in the growth, development, functioning, and reproduction of all known living organisms and many viruses.' Gains and losses in the DNA double helix occur due to evolutionary pressures. F1 has *history* and it's been pretty successful. Hopefully we can learn from that.

Show or go?

Right now the choice is: 1, let it continue as now, with the richest and most technically competent dominating initially, but eventually all technologies converge on the best solutions. Or 2, entertain those for whom technical branding is of no interest, potentially without the best automobile names in the world. Both require solving overtaking; if the work of Ross Brawn and his gang really addresses the ridiculous downforce levels brought about by all the rubbish hanging off the cars, then great. The last few years have definitely not been entertaining.

But let's look at the technical detail so that we can judge in which direction F1 is going. Two key technologies are in the dock. Tricky/marvellous MGU-H; the 125,000rpm turbo compressor with integrated MGU, harvesting 100+bhp after providing power for the compressor from waste exhaust heat. Relevant because of the efficiency gains, and a big differentiator while other PU manufacturers catch up with Mercedes and Ferrari.

Then there are all the vanes, slots, flaps, vortex generators etc. on the wings, nose, sidepods, floor, and rear wing that increase downforce and make it super-sensitive to turbulence from the car in front. They are irrelevant to road cars. They ruin overtaking and so stop drivers being differentiated. It also takes a big part of the budget and prevents smaller teams competing, even if they have identical PUs to the top teams. Is one, or are both, of these going to be sent down?

And yet they are something to marvel at. If Mercedes and Ferrari no longer feel F1 provides a stage on which they are able to demonstrate the technical superiority that is their brand, they might well depart. That would leave Liberty in an easy position to carry out all the proposals it has made. There is no one better then Brawn to try and find a middle way that meets everyone's expectations; so 2018 is not going to be boring.

And after saying all this, Bahrain delivered a humdinger of a grand prix!

F2 is a spec formula, but the very best drivers will still end up in the very best teams with the best set up racecars

The human element

Has an over-reliance on data and computers cost Mercedes F1 victories?

Modern F1 is not noted for its sympathy to those involved in it who suffer misfortune, but recent incidents have highlighted this in a sorry way. Kimi Raikkonen took his generally laid-back 'I don't care' demeanour to a new high (low?) in Bahrain, receiving much criticism concerning his disregard for his injured wheel-changer, not even being aware of Francesco Cigarini's condition when interviewed later. Contrast this with Romain Grosjean during the previous Australian GP, consoling the weeping wheelman whose pit stop fumble had just cost the Frenchman a probable top-six result.

Williams, while constantly bemoaning the difficulties of competing in F1 as one of the mid-field teams, recently played a less than sympathetic card by being the only outfit to veto Force India's request for some up-front prize money from Liberty (not at all a precedent) to help with early-year budgetary problems. I don't know all the ins and outs of the two teams' relationship, and maybe there is some history here, but it comes across as a rather below-the-belt attempt to hinder Vijay Mallya's equipe so as to gain the advantage in competing for crucial points prize money. It's not as though Force India is a no-hoper set-up, quite the reverse. Is money the only thing that really matters these days at Williams?

Horse whisperer

Ferrari's Maurizio Arrivabene's refusal to engage with the media is perhaps understandable given the undermining effect on the Scuderia that the Italian press in particular has had in the past, but the famous marque needs to show some semblance of a human face, too, not least to the faithful fans and to those customers who buy its glorious road cars. Ferrari should surely have a spokesperson who is capable of communicating some relevant information, without just spouting meaningless corporate blah, that does not encourage unfair pressure on the race team?

F1 isn't called the shark pool for nothing, but am I too naive in thinking that, amidst all the competitiveness and egos, a spot of human empathy wouldn't go amiss? Participants in the WEC and in IndyCar, both prestigious championships with a lot at stake, demonstrate a far greater respect for each other. I guess it's just down to the people involved and the Bernie Ecclestone heritage. Oh, and the money of course.

Quick thinking

The human element also figures in a different way. At the time of writing Mercedes, according to many pundits, have blown the opportunity of three GP victories in succession. Race wins, as anyone who has followed the sport for some time knows, do not always go to the fleetest. The facts are that in all these cases Ferrari or Red Bull were able, for the first time in this F1 era, to really put pressure on the Silver Arrows by constructing extremely fast cars, employing top drivers and making better strategic decisions. Computers don't feel pressure, but humans do, and it's when pressure is applied that human weaknesses start to show. So the prancing horse and the rampant bull were able to capitalise on the race situations that presented themselves – fundamentally, they did a better job.

In Mercedes' case the whole organisation is extremely data-driven and its engineering excellence is such that it has the confidence to run the cars and power units very close to their limits. I'm sure that its strategy for each race is predicated on Lewis Hamilton (preferably) or Valtteri Bottas getting pole position by dint of using a more optimised configuration than their competitors in qualifying – such as minimum cooling for best aero, high-torque PU modes, etc. This advantage off the line then can – *must* – be translated into getting away in front and running in clean air while keeping the multiple elements of the power unit cool and preserving the tyres. Once the VSC interruption caused by the unfortunate demise of both Haas cars came into play in Melbourne, this strategy failed. Overheating of the engine prevented Hamilton from attacking Vettel as he wanted to do, aided by Mercedes screwing-up a timing calculation – one that really could have been done in the head – through total reliance on a digital computation that proved to be flawed.

XPB

Smart reactions in response to a safety car led to Red Bull's Chinese GP victory. It was a great example of how racing nous can trump data in F1

Pressure told in Bahrain when its engineers refused to believe that Vettel's Ferrari could run so long on the soft tyre – this clearly did not fit their preconceived data-fed scenarios. When they, too late, began to have doubts about this, pit wall confusion (if not a certain degree of panic) set in, evident from the less than useful radio messages to Hamilton. These led to the driver being distracted instead of being let loose with the simple message of 'go as fast as you possibly can until you feel the tyres going away/you have to fuel-save'. This seeming lack of ability to think outside the Plan A and Plan B mind-set also compromised Bottas' chase of Sebastian Vettel, the blue touch-paper not being lit until too late. All of these were human decisions, coloured by not being able to stand back from the data to employ some practical cross-checking nous.

Human league

Mercedes' confidence and ability in being able to consistently carry out such a 'close to the edge' strategy with such outstanding results over the past four years has to be very much applauded, as does its management of data-collection, analysis and implementation at all levels. However, now that Ferrari, plus Red Bull (when it has reliability and Max Verstappen calms down), are pushing hard, the risks of this modus operandi are increased.

It is no longer possible for Mercedes to expect a strategy which relies on near-perfect execution to keep working when its position is no longer so dominant. Perhaps greater reality-testing is required, like the office-bound weather forecaster sometimes needing to take a look out of the window. You must never underestimate the importance of the human element.

Computers don't feel pressure, but humans do, and it's when pressure is applied that human weaknesses start to show

Failure

Toyota is a strong favourite to win Le Mans this year but, as *Racecar* discovered, the team is taking nothing for granted and its ageing TS050 has now been beefed up, while a radical battery development is also on the car

By ANDREW COTTON

TECH SPEC

Toyota TS050 Hybrid

Bodywork: Carbon fibre composite.

Engine: V6 direct injection twin-turbo; 2.4-litre; power 368kw/500PS; fuel, petrol.

Hybrid power: 368kw/500PS (front and rear combined); battery, high-powered Toyota lithium-ion battery; front motor, AISIN AW; rear motor, DENSO; Inverter, DENSO.

Transmission: Transversal 6-speed sequential gearbox; constant velocity tripod plunge-joint driveshafts; multi-disc clutch; mechanical locking differential.

Suspension: Independent front and rear double wishbone, pushrod-system; torsion bars; anti roll bars front and rear.

Steering: Hydraulically assisted.

Brakes: Monobloc light-alloy calipers with carbon ventilated discs.

Wheels: RAYS magnesium alloy, 13 x 18in.

Tyres: Michelin radial (31/71-18).

Fuel capacity: 35.2kg.

Dimensions: Length, 4650mm; width, 1900mm; height, 1050mm.

With both Porsche and Audi out of LMP1 Toyota is the lone hybrid entry and it's never had a better chance to win Le Mans

is not an option

The loss of Porsche and Audi from LMP1 has put the FIA WEC into something of a crisis mode. Suddenly balancing the performance of its sole remaining manufacturer and a privateer has become a pressing need, and so artificial limits have been put in place that heavily favour Toyota, yet give some optimism to privateers.

But this is not a process that has just started; the ACO admitted in 2016 that it was preparing the way in case it finished up with just one manufacturer and that it had been exploring the idea of DRS and active suspension to give privateers more speed. However, for the 2018/19 FIA World Endurance Championship the option has been taken to limit the overall race pace of the Toyota through a restriction on the number of laps it can do in a stint, to limit its refuelling times, while also artificially working on a lap time advantage for Toyota against private entries.

It's a controversial process, one that introduces balance of performance to the top class in all but name. It's based on the Equivalence of Technology (EoT) table – which is more commonly known as Appendix B – which balanced diesel and gasoline when Audi was racing its R18. The EoT now caters for hybrid and non-hybrid concepts. Furthermore, at the shorter circuits there may yet be more performance balancing which will be based on the track layout, and here the potential for politics to win races is overwhelming.

Toyota was the manufacturer that, in 2012, stepped into the breach left by Peugeot when the French manufacturer ran into financial difficulty and was forced to cancel its LMP1 project right at the start of the WEC. The Japanese firm therefore abandoned a year of development to go racing instead, and has remained faithful to the series to date. It is now the last manufacturer standing following the withdrawal of Porsche and Audi from the series, and with no new manufacturers willing to come in without a major change in the regulations it stands alone against new challenges from Dallara, ORECA and Ginetta.

Victory at Le Mans has thus far eluded Toyota. Many look at the current state of affairs and consider that this year will be a

Toyota's concentrated its pre-season testing programme on racecar reliability and coping with failure modes

Above: There's very little to distinguish this year's TS050 from last year's example, but the car has had lots of reliability work **Right:** Pit stops are a major discussion point with the EoT and Toyota has negotiated a clear advantage with its refuelling times

'We have completed laps on three wheels, and we have also faked a lot of possible problems, just to see how the team reacts to them'

walkover for it. The EoT also gives Toyota an artificial advantage, and so the question might be asked: why go to Le Mans this year? The answer is that this is no easy option; Toyota has opened itself up to an extraordinary risk. It simply cannot afford to fail. And yet it's not a foregone conclusion that it will win.

Be prepared

Toyota knows this, and has therefore concentrated its pre-season testing programme on reliability and coping with failure modes. In design, it has beefed up the clutch, the wheel arches and the bodywork, as well as practising those failure modes with its drivers in testing. 'We have completed laps on three wheels, faking a lot of possible problems to see how the team reacted,' says technical director Pascal Vasselon. 'At the moment the general feeling in the team is that we are better prepared.

'The game in the previous years was first to achieve performance because to beat Audi and Porsche we first had to out-perform them,' Vasselon adds. 'There was no way to be slower but more reliable. So, first performance, and then make this performance reliable and we achieved that. In 2014, '16 and '17 we had the performance to win and fundamentally we had good reliability in that we were not failing engines, gearboxes or batteries.'

Reliability drive

But the car was still failing, and for similar reasons each time. 'In 2014 we did not have the speed, but the others were quality issues, or difficulty to handle exceptional circumstances,' Vasselon says. 'This time we could handle things differently, with less priority on performance. We have done some, but nothing that compromises reliability. Reliability has been a major priority, but we have a baseline car that is reasonably reliable so we did not need to pile up massive mileage. Then we could dedicate more time and effort to the third item, which was the training of the team to handle the exceptional circumstances. And we have been sacrificing endurance mileage to train the team for things that are outside the normal working range.'

The car is essentially the same design as before, and even the bodywork has been carried over from last year, while just two kits have been homologated; low and high downforce. This may have frustrated the development team, particularly for a manufacturer that has targeted technical development as the reason for staying in the WEC, but on the grounds of costs and lack of manufacturer competition it makes sense.

The tub is the same as was first introduced in 2016 along with the new engine and battery storage system, so there has been no weight saving there; by agreement the three manufacturers would run three seasons with their monocoques, meaning a new one was not due for Toyota until next year anyway.

But does all this mean Toyota has done no technical development for this year? At the

This picture: Toyota's Le Mans prep has gone beyond racking up laps and it has simulated a whole host of possible problems **Right:** The team faces competition from privateers this year and it wants a balance of performance for the shorter WEC circuits

'What we have done was mainly on the hybrid side, on the battery and the cooling of the battery'

pre-season test at Ricard much was made of the improved lap times (five seconds faster than 2016, the last time that the WEC tested here), and Toyota admitted it had turned everything up to the max to stress its cooling system. Yet that cooling system was actually the *removal* of the air conditioning system that the manufacturer used to cool the hybrid battery; possibly, the reason why it failed to win at Le Mans last year.

Conditioned response

Project leader John Litjens explains: 'What we have done was mainly on the hybrid side on the battery and the cooling of the battery. The air conditioning system is out now because from a weight point of view, and we saw at Le Mans, if you have to change the front motor [it took longer]; people said that Porsche was quicker, but they didn't have an air conditioning system.

'You needed half an hour,' Litjens adds. 'Because there was gas inside that you have to evacuate, you have to dry the system and then put it all back again. The compressor was driven by the front motor and was part of the unit so when you change the front motor you have to disconnect the lines and you have to open the system. We then changed the battery too. It is now air- and water-cooled, so normal radiators.

'We had to change the radiator installation because we changed the radiator sizes,' Litjens says. 'The radiators are bigger, but you don't have the condenser or compressor. We asked our Japanese colleagues to work on the temperature because that is how it works. The temperature that the cells work at is now much higher because of the lack of the air conditioning system. We don't have an air conditioning system at all. In the cockpit we have the normal venting and fans.'

This change to the battery is a further step change in the operating temperature of the cells. Toyota was already proud of itself at the start of the 2017 season that it had increased the temperature by 10 per cent, and says that this year it has another 10 per cent improvement through the advanced cell technology.

Total confidence

The change in fuel supplier to the championship could have caused a drama for the teams, but Total has produced a blend that is very similar to that of Shell, which had partnered the WEC from the very beginning. 'The development of the engines is done in Japan, but from a fuel perspective there is nothing to adapt,' says Litjens. 'For sure the risk is the refuelling, and even there we didn't see any surprises. But it could have been major. The target was to get a smooth transition. Total was given a target to make the fuel so that they could not do something out of control. We get the data sheets of the fuel, and the specific calorific energy and things would have been adjusted.'

Number crunching

But beyond all this the big topic of discussion at the pre-season test was the Equivalence of Technology, which limits the Toyota to 11 laps at Le Mans, three short of the distance it claims to be able to go without such a restriction. Lap time will also be tilted towards Toyota, to the tune of half a second to a second per lap at Le Mans, and refuelling times favour the Japanese.

The final figures were not yet published at time of writing, and nor is there confirmation of how further balancing of performance will be managed at the shorter circuits on the WEC schedule, starting at Spa in early May.

'When we develop performance we count in tenths of seconds, and the unit of EoT is 10 seconds,' says Vasselon. 'We did not plan to tackle the EoT circumstance with performance development. EoT is a process that has to be right. Mistakes can be very big because you

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The TS050 was five seconds faster at Paul Ricard than it was in 2016, thanks in part to car development and in part to a new track surface

'It is okay to have LMP1 closer, but not to the point that we are fighting and banging doors'

The aero kits have been carried over from last year. This is despite the fact that new radiators have been fitted to make up for the removal of the air conditioning, which had previously cooled the car's battery

manipulate the major performance drivers and you cannot afford to be wrong because you cannot recover from that. If the EoT is wrong, it is not because we have developed this or that, it is a process that has been clarified, and it has to be right and achieve its targets.'

Delicate balance

But the EoT doesn't really give Toyota anything, Vasselon claims. 'It is giving performance to non-hybrid cars. It prevents us from running 14 laps. Then it is tuning weight and fuel flow for the non-hybrid cars. It is difficult to say if it has been done right so far. We have never been running in controlled conditions yet. It looks like the privateers are competitive. But if we were on the same regulations, then there would be no race. It is not that someone wants a manufacturer to win or not. It is agreed that there was an interest to bring the field closer together. But Our competition is not the non-hybrid cars; it is Le Mans. So, it is okay to have LMP1 closer, but not to the point that we are fighting and banging doors. We need EoT to bring it close, but there should still be a gap.

'It could be a bit less than a second per lap, maybe half a second per lap and five seconds in refuelling, and one lap more per stint, Vasselon adds. 'Everywhere it is bringing us in. We could refuel 18 seconds faster, we go to five seconds, so everywhere we come with a gap within reason. But in principle we agreed to bring the LMP1 cars closer together.'

Table manners

In the past, a simple calculation has seen the EoT tables adapted to the WEC races based on track length, but they have traditionally mainly dealt with the differences between gasoline and diesel. Otherwise, the LMP1 concepts were similar in that they were hybrid, four-wheel drive and all had equal access to development potential. Now, the table has to be adjusted for a car that is not a hybrid and therefore not subject to the same fuel saving strategies.

'There will be a tuning for WEC,' continues Vasselon. It will be different to what happened before, based on simulations, of the relative pace of the cars on the WEC track. Circuit length will still be the main criteria and there will be tuning. It will be complex, but then nothing is simple when you try to balance things.'

One of the big issues that Toyota expects to see is at the end of the straight where the hybrid will have a fuel cut, the non-hybrids will not. That was partly the reason why Nicolas Lapierre crashed out of the Le Mans 24 hours in 2017; as he approached the first corner he passed an LMP2 car, the fuel cut came in, and the LMP2 ran into the back of him. This year, as well as the threat of an LMP2 car, there is also the threat of a similar speed LMP1 car dive-bombing the Toyota into the corners.

Privateer threat

So, with the team having practised coping with unforeseen problems, and with the EoT balancing performance in its favour, this year's WEC is Toyota's for the taking, right? Maybe. But Toyota is conscious that the privateer cars are well designed and capable of challenging. The BR Engineering Dallara has a lot of test miles under its belt, while the ORECA showed pace at the pre-season official test. So this year's Le Mans might yet be a race after all.

In it to win it

Ask ORECA and the Rebellion team that's running its new LMP1 car why they're going to Le Mans and you'll get one simple answer: to win. But has the R13 really got the potential to take the fight to Toyota?

By ANDREW COTTON

The Rebellion-run ORECA R13 showed good pace at the pre-season test at Paul Ricard and, despite a short development programme, it gives the company its best chance yet to win Le Mans

‘The main motivator for Rebellion to come back into P1 is not to win the championship, it is to win Le Mans’

Behind the sole-remaining manufacturer entry from Toyota, three chassis constructors will be vying for at least the final step of the overall podium at Le Mans this year, one of which is ORECA. The French firm’s boss, Hugues de Chaunac, also knows that this is his best chance ever to win the race overall with a car designed by his company, and it has risen to the challenge with its R13 design.

ORECA is no stranger to winning major events overall; as a race team it won the 2000 Daytona 24 hours with the Dodge Viper, and Sebring 12 hours with the Peugeot 908 in 2011. The team has actually won Le Mans overall too, in 1991 running Mazda’s 787B. In 2007 it turned to chassis construction having bought Courage, and the R13 is the latest to bear its name.

Rebel yell

Running the car at Le Mans and in the 2018/19 FIA World Endurance Championship is Bart Hayden’s Rebellion Racing team, a multiple FIA WEC privateer LMP1 champion which is celebrating its 10th year working with the Rebellion watch brand. The link between Rebellion and ORECA goes back to 2014, when ORECA was tasked with designing the R-One (see *RE* V24N7). That was powered by Toyota’s 2013 3.4-litre RV8KLM-L engine, which was adapted to run with fuel flow meters for the

TECH SPEC

ORECA R13

Chassis: Carbon monocoque.

Engine: Gibson GL-458; normally aspirated 4.5-litre V8 with 90-degree V angle; power, 665bhp; max revs, 9000rpm; electronics by Cosworth.

Transmission: Xtrac 6-speed with transversal magnesium casing; electric Megaline paddleshift.

Suspension: Double wishbones with pushrods and rockers; PKM dampers.

Brakes: AP carbon discs and AP 6-piston monobloc calipers.

Tyres: Michelin 31-71/R18.

Wheels: BBS 13in x 18in.

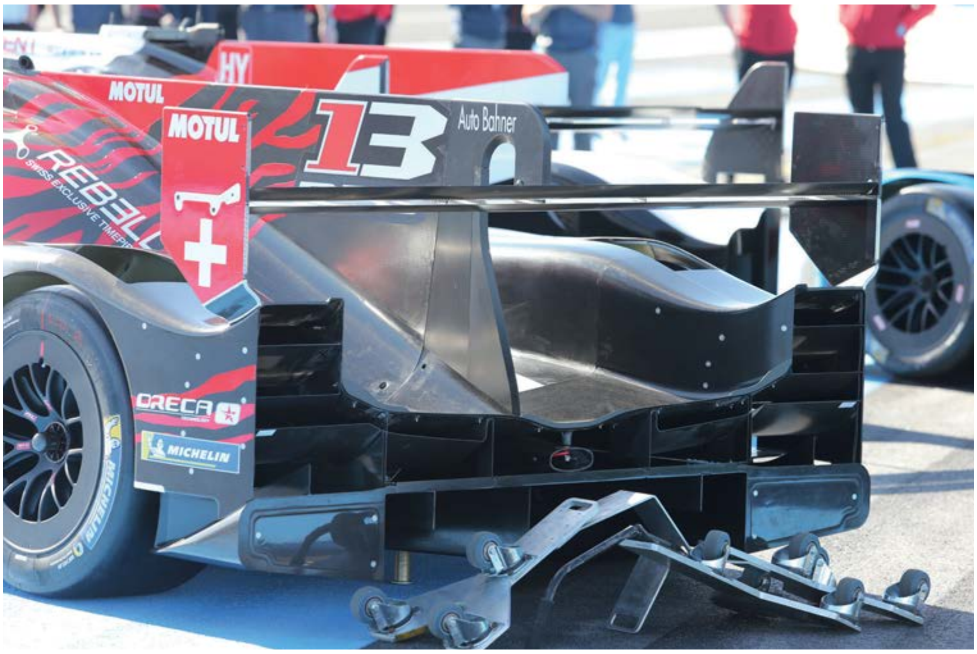
Dimensions: Length, 4645mm; width, 1995mm; height, 1045mm; front track, 1560mm; rear track, 1550mm.

Weight: 833kg.

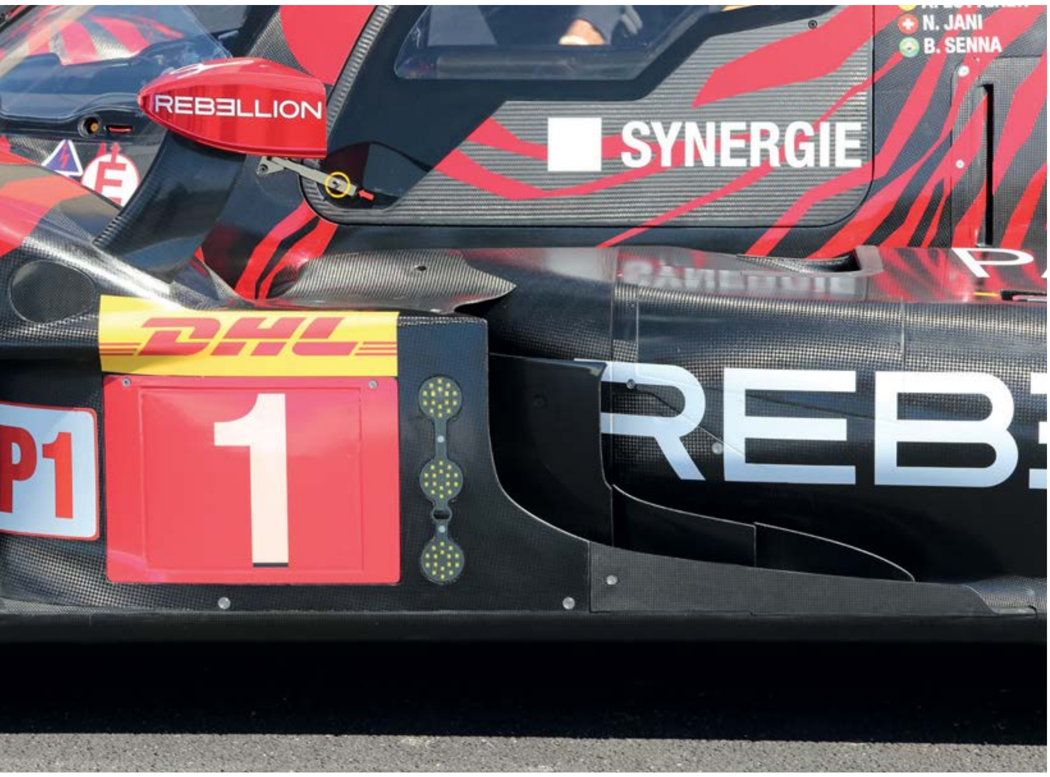
‘We had six months from the day we started the project to the day the car hit the track, so we did not have time to redesign the chassis’

season. Since then, Rebellion has won its fifth LMP1 privateer title in the FIA WEC, and in 2017 entered the hugely competitive LMP2 category with an ORECA packing the LMP2 Gibson engine. This relationship continues with the R13 – a Gibson engine powering a ORECA chassis – but there is a significant difference; this time ORECA is far more involved in the track-side running and design of the car as de Chaunac recognises this golden two-year opportunity (the 18/19 season runs across two editions of the Le Mans 24 hours).

As is now typical with ORECA’s way of working, the green light was given to the project late, which compromised some of the performance upgrades that ORECA’s technical director David Floury would have liked. The tub is the same as that used in the R-One, and in the LMP2 customer chassis, too. ‘We would have liked to have redesigned the tub, but considering the time-scale to do the project from the start this was not an option,’ Floury explains. ‘We had six months from the day we started to the day the car hit the track, so in this time-scale we did not have time to redesign the chassis. Had we had another 12 months extra for sure we would have considered it. This original chassis was designed to LMP1 2014 regulations, and it is still the monocoque regulation that is valid for LMP1 non-H and LMP2.’



The rear diffuser is a tightly regulated part so ORECA has concentrated on improving the under-car airflow that feeds into it



Cooling system required major development because of the new front aero and the needs of the Gibson LMP1 powerplant

Gram prix

The chassis design is now more than five years old, and Floury believed around 10 to 15 per cent weight saving could be achieved with a redesign, but that simply wasn’t an option given the time scales involved. Without having the luxury of shaving weight from the tub, the design team instead looked around the rest of the car to take the grammes off for competition. To this end ORECA worked hard with the British designers of the Gibson GL458 4.5-litre V8 LMP1 engine the car is to carry. The unit itself is a development of the 4.2-litre GK428 V8 that powers the LMP2 cars in European specification but there was a lot of work done to increase power and reduce weight. However, the block remains the same. ‘It was not realistic to redesign the whole engine, but we had a good collaboration with Gibson,’ Floury says.

This being a customer chassis in concept, there was very little work needed for engine installation. In fact, this chassis has taken up to six engines during its life cycle, including the Toyota in 2014, the Nissan VK45 LMP2 engine, an HPD in the US, and now the two Gibson engines in both prototype classes. ‘[The chassis] was already designed with it in mind that you don’t invest in a monocoque for only one project,’ says Floury. ‘It is a big investment for a racecar manufacturer, so when you do a monocoque you think about future development. It was able to be fitted with different engines from day one, and the choice to use the Gibson engine was an easy one as the monocoque was already designed to accept this engine.’

Power point

Floury says ORECA was happy to work with Gibson because of the experience it had had working with the company in LMP2 back in 2011 and then more recently when it used the Gibson in the ORECA 07 LMP2. ‘We had experience with the engine in the LMP2 car and the LMP1 engine is in many ways similar,’ he says. ‘The installation is the same philosophy so you have already been through the difficulties. It needs more cooling. The racecar from outside looks [to be the same] philosophy as the ORECA 07 LMP2, but the airflow structure is quite

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The suspension has been upgraded from LMP2 spec to meet the greater demands expected and to suit the different tyres

different, because the car in detail is different. We had to work towards improving the cooling and this has been a challenge. The front of the car has quite different aero and that impacts the flow to the radiators,' Floury adds. 'The flow from the front to the back is quite different and that is why in many details you see differences between the R13 and the 07.'

Target practice

The target lap time set by the ACO and FIA around the Le Mans circuit is already significantly faster than the old R-One managed. Then, the factory cars qualified in 3m21s and the R-One in 3m29s, but already the LMP2 cars in 2017 were qualifying in 3m25. The R13 has been targeted to be 'significantly quicker than that', according to Floury, and the estimation is that the ACO wants it to be hitting around the 3m13s mark, which the ACO and FIA believe the Toyota is capable of this year. It's a huge hike in performance, and that has affected everything from the weight distribution to the suspension design and the steering concept.

The splitter, floor, and flow to the tightly regulated rear diffuser are all major areas of development and ORECA says that there is hardly any carry-over of bodywork from one version of the car to the next. 'Nothing is carried over from the LMP2,' says Floury. 'The steering is different [although the supplier is the same], the suspension geometry is different, because we don't use the same tyres, and it is not the same characteristics in terms of weight, cornering speed and so on, or in terms of engine characteristics. Weight distribution is different, and from the P2 we had to save a lot of weight, so if you keep everything the same then you don't hit the target. We carry quite a lot of ballast in P2, but we still had a lot of weight to save for the P1. The target was not only a matter of hitting the minimum weight, but hitting the weight with ballast.'

The short time-scale meant that anything that appeared too risky was rejected

Another area of development was the Xtrac gearbox, where weight saving was once again a key performance target, as well as improving the efficiency of the transmission. 'All the details have been looked at, but conceptually it is not a new gearbox,' says Floury.

After a somewhat painful start to the LMP2 programme in Daytona and Sebring in 2017, where Rebellion suffered a number of electronic problems which were solved by the start of the European season, the LMP1 project has still kept faith with Cosworth as the electronics supplier. 'The start in LMP2 has been a bit of a challenge from the electronics side,' says Floury. 'But now the system is operating well, so the idea is not to go through a development stage again. The time-scale does not allow that, so we went for an evolution of what we know.'

Risk averse

This short time-scale meant that anything that appeared too risky was rejected, and the team knows that it has to be reliable at Le Mans if it is to stand any chance of getting on the podium.

With Silverstone as the third round in August, more than two months after the low-downforce package has been in its element at Le Mans, there is a large upgrade planned for the British race. Beyond that eyes will already be on June 2019, for with the season running to Le Mans next year the Rebellion team might have hopes of winning then if it does not manage to upset Toyota's bid this year.

'The main motivator for Rebellion to come back into P1 is not to win the championship, it is to win Le Mans,' says team owner Bart Hayden. 'You have a car that looks similar to the 07 P2 car, but it generates more downforce for less drag, weighs 100kg less, has got 60 to 70bhp more than the P2, in Le Mans trim, so it should be pretty handy. But I am not sure that it is handy enough to keep up with the Toyota.'

On the level

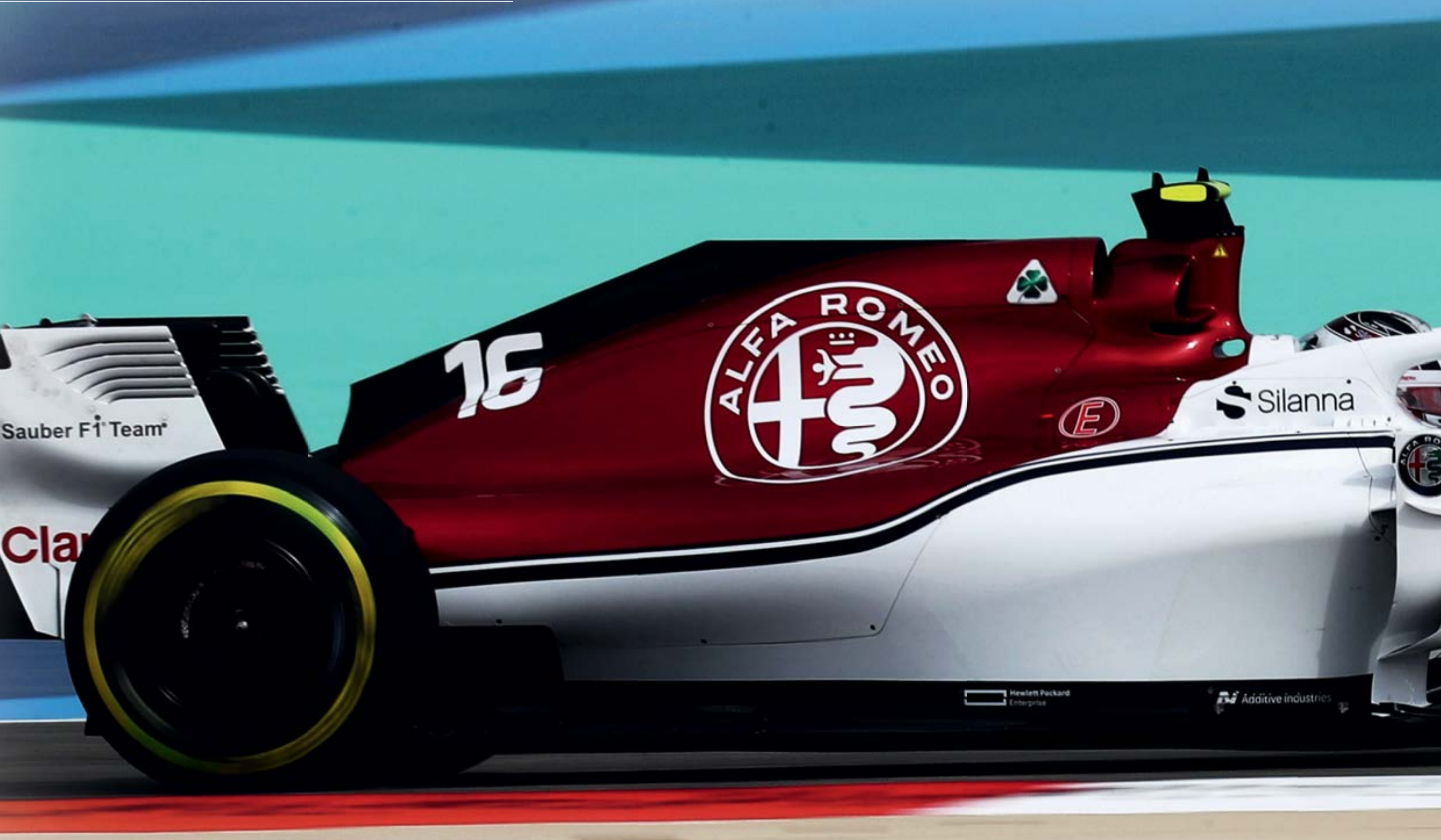
That will largely depend on the equivalence of technology. Even with a foot in both camps (ORECA actually provides the track support for Toyota's LMP1 project), Floury is unable to say whether or not the EoT table is correct yet. 'It is clearly a difficult situation in terms of that it is a transition period and you try to have cars compete together that have very different working points,' he says. 'In terms of hybrid, four-wheel drive, and all technology and systems that are linked to hybrids and go beyond just putting power through the tyre, it is two completely different types of cars that you try to have competing together, so it is a big change, and to capture all the performance parameters it is not an easy thing, particularly with all the new cars coming so late. It is a work in progress and clearly not easy. It is necessary to make sure that there is a race. Everyone agrees on this, and after that it is understandable that Toyota wants to protect themselves.'

Against all odds

However, even here there is a limit to what can be achieved. 'The regulations, as I understand them, don't allow the Toyota to be slowed down, they only allow the non-hybrids to be speeded up, but there is a cap on how much more can be given to the non-hybrids and we are not far from that cap now,' says Hayden. 'They can't take any more weight off because we are at the minimum. The only tool that they have available to speed us up is to give us more fuel in terms of flow rate, but there is a limit that they can give, which is around 115kg/h, and we are currently at 110kg/h.

'The other thing that we weren't happy about was that they were going to impose a refuelling rig restrictor on the non-hybrid cars, which meant that to fill the racecar with fuel would take us five seconds longer than it would take Toyota,' Hayden adds. 'We think that is completely ridiculous.'

There are challenges to overcome if a privateer is to beat Toyota at Le Mans this year or next. It's had short development time, but this ORECA could be the one to do it.



Swiss timing

A deal to stick with Ferrari power rescued Sauber at the eleventh hour last year, but then the Swiss team faced a race against time to get its radical C37 car concept to work with a completely different PU. Here's the inside story

By SAM COLLINS

For much of 2017 Sauber was looking towards the 2018 season with great optimism. It had new management, and manufacturer backing from Honda. With this in mind the technical team, headed by Jorg Zander, embarked on an innovative and highly complex new car concept in an attempt to move the team back up the grid.

Then things started to go wrong. Just before the summer break news came that Sauber's deal with Honda had collapsed. Seemingly the team could not then be assured of a supply of transmissions from McLaren, which had cut its ties with Honda anyway, and without its own in-house transmission programme Sauber needed a gearbox deal to go with a power unit.

Alfa bravo

In the end an agreement with existing supplier Ferrari for power units and gearboxes was hastily made, and this turned into a more fruitful deal than initially expected as a new long term technical partnership with Alfa-Romeo was also announced. As such, the 2018 car is officially called the Alfa Romeo Sauber C37.

'It was a bit intrusive to change the engine and drivetrain so late,' Zander says. 'Basically, after the summer break the whole rear end of the car had to change and the wheelbase was extended by 40mm, which was not part of the original concept. We had to redesign the rear of the monocoque, and in terms of the fuel tank integration we had to make quite a few changes there as we did not want to compromise the

The C37 has already proven to be a much more potent design than last season's C36, having scored points in its second race

length of the car too much. We had to make sure we achieved our fuel volume, while not extending the monocoque, it was quite an exercise and it took us some time. It was not a case of adding or shaving off 10mm here and there, it was quite detailed.'

Keeping faith

Yet despite the engine change the overall car concept remained largely unchanged. This is perhaps fortunate as the C37 is the first Sauber in some years which has fully exploited the full range of facilities at the team's base in Hinwil, Switzerland. Development of previous designs was restricted by the fact that most of the wind tunnel time was booked out by Audi (its technical team was then headed by Zander).

'We were able to adapt last year to having the wind tunnel time available again, and we began to churn out more bits and pieces, but it was a learning process throughout,' Zander says. 'We also strengthened the technical team during that time and that's a process that is still ongoing. As far as the racecar concept was concerned, it was clear we wanted to make a step, we did not want to focus just on evolution as we knew we would run out of potential with the C36 concept.

'One fundamental parameter was the wheelbase, it was obvious that needed to be longer,' Zander adds. 'We achieved that by moving the front axle further forward on the C37. Compared to the 2017 racecar the front wheels are 80mm further forward. The reason to do this was to open up the space between the front wheel and the leading edge of the sidepod, this gives you more freedom to develop the bargeboard area.'

That total wheelbase extension of 120mm was longer than had been intended as the 40mm at the rear was solely a result of using the Ferrari powertrain. However, the 80mm extension at the front is a core part of Sauber's 2018 concept, as the area around the front wheels and the leading edge of the sidepods was a major focus, and it influenced the design of the front wing and nose significantly.

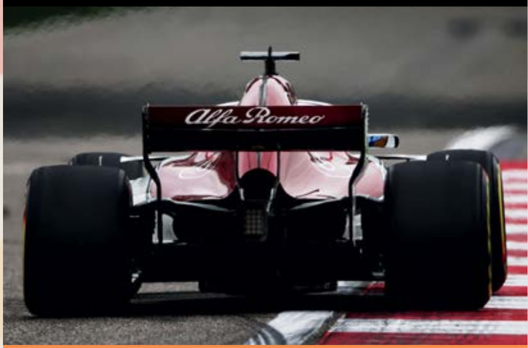
Swiss air

On the C37 there are two holes either side of the front impact structure, exiting on the underside of the nose, along with a large air scoop also located on the underside of the nose. 'What it does is interact with the Y250 vortex, it is all about wheel wake control,' Zander says. 'You want to make sure that you control this vortex in a way that you take away any losses early on behind the front wing and that is where this ducted concept works. It helps to make sure that you get clean and high energy airflow towards the leading edge of the racecar's floor in order to be able to produce a good amount of downforce from the floor.

'Then, of course, usually you are minimising lift in this area; when we first tried the ducts in the wind tunnel we could see straight away that the balance shifted forward quite significantly,' Zander adds. 'When you do that you get a lot of

The wheelbase of the C37 has been extended by 120mm over the previous car; partly due to Sauber moving the front axle forward, in-line with its new chassis concept, but also because of the late deal to continue using the Ferrari power unit and transmission

TECH SPEC



Alfa Romeo Sauber C37

Chassis: in house carbon-composite monocoque.

Power unit: Ferrari turbocharged 1.6-litre 90-degree V6 with MGU-H and MGU-K; 80mm bore, 53mm stroke; 500bar direct injection.

Suspension: Double wishbone; inboard spring and damper unit actuated by pushrods (front) and pullrods (rear).

Brakes: 6-piston Brembo brake callipers; carbon-composite discs and pads (Carbon Industrie).

Transmission: Ferrari 8-speed quickshift carbon gearbox, longitudinally mounted; carbon-composite clutch.

Chassis electronics: McLaren.

Tyres: Pirelli.

Wheels: OZ.

The C37 is the first Sauber in some years that has been able to fully exploit the full range of facilities at the team's Hinwil base

potential from the nose, then you can unload your wing. Doing that allows you to use the front wing entirely differently, you don't need to load it as you would do in a conventional fashion, you have a lot more potential there.

'As you are not loading the front wing that much the losses in its wake are lessened and you get more energy behind your front wing which you can use for the floor or you can channel it to the rear of the car, either on top of the floor or to the diffuser area,' Zander says. 'One part of it you want to use on top of the floor, in order to achieve some kind of sealing of the rear tyres to prevent too much interaction between the rear tyre jet and the diffuser. That's quite a complex thing and difficult to achieve.'

The leading edge, and indeed the whole sidepod, is a particularly interesting area of the C37. Sauber has a unique solution, opting for an extremely narrow sidepod, with two entirely separate inlet ducts on both sides. 'We have taken one route and other teams have done other things,' Zander says. 'You will see a lot of teams have very high cooling inlets on the sidepod with huge undercuts. A good example is the Williams which has a crazy undercut. Perhaps the Red Bull or Ferrari is more natural, but it leaves a lot of space in this area to ensure that you get a decent amount of energy to the back of the car. In that regard it's a bit of a compromise. We instead opted to go for a very narrow package. We did this to prevent the front upper tyre wake getting attached to the sidepod. If we didn't do that it would interfere with the rear end, so it offers a lot of potential. It also has some advantages in yaw conditions.'

The twin inlet arrangement was not originally part of the plan, but as the car was developed it was clear that a second inlet either side was needed. 'Initially the idea was to lower the side impact structure and have a single inlet,' Zander says. 'But then we struggled a little bit to achieve the target parameters in terms of width, and we didn't have enough inlet surface, so then we came up with the arrangement you can see on the car. So we just thought it was a neat idea to have this double-decker arrangement.

'We have engine water cooling on both sides, with the coolers in parallel. They are fed from the main duct. The engine oil cooler is on the left hand side, you have ERS oil and water, MGU-K cooling and intercoolers,' Zander adds. 'With the aero targets set for the sidepods and the packaging requirements we set ourselves we ended up with this concept and we are very proud of it. A lot of work went into the individual cooler arrangements, you'll find multiple cross counter-flow and cross counter-pass arrangements. We looked for a way to find new thermal insulation techniques in order to avoid conduction between those multi-pass elements and we put a lot of work into that and trying to meet the heat rejection requirements of the Ferrari PU, which we achieved. Overall we maintained the same volume, the same weight in terms of specific cooling, and as far as efficiency is concerned we have about 10 per cent more cooling. It's a big step in efficiency.'

The C37 has a unique double-entry narrow sidepod design, said to be 10 per cent more efficient than a conventional layout


The front wing design is the result of an innovative new aero concept – note the ducts on either side of the impact structure

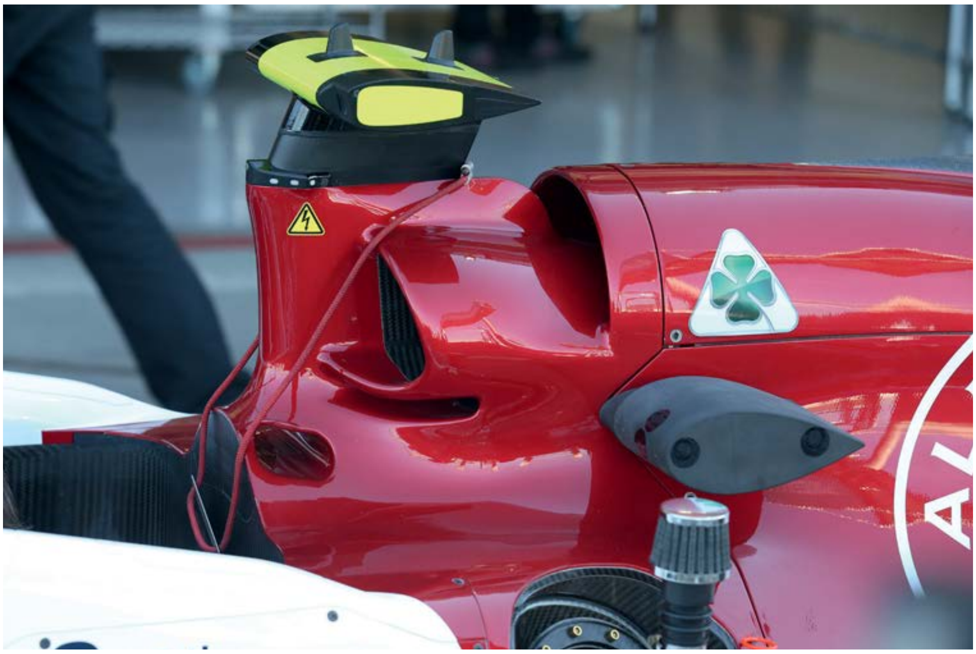
Roll play

As was the case with the C36 and a number of current F1 designs, some of the coolers (including part of the charge air cooling system) have been relocated from the sidepods to the centreline, fed by ducts around the roll structure. Sauber has continued the approach it used in this area in 2017 with a number of almost organic looking ducts either side of a single solid roll-over structure.

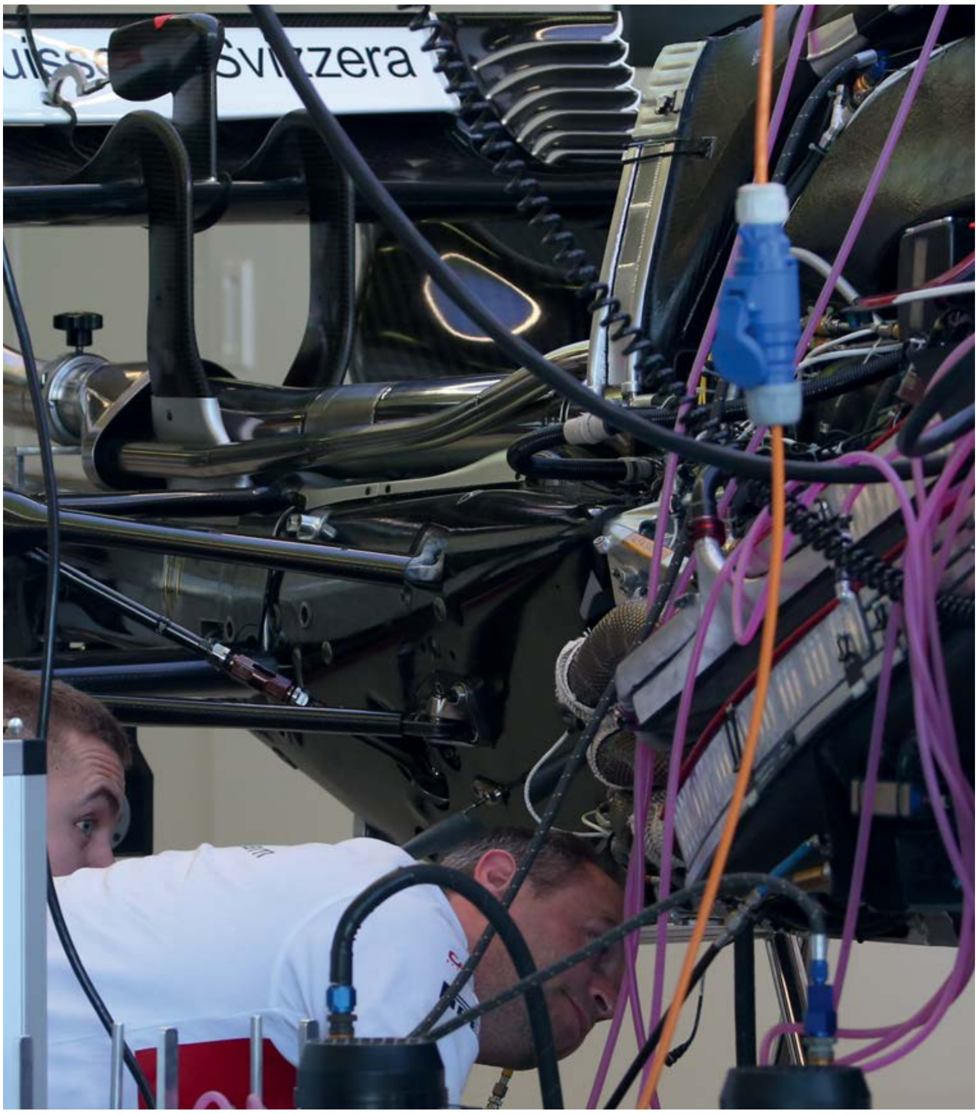
'When you look at the engine air inlet you can see we also have a staggered layout so you can imagine we put quite a lot of time and effort into it,' Zander says. 'Again, from an efficiency point of view, it was very good. We were trying to minimise the area and the impact on the flow to the rear wing. All the CFD investigations said this was the way to go, and that was confirmed in the wind tunnel. Obviously, we had a little bit of a doubt that we may take a hit in yaw, but given the changing speed in those conditions we have not seen any negative impact in performance. Yes, we can see that there is some unequal flow, but it does not have any detrimental impact in terms of aero or cooling performance, or even engine intake quality.'

But this cooling layout could add weight to the car overall, something that the team was particularly sensitive about after the 2017

‘Our car was as much as 9kg overweight mid-season last year, so we had to focus on getting below the limit, which we’ve achieved’



The C37 is the only Formula 1 car to use a roll-over blade rather than a hoop and the ducting around it is hugely complex



The cooling system is very narrow but features some innovative thermal barriers to avoid conduction between its elements

season. ‘We had to make sure the car did not get too heavy, that was a big concern for us,’ Zander admits. ‘Last season our car was as much as 8kg or 9kg overweight mid-season so we had to focus on having a car below the limit, which we have achieved. On the upper roll structure we have refined the concept further over the C36 and knocked off 700g, which is massive. As far as the side impact structure location is concerned it’s not the optimum, we know that. We had to optimise the whole tub around this particular insert. It’s perhaps only 200g heavier.’

Rear view

Ferrari not only supplies the power unit and gearbox, the C37 also utilises Ferrari suspension, while the uprights and the brake calipers are also supplied by the Italian team.

‘In terms of aerodynamics I think we had similar concepts in mind,’ Zander says. ‘The one thing I can say is that we inherited the rear suspension functionality and kinematics at a time when our front end concept was already defined, so that is clearly something we now need to spend some time on to make sure that those suspension systems are harmonised and work well together. There are a couple of things we have identified already which will help us in terms of things like the dynamic mechanical balance shift we wanted to achieve. But it meant that we had to also design Sauber suspension systems which had to be incorporated into the Ferrari suspension system.’

Design restrictions

Using Ferrari’s rear suspension has restricted Sauber in some areas, though according to Zander it’s not been too restrictive. ‘The rear ride height, for example, is defined by a combination of the inboard geometry, of all your elements, springs, dampers and suspension travel,’ he says. ‘We are doing the best we can with what we have but there are of course limitations in some areas. For example, if we wanted a 60mm rear ride height it would be impossible, but we wouldn’t want to do that anyway! In other areas we have found ways to make it do what we want. We have come up with our own top brackets on the top of the upright – we call it the F-bracket – depending on the height of this point we can adjust some parameters of the geometry and the kinematics, so we designed some options there which work at certain tracks.’

At the front of the car the suspension layout is all Sauber’s own, with the upper and lower wishbones both raised for aerodynamic reasons, and a new inboard component layout too. ‘We changed the whole arrangement, where we had torsion bars before and the anti roll bar, now we have this bending plate arrangement

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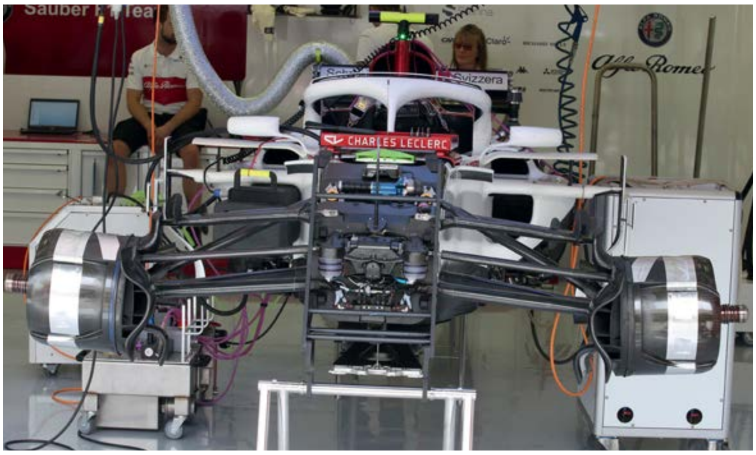
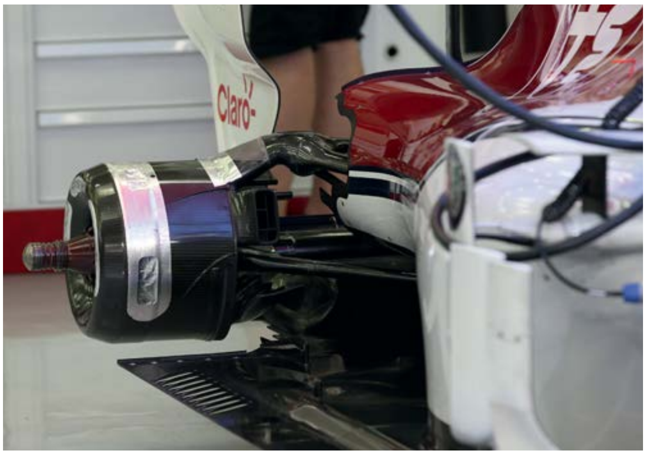


Front suspension is an entirely new design, featuring a central element supplied by Multimatic



The complete rear suspension, including the uprights, is lifted from the Ferrari

Sauber uses the upper front wishbone concept pioneered by Toro Rosso in 2017

The C37 has struggled for pace so far but Sauber believes it will be able to find more downforce

in line with the rocker axis, so that's quite neat,' Zander says. 'Then the old arrangement with dampers was rather complex, with central heave elements and inerters, so now we have moved on to a Multimatic arrangement where we have got this central element in line with the inerter. It is a much neater and more compact solution. We managed to get some weight out there, which was important. We still have the conventional side damper arrangement, though they have now shrunk in size a bit.'

Tyre issues

During winter testing Sauber realised there is still a vast amount of work to be done on getting the most out of the Pirelli tyres. 'There was a small tyre shape change this year,' Zander explains. 'We knew that the front construction would differ slightly and have a slightly different deflection mechanism, but this has not got too much of an impact in terms of the global flow structure, it is more about the rears which have a huge effect on the diffuser and how the rear part of the floor works.

'We had expected that the rear tyres would be the same as 2017, and that is the indication we got from testing in Abu Dhabi last year, so the 2017 car worked very well with the 2018 tyre,' Zander adds. 'We had no indication that anything would be different, but what raised a question for us was that the 2018 wind tunnel tyres performed slightly differently, but as there was no indication from Abu Dhabi that the 2018 tyres were different, we went with what we knew. Now we are looking at it a lot more, it is still not fully understood, and it's critical for every team. You cannot forget tyre management, you can easily lose a second in lap time if you don't get it right. You can only extract the potential of the car if you get the tyres right, we are working on that a lot but I tell you every track we go to it's a new challenge.'

Making progress

The C37 has already proven to be a more potent design than the C36, having scored points in its second race and having battled with cars from bigger teams. But Zander is not content with the performance. 'Right now we are not meeting our aero targets in terms of mid- to high-speed grip, so we need a bit more downforce. But in Bahrain, for example, the car was very good. This year it's clear that we are much closer to the fastest lap already. I'm optimistic, we have some tweaks coming and I think we know what we are doing to move forward.

'We know there are areas of the car where we can make big gains,' Zander adds. 'For example, we know extending the wheelbase was a good thing but we have not yet really exploited the whole mid-floor area of the car, we are behind there and there is a lot of potential to be extracted. It is all so complex, aerodynamics is a very particular science and you need a good portion of luck as well. When you work in this area you can come up with some good ideas, but then you get correlation issues between wind tunnel, CFD and real world. There are tiny sensitivities, shifting things around slightly, adjusting various radii can make big differences. You just have to spend that time and get all the details right. That's why aero development does not come fast, you have to use your time wisely and just get things right. It takes time, and it's an iterative process, and that needs to be very well organised and structured.

'We have a huge bunch of very good and competent aerodynamicists,' Zander adds. 'They are pretty much focussed on getting the most out of their local development area, but what you need to be careful with is that you then harmonise all of these areas.'

As Sauber develops the C37 it will be interesting to see if other teams start to explore some of the innovations it features, only then will it be clear if the car's concept is a trendsetter, or something of an outlier.

There's still lots of work to be done on getting the most out of the tyres

Recovery position

Mercedes' decision to leave the DTM at the end of this year, along with falling spectator numbers, has left the touring car category in crisis – but with new crowd-pleasing regulations will it be able to fight back? *Racecar* investigates

By LEIGH O'GORMAN

'The most important thing when we started to create these regulations was to make the people in the grandstand happy'

Few would argue that the past few years have represented a rocky road for the DTM. From a field of 24 cars in 2016 – eight each from Audi, BMW and Mercedes – it was then agreed to reduce the field to 18 entries (six per manufacturer) and then, last summer, Mercedes announced its intention to withdraw from the series at the end of 2018. Paired with falling television numbers and track attendances, the future was looking precarious for the German championship.

Yet, despite all that, leading members of the category appeared quite upbeat at this year's media and opening test day at Hockenheim. Decisions to reduce costs by standardising certain aero elements, alongside strict limits on the use of wind tunnels and a severe reduction in testing, has found favour in the paddock. DTM's biggest change comes in 2019, of course, when the series officially pairs regulations with GT500, but in the meantime it needs to survive and prosper through the 2018 season.

Jettisoned ballast

Some major changes were, in fact, brought in last year, chiefly with ITR chairman Gerhard Berger announcing the abolition of DTM's performance ballast system with immediate effect following the Nurburgring round toward the end of last season. It was a decision that revealed just how far ahead Audi's basic RS 5 package was, compared to the BMW M4 and the Mercedes C63, with the Ingolstadt squad taking three of the final four races. Indeed, Audi drivers ended up taking the top four positions in the drivers' championship, while Audi also won the manufacturers' crown and Audi Team Rosberg the teams' championship ahead of Audi Team Abt Sportsline. It was a whitewash.

At season end, there was already talk of aerodynamic changes ahead, not only to attempt to balance the cars, but also to make the DTM machinery appear more spectacular and to improve the on-track product, as Rudolf Dittrich, general manager of racecar

Main picture: In recent years the DTM has been a three-way fight between BMW, Audi and Mercedes, but the latter is to say goodbye to the series at the end of this season **Right:** At the time of writing how the Hankook tyres would perform in the reduced-downforce DTM was one of many unknowns in the wake of two inconclusive pre-season tests

development at BMW Motorsport, explains: 'The main goal was to reduce downforce, which for motorsport makes perfect sense in my opinion. What we have done is remove quite a few flicks and things from around the underfloor – none of these things that the spectators can see. There is a lot of simplification going on and increased robustness to help make the car less pitchy, less nervous, while also less reactive in traffic and more robust for car-to-car battles.'

Michael Bernard, head of DTM's technical department, says: 'The most important thing when we started to create the regulation was to make the people in the grandstand happy. Of course, if you go down to the pits, you will find a lot of engineers who are a little bit pissed off, because all their knowledge is worth not as much anymore. But at the end of the day, this was the headline – make everyone able to build, run and maintain a winning car.'

Trimmed aero

For this year, DTM cars are only allowed one aero flick to be used either side of the front splitter, while the front skirt has minor adjustments. As well as that, the side channel behind the front wheel leading to the door-frame has been simplified and the side plates that sat below the doors have been removed. Aero flicks in the area behind the rear wheel arch have also been discarded. 'It does change your full throttle percentage over the course of a lap,' says Dittrich. 'The full throttle percentage will drop by about five per cent. That means, on a track like Hockenheim, drivers have to work for around five seconds longer per lap. Driving on a straight [anyone] could do it, but it's the other bit that really makes a difference to a racing driver.'

In the balance

As noted above, the abolition of performance ballasting last September brought Audi to the fore. 'I think performance-wise Audi was a very strong package, maybe the strongest one,' notes Hubert Hugle, director of development at HWA (Mercedes). 'The removal of the performance ballast is, for me, the right decision and I assume this year's cars will be closer together than the year before. At the end, last year's cars were mainly aerodynamic driven, so [in] this year's car, the driver is more relevant.'

But Audi's head of motorsport, Dieter Gass, believes its advantage was somewhat overplayed. 'It is much more a question of "what is the effect of the car between the three manufacturers?" Everyone was saying that we had aerodynamically the best racecar last year. But that means that automatically when you go from having something that is the best package to a standard package, we would then lose a little bit more than the others.'

Bernard agrees, but then insists that any subsequent balancing has amounted to minor adjustments; however these still brought problems beyond the track. 'What we realised is that whenever you are talking about balancing, […] always someone is complaining about the other one. It was always negative. I've never heard anybody say "oh great job, it was a fair deal". But this sport is made to sell cars […] and this is why we need to create a tool to give to manufacturers and say, that if you compete in DTM, or in Class One or however you call it, you have the chance to show customers at the circuit that you build a good car, a winning car.'

Aside from the aerodynamic alterations, the series declared that the third element of the front axle was to be dropped and that only linear coil springs could be allowed in the suspension, while there has also been a reduction in the number of bump stops and dampers. But for Gass, it was too early to say how this will affect the machines, due to the lack of clean running in testing. 'You have to wait a little bit to really see what the effect is. For sure, it is more complicated, if not impossible to bring the car in the right window. It's a bit of a challenge to find the right compromise.'

Hugle goes further: 'The DTM car was running a lot on the front third [element] and it really was a performance tool. We have to look again around how to set up the racecar without the third element on the front.'

The future of the DTM could very much ride on its ability to get a third manufacturer on board once Mercedes departs

Hugle also notes that on the 2017 C63, the third element was used as an end-stop on straights, to give the car a certain dynamic ride height at the end of the straight. 'This is not as easy as last year, because the third element is banned, so we have to work around with other tools and this is more or less simply the bump stop, the packers and linear springs,' he says.

Combat ready

The series should now also see less race-defining damage with the updates, as Dittrich explains: 'Car-to-car is usually where we get most of the significant damage. The flick that is hardly visible from the grandstand [gets damaged], and suddenly the car is half-a-second slower. This is something we are trying to avoid.'

Incidentally, the ditching of the third element also has the effect of raising the DTM car slightly, effectively reducing downforce from the underside of the car, and allowing the drivers to take more aggressive lines through corners and attack kerbs, with less risk of damaging the front splitter or floor.

For 2018, the DTM cars have also dropped weight, but each of the manufacturers are keen to point out that the loss is minimal, with Hugle noting that the C63 has shed a mere five kilos.

With fewer aero add-ons the cars should slide more while also being less prone to race-ruining damage in on-track clashes

The loss of the third element from the front suspension will raise ride height in turns and allow the drivers to attack the kerbs

Slide rules

Even though the teams enter the new season with an updated aerodynamic profile, Hankook will (at the time of writing) utilise the same tyre compound formula it ran in 2017. While the DTM racecars will no doubt slide more, Gass does not see this becoming an issue when it comes to wear rate, consistency and lifing. 'It is still early days to say, due to the lack of testing. I wouldn't expect massive differences, though,' he says. 'We had a few races last year, where one or the other [manufacturers] were on the limit of [tyre] reliability and we had seen some failures as well – luckily we didn't experience them. But I actually think this should be less now with less load from the aerodynamic side.'

New blood

However the regulation updates work out, the DTM is still staring at a key juncture at the end of this season and the future of the series could very much ride on its ability to get a third manufacturer on board once Mercedes has departed. Rumours that Alfa Romeo or Volvo may enter the DTM have fallen quiet in recent months, and there appears to be little to suggest that a GT500 manufacturer is looking to join. Despite this, Gass is optimistic that a new entry can be found. 'All the measures that have been installed in previous years will make a benefit, and then the co-operation with the Japanese to run together and potentially have a championship, I think that is going to boost the return on investment for DTM.'

Bernard is keen to underline this, and places emphasis on these new simplified DTM regulations as a potential draw. 'Our job is to show that, first of all, you only need a reasonable amount of money and that you can come into the championship and be on the podium from the first day. This is one of the major reasons we say, keep everything simple.'

Bernard explains that it should not be necessary to have to run constant development on a car and contends that spending endless hours in a wind tunnel or running CFD programs to become competitive is the wrong way to go, adding, 'You just take the parts you get, you put the car together and you need to build the engine – the most important part that you do on your own – and then you are able to win from that moment onward. I think this is the right way. We have learned the lesson; we needed to do something to get the people back in the grandstands. You get much more than just a racecar; you see great wheel-to-wheel racing; it's coming back to basic racing.'

Alpine sports

An all-new Alpine is the latest offering for the burgeoning GT4 market, and with its driver-friendly design philosophy and evocative badge, Renault may well have a winning product on its hands with the A110

By SAM COLLINS

The GT4 class is perhaps the fastest growing racing category in the world (along with TCR) with privateer teams and drivers switching to it from the increasingly works-dominated FIA GT3. This growth in popularity has not gone unnoticed by manufacturers and a number of major marques have introduced GT4 racers in the last year. The latest of these is the Alpine A110 GT4, developed by Renault's sporting sub-brand.

A new Alpine customer competition car has actually been long expected. In 2012 the brand partnered with Caterham with the plan of producing a new sportscar, but that project failed to result in a finished car. Then at the 2015 Le Mans 24 hours a new concept car – which ultimately formed the basis of the new Alpine A110 – was demonstrated briefly on track. The final A110 road car was launched in 2017, with the model going on sale in early 2018.

Alpine stars

From the start of the 2013 season Alpine has been represented in sportscar racing by the Signatech team using re-badged ORECA chassis in the LMP2 category of the ELMS and WEC, notably scoring a class win at Le Mans in 2016. This works team is something of an anomaly in LMP2, which is otherwise exclusively reserved for privateers, and its participation in the class led directly to the creation of the Alpine GT4.

'Originally, when we started developing this car for racing we were doing a GTE car. We wanted to do Le Mans with it,' says Lionel Chevalier, technical director of Signatech (who is responsible for the development of all Alpine competition cars). 'The ACO were pushing us quite hard to switch from LMP2 to GT and it does make sense to do that, but the A110 is

TECH SPEC

Alpine A110

Class: GT4

Engine: Renault turbocharged 1800cc in-line 4-cylinder. Over 340bhp.

Transmission: 3MO 6-speed sequential gearbox with bespoke casing; XAP shift actuation; twin plate clutch.

Brakes: Brembo 355mm discs (front), 330mm (rear).

Suspension: 2-way adjustable Ohlins dampers.

Driver safety: Sabelt composite seat and belts.

Electronics: Magneti Marelli SRG 140 with XAP driver interface.

Fuel tank: FIA FT3 spec, 95 litres.

Dimensions: Wheelbase, 2419mm; length, 4178mm; width, 1798mm; height, 1190mm.

Weight: 1000kg (regulatory).

Right top: The ACO wanted Alpine to develop a car for GTE but its new A110 was deemed too small and the marque opted to build a GT4 version instead
Middle: Aerodynamic development has been a balancing act between creating downforce while maintaining stability for the gentleman drivers
Bottom: The front splitter complements the large wing at the rear. The racecar is styled to resemble the competition A110s of the 1960s and 1970s

really just too small for GTE; not just in terms of the engine, the physical size of the car is just too small, too. Even for GT4 it was too small, really; there is just no space, you struggle to get the big wheels in even. It's a nightmare.'

Little wonder

Once it was realised that the A110 was far too small to use as the basis of a GTE car, work was directed into a new lower spec one-make Cup car, which in turn formed the basis of the GT4. 'We are really proud of the chassis. Only the centre part of it remains from the production car,' Chevalier says. 'The front and rear are fully machined aluminium parts, so this is a bit more than a tuned production car. It really is a real racing car. In fact, the driver feedback on it so far has said as much, it is really very stiff. The GT4 car is based on that Cup car chassis, with the same general layout, and the dampers and braking system carry over completely.'

That braking system comes from Brembo and is one of the first applications for a new family of calipers from the Italian firm.

'We have a 6-piston caliper which has an asymmetric design so it's fully optimised for

'The GT4 regulations give us more surface area so that has also allowed us to massively increase the cooling'

torque, weight and stiffness,' Chevalier says. 'It is similar to the Radi-Cal concept introduced by AP about 10 years ago. We have a 28mm pad in there which lets you do a 12 hour race, or 24 hours, with a single pad change.'

The Alpine GT4 also features a bespoke transmission from 3MO, a 6-speed sequential with XAP electro-magnetic shifting.

Power boost

One of the major differences between the production car, the Cup car and the GT4 is the state of tune of the Renault 1.8-litre turbocharged in-line 4-cylinder engine. In standard trim it produces 249bhp, while in Cup spec it's 270bhp. But in GT4 trim it is significantly more. 'The overall engine package is a lot more powerful with this car; the BoP is set at 330bhp compared to 270bhp in the Cup car, but actually the engine has a bit more than 330bhp,' Chevalier says. 'It's the same engine but with a new bigger turbo package. That means we needed to do a lot [of work] on the cooling system. Getting the best efficiency was really the biggest concern when we were creating this car with the turbocharged engine, making power is easy, you just turn up the boost, but with that you increase the temperatures.'

That additional cooling requirement was, then, always in focus when it came to the car's aerodynamic development, conducted exclusively using CFD rather than with wind tunnel testing. 'There are two water/air intercoolers at the rear while at the front there are three radiators [that are] only for turbo cooling,' Chevalier says. 'The GT4 regulations allow us more surface area so that has allowed

'The cockpit and controls in this racecar are two things we are really proud of'

us to massively increase the cooling. The external shape has to remain the same but under the skin everything can be changed in terms of air flow, so we worked a lot on that.'

Alpine air

Clearly there have been performance focussed developments on the A110's bodywork over the Cup spec car – the large rear wing the most obvious – but according to Chevalier, designing this package forced the engineers at Signatech to consider other factors beyond the aero performance, because this is a high profile new product from a major manufacturer.

'Another factor in developing this car was that the styling department at Renault was involved,' Chevalier says. 'Luckily we have a strong relationship with them. A lot of the younger stylists there are really into racing so they have been with us in the factory working on this. But there is a compromise to be made at times, so when I come up with an idea for the aerodynamics I first showed it to the head stylist to make sure he is happy with the way it looks, but normally he just says "if it works I like it".

The steering wheel and dash has been especially designed by XAP for the A110 and is similar in concept to an LMP2 wheel

'They are not just stylists there, they are also interested in the function of the parts and for me that makes them real designers,' Chevalier adds. 'If it does not work, what is the point? They have this approach and it is really good to work with them. The result is what you see here.'

The aerodynamic package now features a different front end with a proper splitter, for downforce, that rear wing and, as mentioned earlier, an optimised cooling package.

Driver friendly

Beyond the styling there was another reason the emphasis for the aerodynamic development was not ultimately all about creating the fastest car possible. 'When we are looking at the aero there were really two areas to look at, pure downforce generation for performance, then there is the stability overall,' Chevalier says. 'I was really more interested in the second of these because it is not all that easy to make a lot of downforce on this kind of car, and secondly we simply don't have a lot of power, so drag would be an issue. Ultimately, this car is for gentleman drivers. We could get a high level of downforce, but those drivers simply could not utilise it.'

Another area where the ability levels of gentleman drivers has been taken into account is in the cockpit of the car, where all of the control systems, and indeed even the seat, are either bespoke or new products to the market.

'For us, the cockpit and controls are something we are really proud of,' Chevalier says. 'Take the seat, for example. It is a new concept from Sabelt, where you have a large seat shell and you change the pads to suit the drivers you have. This is quite a big advantage for this type of car with gentleman drivers who are not all the same size and shape like the professional drivers, this is the first time it has been fitted in a car. It lets you adapt really quickly.'

Reinventing the wheel

That thinking carries over to the dash, but then goes much further. 'In terms of the electronics, we have a Magneti Marelli ECU,' Chevalier says. 'But the steering wheel including the dash is a bespoke design for us from XAP. The concept is to have the same kind of wheel as the LMP2, we want just the master switch on the panel and pretty much everything else on the wheel, like a sports prototype. The car has variable ABS so the driver can adjust it through 12 positions; there is a TC [traction control] map rotor, different maps, with the usual alarms and things.'

This approach of making the controls similar to the LMP2 might suggest that there could be more to come from Alpine. And while Chevalier declines to comment, beyond a telling smile, rumours in France suggest that a R-GT Rally specification version of the A110 is also under development, while an all-new production car, possibly using the Nissan GT-R platform as a basis, could perhaps be turned into that GTE the ACO wanted Alpine to build all along.

Back on track

What would it take to get a very special ex-Brun Motorsport Porsche 962 Group C racer that had not seen action since 1991 race ready again? *Racecar* visited Classic Revival in New Zealand to find out

By DR CHARLES CLARKE

PHOTO: RICHARD OPIE

Group C is generally regarded as a golden era of world sportscar racing. Spanning 1982 to 1993, it was a time of legendary drivers, teams and racecars. And one car stands out in the record books of that time – the Porsche 956 and its younger sister, the 962C.

The 956 first appeared at Silverstone in 1982 and the last 962 iteration of the model finally retired from racing in 1994. The stats over its lifetime are impressive: six Le Mans wins in succession and seven overall; five FIA world championships as well as three IMSA titles and five Daytona 24 hour victories.

These days Porsche 956/962s are a common sight at Group C revival races at historic meetings throughout the UK, Europe and the USA. However, they are a very rare sight in New Zealand.

Auckland-based Classic Revival (see box out) is going some way to putting that right, though. Pride of place in its workshop is an ex-Brun Motorsport, Hydro Aluminium liveried, Porsche 962C that was raced in the 1989 World Sportscar Championship and at the Le Mans 24 hours in 1989 and 1990.

Walter Brun's team was based in Switzerland and was a mainstay of Porsche's customer racing programme in the Group C era, starting with a 956 in 1983 and winning the world championship outright in 1986. It also had success in the US, finishing second at the Daytona 24 hours in 1987 and third in 1989.

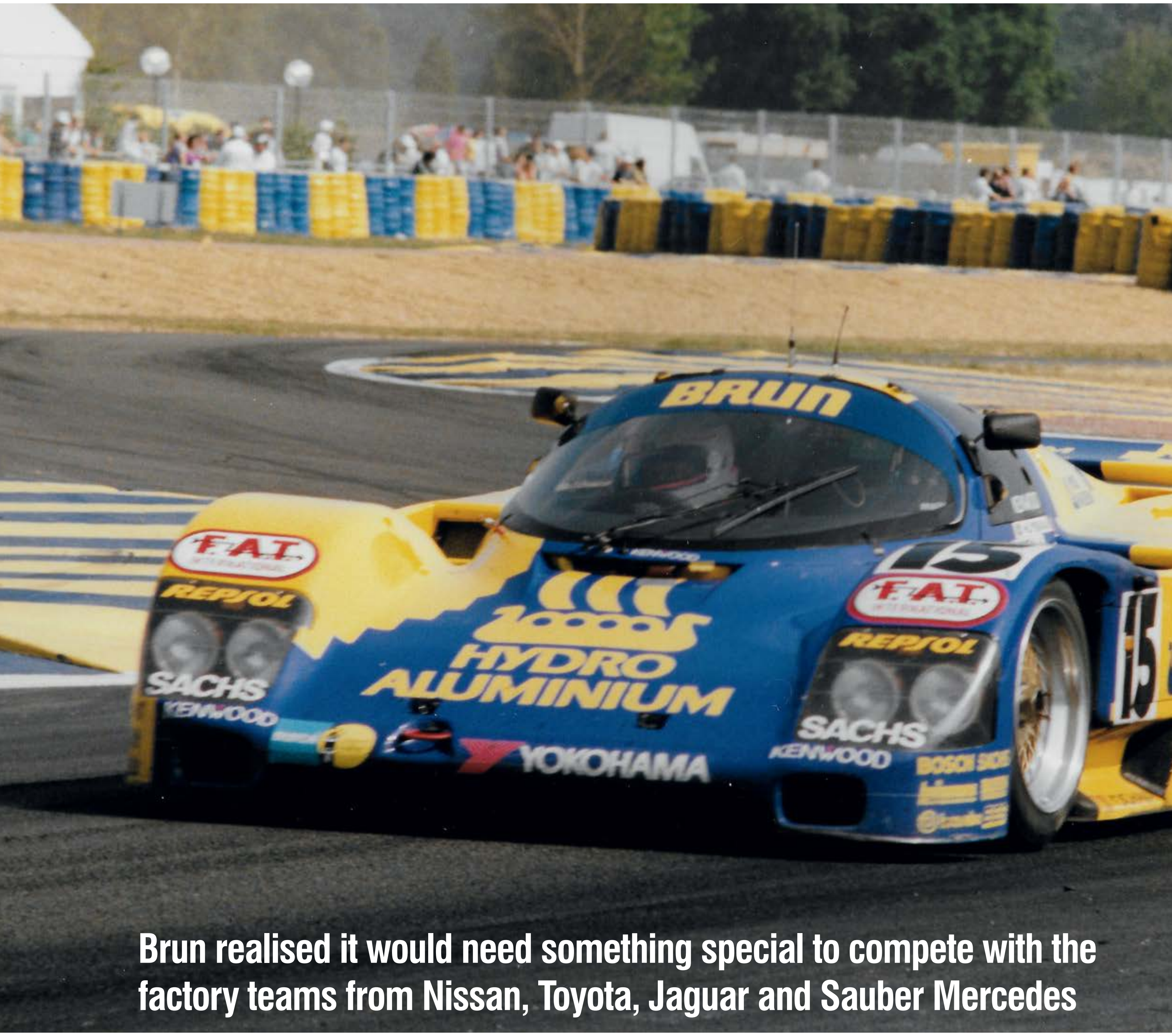
As well as driving himself, Brun employed some of the best sportscar drivers in the world at that time to pilot his racecars, including Stefan Bellof, Oscar Larrauri, Hans-Joachim Stuck and Derek Bell.

Private enterprise

With the Porsche factory withdrawing from full-time Group C competition at the end of 1987 and offering equal support and development to the customer teams including long-time customer team Joest, Kremer and RLR, Brun decided it would need something special to compete with the factory teams from Nissan, Toyota, Jaguar and Sauber Mercedes.

The team developed its own chassis with John Thompson at TC Prototypes in the UK. It addressed two of the Porsche monocoque's shortcomings – the lack of rigidity compared to the full carbon chassis of its competitors, and safety – with a mixture of carbon fibre and aluminium honeycomb. Porsche engineers contest that it was stiffer, but not that it was cheaper!

'We're not expecting much difference in overall performance from when the car was first raced'



Brun realised it would need something special to compete with the factory teams from Nissan, Toyota, Jaguar and Sauber Mercedes

The rest of the car was more or less the same as the factory built 962. In total eight cars were built by Brun; 962-001BM first appeared in early 1987, with 002BM being completed by mid-year. Both of these racecars were powered by the early 2.8-litre air/water engines (water-cooled heads with air-cooled barrels) running on Motronic 1.2 engine management. The other six chassis had the later factory spec 3-litre fully water-cooled engines running on Bosch Motronic 1.7 engine management.

Class of '89

The Classic Revival car is 962-003BM, the third car built by Brun, which first appeared at Suzuka in April 1989 for the opening round of the World Sportscar Championship. It featured the Hydro Aluminium livery and had a short-tail body developed by Bombien specifically for the Brun team. Its design included a double-element rear wing separate from the engine cover, and distinctive cut-outs in the lower part of the sidepods behind the front wheels.

Chassis 003BM was central to Brun's 1989 world championship campaign. Its best results were a fifth place at Donington and second overall at the final round in Mexico, for both of these Harold Huysman was partnered by Oscar Larrauri. The car's result in Mexico proved to be the last time a 962 finished in second place in a World Sportscar Championship round.

After making just one appearance in the 1990 World Sportscar Championship – at Monza in red, white and green Torno colours and driven by Massimo Sigala and Eje Elgh – 003BM returned to Le Mans for a second time. Back in Hydro Aluminium livery and driven by Huysman, Sigala and Bernard Santal it was fitted with the latest up-rated full works spec 3.2-litre Andial built engine. It started mid-grid after issues in qualifying, but climbed up the order and finally crossed the finish line in 10th place.

Game over

After Le Mans the car was used to test the installation of the Neotech V12 engine that Brun was developing for 1991, in readiness for the introduction of the 3.5-litre normally-aspirated Group C regulations.

The 003BM car was then sold by Brun at the end of 1990 to German privateer Willy Koenig, along with the sister 006BM chassis. But after doing just three Interserie races in 1991 the car was retired from competition. It spent most of

Porsche 962-003BM as received. The car came from a museum and had been pretty much untouched since the early 1990s

Disassembly begins. The gearbox was fully stripped and crack-tested and then rebuilt with a new crownwheel and pinion

Porsche 962-003BM in action at Le Mans in 1990, where it was fitted with the latest uprated full works spec 3.2-litre Andial-built powerplant. It started mid-grid and finished in 10th place

The tub is straight as the car was never involved in any major shunts when it raced, but there was a problem with the floor

the 1990s in a private collection in the UK and it then became part of the world-famous Historic Porsche Collection of Group C cars in 2001.

The car was then bought by a private collector in early 2016 and it has now made its way to New Zealand, where it has returned to the track for the first time since 1991.

'Luckily, it hadn't been touched and was pretty much exactly as it left the track in 1991, grime and all,' says Paul Higgins, the owner of Classic Revival. 'Often old racecars get modified, updated, repaired or changed by intervening owners, but that wasn't the case with this racecar, so we have been able to document exactly the way it was built by Brun. Because the car was in such good condition we had to replace very little. The tub is still very straight and it has never been in any major incidents.'

‘These engines are producing about 900bhp and they typically run at about 720bhp in race trim’

The plan was always to restore it sympathetically, keeping as many original parts as possible, while also making sure it was as safe and reliable as possible. ‘A lot of classic racecars have been rebuilt or renovated and very little care has gone into maintaining their originality or authenticity,’ Higgins says. ‘We wanted to make a car that could compete in the present day, but one which retained its original look and feel. Whenever we replaced a classic component with something more modern we made sure that we could reverse the process to preserve the ultimate originality of this racecar.’

The engine has been restored by UK-based specialist Xtec, which also suggested the switch from a Bosch to a Motec ECU

RICHARD OPIE

Apart from the Motec display unit the 962’s dash is completely original and wholly operational. Note the Porsche keyring fob

It was stripped down while still in the UK, with all parts cleaned, labelled and inspected. Fortunately, apart from the expected racing wear and tear, there were no hidden surprises as the team got further into the strip down.

The X factor

The engine was then sent to Xtec Engineering in Birmingham. ‘We had known of Xtec’s reputation with turbocharged Group C 962 engines, so they were the only real choice for the engine work. This was the first time we had worked with them, but we quickly developed a good relationship,’ Higgins says.

Once the racecar was stripped to the bare chassis, decisions were made with regard to the programme of work. As the car was going to be raced in the European Group C historic series there are several modern safety requirements that needed to be met. All of the suspension, uprights, steering rack and column, pedals and wheels were sent away for blasting and crack testing, the fuel cell was replaced with a modern certified version and a new fire extinguishing system was installed.

‘The great thing about the Porsche 962 is that there are so many of these running that it’s fairly easy to get the parts for them,’ says Higgins. ‘There are people making cylinder heads, cranks, pistons and gearbox casings, not cheaply, but these parts are available.’

Electric switch

On the recommendation of Xtec it was decided to replace the original Bosch Motronic electronics with a Motec system. ‘There’s nothing wrong with the Motronic ECU, but if something goes wrong there’s no way to fix it without sending it back to Germany. With the investment required to run a New Zealand-based car in a European championship, it wasn’t worth risking missing a race or even a whole event due to an electronics issue,’ says Higgins. ‘With Motec there’s always a Motec engineer at the track, so it was a no-brainer.’

The car uses an upgraded version of Motec’s popular M800 ECU with a CDi8 ignition box, connected to an L180 blind logger and a D153 mini-dash. Motec’s Power Distribution Module (PDM) runs all of the electronics on the racecar, adding an extra layer of reliability.

‘It’s also possible to make fine adjustments as all the electronics have been brought up to date,’ says Higgins. ‘This is important because the fuel used will vary across the world, and it is useful to be able to tweak the ECU map to allow for differences in local fuels.’

To maintain the appropriate period look, a replica of the Bosch Motronic ECU box was machined from billet aluminium. This now houses the Motec ECU and boost controllers. It was also decided that, rather than modify and piggyback onto the original wiring loom, the complete original loom and ECU would be removed and kept in one piece, in case it was

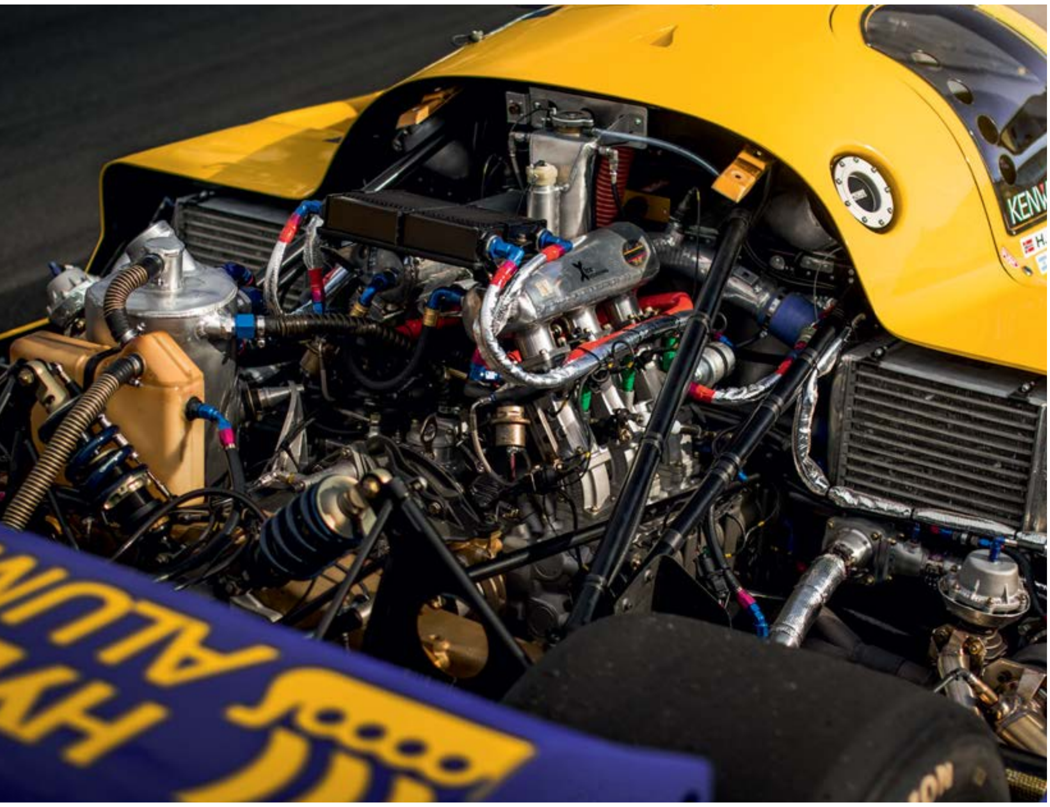
‘Often old racecars get modified, updated, repaired or changed by intervening owners, but that simply wasn’t the case with this car’

RICHARD OPIE

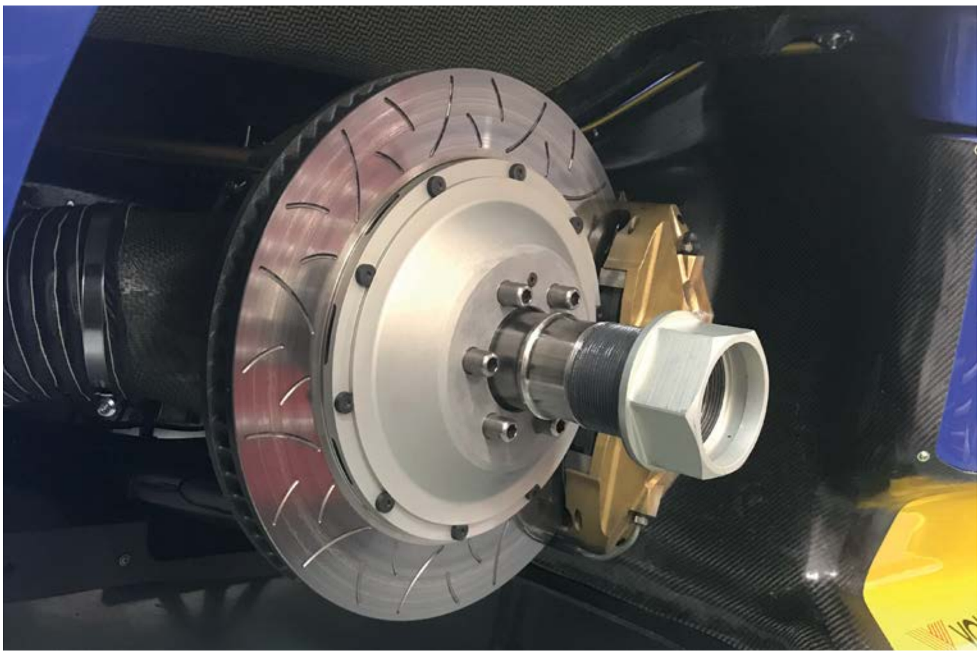
ever decided to return to the Bosch system. A complete, new, custom mil-spec loom was built prior to the car being shipped to New Zealand.

‘We are quite proud of the fact that we have been able to keep almost the entire dashboard in the car original and operational,’ says Higgins. ‘The only difference is swapping out one of the Bosch display units for the smaller Motec version. All of the warning lights, buttons, switches and knobs work properly.’

Performance is also unchanged. ‘We’re not expecting much difference in overall performance from when the car first raced,’ Higgins says. ‘In qualifying trim these engines are producing about 900bhp and they typically run at about 720bhp in race trim. They were fuel limited in the old days, as we are now, so we can’t run full boost even if we wanted to, because we would run out of fuel.’



New water radiators were fabricated while the original oil coolers and intercoolers were restored to an as-new condition



The car is still capable of 300kmh so many original parts were re-manufactured for safety reasons, including brake discs

Yellow fever

With the engine rebuilt and running well on the dyno, the car was then shipped to New Zealand. Parts were unpacked, inspected and separated into jobs. Some required stripping and re-coating, others needed repair or replacement.

With a fresh coat of bright yellow and blue paint applied, the rebuild began. All of the crack-tested suspension was re-coated and rebuilt with new rod ends and spherical bearings. Uprights were chromated and rebuilt with new wheel bearings. New driveshafts were machined based on the originals and were refitted with new CV joints. New water radiators were fabricated, but the original oil coolers and intercoolers were brought back to as-new condition. All of the oil and fuel plumbing was replaced, as were the fuel coolers that sit on top of the massive intake manifolds.

Because these 30-year-old cars are still capable of reaching speeds of over 300kmh, a lot of the original parts were re-manufactured for safety, including the brake discs, wheel nuts and the custom titanium bolts that Porsche used on the 962s. Meanwhile, the gearbox was fully stripped, crack-tested and rebuilt with a new crownwheel and pinion and new bearings.

Floor flaw

The most time-consuming job was repairing the bodywork and floor. This particular Brun 962 has several unique bodywork design elements, so there were no moulds available for new parts. All repairs had to be done without distorting any of the original panels. The massive underbody section was the most difficult to sort.

With the racecar sitting for so long, oil had seeped back down the turbocharger oil scavenge lines and had leaked out of the turbos, eventually working its way into the carbon fibre of the floor. Much of the honeycomb in the floor had to be carefully removed and replaced, before a new skin was laid over the top.

The nosecone revealed 17 layers of paint and undercoat. Brun cars at that time were constantly changing liveries as they switched between multiple championships, often changing colours week on week. In the days before vinyl wrap, the only option was to repaint on top of the old livery to save time. It was decided to remove all the paint and filler from previous repairs and do the repaint job properly, rather than just re-coat. After three days of sanding and scraping over 10kg of weight was removed from this one piece of bodywork alone.

The car has both the short- and the long-tail rear bodywork, but it will be raced in short-tail configuration. ‘The only place where the long-tail version really worked was at Le Mans on

After three days of sanding and scraping, over 10kg of paint was removed from the nosecone

RICHARD OPIE

The car has both short-tail (pictured) and long-tail bodywork but the latter is not suited to modern tracks so it won't be raced

the pre-chicane track prior to1990, so there is really no point in using it other than on demonstration runs,' says Higgins. 'The long-tail does look nice and it's great for display and demonstration purposes, but it serves no useful purpose on modern race tracks.'

Reverse engineering

As some classic racecar parts are in very short supply, having the ability to reverse engineer and re-manufacture parts to the same or better quality is absolutely vital with this sort of project. Classic Revival has developed close working relationships with several key technical partners, two of which were instrumental in helping to revive 962-003BM. The JWB Group is a high-tech engineering company and, in conjunction with the NZ arm of Haas Automation, it provided Classic Revival with access to a fully-equipped advanced CNC machine shop.

When the plastic side windows needed replacing, rather than source new ones in Europe and risk them not being the right shape or colour, JWB was able to digitise the originals and machine a mould to the exact shape, from which a pair of new windows were formed. These included the distinctive air scoops fixed to the windows to feed fresh air into the cockpit.

Finishing touches

In period this racecar ran several different configurations of canards on the nose at various tracks, which again were specific to the Brun body. Only one side of one type survived. Kinetic Simulation, a company specialising in aerodynamic design, computational fluid dynamics and finite element analysis, was able to scan the surviving side in 3D and model a pair of bucks. JWB machined these from foam, from which moulds were made and a new pair of carbon fibre canards produced.

Another missing part was the cover for the four main fuel pumps, which are located in the passenger side of the cockpit. This was pretty important, as safety regulations require that these be covered, so the cockpit was also 3D scanned and a custom carbon fibre cover produced to fit this intricate space.

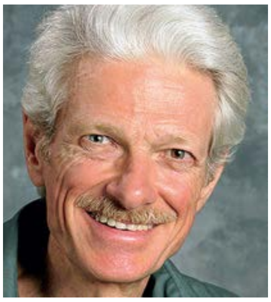
A complex and lengthy process, involving organisations on opposite sides of the globe, has brought this iconic Porsche 962C from a staid existence as a museum piece to being able to compete again. It recently completed a successful shakedown at Hampton Downs in Auckland prior to being shipped back to Europe, where it is scheduled to return to Le Mans for the 2018 Le Mans Classic, before heading to the USA for the Rennsport Reunion at Laguna Seca, and the Daytona Classic.

Revival of the fittest

Classic Revival has been involved in motorsport for over 30 years and is no stranger to racing famous Porsches, having won a couple of New Zealand Supercup Championships in the 1990s with a former Spa 24 hour-winning 911 RSR.

More recently it has turned its hand to historic racing, winning the 2014 and 2018 Tasman Revival Formula 5000 Championships – the premier historic series in New Zealand – with a Lola T400 and a T332.

Its workshop also contains a Leyton House March F1 car from 1989, recently restored and reunited with its original driver, Ivan Capelli, at the 2016 Adelaide Motorsport Festival. A 1991 Leyton House is also about to enter full restoration after being left neglected in an Italian collection for the last 20 years. When this car is finished it will be the only restored Ilmor V10 powered Leyton House F1 car in the world. There's also a March 742 F2 car in restoration, while several ground-effect Formula Atlantics are being prepared.



Tuning a Lagonda for track day action

The debate on the suspension quirks of an old classic continues

QUESTION

Following on from last month's question regarding my 2.6 Lagonda, I have a more ambitious objective for another car, which is to make it into a track day and hillclimb car. This is to be created from a 2.6 Lagonda that is in need of total restoration. It will never be a competitive proposition, as with a dry weight of 29cwt (1473kg) it is going to be far too heavy, so this project is just for fun.

The original tyres were 600x16 cross-ply on 4in wide rims. Radials seem to be a much better modern alternative, and the equivalent is 185x16: options are Avon Turbosteel, Vredestein and Michelin X. All need wider than a 4in rim, something we're working on

I have run the saloon with Vredestein tyres on original wheels re-rimmed to 6in, and with the rear wheels at zero camber it does feel close to a modern car in normal road driving. Just don't lift off in the middle of a fast bend!

Camber changes

It is easy to change the rear wheel chamber by simply backing off the torsion bar adjusters. This does, of course, also drop the ride height. Ride height is often given at a bit over 7in. With the rear wheels vertical the clearance under the rear cross-member is about 6in. Hopefully, this will be okay for modern, normal road conditions. The track day car can be as low with as much negative as seems prudent.

Another easy mod would be to fit the torsion bars from the 3-litre, which has a larger diameter, and so an increased spring rate. The 3-litre is about 150kg heavier than the 2.6; I think almost all the increase is on the back axle as the major change for the 3-litre (apart from engine) was a big increase in the depth of the boot, and the front springs were not changed. The 2.6 torsion bar has a diameter of 7/8-inch and the 3-litre is 15/16-inch. The only downside is that there is a register in the splines at both ends. I suspect there's not enough adjustment to correct for the higher rate and lower the car to get the wheels vertical.

I've read that a rolling radius for the (cross-ply) tyre is 13.35in, but this may not be generally representative as it is part of a load calculation on the rear wheel-carrying member at the limit of cornering grip. We have used 13 1/4-inch as a rolling radius for 185x16 tyres on 4in rims for the purposes of recalibrating the speedo, and this has worked out pretty well.

The pictures (bottom right and next page) might give you a better idea of the rear suspension on a Lagonda. The wooden blocks in place of the bump stops have set the rear wheels vertical, which I propose to use as the set-up height for the rear suspension: 6in under the rear cross member. The front of the car is set to give the same ride height at the lowest point on the front of the car, which is the bottom of the steering rack.

As for both front and rear suspension we are moving the ride-height position closer to the full-bump position so there will be less free movement in bump. The original Lagonda design was for 3in bump and rebound.

Also, as the front of the car will be running lower we need to change the front coil springs, so they can be made stiffer at the same time.

Anti-roll bar

The 3-litre Lagonda, which uses essentially the same chassis frame as the 2.6, was fitted with an anti-roll bar at the front, so we can use that, or something similar. I suppose we could make the rear suspension 'in-series' rubber spring softer by changing the rubber, thus softening the rear role mode.

Another thing that would be relatively straightforward to do would be to switch from old lever-arm dampers to modern (in this context 1990s Konis, say) telescopic dampers; and if adjustable that is something that could have one setting for the road and another for the track. Is this a good idea?

Front suspension as original has 1.5deg positive camber (not adjustable without surgery, which is possible) and 2.5deg caster (which to some extent is adjustable by shims).

THE CONSULTANT

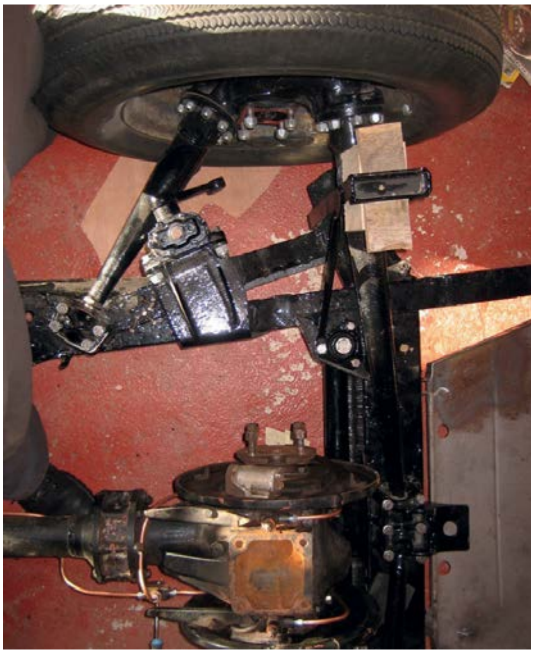
What will really help is a ride-only spring in the rear (Z bar or swinging leaf spring) and a roll-only spring (anti-roll bar) in front. In most cases it is possible to make these a reversible modification, which benefits the resale value of a restored car; you can return the car to stock configuration if desired, with perhaps just a few non-original mounting holes here and there.

What bolt pattern do the wheels on this car have? How much ground clearance do you think you need? How funny looking can you stand to make the car? It definitely helps with swing axles to run a small tyre diameter. Yokohama has a 195/40-16 with a 300 tread wear rating that is only 22.1in OD, and a 175/50-16 that is 22.9in. There are a variety of other less extreme options in 16in, and lots of other possibilities if you swap wheels.

THE QUESTIONER

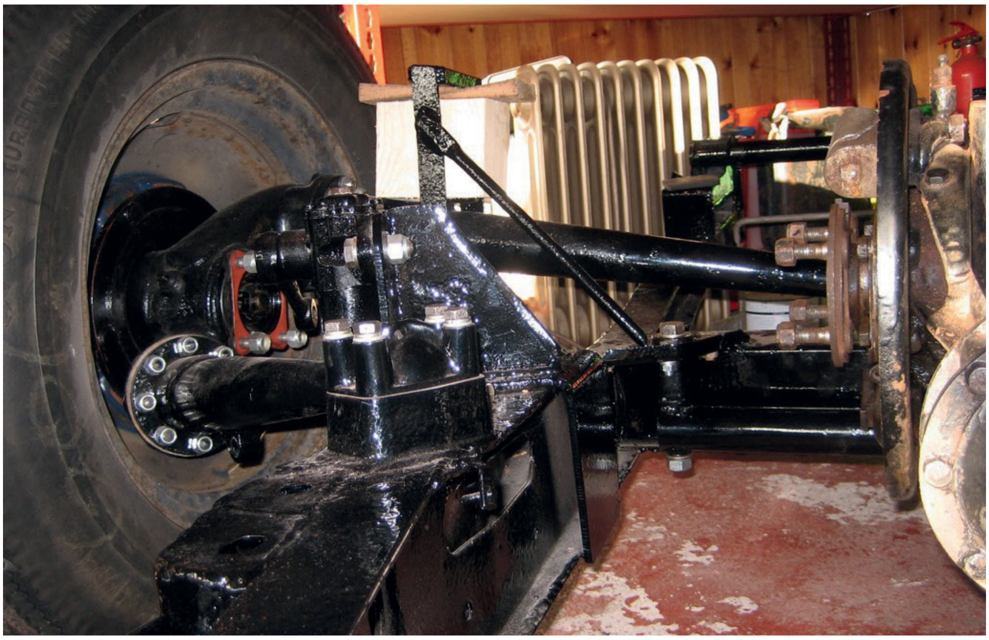
Wheels and tyres: five stud on 8in(203.2mm) pcd and, apparently, unique. It is very close to the VW wheel (205mm) but not close enough to use one of the many VW wheels available.

Lagonda wheels have a rim riveted to the centre. So far we cut off some old, rusty rims and made a few wheels with new 6in rims welded to original centres. As well as the wider rim being a much better support for a modern



Typical Lagonda rear suspension; the wooden blocks are in place of the bump stops. The diff can be seen at the bottom

We really want the rear suspension stiff in ride, not just soft in roll



Could connected ride assist air springs be fitted in the area around where the bump stops should be (wooden blocks)?

radial tyre it also means that without the rivets there is no need for an inner tube.

This is okay up to a point, but the only really satisfactory long-term solution is to have new centres pressed; eventually there may be enough demand to make this a possibility.

As to the tyres, the Vredestein 185/16 radial is the mandated tyre for the Jaguar race series – which features old MkIIs and things like that. So this is the current choice for the Lagonda. For road use the 185x16 Firestone is cheaper, and slightly taller, so more suitable as a road tyre.

But I was also thinking; how about two linked air springs? Same effect as a swinging leaf spring? I am told ride assist air springs (for towing) in doughnut form are available, and maybe a suitable size could fit round the rear bump stops [where the wooden blocks are in the picture above]? The ground clearance is 6in for road, a little bit less for competition.

THE CONSULTANT

As I noted last month, and as you have correctly understood, the Lagonda system is like the Triumph swing spring. But a roll-only spring in series with the ride springs is not quite the same as a ride-only spring in parallel with them; it softens the roll mode rather than stiffening the ride or two-wheel heave mode. Theoretically, if we can specify any rates we want, we can get similar results either way. However, starting with a given set-up, softening roll is not quite the same as stiffening ride. The effect on the relationship of the two rates is similar, but that's not all that matters.

All other things being equal, reducing rear elastic roll resistance reduces jacking force, but for any given jacking force, the amount that the car jacks depends on how stiff the rate in ride is. So we want the rear suspension stiff in ride, not just soft in roll.

We would also like to have a rear suspension with little or no elastic roll resistance. This works well on Formula Vees. There will still be lots of geometric roll resistance. But we don't want the car to roll a lot. Therefore, we want to add front roll resistance. Adding front roll resistance reduces load transfer at the rear, just like reducing rear roll resistance. Most cars with swing axle rear suspensions use front anti-roll bars.

Air springs

Connected air springs are definitely a possibility. Renault did this on the Dauphine to tame swing axles. The bags went inside the coil springs that were the only springs the car had as originally designed. I can't find any confirmation of this now, but I think the air bags were first introduced by Amedee Gordini on the performance-tuned Gordini version of the car, and were then added on to all Dauphines later in the production run.

One disadvantage of air springs for this application, compared to other options, is that air springs are generally rising-rate. If anything, we want falling rate for this; the important thing is to increase the wheel rate in ride or two-wheel heave, when the suspension extends beyond the static setting. That is what reduces the ride displacement when the system tries to jack. Another concern would be whether the torsion bars can be adjusted low enough to give the desired ride height when the air bags are inflated.

What we would really like here would be connected air bags arranged to compress the suspension rather than extend it. That might be possible. I'm really not so sure it would be easier than a torsion bar or leaf spring, but there's probably a way to do it.

Zero camber gives good tyre life on the street, but to make swing axles work well in hard driving you need two to three degrees negative, statically. That will correspond to about an inch lower ride height.

We can play around with various springing arrangements to crutch the existing suspension, and it will be interesting to do so. However, I think maybe I see a way to really fix the car: actually solve the geometry problem rather than crutch it with springs.

It looks to me like the system could easily be converted to a DeDion system, as a reversible modification using entirely bolt-in parts – at least if there aren't packaging issues with parts not shown in your pictures. This could produce a car that can run a soft set-up and ride bumps well, without having snap oversteer. With swing axles, we inescapably have to either live with the snap oversteer if we want the car to ride bumps well, or put up with the consequences of hard ride springing if we want to get rid of the snap oversteer.

The next step

Looking at the mount for the rear arms, the one right behind the diff with the six bolts (in picture previous page), that mount has a tab hanging off of it that looks like it mounts something – perhaps the body, or perhaps the fuel tank. What attaches to that?

Is there room for a DeDion tube to move up and down behind the diff when everything is assembled? It would be a tube about two inches in diameter that would need to move up and down as much as the wheels do (about three inches each way, I think?). It looks like it would clear the cross-member and the diff, but does something else live in there?

Next month: we further explore the possibility of a DeDion conversion.

Zero camber gives good tyre life on the street, but to make swing axles work well in hard driving you need two to three degrees negative

CONTACT

Mark Ortiz Automotive is a chassis consultancy service primarily serving oval track and road racers. Here Mark answers your chassis set-up and handling queries. If you have a question for him, please don't hesitate to get in touch:

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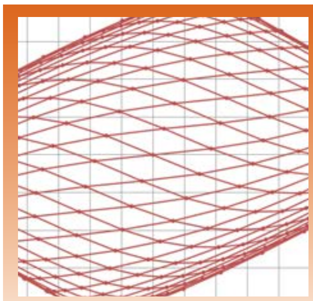


Slip Angle provides a summary of OptimumG's seminars

Formula Student 101

OptimumG's 101 top tips for Formula Student success concludes with Claude Rouelle's final 26 pearls of wisdom – including advice on bump-steer, stability and communicating with drivers

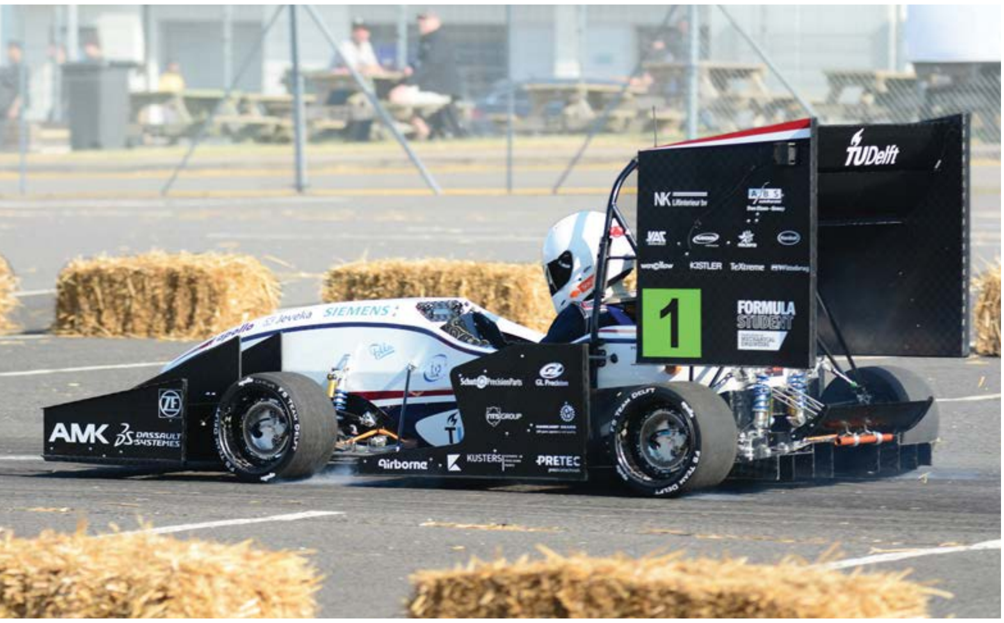
Besides his leading role at OptimumG, Claude Rouelle also often offers his services as a design judge in many Formula Student competitions. He started his 40-year racecar engineering career by designing and building a racecar and a wind tunnel; it was his engineering degree master thesis. The challenges he faced then were similar to those faced today by students building a first car for Formula Student competition. He is then, ideally placed to offer his advice. Below are his final 26 short engineering and team building tips (see the last three issues for the first 75). And if you're not a student? Well many of these gems are also applicable to professional race teams.

76. When you design your Formula Student car, think about the installation on the chassis of the tools that you will be using to measure each wheel's toe: fishing string or, much better, laser beam on a flag. The fixture of these tools on to your chassis should be part of your racecar design.

77. A bump-steer target should be part of your set-up sheet. You need to define how to measure the toe variation versus the ride height variation. Without compliance, the toe measured with step by step dummy damper length reduction on a set-up pad (or blocks of wood of different thickness between the set-up pad and the bottom of the chassis) versus the ride height variation will give you a bump-steer law that most kinematics software with no compliance will give you too. With compliance it is worth adding load (sandbags for example) to simulate the aero load and/or the longitudinal weight transfer. You do that with real springs and real tyres at hot pressure and measure the toe variation and the ride height variation. The ratio between these two measurements will give a more realistic motion ratio number. The other alternative could be, lucky you if so, putting your car on a K&C rig. But the usefulness of these K&C tests depends very much on the test preparation.

78. You can't perform serious tests without an accurate set-up procedure. You need a set-up pad with four scales that are perfectly horizontal. It is well worth making sure your measurement reference plane is, and stays, horizontal.

79. Car balance is very sensitive to the tyre static load variation. On an FS car 0.5kg of cross weight difference (LF + RR compared to RF + LR) statically with an asymmetric set-up, or dynamically, with for example an anti-roll bar adjustment, could change yaw moment (and hence car balance) by as much as 20 per cent: a huge difference in the car's behaviour.



Drivers are much more sensitive to the racecar's balance than they are to the amount of grip available

80. It is worth putting your car on the set-up pad and turning your steering wheel from full left to full right and return, and let's say every 30 degrees of steering wheel movement, measure your LF, RF, LR and RR ride heights, your corner weights, your cambers, your damper lengths, and your LF and RF steering wheel angle. It will give you camber, corner weight, ride height, motion ratio and Ackermann curves that will be worth comparing with your simulation curves. Moreover, if these curves are different from turning the steering wheel from full left to full right and full right to full left, you know there is an asymmetry in your car and it is worth investigating what the causes of this are.

81. In the same spirit, it is useful to load your Formula Student car step by step with sandbags and measure your dampers' length, your tyres' loaded radius, chassis ride heights, cambers and toes. It will give you very useful information that is worth comparing with your simulations. In any case, always believe more what you measure (if you measure accurately) than what you simulate. Simulation is for trends and sensitivities (the slope of the curve) not for absolute value.

82. There are four ratios that are, ideally, linked and which will determine your racecar grip and balance. These are the weight distribution, the tyre cornering stiffness distribution, the aero-balance and the anti-roll stiffness distribution.

83. In a rough estimation, the front and rear tyre cornering stiffness ratio is within a few per cent of the front and rear tyre width ratio. But that really is a rough estimation. Ideally, you will have to look at your front and rear tyre cornering stiffness from your non-linear tyre model. Beware: a tyre cornering stiffness (N/deg) is not the tyre lateral stiffness (N/mm). They are related though; a larger tyre will give you a bigger lateral stiffness and a bigger cornering stiffness but the ratio between the two stiffnesses is not necessarily linear.

84. On a rear-wheel drive car that has the same front and rear tyres your simulation will show that your best lap times are reached when your weight distribution is about 46 to 49 per cent. That is often the best compromise found between pure cornering (skid pad for example), pure braking or

Formula Student corners are so tight and so low-speed that stability is less of a concern than on more normal race tracks

acceleration (in a straight line) or a combination of both braking and cornering (in the corner entry) or acceleration and cornering (at the corner exit). If you are outside that percentage, you are probably compensating undesirable chassis and/or suspension wishbone and upright compliance with your springs and anti-roll bars.

85. I have no problem with a Formula Student racecar with a weight distribution of 40 per cent front and 60 per cent rear, but that car should necessarily have larger rear than front tyres.

86. Usually, on a good car with limited compliance, the weight distribution (front weight / front + rear weight) and the cornering stiffness distribution are within one or two per cent of each other.

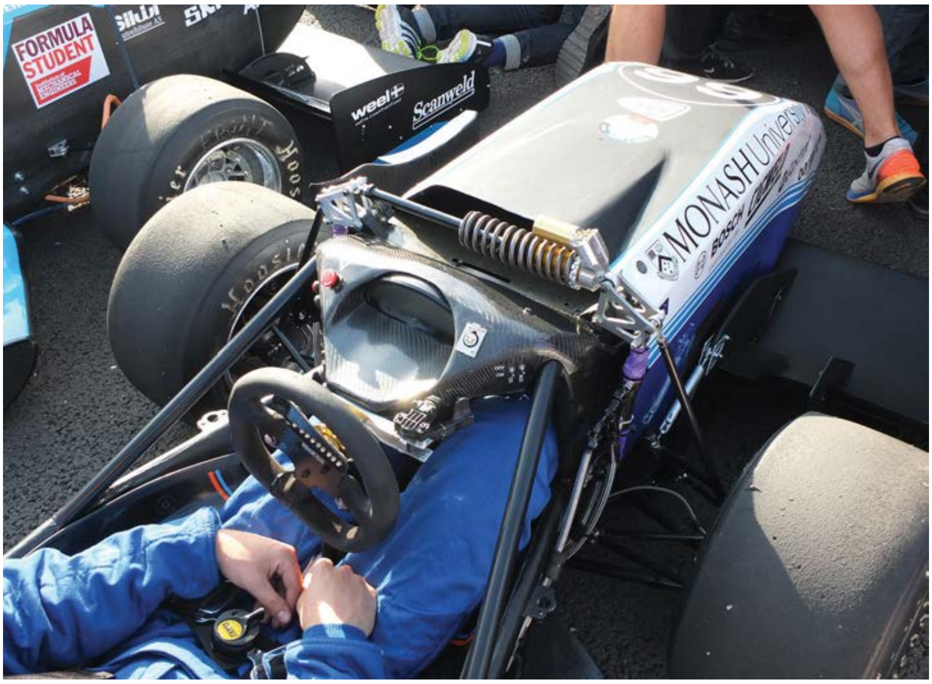
87. The wheel rate is the spring rate divided by the square of the motion ratio. Motion ratios are rarely constant by design (and/or by compliance); for an aero car you want a decreasing motion ratio (increasing wheel rate) versus ride height as the downforce is square-of-the-speed sensitive.

88. Usually the front to total anti-roll stiffness (spring and anti-roll bars in parallel, themselves in series with the tyre wheel rate) distribution percentage (front Nm/deg / [front + rear Nm/deg]) is not far away from your weight distribution. If there is more than five per cent difference that means you compensate severe chassis or suspension compliances with your spring and anti-roll bar stiffness. Patches on patches: you could get a good balance (yaw moment) but not the best possible grip: less lateral acceleration than your tyres should give you.

89. The need for stability increases with the speed. On most racecars the aero-balance percentage is one or two per cent smaller than your weight distribution. In other words, the centre of pressure (CoP) is always behind the centre of gravity (CoG). That number could go up one or two per cent at very high speed. But a Formula Student car is a different animal; the corners are so tight and so low-speed that stability is less of a concern than on more usual race tracks. It is very possible to have a five per cent, or even more, bigger aero-balance number than the weight distribution.

90. There's no such thing as understeer or oversteer. There is under yaw moment (or under yaw acceleration) or over yaw moment (or over yaw acceleration). The goal is to get the biggest possible lateral acceleration and the yaw moment you want when you want it. There are 12 causes of yaw moment: four tyres *Fy*, four tyres *Fz* and four tyres *Mz*. Good vehicle dynamics knowledge will help

With suspension you should always put far more faith in what you measure than in what you simulate



It is good practice to have a driver report car balance, grip etc on a sliding scale rising from zero to 10

you to decide how to change your set-up and from there your tyres' forces and moments, and from there your balance (yaw moment). You will know the yaw moment you need at every part of the circuit if you have a good car, tyre aero model, and you know the shape of the trajectory.

91. All drivers are much more sensitive to balance than grip. I defy even good drivers to feel a difference between 2.1 and 2.2*g* lateral. If you remove the lap time from the dashboard they will not feel a 0.5s lap time difference, although the best ones will conclude they have a better car because at the corner exit they change gear earlier. But give them a touch of understeer or oversteer and they will complain, believe me!

92. Lap time simulation is good, but not good enough. Many students will use it, often randomly changing the set-up, and see improvement, but do not often understand, qualify and quantify the why and the *how* of the set-up change on performance.

Race engineers should 'translate' their simulation results or data analysis into a language that the car's driver can understand

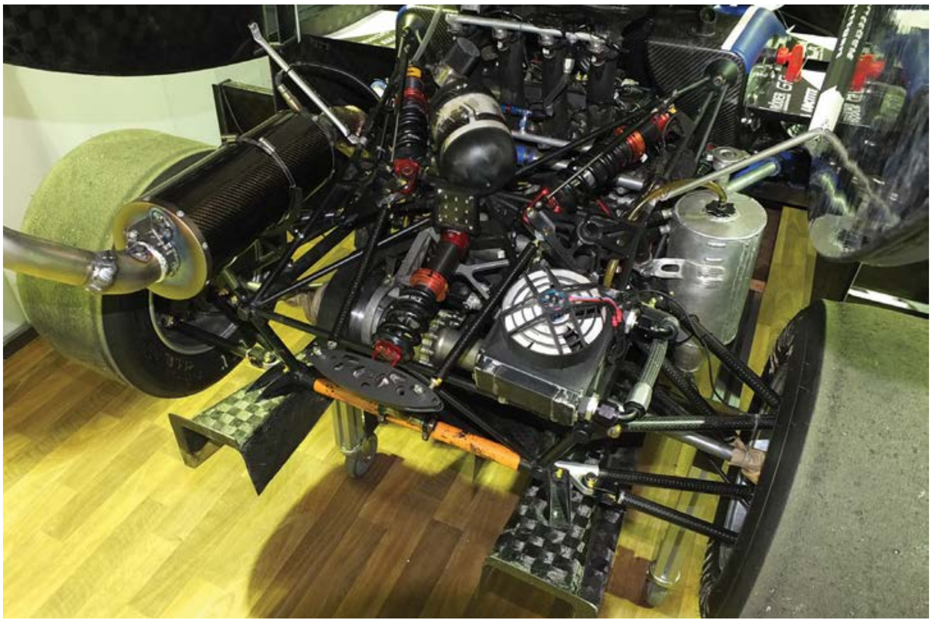
93. It is a bigger priority to first understand how your racecar design and set-up parameters influence these six essential targets: grip, balance (yaw moment), control (yaw moment created by a given steering angle variation, in Nm/deg), and stability (yaw moment created by a given yaw angle variation, in Nm/deg) on corner entry and in the corner, and stability at the apex.

94. Let's go testing. Testing what? How? When? In which order? You can't go to a race circuit to test your racecar without a test plan.

95. A good mechanic is a clean mechanic. You should be able to work on your car all day long wearing a clean white shirt. If not, that means your car is dirty. This leads us to the next advice on the order in which you should perform the different tasks; you clean, you inspect and maintain and only then you set the car up. Cleaning the car helps you to inspect it in every detail. What is the point in adjusting the ride height with a 0.5mm accuracy if you have not seen a crack in an upright?

96. The goal of the racecar engineer is to correlate subjective feedback from the drivers as well as objective simulation/data results. Most engineers are not good drivers and good racing drivers are rarely good engineers. Race engineers should 'translate' their simulation results or data analysis in driver language. The driver involvement in the racecar design and set-up is valuable but has its limitations. His or her focus should be to get the best out of the racecar out on the track, whatever the car's strengths and weaknesses are, and get back to the engineers with the most accurate and detailed racecar behaviour description.

The driver's role in the build is valuable but has limitations, and they should concentrate on the driving



Every part of the car should be spotless. By cleaning it carefully before setting up you might spot issues

97. A good way to help each other as an engineer and driver is to create a correlation between subjective and objective measurements. Here is an example of how this can be done. The driver is asked to quantify the racecar stability from zero to 10. Based on previous debriefs, the race engineer knows that when the driver's happy (a 10) the stability number at corner entry is, for example, 4000Nm/deg. But today the driver is not happy and gives a four on the stability subjective quantification. The engineer sees the stability number is 2500Nm/deg. With good vehicle knowledge and a good simulation software and a bit of experience, the engineer will know what to change to go from 2500NM/deg to 4000Nm/deg.

98. A design judge will want to see your internal engineering reports, not only the eight-page design report that teams will submit a few weeks ahead of the competition. He will want to see the big binders with calculation methods, test reports, lessons learnt from success and failure, the 'if-money-and time-were-not-an-issue' dream to do list. It shows how well the knowledge is transmitted inside the team from one year to another.

99. There are two questions a design judge will ask himself when he looks at your racecar: 'If I had the opportunity would I like to drive that car?' and 'If I had to buy a Formula Student car, would I buy this one?' Some Formula Student cars could be fun to drive but not to buy because their maintenance cost and reliability are questionable.

100. If you have 100 teams at a competition you will only get one winner. Does that mean you have losers? No. There's always something to get from these events. What every student learns at a competition is teamwork and delivering on-time, on target performance, as well as leadership – and God knows this world needs leaders.

101. There is no need to panic in design judging. And remember, this is not about life and death. It's much more important than that!

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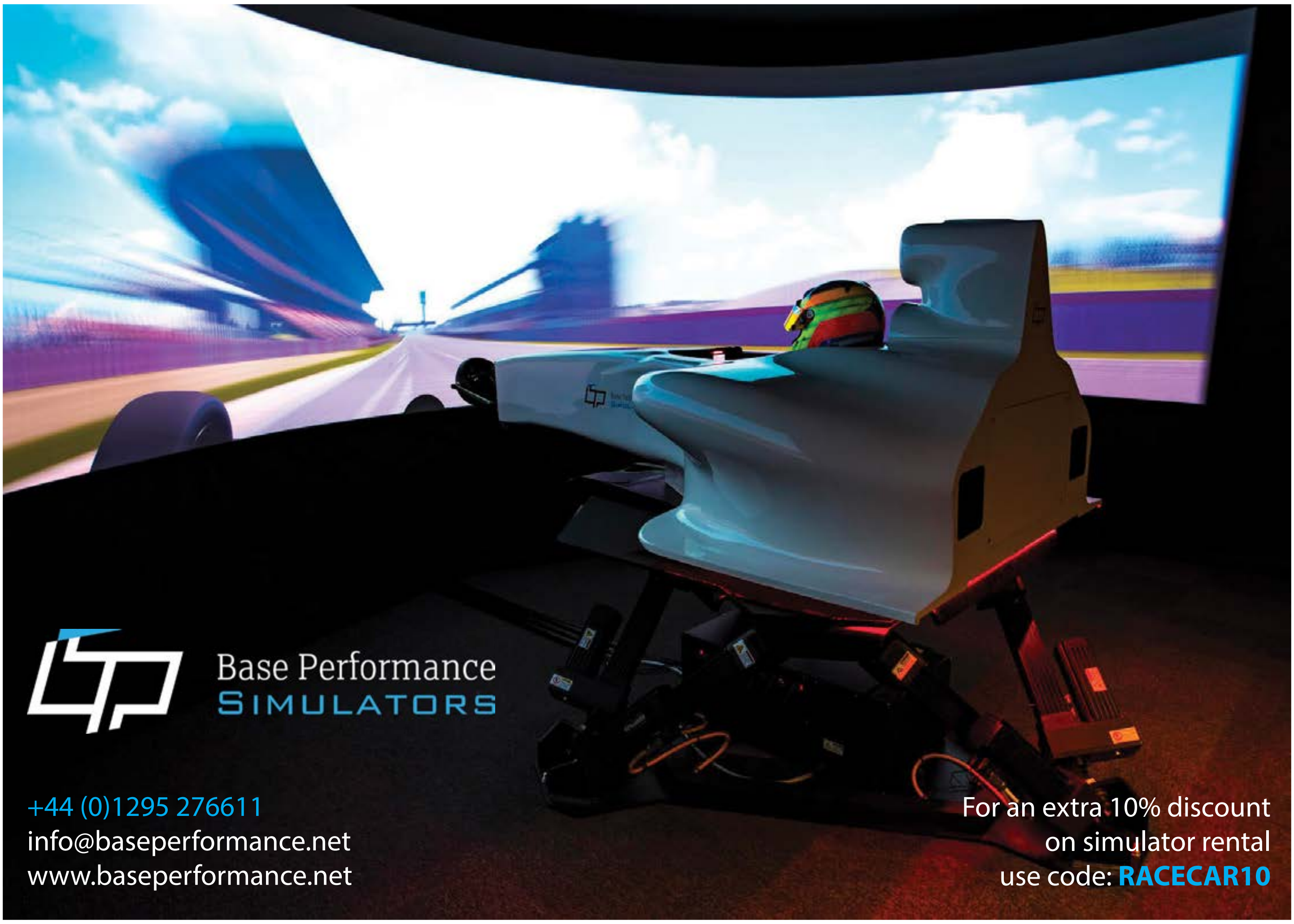
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Slope scope: rake changes on a Ligier

Our LMP3 aero study concludes with ride height adjustments

We have been fortunate enough to spend some time in the MIRA full-scale wind tunnel with one of RLR Motorsport's Ligier LMP3s recently. Team principal Nick Reynold's objective for the session was 'to find the most efficient way down the straights', a somewhat different emphasis to most of our sessions where we are generally chasing total downforce and best balance. However, it seems that as the cars have been set up at the various tracks that LMP3 races on, the Ligier has developed more drag than the opposition, and RLR wanted to address this issue while preserving or improving balance and overall efficiency.

In the previous two issues we examined the removal of the optional rear body Gurney, the removal of the rear wing Gurney (only allowed at Le Mans) and reducing rear wing angle. And we also looked at removing the front dive planes, along with re-balancing the front to rear downforce split with wing adjustments. An overall drag reduction of nearly 13 per cent was obtained, with an arguably better balance (at least for qualifying) and, because the drag reduction was greater than the overall downforce reduction, an improvement in aerodynamic efficiency (-L/D) of 3.5 per cent was also achieved. So, despite the loss of downforce, it was smiles all round. But the improved set-up was about more than just the removal of Gurneys and dive planes and the wing angle adjustments.

The RLR team wanted a less draggy racecar and our next step was to experiment with the Ligier LMP3's ride height

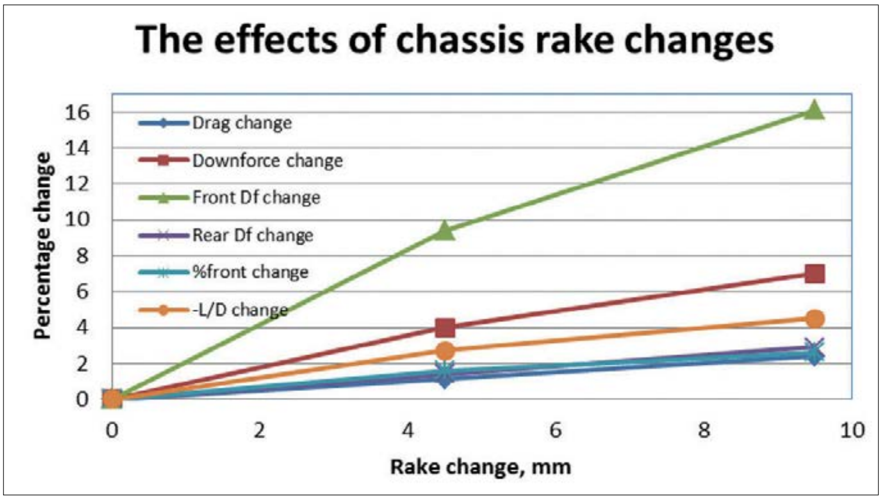


Figure 1: The impact of rake changes to the aerodynamic indicators. Note the big effect on the front downforce

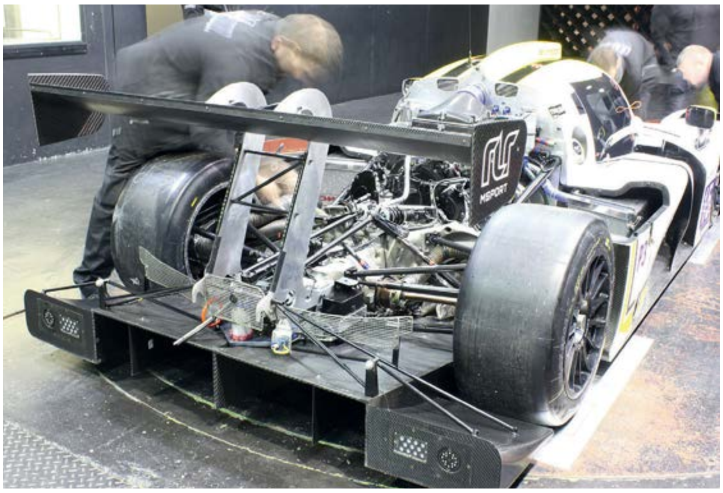
Inclined to perform

From the previous paragraph it will be apparent that most, though not all, of the drag savings were found at the rear of the Ligier. Removing the dive planes from the front also had a drag reducing benefit, and helped to restore some of the car's downforce balance too. But in order to address the issue of balance and overall performance more fully it was also necessary to do some ride height adjustments. The team was well-equipped to make quick, efficient changes simply by turning the suspension pushrods, which meant there was no time wasted on careful re-positioning and aligning of the racecar, as must happen if jacking the car is required. Various ride height combinations were tried at different stages of the session, but the generic effects were comparable in each case, so one set of data will be produced here to illustrate.

Once again, we were not permitted to publish absolute numbers, so the accompanying graph plot in **Figure 1** shows the effects on each aerodynamic parameter as percentage changes arising from changes to the overall rake of the racecar.

The stand-out parameters that were most enhanced by the addition of rake were front downforce and overall downforce. Front downforce increased by over 16 per cent over the full rake range tried here, and total downforce increased by a healthy seven per cent. Drag, however, was only modestly increased, by just over two per cent in fact,

The stand-out parameters that were most enhanced by the addition of rake were the car's front downforce and the overall downforce



Quick ride height changes could be achieved simply by adjusting the suspension pushrods

Gurneys on the leading edges of the front wheel apertures were found to be beneficial

The mandatory front wheel arch apertures do allow the air to escape in a helpful manner

Table 1: The effects of front wheel arch Gurneys

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
With Gurneys	-0.4%	+0.7%	+5.0%	-1.8%	+1.5%	+1.0%

Absolute rather than relative difference in percentage front.

It seems odd that there haven't apparently been any attempts at detailed shape optimisation ahead of these apertures

so increasing rake was a pretty efficient means of generating more downforce. Indeed, -L/D saw the third biggest change of our indicator parameters at 4.5 per cent gain overall.

Interestingly, rear downforce also increased by nearly three per cent, too, which meant that the balance shift in %front terms was not as big as might have been supposed, at around 2.5 per cent overall. Nevertheless, adjusting chassis rake looked like a very useful tool to alter the level of overall downforce and balance of the car with minor impact on drag.

As an aside to the examination of ride heights, Nick Reynolds remarked that he had seen racecars sometimes running at what looked like 'ridiculously high' ride heights front and rear. So for one quick run the car was jacked up to a ride height that 'made it look like an off-road racer' although in reality it was 10mm higher at each end than the upper extreme of the normal range, and the aerodynamic numbers were examined. In short, the car made more drag and less downforce. So that answered that question!

Wheel arch apertures

So-called 'air extractor' apertures became mandatory on the wheel arches of LMP cars in 2012. They are safety devices intended to prevent excess lift forces being exerted at high yaw angles, that is, when cars get fully sideways, and contributing to lifting vehicles off the ground. However, as we discovered when we first evaluated them in prototype form on the Greaves Motorsport LMP2 Zytek in the MIRA wind tunnel six years ago, they do also have not unexpected adverse effects on the aerodynamic performance of the car when running straight or at low yaw angles. It seemed odd to your writer that there haven't apparently been any attempts at detail shape optimisation ahead of these apertures in order to mitigate their adverse effects during normal running. Perhaps it would not be permitted, but it occurred that a little bit of shaping ahead of the apertures might reduce inflow into them. So, out of interest and in the knowledge that small Gurneys on the leading edge of the front wheel arch apertures would certainly not be allowed, we fitted 6mm high Gurneys to the leading edges of the front wheel arch apertures; results are in **Table 1**.

The effects of the small Gurneys were certainly not inconsequential then, with five per cent more front downforce created along with slightly less drag and improved efficiency. And while Gurneys as such would not be allowed, would it not be possible to create a gentle, blended 'flick up' into the shape of the arch, or simply a slightly higher surface at the leading edge of the aperture, that had the same effect as our Gurneys in reducing air entering the apertures? A similar approach could be taken on the rear arch apertures, too, although as we saw in our 2012 Zytek studies the effects of the rear apertures were rather more complex and far reaching. Notwithstanding, it still seems odd that some detail design hasn't been done, so your writer must be missing something obvious, such as 'we tried it and it didn't help'.

Next month sees the start of a brand new MIRA wind tunnel project.

Racecar's thanks go to RLR Motorsport.

CONTACT

Simon McBeath offers aerodynamic advisory services under his own brand of SM Aerotechniques – www.sm-aerotechniques.co.uk.
In these pages he uses data from MIRA to discuss common aerodynamic issues faced by racecar engineers

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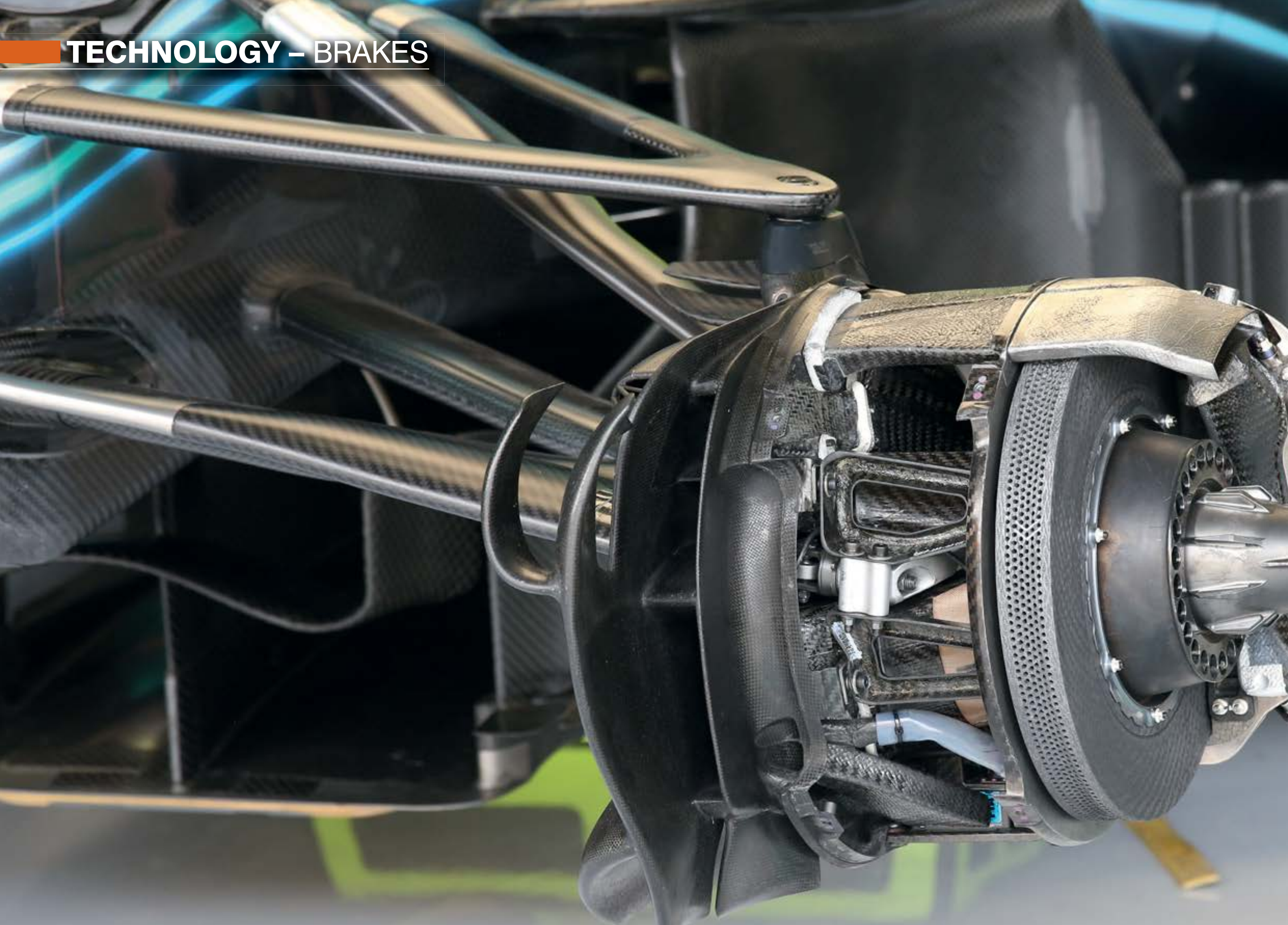


Ground **braking**

In this era of energy recovery systems the brakes have become fiendishly complicated aspects of an F1 racecar and are now as much electric as they are hydraulic – but just how do these modern brake-by-wire set-ups work? *Racecar* spoke to the experts to find out

By GEMMA HATTON

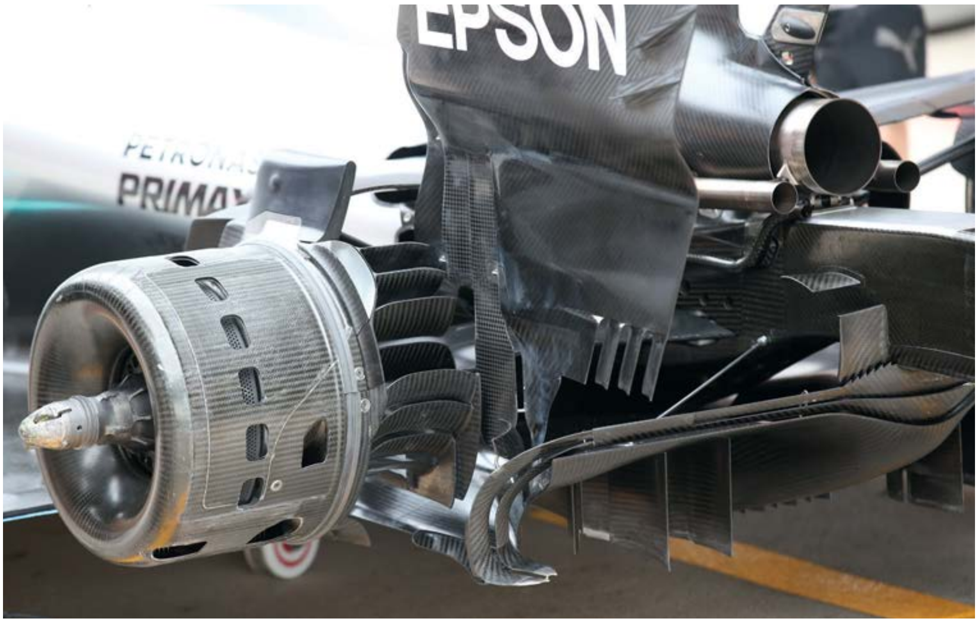
A small compliance chamber is used to simulate the feedback of the pedal to the driver, regardless of which brake system is operating the rear wheels

Did you know that the amount of g-force experienced by F1 drivers in Turn 1 at Bahrain is the same level experienced by astronauts on their return to Earth? Did you also know that the total load applied to the brakes during the Chinese Grand Prix is equivalent to the weight of 440 female adult pandas? And did you know that the rear brakes on an F1 car are controlled electronically, as well as hydraulically?

This is called brake-by-wire and it has been a regular in Formula 1 since 2014, while it also features in the new season five Formula E car. As the name suggests, it is where the pressure required to move the pistons in the brake caliper is controlled electronically, rather than directly from the force generated from the driver's pedal. That might sound simple enough, but as ever in high-level motorsport, it's not.

In 2014, Formula 1 entered a new era of power units with the introduction of the turbocharged 1.6-litre V6, together with the new energy recovery system (ERS). The ERS is predominantly made up of two systems, MGU-H and MGU-K, both of which recover 'wasted' energy through harvesting the heat from the exhaust gases and the kinetic energy from the rear brakes. This energy is stored in the batteries, or energy store (ES), and can then be deployed as extra horsepower via the MGU-K, which acts as a motor during acceleration. The regulations restrict the amount of energy that can be

The introduction of brake-by-wire has added a whole new layer of complexity to F1 braking systems. These were already tightly packaged, as this Mercedes brake assembly shows



Top: **Formula 1 teams use complex ducting arrangements to cool the brakes and prevent overheating during a grand prix**
Above: **Hot air from the brakes is also used to help with tyre warm up; note the ducting to the right of the brake assembly**

recovered by the MGU-K to 2MJ per lap and only 120kW of this recovered energy can be supplied to the powertrain, although this still equates to an extra 60bhp for 33 seconds per lap.

The 2014 ERS regulations allow a lot of energy to be recovered from the rear brakes then. Therefore, the MGU-K is now a more dominant part of the braking system, reducing the importance of the conventional brakes.

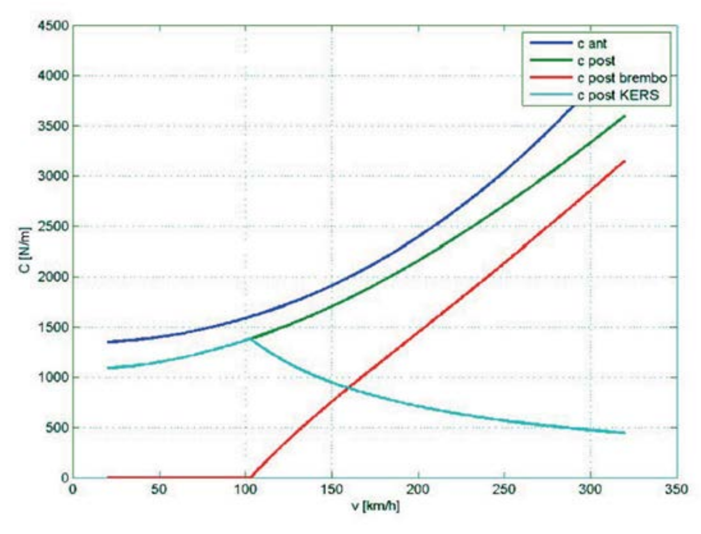
However, once the recoverable energy limit has been reached or the batteries are full, then the MGU-K has to stop and the conventional brakes need to take over to continue slowing the racecar. The vehicle control software dynamically decides how much braking torque is required from the rear axle and the split between the MGU-K and the friction brakes. As the brake-by-wire system breaks the link between the driver's pedal and the rear calipers, a small compliance chamber is used to simulate the feedback of the pedal to the driver, regardless of which brake system is operating the rear wheels.

In a conventional racecar braking system, when the driver presses the brake pedal this force moves a pushrod in the master cylinder, building up hydraulic pressure within the brake fluid. Consequently, this fluid is forced through the brake lines to the calipers where pressurised fluid actuates the pistons which pushes the pads against the brake discs, generating a clamping force. The friction between the pad and the disc creates the braking torque which decelerates the wheels. There is one master cylinder for the front circuit and one for the rear.

In Formula 1 the brake system works as described above. However, there is the additional element of the brake-by-wire system at the rear. When the driver presses the brake pedal, a proportion of the applied force is transmitted to the rear master cylinder and a pressure transducer converts this commanded pressure into an electric signal which is then sent to the McLaren ECU. The rear master cylinder is completely isolated from the rear calipers, and so provides no feedback to the driver, it would be like stomping on the floor, rather than stomping on the brake pedal. Therefore, the rear master cylinder drives fluid into a compliance chamber, which consists of a spring arrangement to simulate the pedal feel of a conventional rear brake circuit. Essentially, at the rear, all the drivers are doing when they press the pedal is signalling their commanded pressure to the ECU.

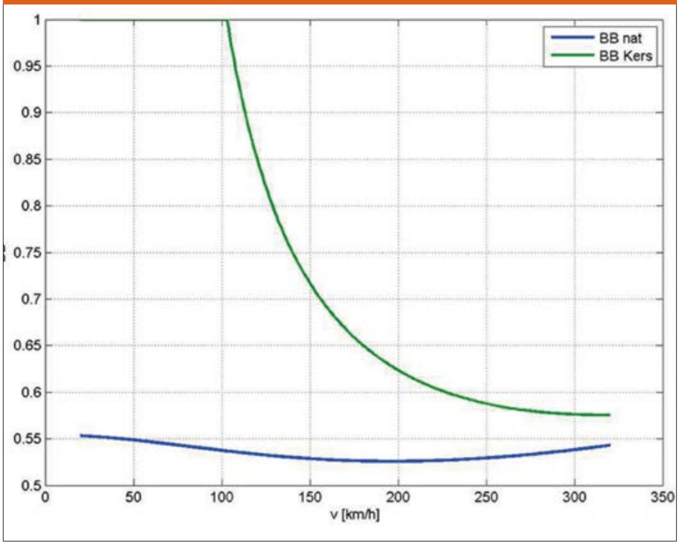
The ECU then does the maths and compares how much brake pressure and therefore braking torque the driver is demanding from the rear brakes with the braking torque the MGU-K is using to recharge the batteries. The

Figure 1: Brake torque *vs* speed



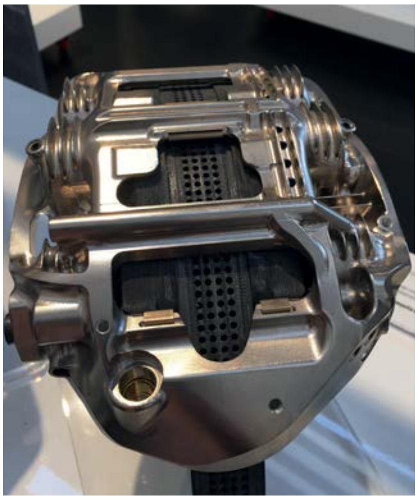
Dark blue is front brakes, green rear brakes, light blue MGU-K, while red is friction brakes

Figure 2: Brake balance *vs* speed



Here blue is the overall brake balance while green shows brake balance from MGU-K

One of the biggest challenges that the introduction of brake-by-wire systems presented to the teams was the mapping of the software



In addition to small holes in the caliper to aid the cooling there are also ridges machined into it, to increase the surface area and dissipate further heat

Up to 1400 holes are also drilled into carbon discs to help with the peak temperatures of 1000degC that these can be subjected to during a Formula 1 race

ECU then calculates the amount of braking torque required from the friction brakes to supplement the braking torque that is already being provided by the MGU-K. The pressure on the rear brakes comes from the high pressure hydraulic circuit of the racecar and is commanded by the ECU via a Moog servovalve which modulates the circa 230bar (3500psi) high pressure hydraulic fluid into an intermediate actuator which then delivers the desired hydraulic pressure to the rear calipers. Therefore, this actuator is essentially the brake-by-wire pressure generator, rather than the driver's foot pressure generator.

Brake from the norm

'When you are driving with the MGU-K disabled, you just get a one to one relationship between the master cylinder brake pressure and the rear caliper pressure, just like any conventional brake system,' explains Martin Jones, motorsport market manager at Moog. 'However, when the MGU-K starts harvesting, then the friction braking must be reduced quickly or the car may spin due to excessively high rear brake bias. The effect can be quite dramatic, for example if the driver is generating 80kg of force, once the calculations have been done by the ECU, actually this only equates to 20kg of effective force on the rear brakes, in addition to that provided by the MGU-K. To avoid de-stabilising the car these connections must be accomplished in a few thousandths of a second.'

Slowing quickly

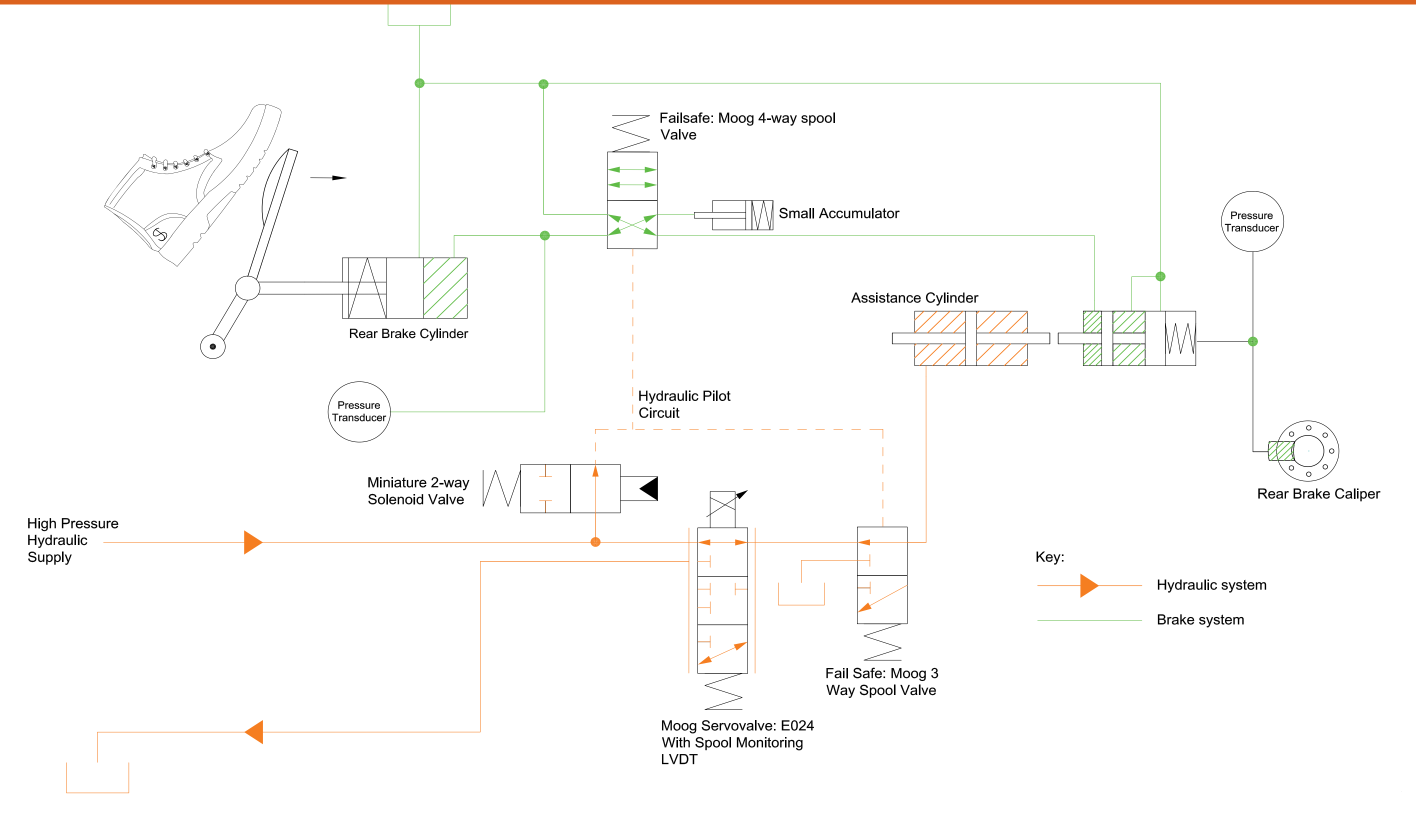
When a racecar is travelling at high speed the downforce generated by the aerodynamics results in a huge amount of grip. Therefore, to stop a car at high speed, a huge amount of braking torque is required to minimise the braking distance, whereas lower speeds demand much less braking torque. This is shown by the dark blue and green traces in **Figure 1** which illustrate how the braking torque decreases with vehicle speed for the front and rear brakes respectively. The braking torque at the front (dark blue trace) is offset higher than the rear, because the majority of racecars run with a forward brake balance.

Now let's consider the 120kW power limit that the MGU-K can apply to the brakes. Power = torque x speed, so if the power is fixed, and the speed reduces, the torque increases. Therefore, the MGU-K can apply more braking torque at low speed than at high speed. This is shown by the light blue trace in **Figure 1**. When the driver brakes at high speed, the majority of the braking torque is applied by the conventional brakes, with a small contribution from the MGU-K. However, as the car continues to decelerate, the amount of braking torque supplied by the MGU-K increases, until the rest of the deceleration can be controlled by the MGU-K alone. At this point the rear calipers are not working, as shown by the red trace.

Braking even

Andrea Algeri, F1 customer manager at Brembo Racing, explains: 'Essentially, at the beginning of the braking phase the drivers brake the old fashioned way, but below a certain speed [100kmh in **Figure 1**] the MGU-K acts as the brakes on the rear wheels. For this reason, there is a large variation in brake balance

Figure 3: Moog brake-by-wire concept sketch (2013)



This Moog design Illustrates the general principle of electronic control of the rear brakes, with a back-up system allowing reversion to hydrostatic braking in the event of a failure

which cannot be managed by the driver with traditional devices such as the balance bar.'

Brake balance is defined as the ratio between the amount of front brake torque compared to the amount of rear brake torque. Ideally, drivers want more brake torque at the front axle than at the rear, because under deceleration, the weight and aerodynamic loads shift to the front, demanding more braking performance. In a conventional racecar with hydraulic brakes, the brake balance is usually around 55 per cent and this can still be achieved with brake-by-wire as shown by the blue trace in **Figure 2**, which is the overall brake balance. The green trace illustrates the effect of the MGU-K on brake balance. At low speed, when all the rear braking is operated by the MGU-K, the brake balance is 100 per cent front. At more than 100kmh, the conventional brakes take over the braking force at the rear.

Pedal feel

Usually, when a driver pushes the brake pedal, the stiffness of the calipers provide resistance which the drivers can feel and use as feedback to judge whether they need to brake harder or softer, as is still the case with the front brakes. However, at the rear, there is no direct connection between the pedal and the rear calipers which is why a compliance chamber is needed to effectively simulate the rear stiffness.

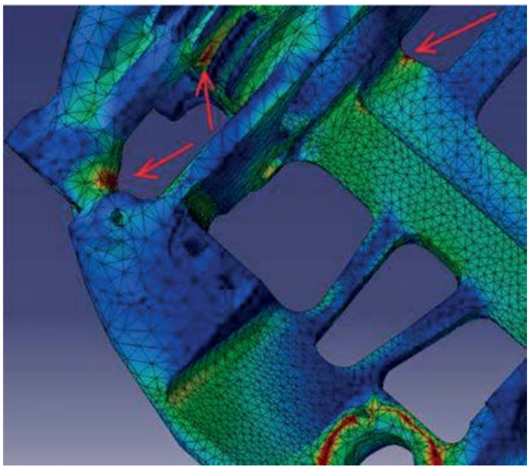
This is why the stiffness of the rear calipers is no longer quite as important as it once was, because the driver is no longer feeling the stiffness of the rear circuit, just the simulated stiffness in the compliance chamber.

With modern technology continuing to rely more heavily on electronics, 'glitches' is now a familiar term, whether it be the dreaded blue screen on your computer or your phone freezing. But the threat of a glitch is not something anyone wants to consider when they push the brake pedal, particularly at 300kmh heading towards a hairpin. But if the brake-by-wire system were to fail, then the pressure from the rear master cylinder would bypass the electronics and go straight to the rear calipers.

'An essential feature [see **Figure 3**], is a fail-safe which disables the brake-by-wire system and immediately re-establishes conventional hydrostatic braking in the event of any control system failure,' explains Jones. 'The control system function is monitored at high frequency and in the event of any failure an electrically signalled solenoid valve and spool valve work together to disable the brake-by-wire system and 're-connect' the rear master cylinder and caliper. The fail-safe logic of the system demands that the solenoid should be energised for the control system to operate in 'automated' brake-by-wire mode and de-energise to give conventional braking.'

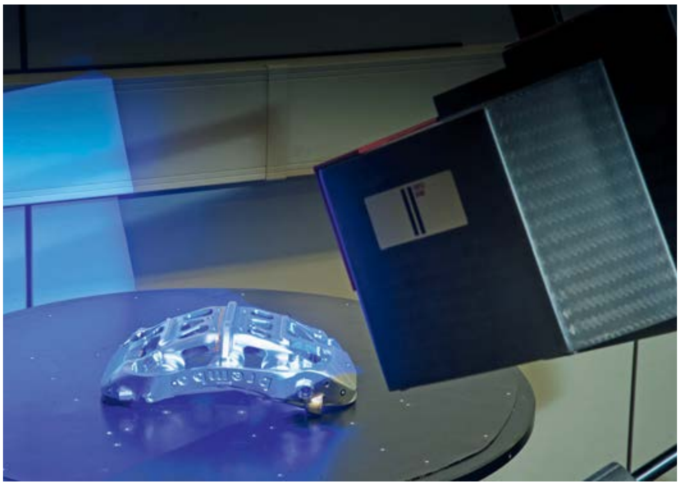
Map makers

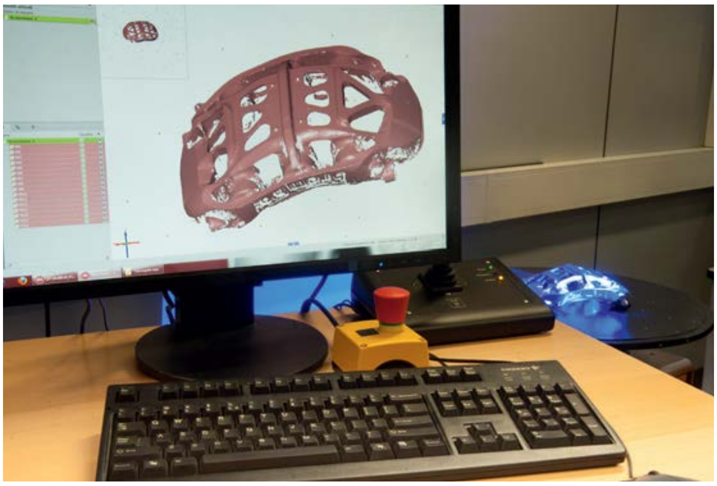
One of the biggest challenges that the brake-by wire-system presents to the teams is the mapping of the software. In addition to determining the brake bias, and the conventional brake maps, teams also have to balance the braking torque coming from the MGU-K with that from the friction brakes. 'We supply the hardware of the brake-by-wire system, but the software and maths behind it are in the hands of the teams,' says Algeri. 'At the beginning of the hybrid era, the brake-by-wire control was quite rough, but now with years of experience and driver feedback, the teams have learned how to guarantee the best feeling for the driver with the fine tuning of the software.'



Caliper design is a compromise between achieving a high level of cooling through the introduction of holes, while still ensuring high stiffness. FEA is a critical tool in helping to achieve this balance

Braking performance is measured by three indexes. Firstly, there is the *bite* which is the first sensation where the brakes need maximum efficiency. Then there is the *modulation*, which





One way that the dimensional accuracy of a caliper can be checked is through the use of a specialised camera that can import a cloud of captured data points into CAD for analysis

is the amount of friction during the braking phase as the driver continues to press the pedal. Finally, there is the *control* which relates to the amount of friction when the driver releases the pedal; this can affect things like wheel locking.

Another map that the teams have to fully understand is the behaviour of the carbon discs and pads in relation to varying temperatures and pressures. The torque applied to the wheels is a function of the mechanical performance of the carbon, and like the rubber used in the racecar's tyres, the properties of carbon change with temperature. This results in different friction coefficients and therefore wear, which can affect the three performance indexes.

'At the beginning of the hybrid era, the brake-by-wire control was quite rough, but the teams have learned how to guarantee the best feeling for the driver with fine tuning of the software'

Therefore, the brakes operate at their best within a specific temperature window.

'It is important to achieve homogeneous wear for all the carbon discs and pads to ensure that the driver has the same deceleration feeling and same pedal travel from the beginning of the race until the end,' explains Algeri. 'When the temperature of the carbon is too low, approximately below 350degC, a shiny layer can be generated on the surface of the disc and pad leading to a lower coefficient of friction and high mechanical wear which is called glazing

'Therefore, it takes about half a lap to warm up the brakes,' Algeri adds. 'However, when the temperature is too high, above 600degC, then the carbon inside the matrix can start to burn and the density of the disc decreases, increasing the wear. This is why the Brembo material is so good in this sense, because it has a wider temperature range, so the pads and discs will start to work at low temperatures and have less wear at higher temperatures.'

Slow burn

Watch a Formula 1 race and you will often see glowing bake discs along with the occasional puff of brake dust as the disc and pad material wears. To mitigate these effects, brake suppliers work with each team to develop fully customised brake systems, complete with the team's desired cooling strategy.

This can include additional ridges on the caliper to try and increase the surface area to dissipate the heat, but of course this all adds extra weight. This is why the most common method of cooling the brakes is through ventilation holes in the discs, which aid the cooling without the weight penalty.

'Five or six years ago, we used to have around 200 holes in each disc, and now we can have up to 1400 holes,' says Algeri. 'These holes used to be 5mm in diameter, but now we can achieve 2.5mm in diameter. However, because the holes go through the entire thickness of the disc, we cannot machine these holes any smaller as the tool could break. It's better to have more holes with smaller diameters because it allows more air to come into contact with the carbon material which helps to dissipate the energy better and minimise temperature build up on the disc.

'The higher downforce 2017 regulations increased the thickness of the front discs from 28mm to 32mm, which allowed us to drill more holes,' Algeri adds. 'The pads are also drilled with about 90 holes along two or three lines across the thickness of the pad, although this compromises the stiffness of the pads. We try not to drill just below the piston as this will affect the structural integrity of the pad too much, so it's a balance between achieving high stiffness as well as high cooling.'

Point brake

The four corners of a Formula 1 car are now intricate, compact designs where teams have invested huge amounts of R&D to achieve the optimal packaging of the calipers, pads and discs within the wheel hub, all with the aim of reducing unsprung mass. Add to this the innovative ducting solutions that surround each brake arrangement to maximise cooling and improve tyre warm-up, and it's fair to say that each corner is nothing short of an engineering masterpiece. However, brake-by-wire has added a whole new dimension of complexity as teams have had to balance energy recovery with braking performance, whilst satisfying driver feel – a task so great that only now are teams finding their optimum strategies.

Servovalves

To allow brake-by-wire systems to convert the hydraulic pressure generated at the driver's brake pedal into an electric signal and then back to a hydraulic pressure again at the calipers, high performance servovalves with fast response times and good resolution are essential.

The servovalve is a device controlling hydraulic fluid flow that can be electronically commanded from a computer. In conjunction with a sensor or transducer it can be utilised to control position, speed or, in the case of the brake-by-wire system, to modulate pressure. 'The E024 Series valve widely used in F1 was developed specifically to meet the demands of motor racing,' says Martin Jones from Moog. 'It can control up to 3.2kW of hydraulic power, operate at over 280Hz and has a mass of just 92g. The beauty of this device is it has very high power density, is extremely fast and can withstand the extreme heat and vibration of operating in a Formula 1 car.'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Tread carefully

It's not just the drivers who need to look after the tyres, for as our in-depth guide to using race rubber shows, engineers can also do much to make sure they're getting the very best from them

By RICARDO DIVILA

The tyre temperature is generated from within the tyre rather than being the result of friction between the tyre tread and racing surface

Maximising a racecar is ultimately about maximising the performance of the tyre, which is the link between the car and track through its contact patch

The running of a racecar entails the management of many components and fields: structures, engines, aerodynamics, damping, gearing, vehicle dynamics, geometry, child psychology (applied to the driver), and the supply of coffee to the engineers. But apart from that last one, the one that will give the biggest returns is using your tyres to their best capability.

Tyres are the essential link between the vehicle and the ground through the contact patch, where everything happens, and most of the other items are optimised around this.

As the tyre gets loaded vertically (through transfer or aero) or laterally (cornering) and longitudinally (braking and accelerating) it will continuously change its shape and size. This is what you control through pressures, cambers and roll-couples. This, in turn, will give your racecar its handling and grip. Have more power? It will have to go through the tyres. Need to turn it, and how fast you corner? It is the relationship between the four contact patches that will determine how well you do so. Need to finish the race and win? How you use and save your tyres will determine your probability of achieving this. They are then, very important.

Black magic

The fact that they are round and black is just a minor thing, really; there is a lot more to a tyre than its appearance. Yet that can also give you a read-out on what is happening; if you look at the contact patch closely.

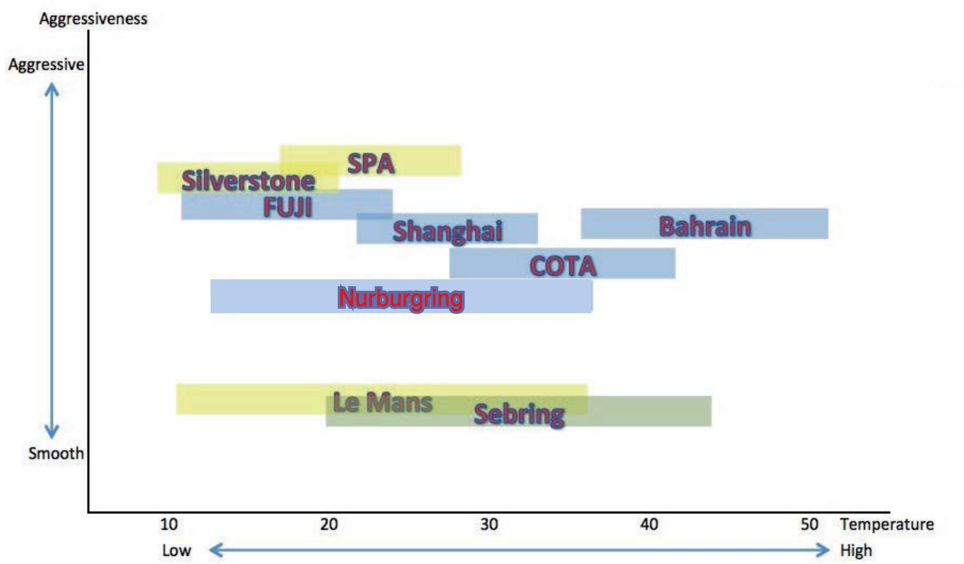
The sheer amount of engineering, chemistry and preparation for repeatability that goes into tyres is directly related to how they work. Always bear in mind that everything is non-linear with rubber, and because of the chemistry and pneumatics it is a bit of a black art, dependent on track conditions, weather, the type of race or session, and driver use or abuse.

Different classes with different rules will either have you running control or spec tyres, where all use the same rubber, or there might be a full-blown tyre war, which makes choice of tyres even more complex, as here you can juggle with carcass construction and compounds, even sizes if stagger is involved. In the past the easiest way to sort out handling changes on ovals due to track evolution was at pit stops, choosing from a selection of diameters so the next set would change the cross weight of the car, to be less loose or have less push.

On road tracks it is a bit more difficult, but one of the imperatives of the engineer's job in cross-ply tyre days used to be to make sure all his sets were the same diameter and matched, there being a considerable variation in these hand-built tyres. You would also try to ensure the coding on the side showed that it was the same fabricator that had made your set.

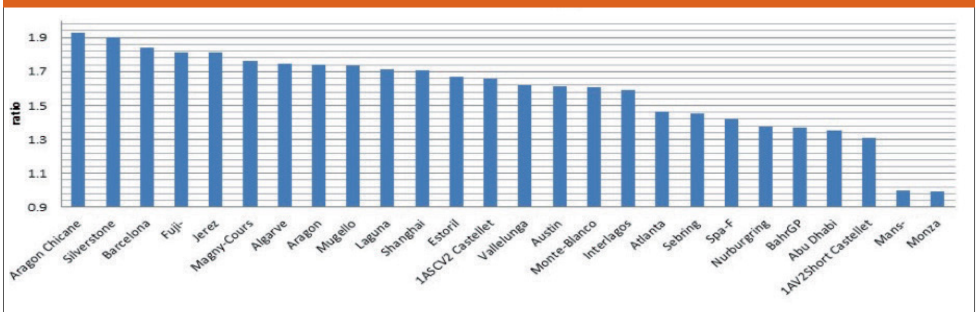
I was not very welcome at several tyre-fitting tents, turning up and asking for tyres to be

Track surface temperature *vs* aggressiveness index

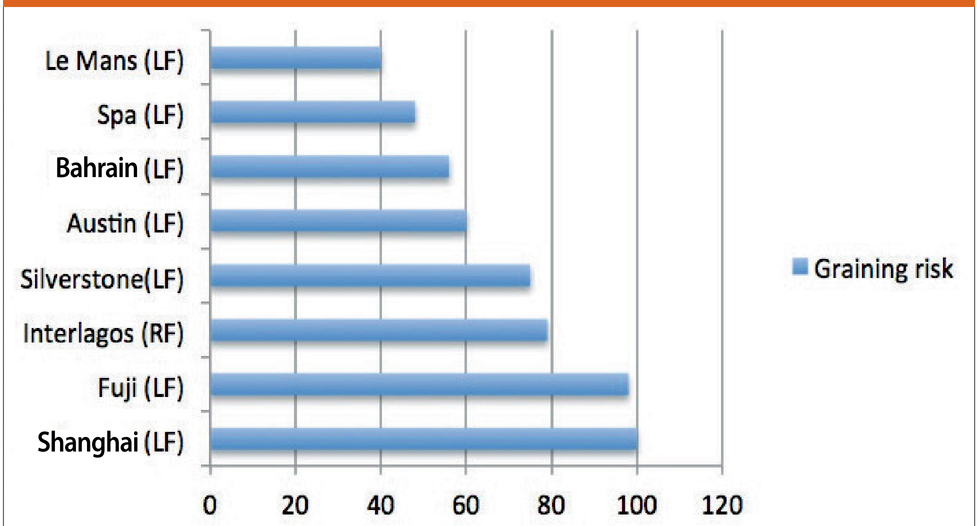


Ratio energy balance

Ratio total energy



Graining risk at specific circuits



changed to match so often that eventually I found the supplier pre-sorted them out when mounting my sets. A diameter tape was a very effective performance tool back then. This habit was kept for several years until my records showed that varying diameters were a thing of the past on radial tyres, the belt doing a good job of keeping them pretty much identical.

On the edge

Most racing tyres are now radial, as increased cornering stiffness is associated with a higher yaw rate gain and shorter response times. This is the reason why radial tyres are now preferred to cross-ply tyres in motorsport. However, radials do have a less linear response on the edge of adhesion and so can break away rapidly, whereas cross-ply tyres give more warning through the pneumatic trail torque felt at the steering wheel as you reach the limit, the steering effort dropping off slower.

What used to be a fairly free weekend tyre allocation limited only by your wallet has now evolved so there is now only a limited number of sets you can use, making tyre management even more crucial to your performance.

Over the years we have accumulated an extensive collection of tyre surface photos of the four corners and notes regarding set-up and handling, with all the variations of conditions and how to read them to try to make sense of what they are trying to tell you. Some of these are dotted throughout this piece (see Reading tyres box outs). These give examples from different manufacturers and classes in different track conditions and temperatures. Here we are only looking at the appearance and will not delve into the vastly more complex reasons for what happens. That will be for another article.

Slick work

Let's start here with how a racing tyre works. The tyres are so fundamental to a racecar's behaviour that basically the cars are designed around them, or the tyres will be designed specifically to respond to the car characteristics, within the limits of known tyre technology.

Tyre behaviour will depend on two different elements. One is carcass and the other is compound. These are fixed, but utterly dependent on variables that are, well, very variable, such as track temperature, tread temperature, pressure, camber, camber gain, toes, weight transfer and driver aggressiveness.

Carcass is what gives the tyre its shape, and it is not a simple matter. The amount of rubber in an inflated tyre is small and the whole structure is formed by the plies and weaving of them to keep a desired shape for it to function when inflated to a given pressure.

Part of the requirement is to allow a deflection of the cylindrical shape to give an adequate contact patch with the correct loading. A tyre pressure that is too high will reduce the contact patch area, thus loading

Sideforce coefficient for different surfaces

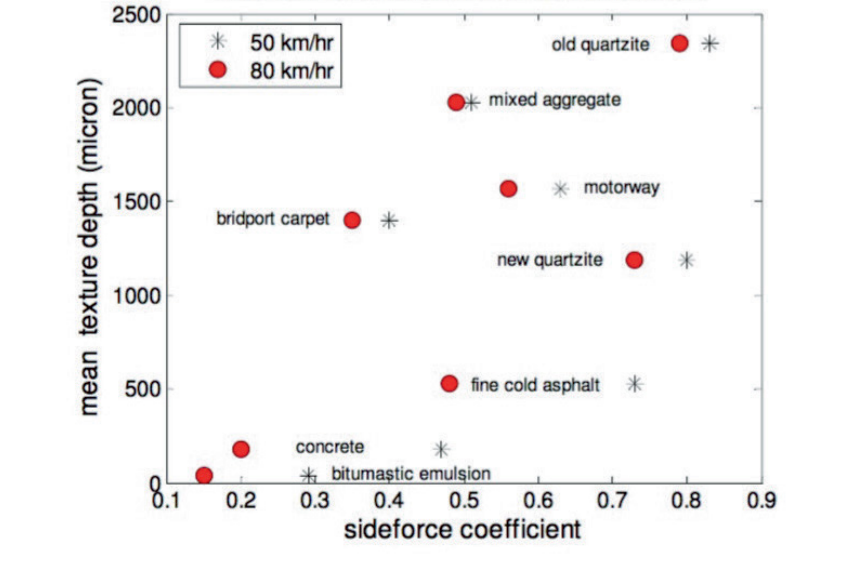


Figure 1: Japanese race tyre parameters

	Front		Rear	
	"X"	Index	"L"	Index
	A1	100	AA	100.0
Vertical spring	A2	101.05	Ab	93.4
rate	A3	100.5	Ba	90.1
	B0	94	BB	98.9
	E1	97.916	BC	95.9
	E2	92.12		
	B1	93.436	Da	90.1
	B2	92.502	Dg	92.7
	E3	94.183		
	E4	94.931	Ta	98.8
			TR	90.1
			RD	90.1
	A1	100	AA	100.0
Lateral	A2	103.4	Ab	90.3
rate	A3	102.15	Ba	89.8
	B0	93.4	BB	106.0
	E1	101.51	BC	93.1
	E2	99.284		
	B1	91.158	Da	90.2
	B2	98.725	Dg	91.5
	E3	103.46		
	E4	100	Ta	95.0
			TR	94.8
			RD	97.4

The major manufacturers have a complete database of encountered wear and even samples of the race track surfaces

each square millimetre of the patch higher, stressing the rubber more in shear, while also heating it up more on the surface.

Carcass heating will be less, as it will deflect less in each cycle. As the tyre/suspension pair is effectively springs in series, you can also change the total corner rate by the variation of pressure, a couple of psi being roughly equivalent to approximately 50lb/in for the tyre itself.

Compound interest

Compounds are the result of tweaking elements that go into the tread rubber to vary its temperature operating window and coefficient of grip. Remember that the compound interacts with the carcass and vice versa. An example is the use of a different compound on the same carcass, a softer compound making the vertical stiffness of the tyre change, because the stiffness of the rubber hoop around the tyre is softer.

The tyre temperature is generated from within the tyre rather than the result of friction between tyre tread and racing surface. It comes from hysteresis, from the flexing of the rubber.

Because the temperature is generated inside the tyre, reading tyre tread temperatures can give misleading information on set-up. IR heat sensors can collect data but the information has to be analysed carefully; it is not the whole story. Needle pyrometers will measure core temperature across the tread.

Track analysis

The choice of compounds by the tyre manufacturer will come from extensive analysis of the track surfaces, major manufacturers having a database of encountered wear and even samples of track surfaces. This gets condensed into charts showing the energy input into each corner and thus the tyre work, enabling you to even have split compounds on different corners, if they are available.

Reading tyres: 1

A race tyre after a short run on the track. The surface can be scraped clean to measure wear at the pins. This example has some light pick-up at the right place, and the surface is pristine. Light ridging has not begun to grain yet. This particular tyre is very much in the sweet spot.

Reading tyres: 2

Here the centre pin is worn more than the shoulder pins, which shows this tyre has been running with a higher than normal pressure, either because there was too high an initial pressure, or because the tyre has over-heated more than expected. It's still in the compound temperature envelope as the surface condition is still good and there's no graining. This type of pin is particularly good for quick visual checks during pit stops; it can be checked during refuelling. Each row has varying depths in half-millimetre increments.

Tyre rubber hardness is varied by changing the proportions of main tyre ingredients such as carbon, sulphur and oil. The more oil in a tyre, the softer it will be. However, in line with the 'no free lunch' law, while softer tyres should be quicker than harder ones, they also wear more.

Years of racing in Japan, where there was a tyre war, led to a very complex tyre choice matrix, as tyres had to be chosen for a given track in a pre-season test or fixed championship test dates, and extrapolated to what were the probable conditions for the race date, sometimes a couple of months in advance. We also had a choice of constructions, with different vertical and horizontal carcass stiffnesses further complicating matters. It was not unusual to find the factory team and the different satellite teams ending up with different spring, bar, cambers and aero settings according to the carcass choices. During a period of time it was more productive to change carcass than change the set-up, as you could dial the car in just on these, until sanity prevailed and the choices were narrowed; see **Figures 1** and **2**.

The tyre rubber is never fully vulcanised, it would be too hard to produce usable grip if it was

Choosing a compound for the race would then look at expected temperature and track conditions (**Figure 3**). As the previous racing result could change your car weight due to the handicapping (pole would add 10kg, a win 50kg) there was another factor to put in to the equations for the long range forecast.

Figure 2: Carcass vertical and lateral stiffness relative to base tyre

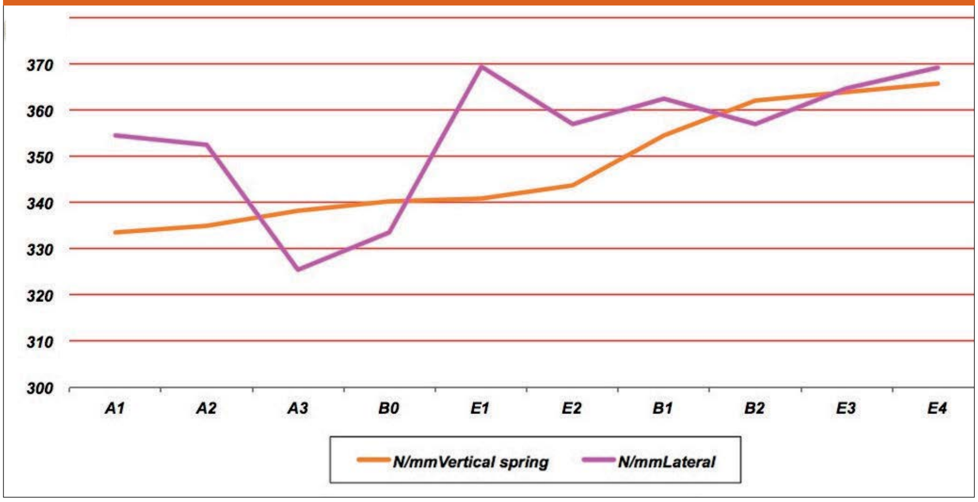
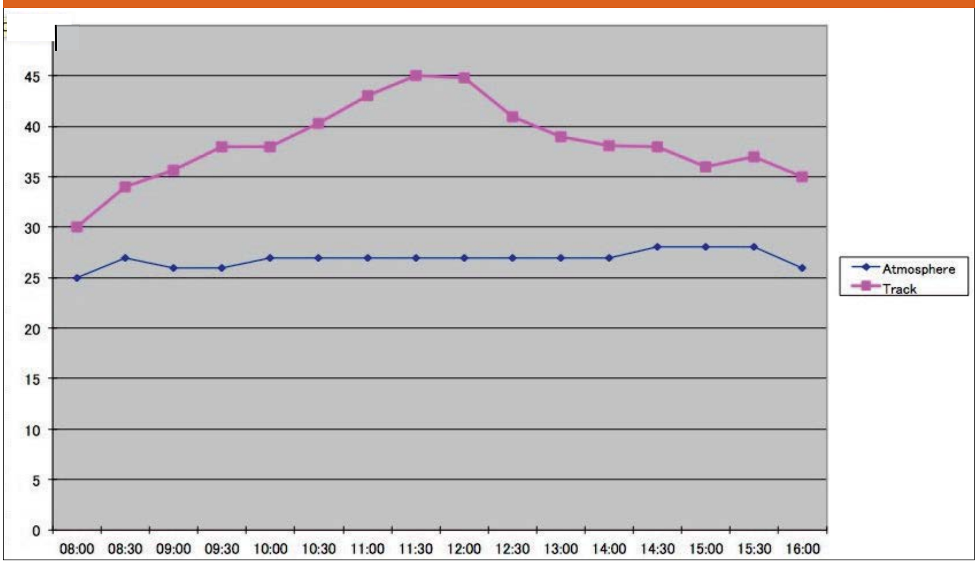


Figure 3: Expected temperature and track conditions



Grey matters

Sunshine inputs a lot of energy into the track surface. Conversely, even a very hot but cloudy day can see track temperature very close to ambient. Concrete surface tracks heat up less than asphalt topped ones, while tracks don't necessarily have the same surface all round, a prime example being Le Mans, which uses part open road and part closed track. Then there's Sebring, which has over 30 different types, from cracked concrete on the old airport perimeter, to asphalted sections. Having an extensive database of previous years and weather data, all this would be ploughed into the choice.

Car settings and tyre pressures will also make your tyre work differently, and are part of your set-up. Reading tyre temp spreads allows you to make these choices, always bearing in mind that what you read off your pyrometer is the residual temp as you roll in to the pits. The last corner and the speed at which you came in to the pits can change your readout. Not only that, your temperature is varying continuously as you're on the straight or in a corner, as seen in **Figure 4**. The same set-up is shown in **Figure 5**, but using different pressures. With the lower pressures the tyre is not working at its ideal compound temperature/grip envelope (example is off a relatively hard spec single seater tyre of simple element elastomer SBR – styrene butadiene copolymer). Comparing temperature spreads, we can see that the 23/20psi tyre is already at the optimum compound temperature for most of the corner, whereas the 18/15psi does this only when it's exiting the corner.

Rationed rubber

When your number of tyres is fixed by the regulations, say four sets for the race weekend, if you have a choice of compounds it will entail the juggling of all the characteristics for the combined free practice, qualifying and race.

You would want the softest tyre possible for a qualifying lap, the most consistent for the race,

Reading tyres: 3

This shows medium wear with cold graining on the outside shoulder. The tyre is running with some excessive camber, so wear and surface is normal on inner shoulder and centre, but in corners the outer edge is still cold and it tears when loaded on roll, or when the carcass deflects.

A blue sheen is a clue that the compound might be several notches harder than spec

with abrasion wear and carcass give-up tailored for the race or stint distance. As always, it will be a compromise. Spec tyre races don't have this problem, but you might find that conditions on a given day may be on the edges of the tyre's envelope, due to track temperature.

Doubling up

Incidentally, tests were once carried out with double compounds, there were tyres where the tread was in a harder compound rubber at the base, and with a thin 1 or 2mm thick soft compound to be used in qualifying and then worn away, leaving harder rubber for the race. Managing this and manufacturing problems quashed the idea, but the concept was valid.

Another noteworthy point. In some championships that make use of road car tyres, you should never go to the local dealer, because you will never know when the tyre has been made, or how it had been stored, or for how long. The best performing tyres are the latest batch sourced directly from the manufacturer.

The blues

It's also worth saying a few words here on blue tyres. As the rubber ages, either by time, being stored in hot containers or, worse case, exposed to sunlight – plus the natural heating while being used – the oils in the mix will be burned or will exude from the surface, giving a rainbow spread of colour, but tending to the blue. A blue sheen does not mean it's done for, but it is a good clue that the compound could be several notches harder than the spec. A particular manufacturer has tyres that always turn up bluish, but as it is not one of the leading ones, I will let this go without comment.

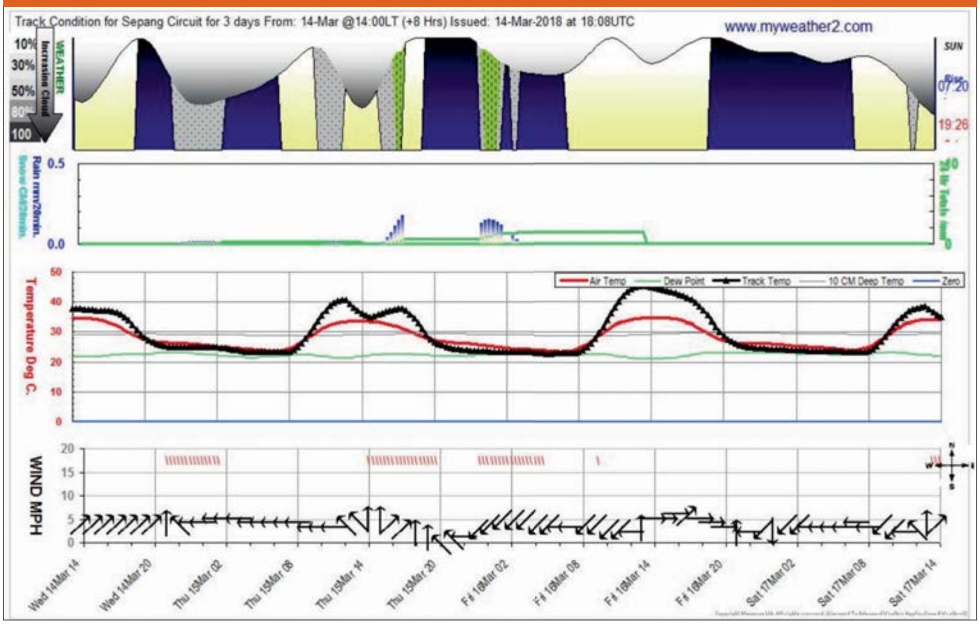
Why blue? Tyres contain oils that keep the tyre soft and the blue/green tint you can see is just the oils coming to the surface. Why on the surface? After the tyres have been heated significantly, when cooling down the oils in the tyre will come to the surface. On the next outing they are scrubbed off. At each cycle you lose some of the oils that keep the tyre soft, the more heat cycles a tyre goes through, the less effective the rubber is going to be.

Tyre care

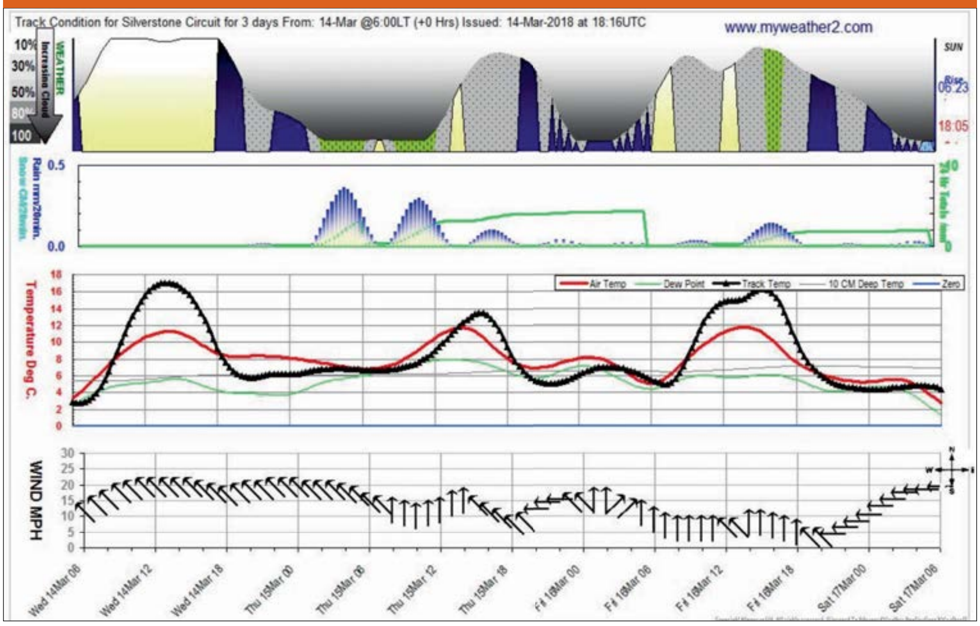
As you usually have to re-use a tyre, taking care of it for a second run is essential. With soft compounds, lift the car as soon as it enters the garage, don't let it cool down on the floor, there will be an uneven cooling rate, which will cause the carcass to keep a flat spot. The next time you use it the driver might come in to complain of a vibration, if it does not warm up enough to regain its shape. When taken off the car inspect it while hot, it makes reading the surface easier, especially if you have graining and pick-up. With the advent of smart-phones there is no excuse not to record the surface state and fill in your tyre records. It takes little time and will build up your database for future reference.

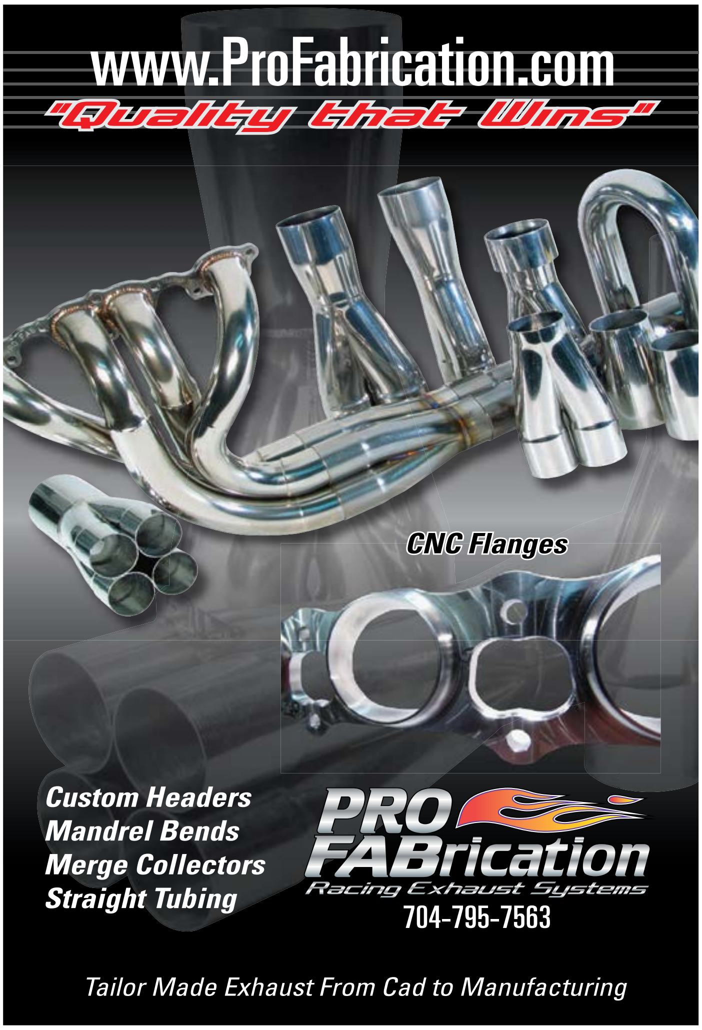
A new tyre will have its peak performance in the first couple of laps, and will degrade after that. Stopping and going out for another outing will lose you a couple of tenths after the heat cycle. This can be turned to your advantage if your compound is already on the edge of the envelope towards being too soft. A gentle heat cycle over a couple of laps will ensure it is half a notch harder for the race and might just

Temperature profile for Sepang



Temperature profile for Silverstone

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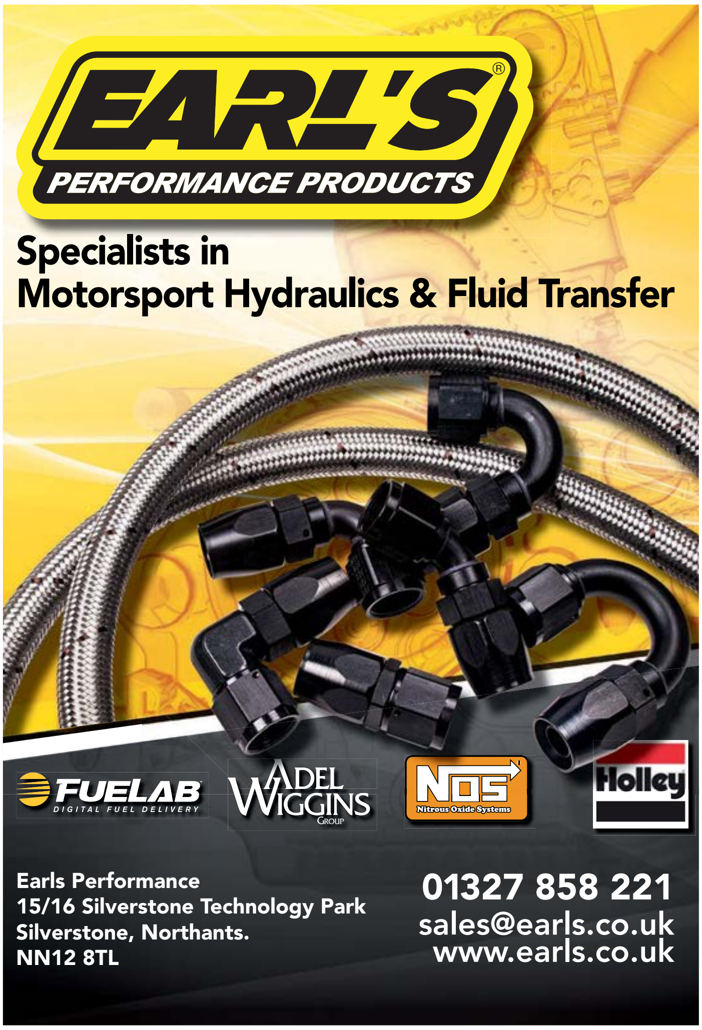
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Reading tyres: 4

Major tyre pick-up. With a lightly loaded tyre, you may achieve temperature by carcass deflection, only to find it just warms up enough to collect all the marbles. When scraped there is a virgin tyre surface underneath, like new. This can happen when there are many cars running tyres from a different supplier with a different compound from the one you're using. Marbles off-line are a much bigger problem than in previous decades. Part of the reason is the change in materials allowed for the compounding, with a banning of several chemical elements for health reasons. Pick-up management is the responsibility of the driver.

You need to always bear in mind that everything is non-linear with rubber

You never want to see this – when the cords are visible you are very close to a total tyre failure

Figure 4: Configuration 23/20 PSI

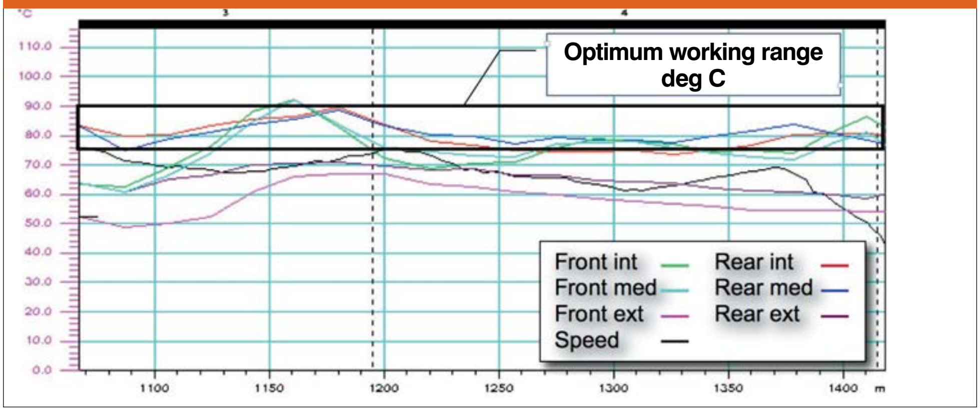
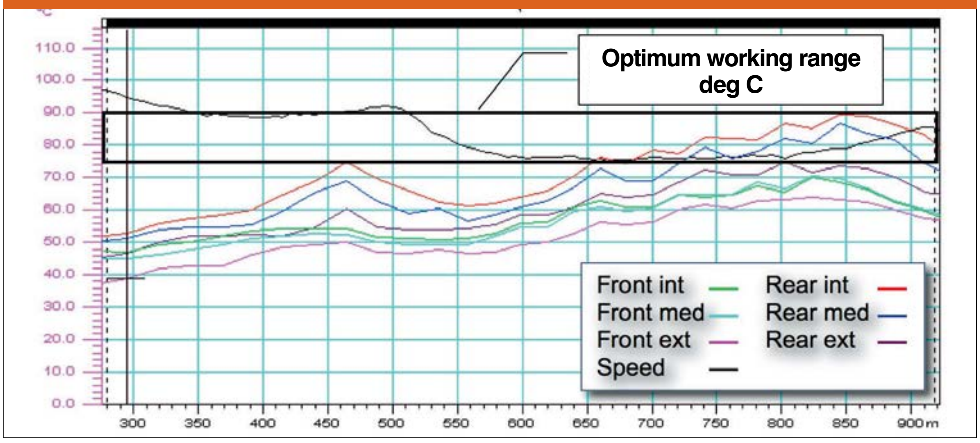


Figure 5: Configuration 18/15 PSI



make it last that much longer. Fine judgement needs to be exercised and this is dependent on experience, as not all manufacturers have tyres that will respond similarly.

Degradation

Why do tyres degrade? When tyres are manufactured the materials used go through several heat and pressure cycles in a mould. When used, mechanical stress and temperature cycles can be close to those of manufacture, which will change their characteristics, always for the worse for racing purposes; harder, less flexible, less sticky. The tyre rubber is never fully vulcanised, it would be too hard to produce usable grip if it was, so we can call the material semi-stable. Cycle it a couple of times, expose it to UV (in sunlight) and it will continue to vulcanise (or cure). It is the combination of cyclic stresses, high temperatures and abrasion which produces the chemical and mechanical changes in the compound and carcass.

Stress softening

Stress softening is caused when the polymer network junctions are displaced, breaking some of the long chain bonds. There are other factors, too, as Paul Haney explains in his book, *The Racing and High-Performance Tire:* 'The presence of fillers [carbon black and silica] introduces possible additional softening mechanisms, including breakage of rubber/filler attachments, disruption of filler structure, or chain slippage at filler surfaces. When intermolecular structures are irreversibly disrupted or reform in new positions while the polymer is extended, the result is permanent deformation. The rubber is said to have "taken a set". A rubber compound is a mix of many materials, including chemically active agents. An excess of certain kinds of active agents can provide an opportunity for a disrupted or broken bond to repair itself by re-bonding at the same location or in a new location,' Haney writes.

Structurally the cords in the sidewalls and belt will start to breakaway from the entangled rubber through mechanical degradation, making the carcass softer.

Ultimately abrasion will reduce the amount of rubber on the surface of the tyre, making it too thin to generate heat and to keep it, cooling down faster down the straights and not working at the correct temp. When you see the cords it's definitely game over.

Here's a story to finish on. For a couple of years the peculiar tint of my sunglasses had the side effect of allowing me to see the sheen of escaping oils from the tread, this happening according to the surface temperature. After a while, by correlation with the temp slips, this allowed me to *see* the temperature spread on the tyre without needing a pyrometer. Today you can do it with infra-red scanners, add-ons for smart-phones like the SeekThermal, or even with an app for your smart-phone.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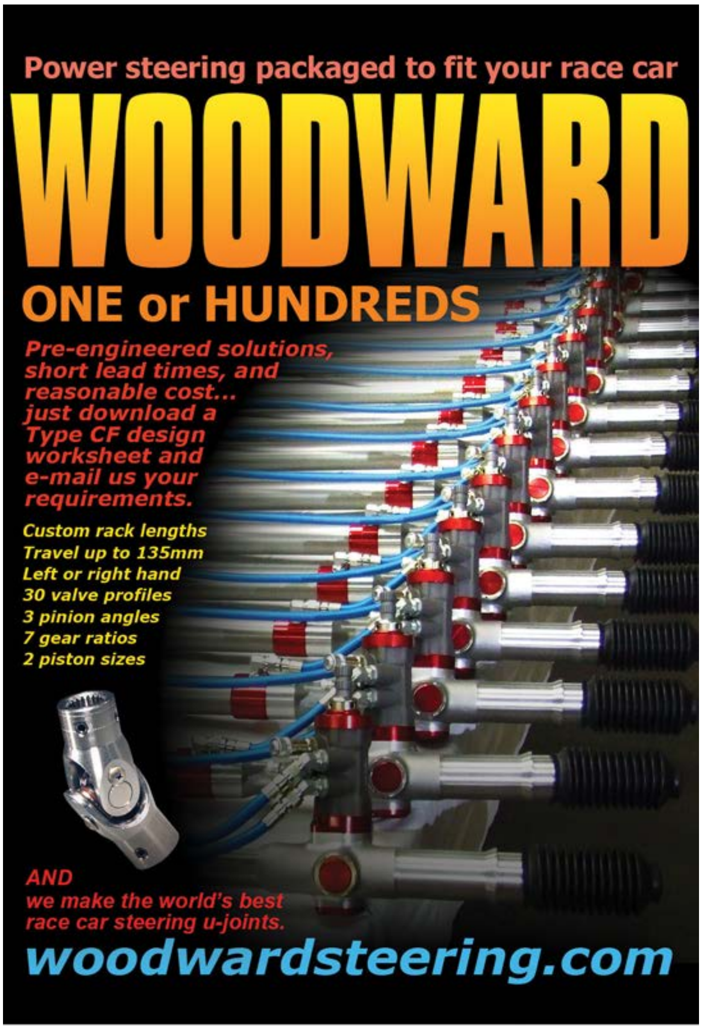
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All **shook** up

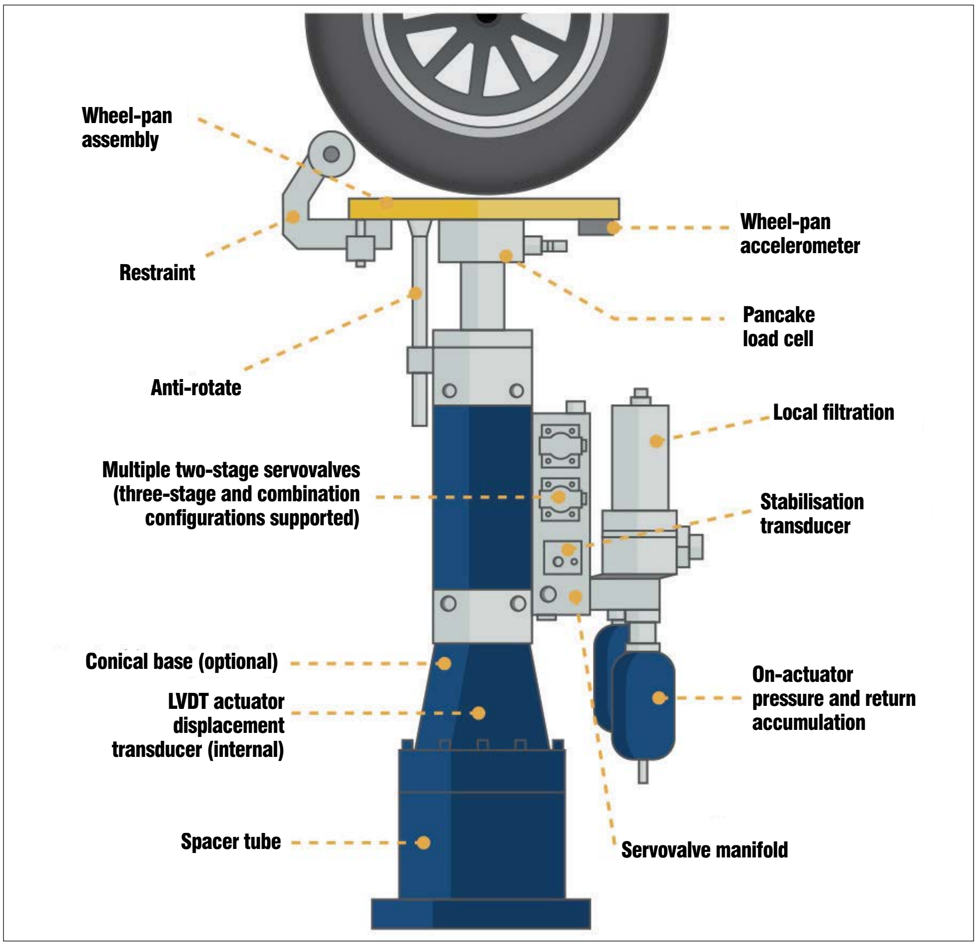
If on-track running is severely restricted then there are always test rigs to help evaluate and develop your suspension. We spoke to the movers and shakers in this sector for an insight into the technology that's rocking their world

By GEMMA HATTON

If you're not moving forward in motorsport, then you are standing still – the cliche that underpins every racing team across the globe. That burning hunger to claim the top step on the podium is what drives teams to continuously develop, improve and optimise the performance of their racecars and drivers. Unfortunately for them, the governing bodies have a different role to play and roadblock the teams at every turn through regulations. Arguably, the most challenging of these roadblocks is the heavy restrictions on track testing, which is often implemented to try and establish some control of costs.

With no better platform to test a racecar than a track, the teams react by spending even more money on developing driver-in-the-loop simulators and other simulation tools, but also test rigs where the real car can be evaluated. 'The use of seven-post rigs depends on the culture of the team. For us, we believe it is extremely important to test the real vehicle as

Renault is a great believer in making use of shaker rigs and it says that in the past it has developed technology like its F1 mass damper with them



Displacements are driven into the car's wheels through the wheel pan actuators. These can switch between two-stage and three-stage servovalves depending on the required power of the test, or on the application of the vehicle that is being tested

'We believe it is extremely important to test the real vehicle as much as we can, to help optimise the car when at the race track'

much as we can to help optimise the car when at the track,' explains Rene Torcato, lead R&D engineer at Renault Sport F1. 'This has been proved by past championships; mass dampers were developed here using these rigs, so we don't see our future without them.'

Shake down

The primary purpose of a seven-post rig is to not only understand the suspension design, but also optimise it for each track. This is achieved in two ways. Firstly, frequency sine sweep tests are conducted to characterise the vehicle. This is where the input signal starts at high amplitude and very low frequency and, with time, the frequency increases, while the amplitude decreases. From this engineers can understand how the car responds to that frequency range.

'We also use our seven-post rig to replay the profile of different tracks to see how to set up the racecar and what compromises to make between grip and aero levels, depending on the demands of each track. For example, Monza is more aero dependent, while Monaco is more grip dependent,' Torcato says. 'The advantage of this is we can make a set-up change and immediately evaluate this change on the first five tracks of the season, for example. This allows us to see how that change affects the car's response to specific corners under specific conditions at each track independently.'

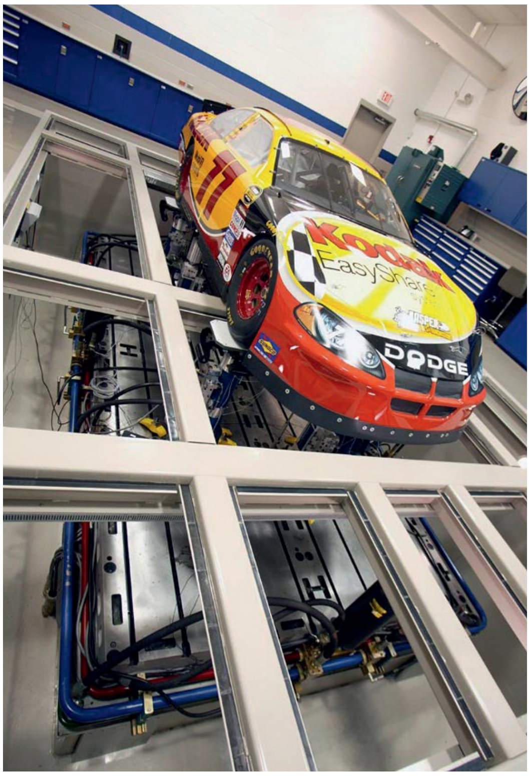
Good vibrations

As well as optimising overall suspension performance, seven-post rigs enable teams to test specific components in isolation or investigate particular issues in a controlled environment. 'Some teams want to analyse specific scenarios such as hitting kerbs, which can cause the car to unsettle, so we have a kerb file that teams can use,' says Christer Loow, engineering manager at Ohlins. 'When you actually stand next to the rig, the movement of the suspension can be extremely violent, but that's what happens in reality. Sometimes it's quite useful for teams to see close-up how the suspension components move because they may realise that they need to make specific parts stronger, which is something they would never see at the track, until it broke.'

Of course, there are some limitations with rig testing as not every condition can be modelled; variables such as wind direction, tyre wear and driver behaviour can't be incorporated into these rig tests. However, interestingly, this allows the suspension behaviour to be isolated and tested within a very controlled environment, so only the desired variable is changed, while everything else remains constant, which is almost impossible to achieve at a race track.

'For new tracks, we can actually build up a track using real data,' Torcato says. 'So we start with a bit of white noise and then from the response of the vehicle to the known inputs we can do some mathematics so that the rig understands what input is required to

A rig allows the suspension behaviour to be isolated and tested within a very controlled environment



For oval track racers such as NASCAR stock cars the triangular configuration of the aeroloader actuators are often placed with two on one side and then one on the other, rather than one at the front and two at the back. This is to help replicate the lateral forces

have the output that matches the real data. It requires several iterations and the software will automatically start modifying the input until we have the output from the sensors on the rig reading similar to the car on track. We try to automate our processes as much as possible, but it's still important to allow some flexibility if we need to change anything.'

There are a range of static and dynamic test rig types teams use to optimise their set-up. Four-post rigs are arguably the most common, and this is where four servo-hydraulic actuators are used to drive precise displacements into each wheel of a racecar via an instrumented wheel-pan. These displacements are determined by a test track specific drive file which has been derived using iterative techniques from track data, including hub accelerations, pushrod loads and damper displacements.

Shaken not stirred

As useful as four-post rigs are, they have their limitations, chiefly because at over 100mph the suspension has to cope with an entirely new input: aerodynamic downforce. To simulate this downforce, additional aeroloader actuators are used, most commonly three but sometimes four, converting the original four-post rig into a seven- or eight-post rig. These extra aeroloaders are programmed by an aeroloader map within the control system and need to attach to a rigid area of the vehicle's chassis, which is why they are usually mounted in a triangle configuration, with one at the front (under the nosecone) and two at the rear for single seaters. However, for oval track cars like NASCAR, two of the actuators will be on one side, with the third aeroloader on the other side. This triangular configuration allows the effect of weight transfer under acceleration and braking as well as pitch and roll to be more accurately simulated.

The aim of the aeroloaders is to pull down on the entire vehicle chassis, to simulate the overall effect of downforce. The challenge is, that these aeroloader actuators essentially act as viscous dampers, which, unless mitigated, can disrupt the natural body motion of the racecar as it responds to the controlled inputs at the wheel-pans. The loop-gain of the aeroloader load control cannot generally be increased sufficiently enough to minimise this damping to an acceptable level without the risk of instability. Furthermore, the mechanical impedance of the car at the attachment points is also included in the load control loop and so is heavily affected by any set-up changes.

To mitigate these effects, one solution is to include some form of mechanical compliance, such as a spring arrangement, within the aeroloader actuator load path. Here the actuator is coupled to the vehicle through a 'compliant link', which is essentially a clever set of springs that isolates the motion. Therefore, load can be applied to the vehicle, while retaining sufficient compliance so that the racecar is still able to move, without having to move the actuator. Unfortunately, when used in isolation this compliance means that the large downforce loads experienced during braking cannot be simulated and, depending on the configuration, the mass of the moving parts may increase the overall mass of the racecar as well.

Linked-up thinking

Another strategy is to try to predict the velocity of the test vehicle chassis and to control the actuators so that they follow the car body's motion. However, these velocities would change with any set-up modification and the measured velocity would tend to de-stabilise the aeroloader load control loops.

'If you only use a compliant link that can give you one set of issues, while using velocity feed-forward alone can lead to stability challenges,' says Frank Blows, chief engineer at Servotest. 'However, by combining the two and using a compliant link together with a velocity feed-forward algorithm, then you achieve a workable solution to simulate the effect of downforce on a seven-post rig.'

This design not only removes the de-stabilising effect of the feed-forward signal, but the impedance is no longer included in the aeroloader control loop, making it independent of set-up changes and the mass of the moving parts is driven by the aeroloader itself.

To translate the electrical demand signal from the control system into the movement of hydraulic fluid in the actuator, two stage servovalves are used. These are low flow devices at around 40l/min and relatively low power, up to 20kW. 'The beauty of this type of servovalve is its fast response to command signals, they are even capable of operation at over 200Hz,' says Martin Jones, motorsport market manager at Moog. 'They are similar in principle to the much

The main tests conducted on seven-post rigs are sine sweeps which help to characterise the suspension, and track replays where constructors or teams can tune the suspension set-up to optimise performance before the car actually hits the track

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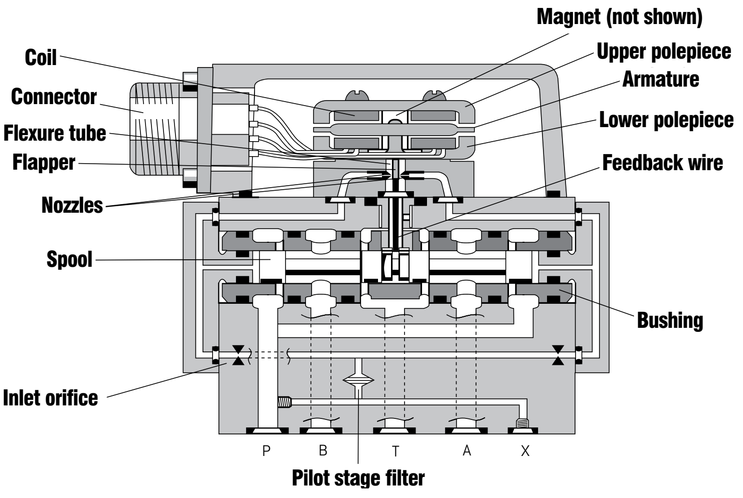
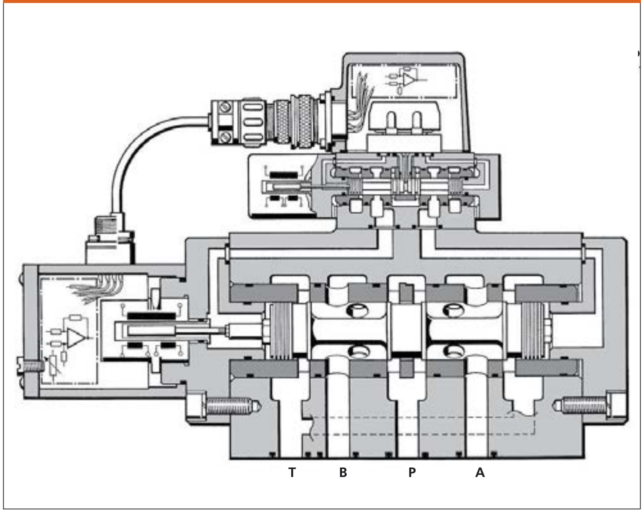


Three-stage servovalve D792 with pilot valve D765 series



Cutaways showing a Moog two-stage servovalve (left) compared to a three-stage servovalve. These components play a crucial role in operating the actuators on seven-post rigs

smaller E024 valves used in F1 brake by wire systems [see p64]. Essentially the servovalve is an electronically commanded spool valve that can be applied to provide fast and accurate control of force or position through a double-acting cylinder. The power limit inherent in this type of valve can be overcome by using two or three units in parallel to supply enough hydraulic power for fast vehicle movements while retaining the high resolution required to follow complex waveforms.'

Rough and ready

For other types of race vehicles such as rally cars and other off-road cars, higher-performance rigs may be required. These typically offer longer-strokes and higher wheel-pan velocities. While two-stage servovalves are still required for some of the testing on these rigs, the high velocity tests may require an alternative approach. For such rigs high-flow three-stage servovalves can be added, typically with hydraulic isolation slices when being operated in low flow mode.

A three-stage servovalve is essentially a two-stage servovalve sitting on top of a larger high-flow valve. The two-stage valve acts as a 'pilot' to a much larger and higher-flow third-stage spool, which has the capability to shift substantially more oil into the wheel-pan actuators.

For aeroloaders, neither conventional two-stage or three-stage valves provide sufficient performance. Therefore, these actuators use dual electronic feed-back valves (EFBs) which deliver the fast response required by the velocity feed-forward control to accurately track the movement of the vehicle's chassis.

'In normal mode, teams would operate the rig with a couple of two-stage valves. But if a customer was testing a rally application, then not only do they need actuators with a bigger stroke, but they would also need to enable the three-stage servovalve to achieve the higher wheel velocities and drive the rig,' explains Peter Rogers, marketing manager at Servotest. 'The servovalve configuration can be switched automatically to suit the application, with two-stage valves delivering the control required for conventional seven-post tests while retaining the performance advantage of a three-stage valve for those required cases. It would be like trying to go shopping in a Formula 1 car; you would get there quicker, but you wouldn't be able to control it enough to park it. Similarly, teams mostly utilise two-stage servovalves because they are controllable. However, when they really want to go racing, they use the three-stage servovalve.'

Rigged for efficiency

As with any simulation tool, efficiency is key to achieving realistic results with rigs. With seven-post rigs the fidelity of reproducing time domain signals is critical to providing a realistic physical simulation. One key to this is minimising the effects of friction within both the wheel-pan and aeroloader actuators. This can be done with hydrostatic bearings at the rod end as well as the base end of the actuators. Hydrostatic bearings use two pairs of opposing rectangular pockets of high-pressure oil within each bearing head to both centre the piston rod and lubricate the bearing surfaces, eliminating the friction and wear that can occur with less sophisticated polymer-bearings.

Servotest also utilises a seal-less piston design on its actuators, which relies on tight tolerances between the piston and the cylinder bore to minimise leakage and eliminate the motion distortion due to the static friction (or stiction) that is characteristic of sealed-piston actuators at each end of their stroke. Also, the surface of each wheel pan has been made to be extremely low friction to deliver the highest possible quality of motion simulation.

Another, often overlooked, practical aspect of seven-post rig design is that test rig operating pressure and associated actuator force rating (and therefore piston area) can be matched to the test vehicle characteristics and the required rig performance. For Servotest, this allows the size of the hydraulic power supply to be optimised with an associated reduction in long-term running costs, something that just isn't possible for suppliers with a discrete range of actuator sizes and a fixed operating pressure.

Quake up call

It is not just the individual components that require careful design consideration, the overall rig does too. The pit layout can vary depending on the size available and the rigs are often mounted on a heavy, often concrete, seismic base. This ensures that vibrations from the rig are not transmitted to the rest of the building, which is essential if there are manufacturing or metrology offices nearby, but it also avoids any vibration from adjacent facilities affecting rig performance. This seismic block can either be 'in-ground' where it is connected solidly to the ground, resting on rock or sand, or 'floating' where it is suspended on metal spring-boxes or air springs, although the latter is more expensive with high maintenance costs.

Typically, seven-post rigs are built into pits with the active components housed below ground level. This means that the racecars can be wheeled directly on to the

With seven-post rigs the fidelity of reproducing time domain signals is critical to providing a realistic physical simulation

wheel-pans without the need for lifting equipment. Above-ground installations are also possible, but they are less common.

In-ground pit designs vary hugely depending on the company and location. 'At one extreme there are relatively small and shallow pits that are accessed via a trap-door,' says Rogers. 'Typically, these pits can only be accessed safely when the seven-post rig is de-energised. At the other extreme there are large deep pits that are complete with an inspection walkway channel around the bed-plate, typically accessed by a separate staircase. These pits allow commercial clients, sponsors and race engineers relatively safe viewing access to the underside of the vehicle while testing is in-progress. In these cases the hydraulic hard-line – the pressurised oil distribution system – is typically mounted either on to the side of the seismic block on the inside edge of the walkway, or on top of the seismic block itself, allowing unobstructed access around the rig.'

Heavy, often concrete, seismic bases ensure that vibrations from the rig are not transmitted to the rest of the building

The seven-post rig at TRE, which is equipped with Servotest running gear. You can see in this picture the four wheel-pan actuators as well as the three aeroloader actuators, complete with the compliant link at the top (the black cylinder section)

Wheel-pan actuators can be moved laterally and longitudinally on base plates while they also rotate on their own base discs

Cooler shaker

In hotter countries, often the pit area is also fully air-conditioned and climate-controlled. This not only makes the pit environment more comfortable for the rig engineers, but also provides a uniform temperature environment for the test vehicle, suspension components and measurement instrumentation. In some cases this has been reported to have a noticeable impact on test result consistency.

The location of the actuators themselves also need to be adjustable to cater for cars with different wheelbases and track widths. This can be done with four simple bought-in T-slot bed-plates which are bolted together to form a large uniform space. The wheel-pan and aeroloader actuators can be re-positioned in both the lateral and longitudinal directions and held in place by machine clamps. Alternatively, large industrial magnetic bases under each actuator can be locked into place and then unlocked electrically, in which case spring machine ball-lifters, mounted in the actuator base, facilitate the repositioning of the rig components without the need for external lifting equipment.

As ever with any type of simulation, correlation is the biggest challenge. 'Each of our simulation tools need to complement each other as some things are easier to build and run on the real car, while for other things it's easier to create a model or test on the simulator,' says Torcato. 'For example, when we have quite different car designs from one season to the next we use simulations to help us understand the compromises at each track. But each tool has its limitations and it's important to understand what they are and how to compensate for any error that you might have. The aeroloaders, for instance, can result in extra damping on the racecar because they are not perfect in generating the procedural loads, so you need to understand those limitations.'

Testing data

As well as inputting track data into the rig for correlation studies, it's essential to use data from the rig in the set-up at the track. 'It's important for teams to take the data they learn from the rig and go back to the same track and physically test,' Loow says. 'One team understood the importance of this verification and physically tested changes at the track that not only improved the car's performance, but also those changes that worsened the performance as well, to really understand the correlation between simulation and reality.'

Simulation tools like rigs will only grow in importance in racing. Because these days race teams often need to have a racecar that is fast before they even roll it out of the garage.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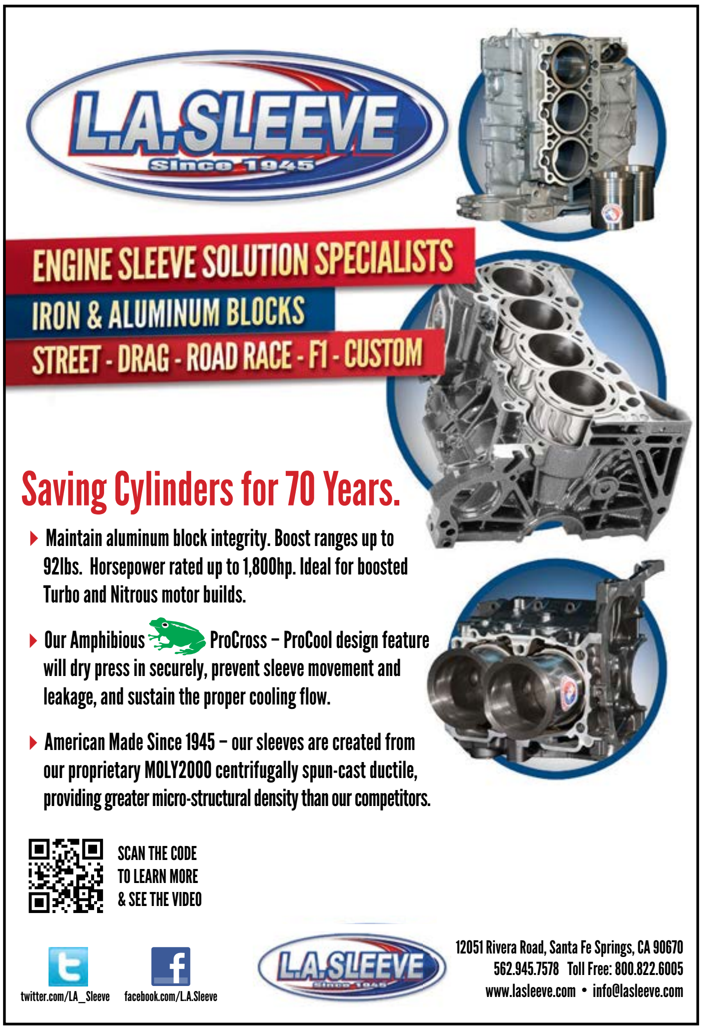
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Hot and tyred

Estimating hot tyre pressures is one of the dark arts of the race engineer, but *Racecar's* numbers man believes he's come up with a mathematical method that helps throw a little light on the matter

By DANNY NOWLAN

Pressures are easy to measure in the pits, but how do you estimate them for when the tyres are hot out on the track?

One of the most difficult tasks for a race/data/performance engineer is estimating hot tyre pressures. It's a critical job because if you mess up the tyre pressure the car will be massively out of its performance window. However, despite the importance of this there are few analytical tools that can help. Fortunately six years ago, when I was developing the internal tyre temperature algorithms for ChassisSim, I happened to stumble upon a rough rule of thumb that has proven to be quite useful. We will be discussing this at length in this article.

However, before we begin a number of things have to be made clear. Firstly, tyre pressure modelling is a very complex endeavour. Consequently, I am providing this tool with no guarantees that it will be accurate to 0.01psi or 3mbar. So, use this at your own risk. That said, I've had enough people use this now with reasonable results to feel it's worthy of discussion, and if you don't have an analytical tool then this is definitely worth a go.

Pressure gauged

Where this all came from was from one of my customers who had access to the Beru F1 internal tyre temperature and pressure sensors. I studied the data with great interest and threw some mud on the wall to see if I could formulate some rough rules of thumb. What I came up with was an empirical formula that used some basic thermodynamics to fill in the blanks. While this is not perfect, at the very least it is a very good starting point.

To begin using this method we will firstly need to know the core tyre temperature and an initial starting pressure. Once we have this then **Equation 1** will apply.

The first part of the method is to calculate the air density from a known reference condition. For the purposes of this study let's just say the parameters in **Table 1** apply.

I came up with my own empirical formula that used some basic thermodynamics to fill in the blanks; it's not perfect but it's a start

The first step is to calculate the air density from the reference condition. So for our Example in **Table 1** we will have **Equation 2**.

Let's now suppose that the hot running core tyre temperature is 90degC; so, from **Equation 1** we now find the hot running tyre pressure should be **Equation 3**.

Hot air

A couple of points to note about using this formula. Strictly speaking when doing the temperatures we should be entering them in Kelvin. However, for differentials you are at liberty to use degrees C. Also, the gas constant will vary from gas to gas. For *R* I used the ISA standard definition for air which is 287.1J/kgK. Also, I can not stress enough that you must work these numbers in strict SI units. I know that will annoy the North American readers, but if you work this in imperial you'll just get lost.

I also cannot stress enough that this is an empirical approach. I am the first to admit that I am committing a multitude of thermodynamic sins here. This is why I'm providing this on a take it or leave it basis, with no guarantees.

Another way you can use this is to predict cold running pressure given a target hot running condition. Using **Equation 1** you then start with the cold temperature as T_{REF} and calculate the density, ρ, from the warm condition. You can then use **Equation 2** to figure out the cold running pressures.

Let's illustrate this in an example, so you understand how the process works. Let's say the hot running target pressure and temperature is 30psi and 75degC, and the cold temperature T_{REF} is 25degC. The density will then be given by **Equation 4**. The cold air pressure can then be calculated by making use of **Equation 5**. Let me once again stress that what has been presented here is a rule of thumb; you should always back it up with your own experience and running out on track.

The upshot of all of this is very interesting. Since this is actual customer data the non-dimensionalised results are shown in **Figure 1**. The blue trace is actual tyre pressure, the purple is the predicted from **Equation 1**. As can be

Equations

EQUATION 1

$$P = \rho \cdot \left(R + \frac{C_V \cdot (T - T_{REF})}{1000} \right) \cdot T$$

Here the variables are:

P = Pressure of the tyre (Pa)
ρ = Density of the air in the tyre (kg/m³)
R = Gas constant of the gas used in the tyre (J/kgK)
C_v = Gas specific heat at Constant Volume (J/kgK)
T_{REF} = Measured core tyre temperature when tyre is cold/first measured (K)
T = Current hot running tyre temperature (K)

EQUATION 2

$$\rho = \frac{P}{R \cdot T_{REF}} = \frac{124.1 \times 1000}{287.1 \times (273.15 + 20)} = 1.474 kg/m^3$$

EQUATION 3

$$P = \rho \cdot \left(R + \frac{C_V \cdot (T - T_{REF})}{1000} \right) \cdot T$$
$$= 1.474 \times \left(287.1 + \frac{1000 \times (90 - 20)}{1000} \right) \times (90 + 273.15)$$
$$= 191216 Pa$$
$$= 27.7 psi$$

EQUATION 4

$$\rho = \frac{P}{\left(R + \frac{C_V \cdot (T - T_{REF})}{1000} \right) \cdot T}$$
$$= \frac{30 \times 6894.8}{\left(287.1 + \frac{1000 \times (75 - 25)}{1000} \times (273.15 + 75) \right)}$$
$$= 1.7624 kg/m^3$$

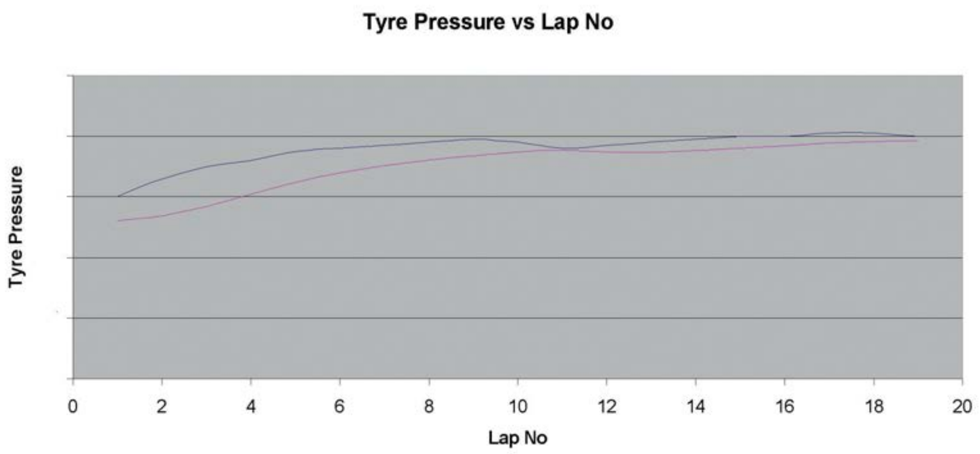
EQUATION 5

$$P = \rho \cdot R \cdot T_{REF}$$
$$= 1.7624 \times 287.1 \times (25 + 273.15)$$
$$= 150.9 kPa$$
$$= 21.9 psi$$

Table 1

Parameter	Value
Start tyre pressure	18psi (124.1kPa)
Start core tyre temp (T_{REF})	20degC (293.15K)
R	287.1J/kgK
Cv	1000J/kgK

Figure 1: Non-dimensionalised results of actual *vs* predicted pressures



This raises a much more important question: are there more exact ways of predicting tyre pressure from cold running conditions?

Figure 2: Example of the ChassisSim track replay feature

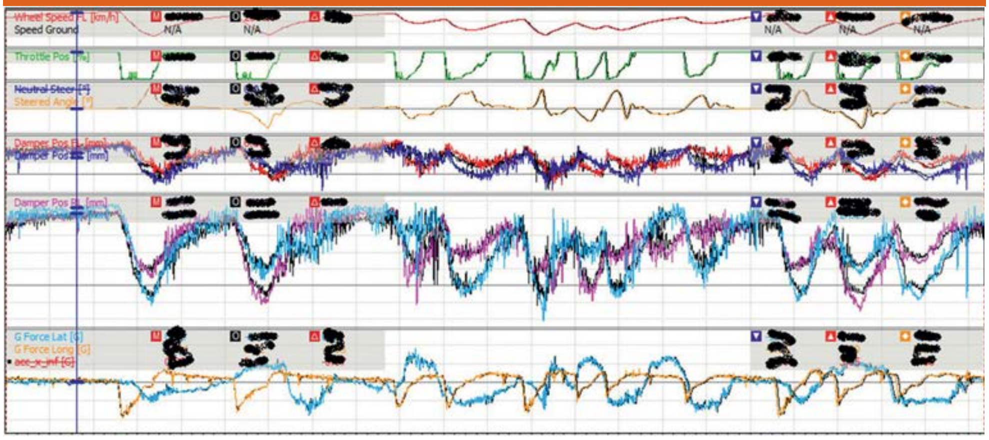
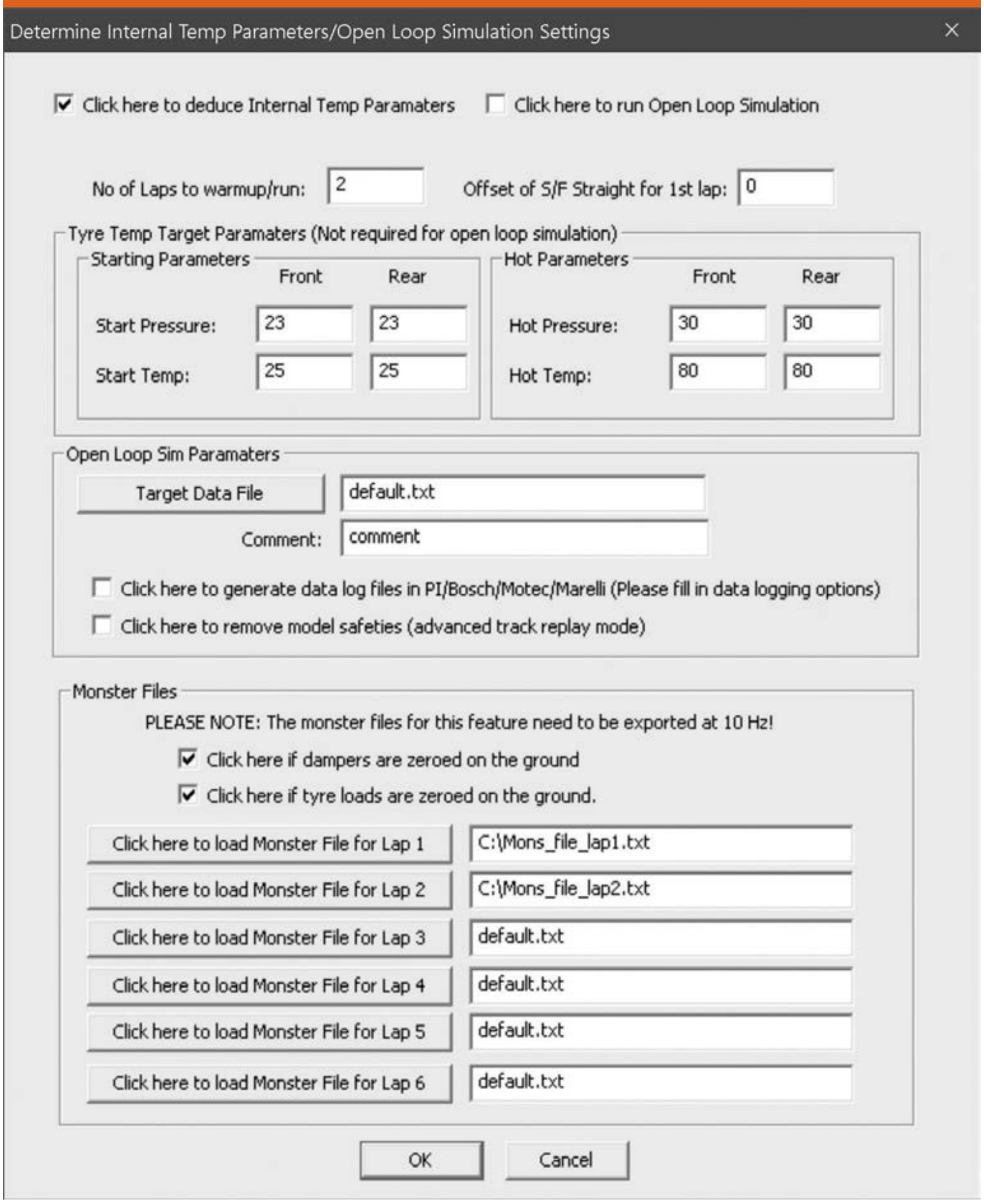


Figure 3: ChassisSim track replay dialogue set to determine internal tyre pressures and temperatures



seen in the beginning of the run we didn't do a particularly good job of predicting the tyre pressure. However, as the stint continued the predicted tyre pressure was within two per cent of the actual pressure. While not perfect, this is something that is not bad, and as a rough rule of thumb it puts us in the ballpark.

Thermal losses

However, this method is not without its drawbacks and it would be unfair of me not to give you the heads up. Going from cold to hot (**Equation 1**) works relatively well. But where it does struggle is going from hot to cold. Typically, it will over-predict the rest condition. A lot of that is most likely down to thermal losses, but I never had the time to chase it down. This is one of the key reasons I'm presenting the formula as I am. I repeat; this is just a rough rule of thumb.

But this raises a much more important question: are there more exact ways of predicting tyre pressure from cold running conditions? This is where the track replay component of ChassisSim comes in; because this can replay a whole stint. An example of the results of this is shown in **Figure 2**.

Track replay

What the ChassisSim track replay will do is, rather then predicting the lap time, it will take, the speed, throttle and steer traces and replay what the racecar did. This has three primary applications: it's excellent at model validation and it comes into its own for looking at channels you can't log on the car. Thirdly, and this pertains to our discussion, combined with the internal tyre temperature, because the track replay can replay an entire stint, you can use it to predict the tyre pressures.

Setting this up is not as difficult as you might think, either. The key things you will need to get going are the following:

- **Cold tyre pressures and temperature.**
- **Hot tyre pressures and temperature at the end of the lap.**
- **Monster files for each lap.**

Also, in the tyre dialogues you will be setting cold tyre pressures and temperatures. Once you have these then setting them up in ChassisSim is nothing less then child's play.

Twisting track

The first step is to run the ChassisSim track replay but this time you're doing it with a bit of a twist. This is illustrated in **Figure 3.**

Before that you have loaded your curvature, bump profiles and altitude road camber files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Think of this as a motorsport calculator to get you in the window you need to be in, if you try to use it as a magic wand you will be disappointed

Figure 4: Tyre pressure log for a simulation run

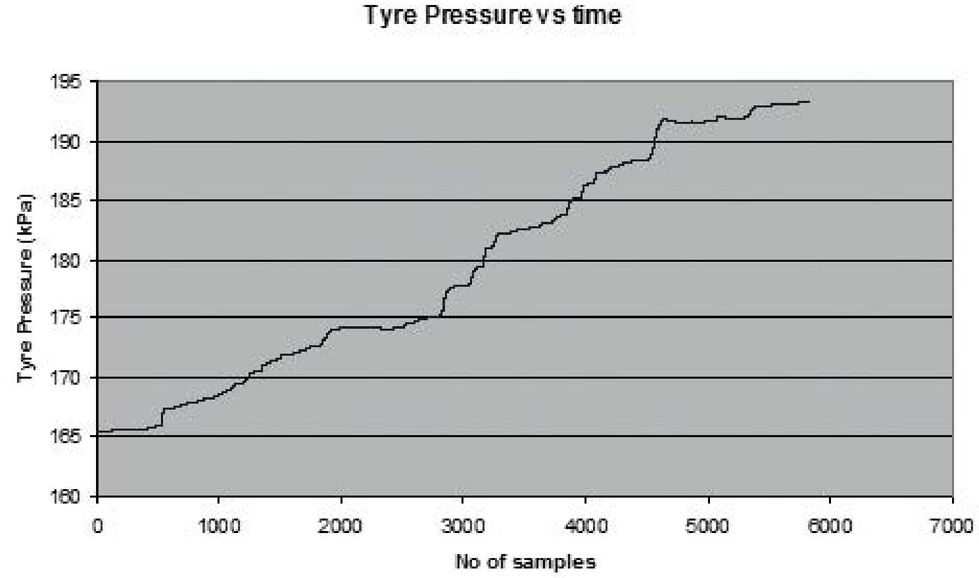
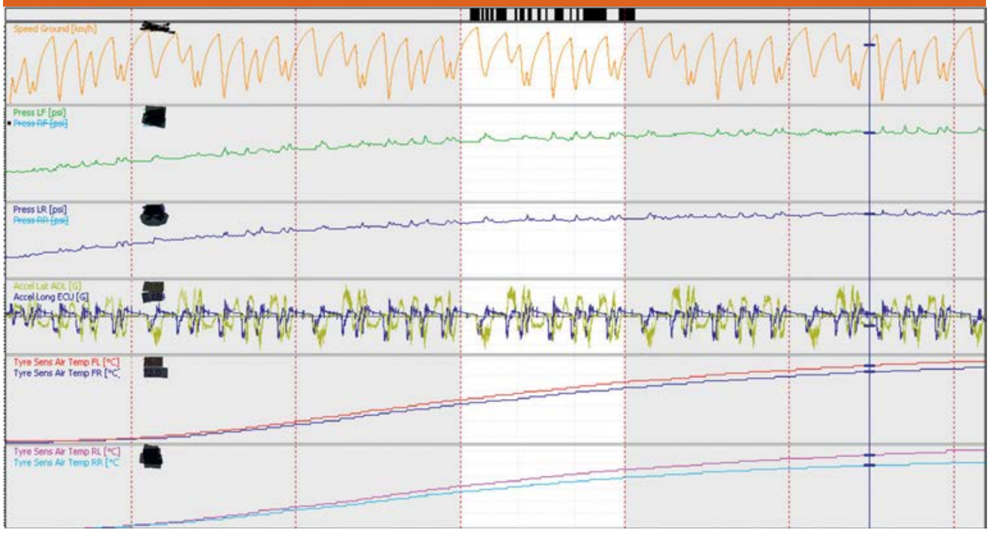


Figure 5: A log of tyre pressures and temps from bf1systems sensors



A little bit of maths can go a long way when it comes to tyres; but results need to be cross-referenced with track data

in the circuit properties. You then just click 'OK' and ChassisSim will determine what the internal tyre temperature parameters are.

Once these are determined and applied to the model you can then run the track replay simulation to determine what the pressures are. These are mechanics to what was done in **Figure 3**, the only difference is you click on the open loop simulation check-box and specify a results file where the tyre pressures can be exported to. An example of the sort of results you will get is illustrated in **Figure 4**.

Window addressing

Perhaps the best example of where this was used in anger was with the Maranello Motorsport F458 entry that won the 2014 Bathurst 12-hour race. That car was engineered by my Australian dealer Pat Cahill.

The first thing to say about all this is that while this is a step up from **Equation 1** do not expect it to give you an exact answer. Anyone who relies purely on simulation data and never cross references with actual data is delusional, bordering on dangerous. Always cross reference to actual data and realise you will never get this exactly spot on. Rather, think of this as a motorsport calculator to get you in the window you need to be in. If you try and use this as a magic wand you will always be doomed to disappointment.

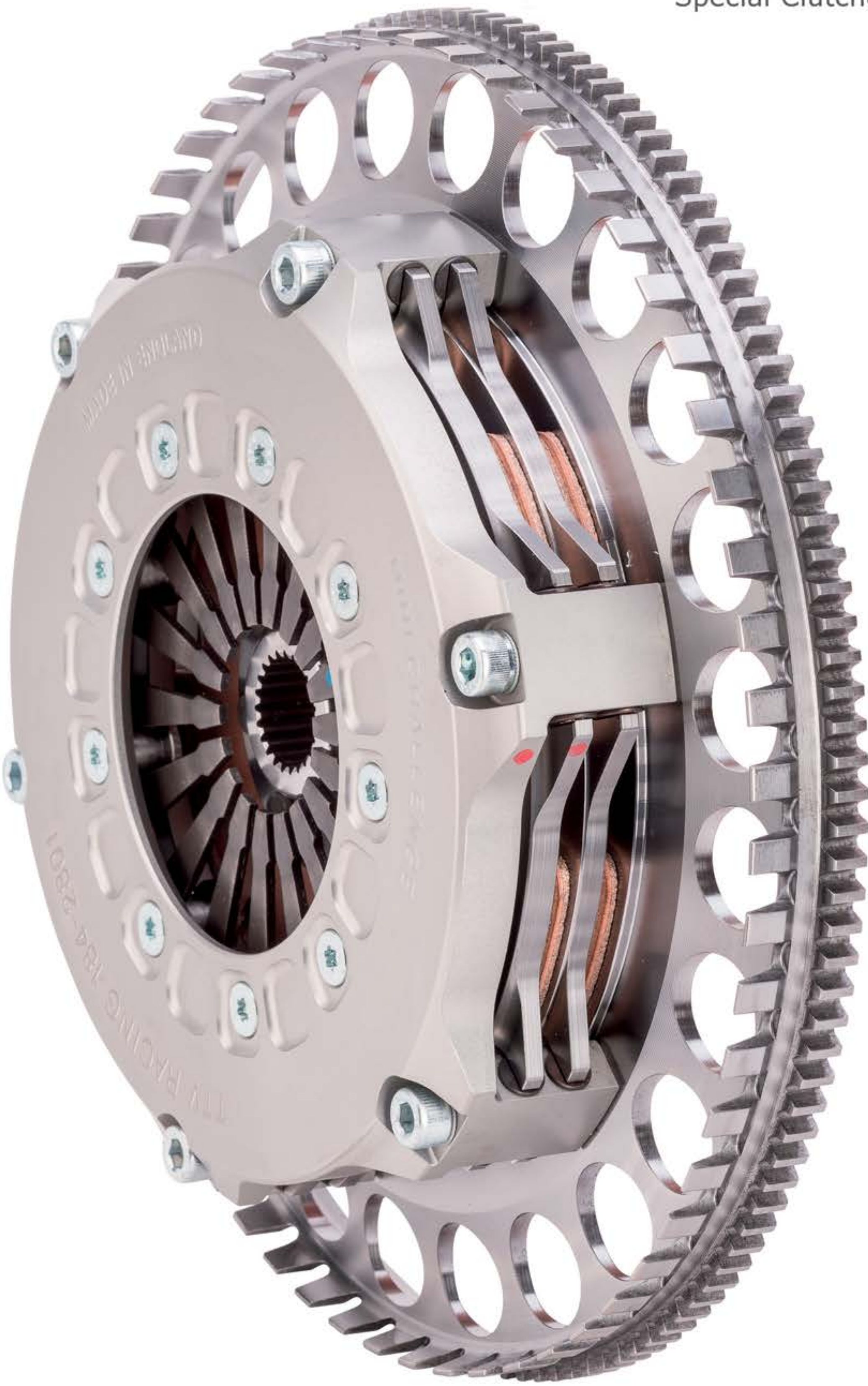
I also want to give a big shout out to my friends at bf1systems here. Without its sensors this article and all the development work that has gone into all this over the past few years would have been impossible. You can find more details on www.bf1systems.com.

However, the proof of the pudding is in the eating. So, I've included an actual log of tyre pressures and internal tyre temperatures. This is shown in **Figure 5** and since this is live data all scalings and numbers have been removed,

Tooled up

In closing, it should be clear to see there are tools at your disposal as a race engineer to help resolve the very important question of what tyre pressures you need to run to hit your hot target temperatures and pressures. As we have seen, the formula we presented in **Equation 1** and the ChassisSim internal tyre temperature model and track replay, are key ways to get yourself on the path to resolving this issue.

However, they also come with an important health warning. Like with all simulation tools, if you use these as magic wands you will be forever doomed to disappointment. But if you use these tools as a calculator and cross reference this to experience and data, they will evolve into tools you can't do without.



Interview – Scott Atherton

Looking good

IMSA's president tells us why he believes its DPi sports prototype category has proved to be such a success

By ANDREW COTTON

'From a business perspective we are in a good place now, the paddock is healthy, the outlook is bright'

We're always told it's supposed to be an entertainment-based business, so aesthetic appeal should be important in motor racing – and perhaps the furore that's greeted the introduction of the Halo in Formula 1 proves that it is. It was certainly recognised as an essential element when IMSA and GrandAm got together to form the United Sportscar Championship in the States in 2014. A couple of years later, out went the dumpy Daytona Prototypes, in came the svelte Daytona Prototype Internationals (DPi), complete with their manufacturer styling cues.

But it was not just about looks; in came a new way of doing things, too, and – so far – with one season under the new DPi's belt and another now well underway, it appears to be working. 'It is our opinion that DPi has exceeded even our most optimistic expectations,' says Scott Atherton, IMSA president and the WeatherTech Sportscar Championship's CEO. 'To have had the three core manufacturers who started with us achieve the success they did, and the concept to have been as well received as it's been by fans, manufacturers, and constructive critics, [it] has been much better than we expected.'

There are now four manufacturers involved, with the addition of Acura, but Atherton tells us more might be on the way. 'I am talking [to] new manufacturers that are either well along in the development process, or new enquiries in recent times simply based on the demonstrated success of those who were the first movers,' he says. 'We [originally] had a lot of feedback from manufacturers who said it is interesting and has a lot of potential, but we want to sit this one out at least at the start and see how it develops. There were many in the beginning who didn't believe that there was enough connectivity for a manufacturer to make it interesting enough or worthy of the level of investment. But now the fact that a manufacturer is able to bring its own powertrain and its own design elements to brand the car in a way that if you peel the logos off you would still be able to recognise one over the other, has been proven to work.'

Brand recognition

There's no denying that this link to street car styling has been one of the main selling points of the new DPi, as far as manufacturers are concerned, but it was never about making prototypes into 'stock' cars, Atherton insists. 'It was never intended to make a prototype look like a street car. It was to give manufacturers the opportunity to put their fingers on the bodywork, such that it wasn't a generic prototype from a constructor, but defined the characteristics of the road car.'

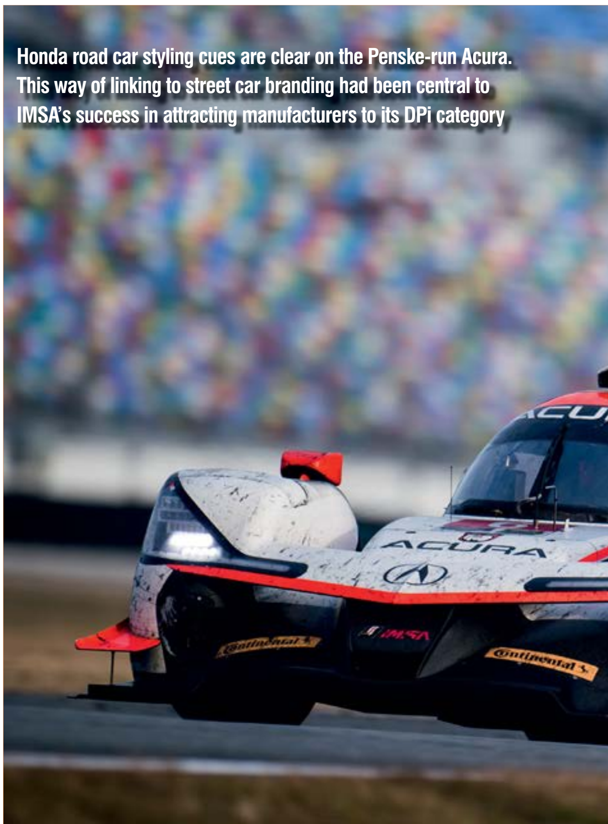
Yet FIA head of technical Gilles Simon believes that IMSA has not, in fact, gone far enough with its DPis' links to their road car cousins. 'It depends on what your ultimate goal is,' Atherton responds. 'If the goal is to truly resemble a car that could be driven on the street, or has very distinct similarities beyond what we have done then yes, you could say that we have not gone far enough. [But] the irony of that statement is that we were very much restricted in what we could do and yet still have the direct link of the performance of a DPi compared to the benchmark of the LMP2 car; that was our guiding principle.

'The argument there is that every constructor that has built an LMP2 car has optimised that car,' Atherton adds. 'It is the most efficient aerodynamic shape possible. If you were to alter that bodywork, that design, then you will only go backwards. The car will lose its efficiency, it will not be as aerodynamically effective as it is in its original form, so we had to strike a balance knowing that we were not going to be able to do any adjustment in performance to the LMP2 car, only the DPi. Now it exists, it would be easy to say that we didn't go far enough, but the reality is that we went as far as we could while still maintaining the LMP2 performance comparison.'

Big hitters

Whether IMSA went far enough or not is a moot point anyway, because its new DPi has done the job of attracting manufacturers, and with them have now come top teams like Joest (with Mazda) and Penske (with Acura), too. But isn't it a worry that having these big hitters might scare off the smaller teams that make up the bulk of the entry?

'That's an easy answer; like attracts like,' Atherton says. 'The validation that has been achieved through the Cadillac, the Mazda, the Nissan and the Acura, we believe validates the concept, and manufacturers are here because they are competitive. They want to demonstrate superiority,



Honda road car styling cues are clear on the Penske-run Acura. This way of linking to street car branding had been central to IMSA's success in attracting manufacturers to its DPi category

XPB

engineering expertise, and compare themselves to the best and show that they are better, and that is one of the most valuable elements of motorsport.'

But big names can also mean big spending, and this is a worry throughout the IMSA field. Give a race team money and it will use it, balance of performance or not, though it's where it spends it that is interesting. 'I think that the fastest way to gain that extra tenth is to invest in a more capable driver, and that is even more difficult to control [than tech development],' Atherton says. 'If you look at the examples of what has evolved since last season, with the arrival of the Penske organisation, and the drivers that they have lined up, with the changes with Mazda and the Joest team, and several of the Cadillac teams, that suggests that has already come into play. But that is what makes this series exciting and entertaining from a fan perspective, to have names and credentials like that sells tickets, brings eyeballs to television broadcasts. So, it is a fine line to manage costs and maintain a category that is appealing.'

On a high

Atherton admits, though, that keeping growth in check remains the major challenge for the series right now. 'The biggest challenge that we face right now is managing the growth and the expansion of the professionalism and sophistication that has occurred in a relatively short space of time,' he says. 'When you look back at the early days of the merger, the first year that we ran together as a single entity, the American Le Mans Series and GrandAm in 2014 … if you looked at the grid, the teams, the cars and the technology and then you look at this grid, you would say "wow, what happened?"

'That is a good problem to have, but we have to be conscious of the peak and valley that has historically been the hallmark of this type of motorsport,' Atherton adds. 'We are at a high peak now, some would say an unprecedented high peak, and as someone who has lived through several of those cycles, the goal is to maintain, and to incrementally grow. No one in our team is expecting exponential growth, and we are conscious of how fragile it still is. There is a statement that I have made to our staff, particularly the new members, which is that "on its best day this is still a very difficult business", and from a business perspective, we are in a good place now, the paddock is healthy, the outlook is bright. But we are being very careful not to be clouded by where we are right now.'

RACE MOVES

XPB

Rob Jones, the chief executive of the MSA – the UK's governing body for motorsport – has stepped down from the position. He has worked at the MSA for 12 years, the last four in the chief executive role. Jones, who also holds a number of posts in the FIA and will continue with these, will leave the post at the end of May. At the time of writing there was no word on who will be his replacement.

Steve Phelps has been promoted to the role of chief operating officer at NASCAR, where he will oversee all the US stock car racing governing body's commercial and media operations. This role was previously held by **Brent Dewar** prior to his promotion to president last year. Phelps joined NASCAR in 2005, after nearly two decades of sports business experience as a senior executive with the National Football League and with the Wasserman Media Group.

NASCAR Cup crew chiefs **Justin Alexander** (No.3 car), **Jeremy Bullins** (No.12), **Derrick Finley** (No.34) and **Chad Johnston** (No.42) were each fined \$10,000 after lug nuts were found to be improperly fitted after the STP 500 race at Martinsville Speedway.

Motorsport entrepreneur and PR guru **Stuart McCrudden**, who for many years ran Ford's one-make racing series in the UK and more latterly headed the FIA Thoroughbred Grand Prix Championship, has died at the age of 71.

Former F1 driver **Pedro de la Rosa** has joined the Techeetah Formula E team as a sporting and technical advisor, a position he took up in time for the inaugural Rome ePrix in mid-April. During his driving career de la Rosa drove for McLaren, Jaguar, Sauber, Arrows and HRT, and he was well-known for his ability as a test driver.

The Sauber F1 squad has signed up **Jan Monchaux** as head of aerodynamics. Frenchman Monchaux, formerly of Toyota, Ferrari and Audi, will report to Sauber technical director **Jorg Zander**.

Former F1 driver, automotive engineer and motoring journalist **John Miles** has died at the age of 74. Miles drove for Lotus in Formula 1, initially helping to develop the Lotus 63 4wd car in 1969, and was then also briefly at BRM, mostly in a racecar development role. He went on to concentrate on sportscars then retired from driving in the mid 1970s. In later years he was employed in engineering at Lotus Engineering, Aston Martin and Multimatic.

Alan Gustafson, the crew chief on the Hendrick Motorsport-run No.9 Chevrolet in the NASCAR Cup Series, was fined \$50,000 and suspended for two races after it was found that a brace supporting the rear window did not meet the specifications at the Texas Motor Speedway round of the series. **Kenny Francis** was to step in as interim crew chief during Gustafson's absence.

Francesco Cigarini, a mechanic at the Ferrari Formula 1 team, suffered a broken leg during a botched pit stop at the Bahrain Grand Prix. Cigarini was in the process of fitting a new left-rear tyre during Kimi Raikkonen's final stop when the Finn was mistakenly given the green light to leave the pit box. Ferrari was fined €50,000 for an unsafe release.

Willy T Ribbs, the first black driver to qualify for the Indianapolis 500, and **Al Unser Jr**, a two-time winner of the same race, have teamed up to form an historic racing team, which is to be called Unser-Ribbs Vintage Racing. They will be supported with car set-up and engineering services by their friend and business partner Steve Erickson, a veteran IndyCar engineer.

Former F1 impresario **Bernie Ecclestone** is set to return to court as the bribery scandal that saw him the subject of legal action in Germany and the UK in 2014 has once again raised its head. A company called Bluewaters claimed it was the highest bidder to buy F1 in 2005, but it insists CVC secured the deal because of alleged bribes. The matter is now returning to court, with London's High Court confirming that a trial date has been set for 1 October 2019.

OBITUARY – Bernard Boyer

Bernard Boyer, best known for designing championship-winning Formula 1 Matras and Le Mans-winning sports prototypes for the same firm, has died at the age of 83.

Boyer was born in Orleans in France in 1934 and came to motorsport first as a motorcycle racer and then as a driver, winning the French Formula Junior championship in '61 and racing at Le Mans in '62 and '63.

But his true vocation was as an engineer – largely self-taught – and racecar designer. He arrived at Matra in 1965 after working at Alpine for two years. He found great success, first in the junior formulae, which then convinced the French concern to step up to Formula 1 for 1968, where its racecars were run by Tyrrell.

The Boyer-penned Matra MS10 won three grands prix in 1968 and in 1969 Jackie Stewart took the title with the MS80 – which Stewart has gone on record to say was his favourite Formula 1 racecar. Matra also scooped the constructors' crown that year.

After its F1 adventure Matra, with its V12 engine, became dominant at Le Mans with the Boyer-designed MS670, winning the classic race in 1972, '73 and '74, a string of results that many have said persuaded Ferrari to cease its top-line sportscar racing activities.

Bernard Boyer 1934-2018

Jackie Stewart demonstrating his old 1969 Matra MS80. Bernard Boyer, who died recently, designed this car, which Stewart says was his favourite in F1

Zak Brown takes on Formula 1 CEO role in McLaren restructure

As part of a restructure of the management of the McLaren group Zak Brown has been named chief executive officer (CEO) of the Formula 1 operation.

Changes in the shape of the McLaren Group have now seen it reorganised into three clear divisions. These are McLaren Applied Technologies, McLaren Automotive and McLaren Racing.

Before the restructure McLaren was comprised of McLaren Automotive (which has its own competition department for GT racing activities) and the McLaren Technology Group, the latter covering three departments: Racing (that is, F1), Applied Technologies and also Marketing.

Jonathan Neale has now been given the title of COO of the McLaren Group, while Brown, who was previously executive director of McLaren Racing, is now its CEO.

Eric Boullier's role as racing director at the F1 team remains unchanged and he will continue to report to Brown. Mike Flewitt remains CEO of McLaren Automotive, while a new CEO for McLaren Applied Technologies is currently being recruited.

Shaikh Mohammed bin Essa Al Khalifa, McLaren Group executive chairman, said of the restructure: 'The work of the past year at a corporate level has been focused on structuring and positioning McLaren for growth. These latest developments are a natural consequence of that work and are designed to bring greater simplicity and clarity to the structure and leadership of the group.'

Zak Brown is now CEO of McLaren Racing, which has become a distinct division within the McLaren Group

RACE MOVES – continued

XPB

Ferrari has signed up FIA safety and deputy race director **Laurent Mekies** in what is, at the time of writing, an unspecified role. Mekies is to continue in his FIA position until he leaves the governing body at the end of June. He will then take six months gardening leave before starting work at Ferrari, where he will report to the Scuderia's technical director, **Mattia Binotto**.

Nico Rosberg has revealed that he became an investor and a shareholder in Formula E 'some time ago'. The 2016 F1 world champion is set to demonstrate FE's Gen2 car, which will be used from the start of season five in the autumn, at the Berlin ePrix in May.

Bob Tullius was honoured by the Motorsports Hall of Fame of America in March, when the career of the former driver and founder of the Group 44 race team was the theme of a special dinner. Tullius was recognised for his great impact on motorsport, particularly as a pioneer of the factory support model which is now very much in vogue, in his case with Jaguar.

Formula 1 broadcasters **Natalie Pinkham**, **Jennie Gow** and **Rosanna Tennant** are now ambassadors of the female motorsport initiative Dare to be Different; founded two years ago by **Susie Wolff** in partnership with the Motor Sports Association to help encourage women and girls of all ages and backgrounds to consider motorsport as a career.

The owner of the Erebus Motorsport Supercars outfit, **Betty Klimenko**, has also joined the Dare to be Different initiative. Klimenko entered Supercars, the premier Australian motorsport series, in 2013 after purchasing the Stone Brothers Racing operation. Erebus won the championship's flagship event, the Bathurst 1000, last season.

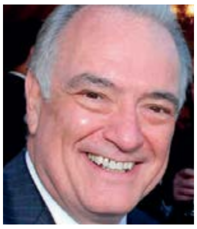
Legendary US race driver and team owner **AJ Foyt** was forced to miss the Sebring 12 hours in March – where he was due to be inducted into the Hall of Fame and serve as grand marshal – after he was attacked by killer bees while working on his Texas ranch. This is the second time he's been attacked by these bees, the first was in 2005. Foyt was expected to make a full recovery.

Allan Dean-Lewis MBE, former MSA director of training and education, has been appointed an Officiel d'Honneur in recognition of his service to motorsport over half a century. Dean-Lewis retired from the MSA in 2015 after a 20-year career at the UK's motorsport governing body. **Jim Kilmartin** has also been appointed an Officiel d'Honneur.

Chris O'Toole, the team manager at the Tickford Racing Australian Supercars squad, looks set to miss several rounds of the championship after breaking his leg in a motorcycle accident. **Matt Roberts** is to take on his duties during his absence.

Zack Young, the jack-man on the No.37 JTG Daugherty Racing Chevrolet driven by **Chris Buescher** in the NASCAR Cup Series, was injured when he was hit by the car in a pit stop during the STP 500 at the Martinsville Speedway. He suffered torn muscles in his leg, abs and groin and has said he expects to be out of action for 'a few weeks'.

◆ 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**



Game changer

The MIA boss thinks a new-look F1 might create more business opportunities

Bob Dylan once sang: 'You'd better start swimmin' or you'll sink like a stone, for the times they are a-changing'. After hearing Ross Brawn outline the proposed changes affecting the future of F1, these lyrics seem particularly relevant.

We now know, unequivocally, that the primary aim of Formula 1 is to entertain a substantially increased number of fans. Although based on the 'cornerstone of engineering technology', F1 owner Liberty Media's research identified current fans appreciate the high technology of the sport, but not at the expense of seeing one driver beating another using their skill and control.

I can see some negatives but if these plans, over the next decade, deliver a stronger, more equitable financial reward base from an entertaining and popular Formula 1 which secures increasing income for the motorsport supply chain from media, sponsors and fans, then I for one will be a happy man (see page 7 for Peter Wright's take on this).

Premier league

Formula 1 is the financial and business pinnacle of global motorsport. Its influence reaches across all commercial motorsport activities – where it leads, others will follow. Liberty, as new commercial owner of motorsport's 'Premier League', was bound to act to ensure a long term, financially healthy, business model for its shareholders and for the teams involved in Formula 1.

FIA president Jean Todt recently said: 'Formula 1 and all motorsport must become more affordable to remain healthy in the years ahead.' So most have known this watershed was imminent. Excessive spending in the top flight of motorsport was unsustainable and damaging to the entertainment value being offered to fans. Given the imbalance, some say unfairness, seen throughout an F1 grid, action is long overdue. Affordability and keeping costs under control while delivering better entertainment is the new order in F1, we're told.

We face substantial changes in transport and automotive over the next 20 years, businesses need to get started on preparing to capture value from the opportunities such change brings. Careful analysis, discussion with your peers, customers and competitors, scenario planning and financial reviews are what are needed, and right now.

No doubt these proposals will evolve and change, and compromises will be reached in the next few months, but as an inevitable starting point they have been well received by most team principals. Clearly, some of the changes are not good news for those who unreasonably profited from the old order, but with good planning, sensible negotiations and regular communication with customers and series owners, the future business of F1's suppliers will be more secure and healthy.

The racing was pretty good in Bahrain but F1's owner is still keen to level the playing field and spec parts are a possibility, which means lucrative supply deals could be in the offing

Brawn declined to confirm a figure for the cost cap that's to be brought in but did say it would exclude marketing and drivers' salaries. But it has become an open secret in the media that the proposed cap is $150m per two-car team, creating an annual spending pot of more than £1bn across the grid. As some Formula 1 teams currently spend more than double that, this begins to level the playing field and in doing so, creates more financially sound business models for teams while, in due course, also delivering a better sporting spectacle.

Show business

Now that Formula 1 seems to accept it is in sports entertainment I expect, over the next five years, other series will follow suit, which is good news. All motorsport needs to increase audiences. Some in management and operations will have a hard job to make the change, but the BTCC, for example, has already seen the light and provides great fan engagement. Those who supply at the highest level in major series must be ready to accept the focus on entertainment and limited budgets.

Road relevance

Future engine supply appears complicated, although the ambition is to open the door to more suppliers and deliver a de-cluttered, cheaper and noisier 1.6-litre V6 turbocharged hybrid power unit that is road-relevant too. As no OEMs are designing such an engine for future road use, it's hard to see the logic in this suggestion, but time will tell.

It is likely cost controls will embrace component supply, perhaps bringing in a single design/supplier for brakes, transmissions, wheels, battery packs and the like. Brawn rather bluntly described these as low performance differentiators and says they are of little interest to the fans.

The MIA is encouraging its members to engage in positive dialogue with their customers to help prepare for and resolve issues which may affect their mutual business. This work can't start too soon. Your knowledgeable opinions and multi-discipline expertise are invaluable and will help F1 and its teams to avoid possible mistakes in their drive to be more affordable.

Suppliers seen to offer helpful solutions could well find themselves winning business. This could be an opportunity for new suppliers to offer products at the best value. However, make no mistake, spec parts will mean substantially increased volume demand on selected suppliers, requiring a high-level of back-up service to all teams and a product of the highest quality. There will be no room for error as all teams will be damaged by poor supply – I hope the FIA takes this into account when selecting suppliers.

If Formula 1 and the FIA can deliver these long-overdue but ambitious plans successfully at the top of motorsport, and awareness of the fun and entertainment of our sport reaches a wider audience across all other motorsport disciplines, then it could be the beginning of a bright new future. I certainly hope this proves to be the case.

The excessive spending in the top flight of motorsport was unsustainable

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Waiting in the wings

The proposals dictating the future of F1 that have been released by Liberty seem to lean more towards entertainment than technical development, but are pretty much what is needed to bring Porsche or Audi into the Formula 1 family, and F1 would like a VW brand in there sooner rather than later. Although Porsche has the engineering team to do F1, it makes little sense. Other than Ferrari, manufacturers competing in F1 are volume car brands (Renault, Mercedes, Honda), while Porsche remains small fry in terms of market share. An F1 programme for Porsche doesn't make sense, but then little in this modern world of racing does at the moment.

Liberty's proposal for Formula 1 indicates a standardisation of parts, for example. It follows an FIA trend to reduce development rather than increase return on investment. Material development and knowledge can benefit other industries, such as defence and marine as has been proven time and again. The same goes for the development of battery cells, as Toyota has been able to do in its new LMP1 car. The removal of the air conditioning system for the battery means that the cells need to run at a higher operating temperature, and the team claims that it has raised that operating temperature by around 20 per cent in the last two years.

The Porsche 919 was faster than an F1 car, sure, but how fast could an F1 car go if unrestricted?

Toyota says that it needs to keep technology development at the heart of the new LMP1 regulations to maintain interest, and this is a shining example of how it could be done. Let's not forget the other shining example of technical development brought about by Formula 1 and the WEC; the perfection of the MGU-H. Having proven the technology, both series now seem set to ditch the system, which is a shame, but it has to be said; it's years since we have written about hybrid systems in Formula 1 or the different solutions in the WEC. It is time for the next step, although the industry is still confused as to what that step is. Natural gas? Hydrogen? Crop-based diesel? I hope that the ACO once again steps up its Garage 56 concept as this is a prime opportunity for manufacturer-led exploration.

Online there are discussions over the relationship of protection of personal data and autonomous cars, and while this is not necessarily linked to electric or hybrid cars, autonomous driving is a Utopian vision of the future that I still struggle to accept. Having witnessed the devastation of the UK health service through a data hack last year, autonomous cars in my mind took a gigantic backwards step.

Meanwhile in production cars, industry leaders say that there is still a future for diesel, but governments are so keen to maintian their course, regardless of evidence, that the manufacturers have no option but to follow them. That means investment in electric mobility over all other technologies, despite public reservations revealed by the heads of major car brands and almost a plea for alternatives. The head of VW, Matthias Muller, went on record to say that the future still includes diesel engines. 'Once the knowledge that diesels are eco-friendly firms up in people's minds, then for me there's no reason not to buy one,' he said in March.

For the government in the UK, however, with financial uncertainty looming due to Brexit coupled with a sustained attack on diesel, new diesel car sales (featuring the most efficient engines that actually help manufacturers meet the emission targets), fell by more than 25 per cent in January compared to the same month in 2017. The SMMT says that the UK new car market fell by 6.3 per cent, and although the demand for petrol and alternative fuel cars grew, it failed to offset the fall in diesel sales. SUV sales grew by 6.6 per cent, suggesting that consumers love the luxury and comfort, yet are being driven out of the cleanest engines.

Back to racing, and Porsche is busy spinning its 919 Hybrid time attack project. Yes, this is engineering, and yes, this is a racing car (or was), but the programme seems to defy logic. Running outside regulations meant the team can run DRS, more boost, more power and less weight. I would have liked to see it compete for something meaningful, or run with a direct comparison.

Porsche wanted to go for the record up Pikes Peak, and that made sense. The top class is unlimited (save for safety), and Sebastien Loeb's record time was set in a car developed from the spare parts bin of the Peugeot 908 HDi FAP. There is no such target at Spa, which left me a bit confused. It was faster than an F1 car, sure, but how fast could an F1 car go if unrestricted? The Pikes Peak effort was dropped as Romain Dumas was contracted to the VW electric effort and no one else knew the course (or the car) quite like him.

It is a shame that we have landed here so quickly after such a development era in F1 and the WEC. I hope that we can get back onto the path of improving production car technology in racing, and take the lead again.

ANDREW COTTON Editor