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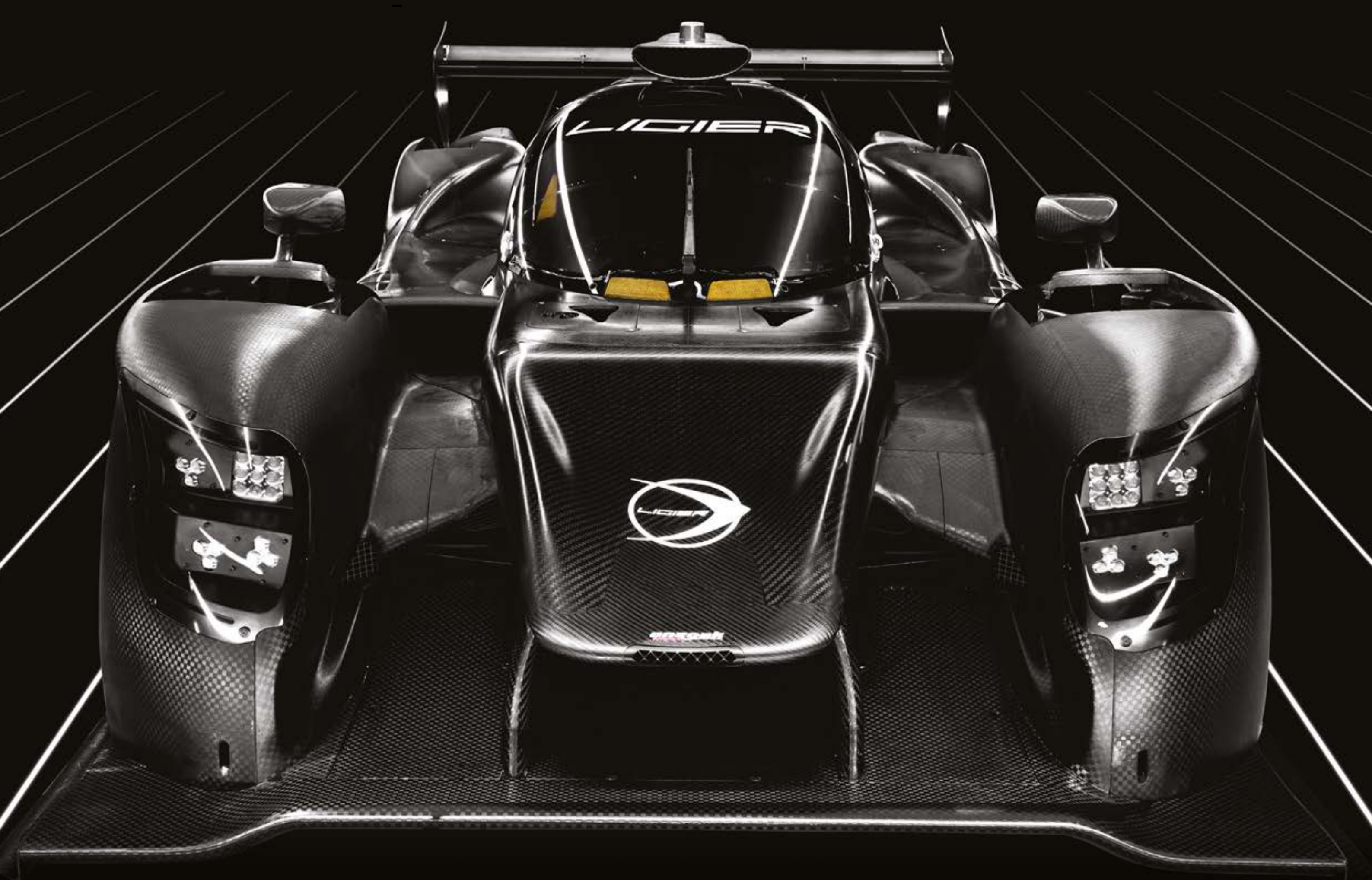


**Indycar 2018**
Aero rule changes that will change shape of US series

**Rear wing studies**
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**Force India VJM09**
Under the skin of Formula 1's most improved car of 2016

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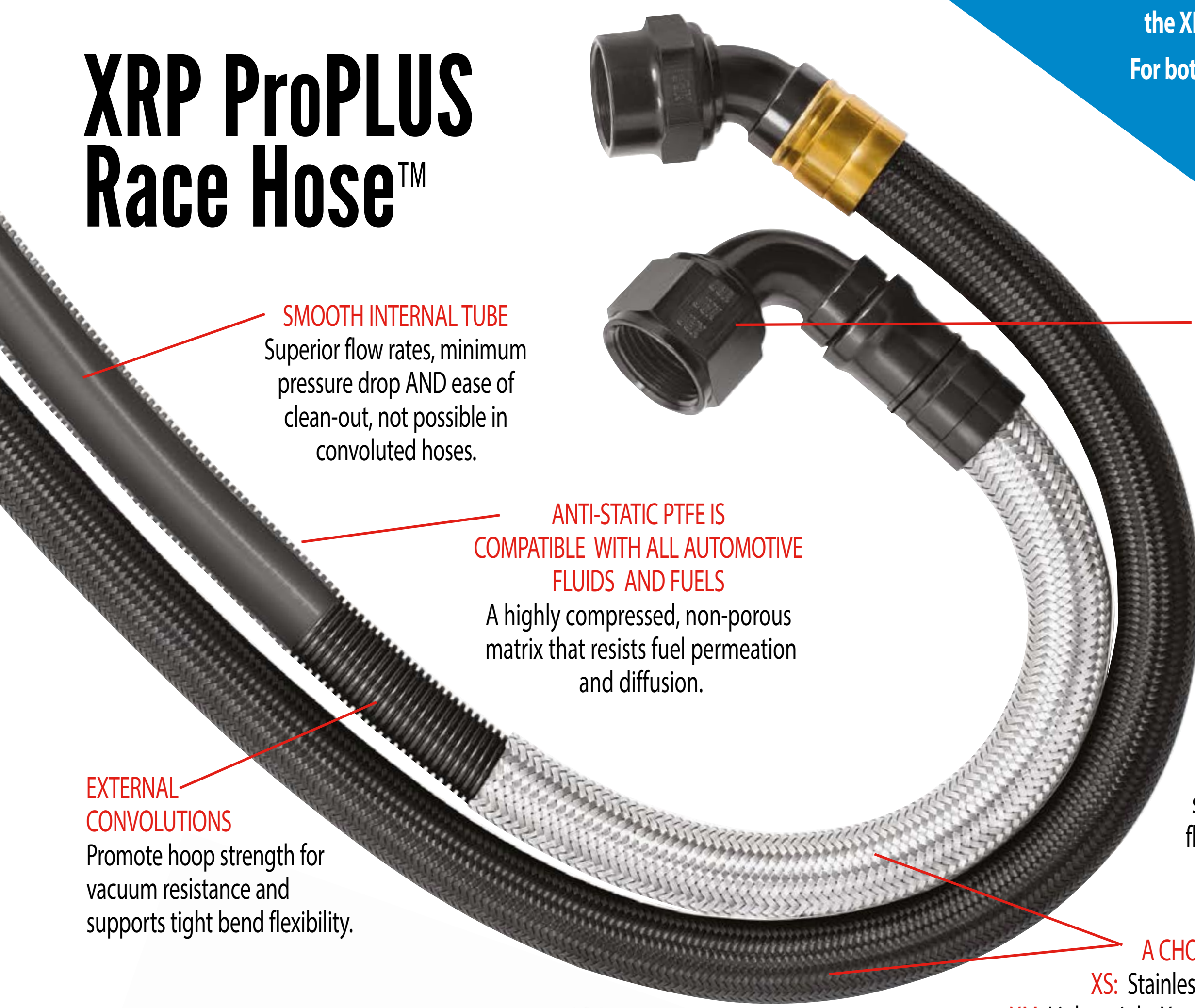

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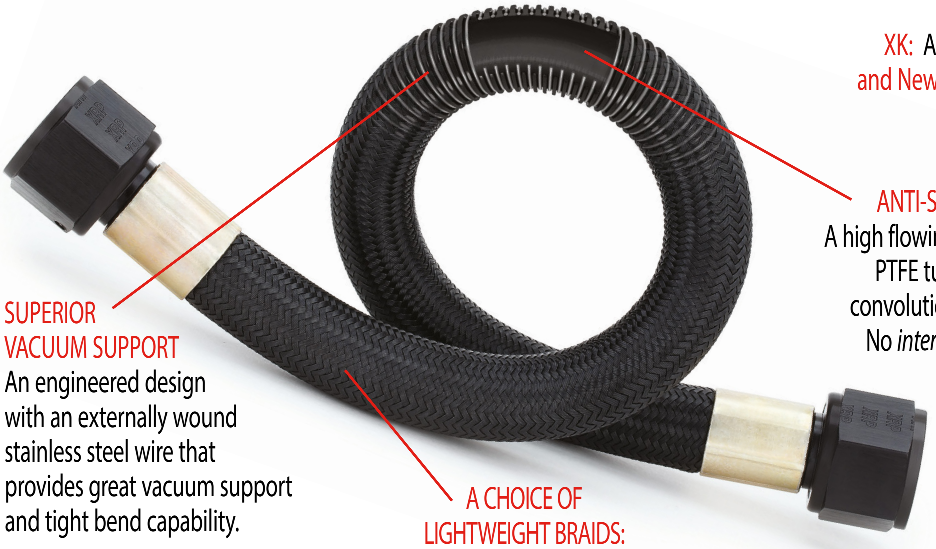

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# CONTENTS – NOVEMBER 2016 – Volume 26 Number 11

## COVER STORY



## COLUMNS



## FEATURES



## TECHNICAL



## BUSINESS NEWS & PEOPLE




Peugeot has pinned its hopes on retaining its Dakar crown in 2017 on the 3008 DKR. Turn to page 34 for a closer look


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# The scales of justice

## How racing has used weapons of *mass* distraction to gain that unfair advantage

Having previously examined time in a previous column, we now proceed to examine mass, or as usually presented, weight, although one must be careful not to confuse the issue. In everyday usage, the mass of an object is often referred to as its weight, though these are in fact different concepts and quantities. In a scientific context, mass refers loosely to the amount of *matter* in an object whereas weight refers to the force experienced by an object due to gravity, so an object with a mass of 1.0kg (the unit of mass) will weigh approximately 9.81 Newtons (the unit of force) on the surface of the Earth (its mass multiplied by the gravitational field strength). Its weight will be less on Mars (where gravity is weaker), but you can be assured that it will always have the same mass.

As we race on Earth presently, the values remain almost constant, although, being pedantic here, weight does drop as you go up in altitude (because of diminishing gravity), though your mass still remains the same. However, the effect is not huge. In Mexico City, you'd only weigh 0.1 per cent less than at sea level, although massing the same.

### Gram prix

At race tracks keeping to the weight limit does not go down to this accuracy, but does involve some juggling pre-race, as the official scales of the governing authority bode no discussion, and the sheer fact of transporting and assembling the measuring kit to the far corners of the world and re-calibrating it can give a small deviation, the same applying to your kit (for calibration, a previously determined weight is used to set the balances parameters, guaranteeing its accuracy).

Having checked your car, driver and his kit pre-race, you then have to cater for his expected weight loss during the race, plus the wear on the discs, pads, tyres and plank (if your class requires it).

Mass is a fundamental preoccupation in performance, so much so that it is primordial in any statement concerning rules, not even being questioned by anyone. It is used to balance performance in some classes of racing, and is also the bane of any racecar builder, as getting the car down to minimum weight and having the weight distribution you want demands careful packaging.

The prime axiom for any car designer is that any racecar puts on weight ineluctably, also known as 'mass creep', which militates for designing cars underweight and ballasting up, to cater for the avoirdupois that will come, giving you also a chance to have the preferred weight distribution.

Mass will determine your lap speed quite precisely, given that physics will require a given amount of energy to accelerate, decelerate and corner. Speed will be limited by the amount of grip that will give the centripetal acceleration to deviate from a straight line. Roughly speaking, the rule of thumb will be that each kilo of mass will cost you around 0.03 seconds a lap for your average track, and a fast, flowing track will be less sensitive to mass than a hairpin-littered stop and go track.

**Smokey Yunick used water-filled tyres to bring the car up to legal weight**


**This Toyota LMP1 weighed 0.1 per cent less at the Mexico City round of the WEC because of the high altitude. The car's mass, however, was not affected**

### Weighty issues

This is why qualifying can be a delicate balancing act. Have just enough fuel for the out lap and a qualifying lap, or have you enough for two laps in case you do not have an optimal one? Tyre grip can go down in successive laps putting a premium on that sticker tyre attack, too. Fighting for pole in some very hotly contested classes can involve sitting out most of the session and going out on minimal fuel with just enough time to cross the line bare seconds before the end of the session and profit from the lightweight, rubbered track, and the knowledge no one will bump you.

When you have qualifying with gaps of 0.025 seconds between cars one can see the reason for going out on the limit, and it has encouraged teams to push those limits, sometimes over the edge of legality. Qualifying cars were rife at a certain period in F1, with the missing mass being made up before the end of the session by replacing the rear wing. The sight of some of this item being carried by two mechanics prior to fitting rather gave the game away, and this practice was countered by having random checks on scales at the pit entrance. One of NASCAR's legends has it that Smokey Yunick used water-filled tyres to bring a car up to legal weight at tech, and changed tyres before and after the race.

Some of the stratagems were blatant, as when there was a dispensation to re-fill all the liquids in the car, like brake fluid or coolant. Brabham and Williams had nominally water-cooled brakes, with rather big reservoirs, that when topped up brought it to the legal minimum.

### Dietary fibber

In 1984 Tyrrell went one step further. Being the only normally-aspirated engine in the field, it benefited from a similar strategy to the water brakes. In Tyrrell's case, the engine was equipped with a water injection system with a supply tank topped up late in the race. It was not only water, it also had 65kgs of lead shot. As it was pumped in under pressure, some of the water and lead shot sprayed out and the FIA looked closely at it after the Detroit Grand Prix, where Martin Brundle had finished in second place for the team.

Following this, it was alleged that the water was in fact 27.5 per cent aromatics and constituted an additional fuel source. Tyrrell was thus charged with taking on additional fuel during the race, using illegal fuel (the aromatic-water mix), equipping the car with illegal fuel lines (the lines from the water tank to the water injection system), while the lead shot in the water tank was seen as ballast that was incorrectly fixed to the car.

Further analysis showed that the actual fuel content of the water was significantly below one per cent and well within the rules, and Tyrrell argued that the shot was contained within the water tank and it required tools to be removed.

However, on appeal, the evidence that the water's fuel content was in fact far lower than originally suggested was ignored, and the charges amended to the fuel in the water and unsecured ballast, thus upholding the original decision. Tyrrell was excluded from the championship and was then banned for the last three races of 1984.

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# Judge dread

Is fear of litigation leading to overzealous safety measures in F1 and the WEC?

My wife was watching the Rio Olympics on TV when I happened to catch part of the cycling road race, and therefore I saw the multiple crashes, including Annemiek van Vleuten's high-side. Apart from being glad that she survived, I couldn't help but compare the greater risks in this sport with those that now exist in most of contemporary motor racing. Many other competitive activities also encompass more danger – so how come the ever-increasing emphasis on safety in our sport, particularly by the FIA and ACO?

Perhaps I am being hard-nosed in suspecting that the growth of litigation globally and the over-imposition of health and safety directives has reached such a level that organisations involved in governing, promoting or running motor races are running scared of potential huge claims being made against them. Litigation following major incidents is not new in motor racing, but now that certain F1 drivers' overall annual earnings amount to tens of millions of pounds, a successful claim for career-terminating injury or death could be enough to bankrupt a governing body. A similar threat could exist when one considers the financial worth of some of the gentleman drivers in endurance racing, for example. The cost of insuring against such claims can put this form of protection out of reach, unless the underwriters can be satisfied that every possible action is being taken to minimise risk.

## Head case

The Halo is definitely happening in Formula 1 because the FIA, as it currently operates, has no choice. Taking the issue of driver head protection, it has become evident from the R&D carried out that the Halo reduces the risk of such injuries. To what degree is arguable but this is not the point. In the event of a claim concerning a serious head injury, among the questions that the prosecuting lawyers would doubtless pose would be 'were all possible means employed, and did the defendants do their utmost, to prevent such injury?' From now on, at least in F1, if the Halo is not fitted the answer would have to be 'No' because this device exists and would likely have reduced the risk. The FIA has bought some time in deferring the Halo's introduction by declaring that further on-track testing is needed, but its hands are tied now (as an aside, surely the only testing of the Halo on-track that will be truly representative from the driver aspect will be in an actual race, especially at the start and first corner where the cars are bunched together and lightning avoidances are needed, relying on the drivers having clear 180-degree vision? How to achieve this *before* it is mandated is not clear). Of course, had the FIA not started the process of testing driver head protection, it no doubt would be open to accusations of neglect on that score. Damned if you do, damned if you don't.

I suspect that the recent policy, unannounced and, in my view, rightly much-criticised, of seemingly now always starting Formula 1 and WEC wet races under Safety Car conditions is largely caused by the same fear of litigation if a major incident occurs and the accusation gets laid at the door of the FIA or the ACO that all available precautions were not taken.

XPB

**We already have Safety Car starts in the wet but might we one day have a ban on first corner passing to stop F1 shunts such as this at Spa in 2012?**

## They shall not pass

One must have sympathy with those who have to deal with these serious matters, and I am not suggesting for one moment here that there isn't a genuine concern for driver safety, but the question must be at what price to the spectacle and challenge of what used to be one of the most 'edgy' of all sporting activities?

A logical progression from Safety Car starts in the wet could eventually be a no-overtaking yellow-flag rule until after the first corner, even in the dry, because this first few hundred metres of the start is the most likely part of a race to result in collisions (cue Spa 2012, among many other examples). Don't laugh; it's not so long ago that Safety Car starts were unknown. The insidious nature of the ever-increasing wrap in cotton-wool, risk-averse, attitude to not just motor racing, but life in general, poses a real threat.

## Elephant in the vroom

I question whether the international motorsport governing bodies have become over-sensitive to the risks; witness the short-lived farce recently regarding the disposal of visor rip-offs! But they are not always as clear in their thinking as they should be. Virtual Safety Car rules as introduced after Jules Bianchi's Suzuka crash (family litigation outstanding) are probably a good thing, but what seems to have been ignored, the elephant in the room if you like, was the presence on the edge of the track of a seven tonne crane. It was solely the impact with this that caused the fatality, and yet I'm not aware of this method of car retrieval having since been banned.

How does MotoGP manage, I wonder, without so much emphasis on safety when the risks are palpably greater. Or even NASCAR and IndyCar in the USA, the country with a culture of suing everyone in sight when any perceived harm has occurred. This includes awards for punitive damages, which have no prescribed scale or limits and are awarded at the discretion of the presiding judges.

It's time that anyone (however prominent and rich) who places his or her backside in a racing car takes back responsibility for what can happen and in doing so irrevocably commits to removing the legal culpability of all other parties, except in the case of proven negligence or malpractice.

Such waivers exist now, of course, but they need considerable beefing-up. Maybe the FIA and the ACO, plus other motorsport governing bodies, should co-operate in lobbying for an internationally-recognised legal protocol that takes acceptance of risk by competitors more into account in judgements of claims, otherwise the increasing mantra of 'safety above all else' could suck the guts out of motor racing.

**I suspect the organisations involved in governing, promoting or running motor races are running scared of potential huge claims being made against them**


# A Force to be reckoned with

**Force India's 2016 Formula 1 challenger may be a development of last year's car but, as *Racecar* discovered, some inspired upgrades have made the VJM09 one of the surprise packages of this season**

**By LEIGH O'GORMAN**

**Force India started the season slowly with a run of disappointing results, but after a timely upgrade to the VJM09 at the Spanish Grand Prix it's taken Formula 1 by storm and at the time of writing the team was fourth in the Constructors' standings**

Force India's battle with Williams for fourth place in the Constructors' standings this season is an interesting one. The top-four finish would pay significantly higher prize money than fifth, yet both teams have turned their attentions to 2017 – when a brand new set of regulations will come into force. So with few, if any, developments coming, Force India is relying on the proven concept embodied in its VJM09 to beat the team that heavily outscored it last year.

For technical director Andy Green and his design team, completely changing direction with the car for this season not an option. 'The VJM09 was a continuation of the philosophy of the VJM08,' Green says. 'We decided not to depart too drastically from the route that we were already on, given the large scale technical regulation changes coming in 2017.

'It didn't seem prudent to be changing direction [for the 2016 season], trying to recover, and having a change of technical regulations several months later, so the decision was made to carry on with the VJM08 design philosophy. We would continue developing that car, because we felt there was a lot more potential that was untapped,' Green says.

The Silverstone-based outfit has not departed too far from the VJM08B concept debuted in mid-2015, then, but the real need to keep pushing hard into this year in order to press Williams resulted in the very effective introduction of a significant update at the Spanish Grand Prix at Barcelona in May.

## Indian summer

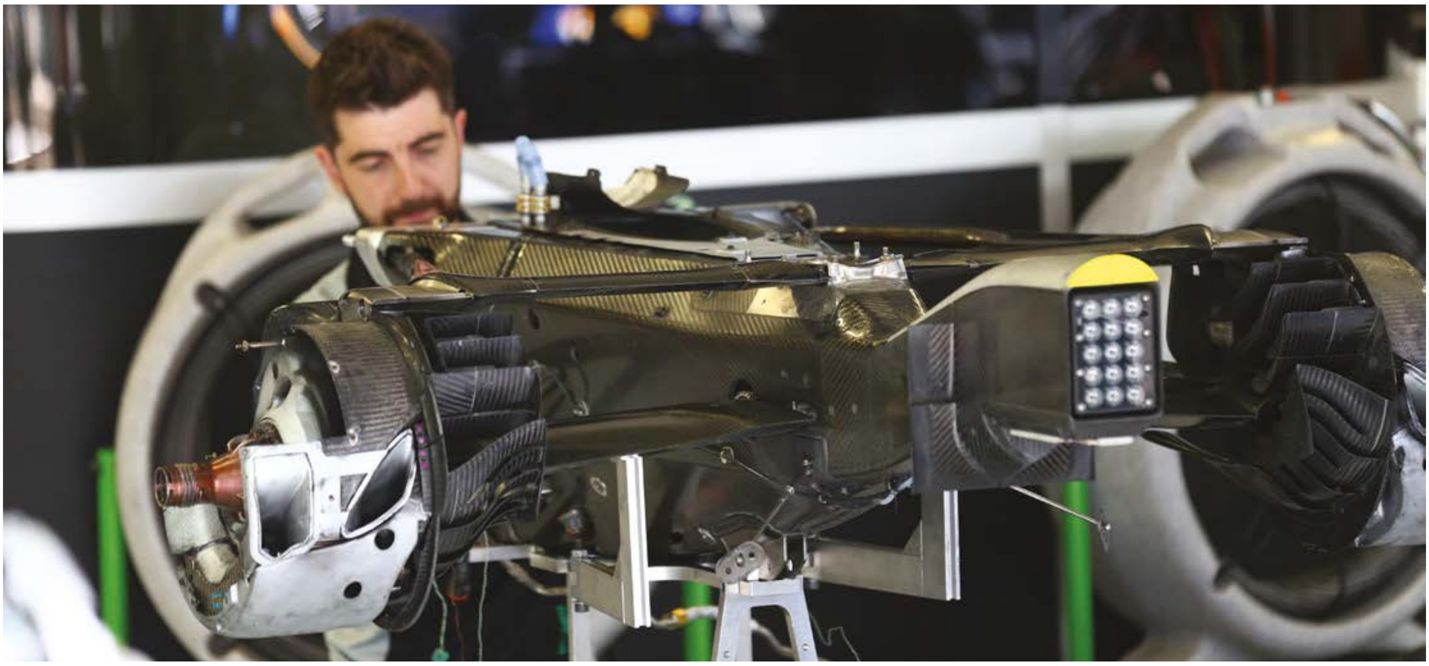
The changes for 2017 also defined how progress would be mapped through this year, with updates discontinuing just prior to the summer break. 'We really did have to start work for 2017 early and it wasn't that applicable to 2016,' says Green. 'The 2017 model [was designed] in June and July time and then work on the 2016 car slowly tapered out up until the summer break started, and since then the focus has been 2017.'

While Force India and its two drivers, Sergio Perez and Nico Hulkenberg, have performed very well, Williams' poorer performances this season have also helped to bring the team into what was initially an unexpected fight. But it was the early season update that really sparked Force India's challenge.

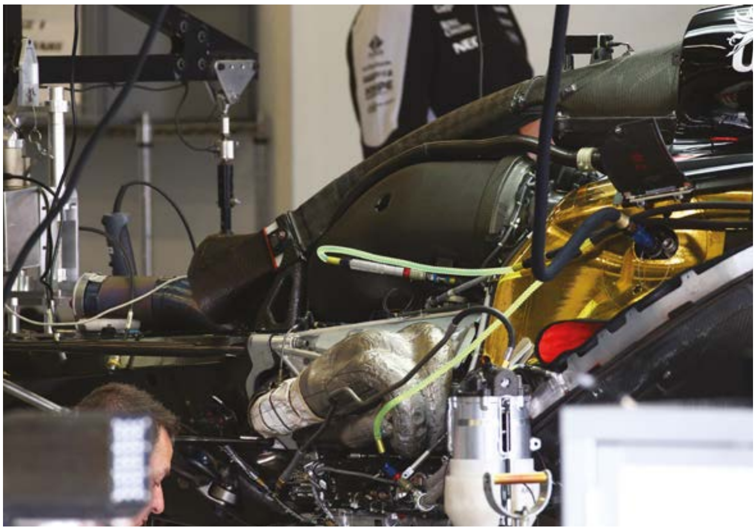
After four races, Force India had registered eight points to Williams' 51, but come the Spanish Grand Prix, it introduced what was effectively a B-spec version of the VJM09. In 11 grands prix since, it has notched up two podium finishes (Monaco and Baku) and scored points in every race bar one. The upturn in form has been enough to lift it ahead of Williams by one point (as of the Singapore Grand Prix).

The Barcelona update saw the introduction of new suspension, bodywork and cooling

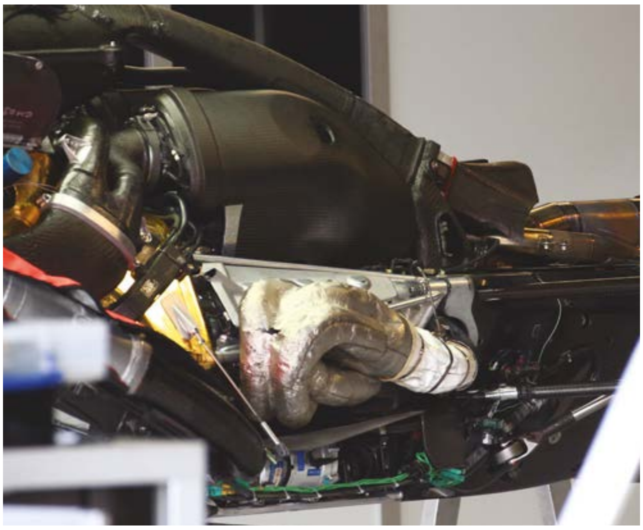
**The Barcelona update saw the introduction of new suspension, bodywork and cooling systems, but the most significant addition was a heavily upgraded front wing**



VJM09 packs a 2015 Mercedes 'box which ties the team's hands a little when it comes to the design around the rear of the car, as it defines suspension pickups and other features



Force India's philosophy with the power unit is to run it to the very limit of the guidelines that Mercedes gives it because every extra degree cooling is downforce that's not being generated



The packaging of the Mercedes power unit is typically neat. Force India has been a Mercedes customer team for eight seasons now and it will remain so in 2017

systems, but the most significant addition was a heavily upgraded front wing.

'Everything we do on the front wing is about generating rear load,' says Green. 'For us, it's all about having a stable wing in all conditions in all ride heights and all attitudes, so part of the philosophy was to improve the envelope for the driver to work in, to give him more latitude to drive the car, make it more consistent, to make the car more balanced. It was significant update at Barcelona, and we felt that was a good step. The drivers felt that was a good step, and our performance seemed to take a good step. That really kick-started our season.'

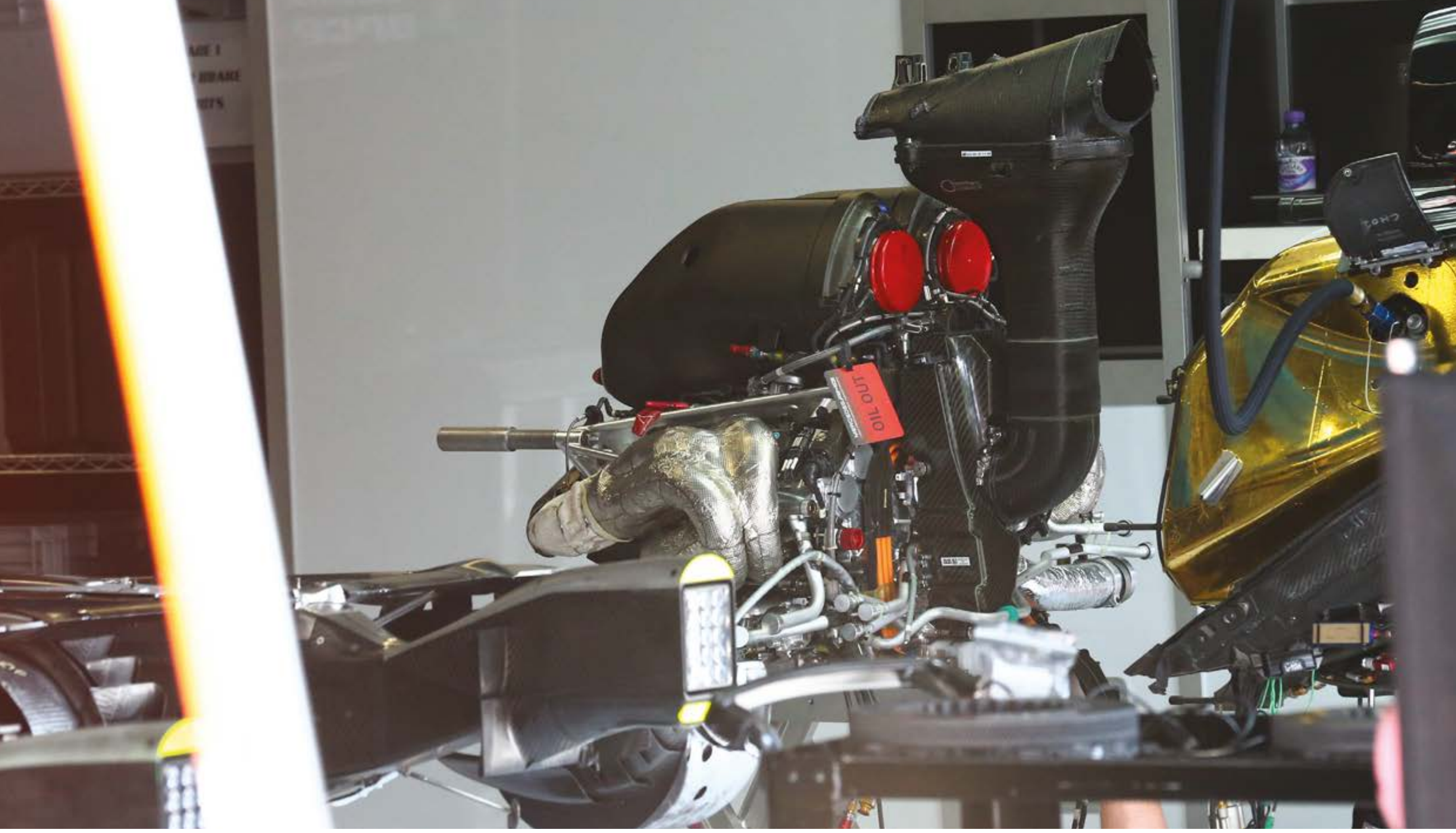
'We decided we would continue developing the 2015 car, because we felt there was potential that was untapped'

## Storm Force

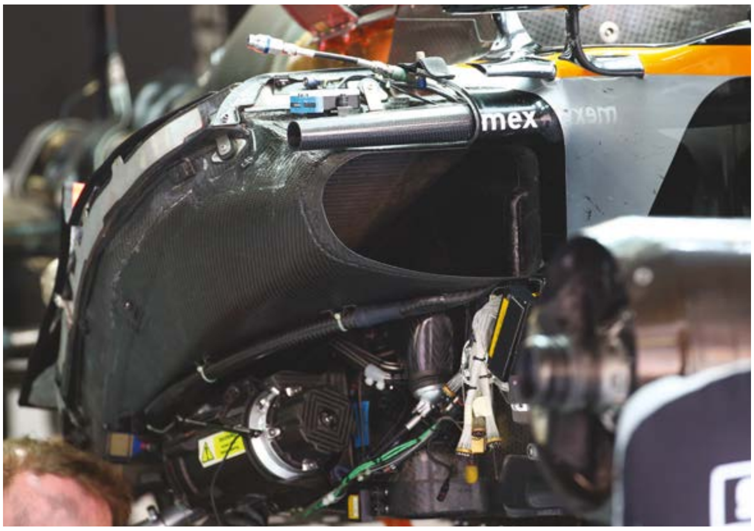
Green says that another part of its update philosophy was the sculpting of the outboard air; how it interacts with the front tyre and how it effectively washes the wake and the dirty air generated away from the rear of the car. Although no further updates are expected, Green did acknowledge there was a Monza-specific front wing for the Italian Grand Prix. However, he also revealed that the VJM09 has reverted back to a Silverstone-update front wing for the remaining races of 2016.

Development of the sidepods was also key to the increasingly potent VJM09, and part of that process meant balancing cooling performance and aerodynamic performance. 'We were looking at increasing the efficiency inside the sidepod with the radiators and the cooling systems on the mechanical side of it,' says Green. 'As we were increasing that efficiency, we found that we could modify the sidepods and squeeze them tighter, and every time you can squeeze the bodywork tighter toward the rear of the car, you pick up rear load, which is what we're always looking to gain.'

Further updates to the sidepods in tandem with track and ambient temperature dependent changes to the engine cover all helped develop the cooling system. 'We use that to modify the cooling capacity of the car. We want to run it on the limit and the limit is set by Mercedes,' Green says. 'We always want to run right to those limits, we don't want to be a degree under, because every extra degree that we're cooling is downforce that we are not generating. We do everything we can to make sure we are running the car on the limit, so a lot of work goes on




**Force India has always been known for the straightline speed of its cars and with the all-conquering Mercedes PU in the back this has been even more the case in recent seasons**




**Development of the sidepods has been key to the car's success, as Force India's been able to squeeze the bodywork at the back, which then helps with its goal of increasing the rear load**

**The roll hoop design carries over from the VJM08 of last season and features the now-familiar pair of forward pillars supporting the triangular-shaped air intake**

[during Friday practices] to determine how close to the limit we are, given the prediction of weather we have been given for Sunday.'

Green adds that the VJM09 uses the engine cover and the back of the engine cover to modify the airflow to the cooling system. 'You tend to see a lot of changes to that area depending on ambient temperature at the track.'

## Core values

The cooling pack has also seen improvements with more efficient radiator cores, while better management of the different areas of the Mercedes 106C power unit have aided Green's aim to get the VJM09 closer to that limit. 'You have got the water, the oil, the ERS cooling and the compressed air through the charged air cooler, so there's lots of different areas of the car and engine that need cooling. And you've got the gearbox on top of that.

'Once we start running, then we understand more about the limit that we can run up to on each of those areas and we trade off one against the other to make sure that under normal conditions they all hit their limit at exactly the same time.' Green adds that such trickery requires what he calls 'a bit of playing around with the configuration of the radiators'. However, once this is then refined, the team may look to making further improvements in the efficiency of the radiator cores, effectively making the whole pack smaller.

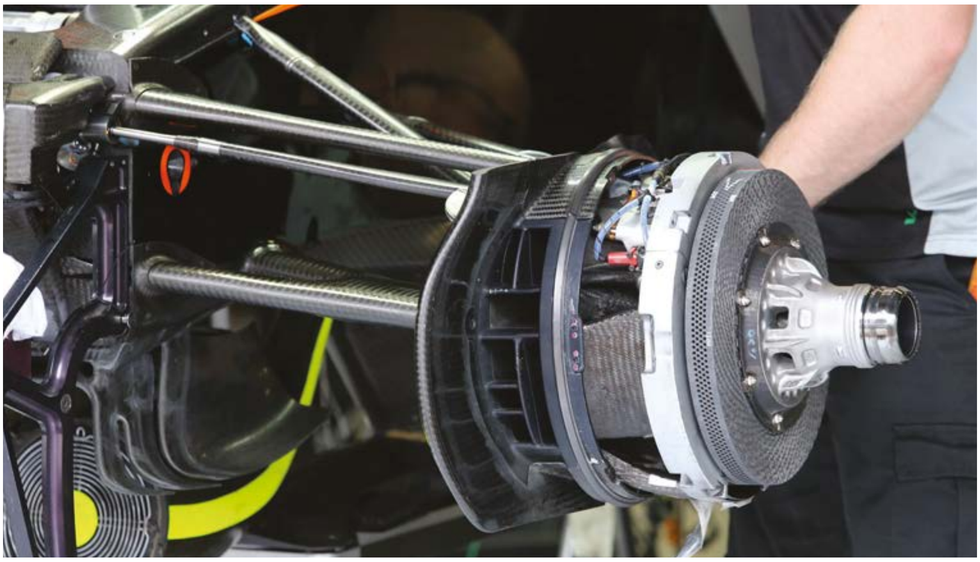
'What we're always looking to do is to balance all of the radiators, and make sure they are all working as efficiently as we know possible, and then make sure they are as small as possible, and that was the round of work that we delivered in Barcelona.'

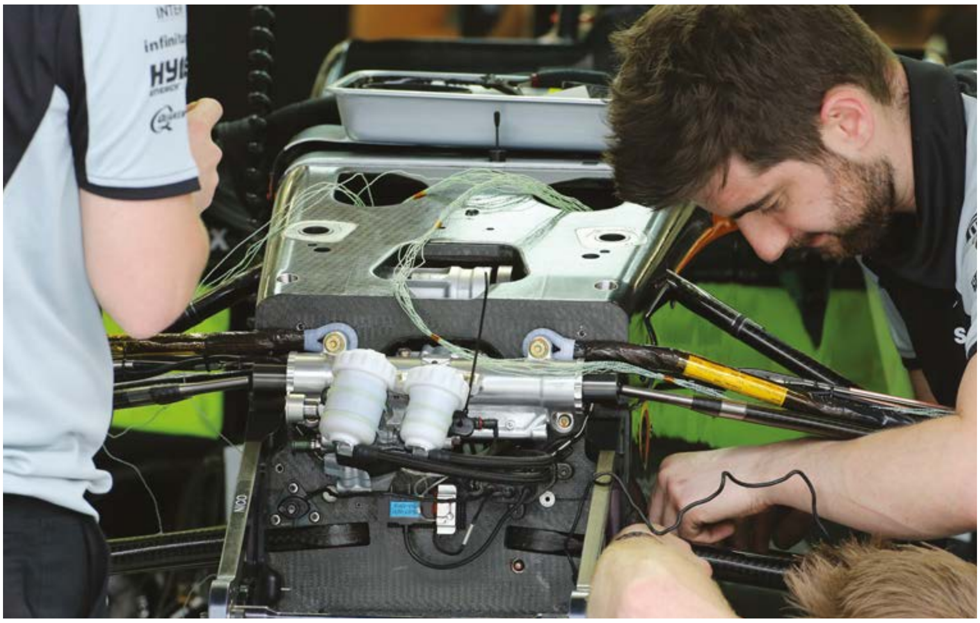
There is also a small winglet mounted behind the exhaust exit that has a small influence on the rear wing. 'There isn't that much to work with, but what there is we try to do what we can with it. It does have an effect on the stability of the rear wing and how hard we can work the rear wing. We use it to tune how hard we work that top [element].' However, the winglet does not have as much influence on the exhaust plume as it used to, due in part to the regulations governing the power unit and ICE.

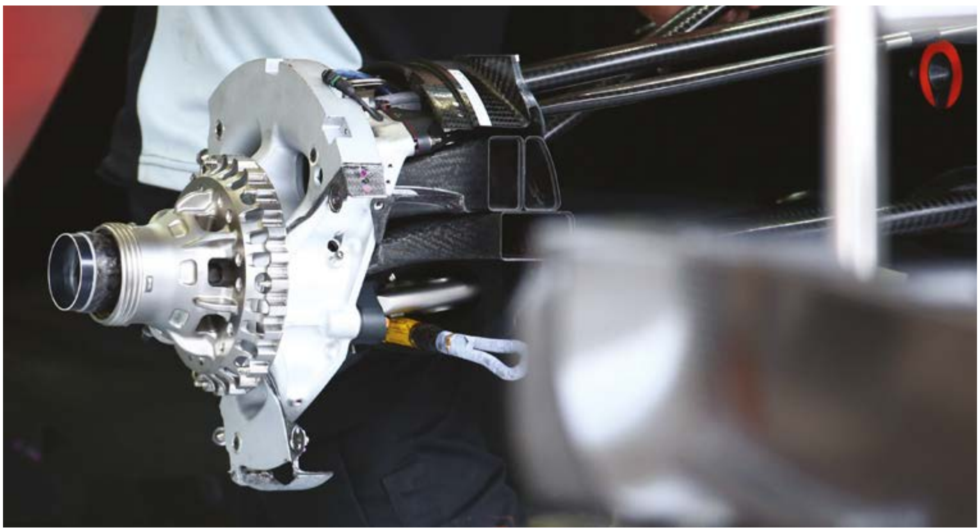
## Energy sapping

A significant portion of the energy from the exhaust is taken out with the turbocharger, vastly reducing power available to the exhaust.

# Importing a gearbox from a manufacturer pre-defined much of the design philosophy around the rear of the Force India VJM09


On the VJM08 the brake calipers were moved from the front of the axle to the rear and this is still the case with the VJM09


The 2016 car runs with vertical torsion bars at the front end. Mounting the front wishbone to the chassis was a challenge


Force India has introduced a new front suspension this year which includes changes to the uprights and blown front axles

For each update to the engine, the power to the exhaust reduces further, improving the efficiency of the engine as more power is delivered to the wheels. But this does reduce exhaust energy and, Green says, it reduces the usefulness of the winglet at particular tracks. 'As we back off the top wing, we can remove that little winglet behind the exhaust, because it is not particularly efficient. It's quite draggy, so you will see it come off at quite a few of the lower and medium downforce tracks, which there aren't that many of at the moment, but there will be next year, so it's really about how it interacts with the upper wing.'

## Blown axles

The floor was also heavily revised, particularly around the rear section. Aimed at modifying the behaviour of the dirty air from the rear tyre that gets sucked into the diffuser, Green says: 'We tend to set up aerodynamic devices in front of the tyre that control the dirty air coming off that tyre and move it outboard. All the vents and slots around that rear tyre are all about generating systems and vortices that interact with the dirty air, the wake of the rear tyre, and move it away from the diffuser.'

Last year, the VJM08B ran relatively unchanged uprights through the season, although Green acknowledged that the architecture around the uprights did develop significantly. This concept was swept aside for this year as the team introduced new front suspension and blown front axles to the car.

The VJM09 also runs with vertical torsion bars at the front end of the car, which Green says was for the purpose of packaging. Due

### TECH SPEC

**Chassis:** Carbon fibre composite monocoque with Zylon side anti-intrusion panels.

**Front suspension:** Aluminium alloy uprights with carbon fibre composite wishbones, trackrod and pushrod. Inboard chassis mounted torsion springs, dampers and anti-roll bar assembly.
**Rear suspension:** Aluminium alloy uprights with carbon fibre composite wishbones, trackrod and pullrod. Hydro-mechanical springs, dampers and anti-roll bar assembly.

**Wheels:** Motegi Racing forged wheels to Force India specification

**Power Unit:** Mercedes AMG High Performance Powertrains (HPP) V6 Turbo 1.6-litre

**ERS:** Mercedes AMG High Performance Powertrains

**Transmission:** Mercedes AMG F1 8-speed semi-automatic seamless shift

**Fuel and Lubricants:** Petronas

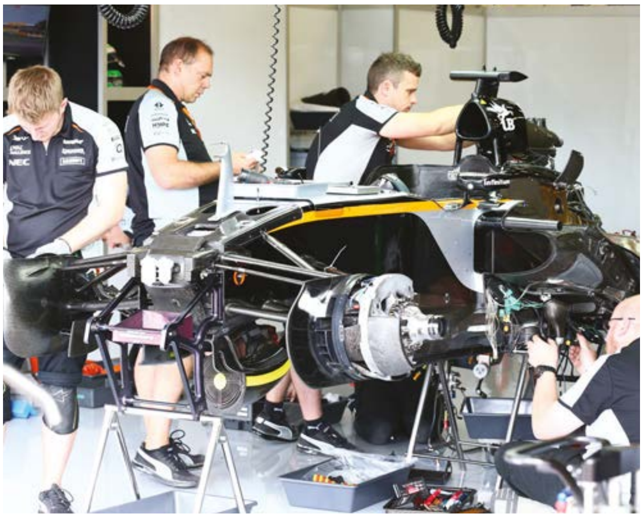
**Tyres:** Pirelli

**Brake system:** AP Racing

**Brake material:** Carbon Industries

**Dampers:** Koni

New heavily modified front wing was a part of the highly successful Barcelona upgrade, its purpose is to generate rear load. Nose still sports the distinctive nostrils introduced last year



Force India had expected to have to make mods to the chassis to comply with new cockpit regulations but in the end the old tub proved to be tough enough

to the very narrow span that Force India had been running, mounting the front wishbone in the chassis was a particular challenge given loads received, as Green explains. 'As the span of the wishbone get narrower, the loads increase accordingly and with the narrow span we are running, the loads going to the wishbone leg and into the chassis are extremely high. By having the vertical torsion bar, it allows us to basically pick up that wishbone leg on the mounting of the torsion bar at the bottom of the chassis, which is a strong point in the chassis and a very stiff point, so it helped that as well.'

Around the rear, Force India introduced a redesigned outboard suspension at Barcelona, for aero purposes, which was a continuation of the direction began on the VJM08.

On the VJM08, Green moved the brake calipers from the front of the axle to the rear of the axle. While not a significant change in itself, the alteration did open up opportunities to develop the architecture around the caliper. This development continued on to the VJM09. 'It's really how you lay out the cooling part of the caliper to the brake discs and also the air that just flows through the upright through the wheel, which effectively does nothing apart from improve the aerodynamics. The reworking of the architecture allows a much cleaner and clearer flow path through the upright and the wheel, but the airflow does not pass through the braking system itself,' Green says.

## Tub thumping

One area where a change was expected, but in the end not needed, was the monocoque itself. Updates to the regulations that govern cockpit safety required head protection structures to be raised by 20mm and be able to resist loads of 50N per 30 seconds. However, these new regulations caused little additional fuss for Force India. 'That was just a local change to the side of the cockpit to allow us to comply with the increased loading,' Greens said, before adding: 'To be honest, it wasn't a particularly difficult test to get through. We were very close to passing it anyway, even with the old design, so it only really needed a very small tweak to get us up to the new loading.'

While Force India may be using this year's iteration of the Mercedes engine, the VJM09 runs a different drivetrain to the Mercedes, as it uses the 2015 Mercedes transmission. Considering the familial concept of the later VJM08/09 series and the significant changes coming in 2017, Green felt there was no burning desire to change this aspect of the

## Designing for 2017

With significant changes to the Formula 1 technical regulations on their way, one ongoing development that has clearly frustrated Andy Green is the still unknown final design of the Pirelli tyres for the 2017 season.

For the coming year, Pirelli is being charged with not only altering the compound of the tyre rubber for next season, but also reformatting the size and structure of the tyre. Ferrari, Red Bull and Mercedes have run tyre concepts for Pirelli, but the lack of information regarding the compounds has hampered Green's efforts in the Force India design office.

'It's incredibly frustrating,' he says. 'We're effectively designing the car blind and we have to give ourselves lots of freedom to be able to move in so many different directions depending on what Pirelli bring. Pirelli don't know what the tyres are going to be yet, so we have got no idea. I think the real challenge at the moment is determining how much of a compromise we will make for the tyres and also for the future development of the car.'

### Designing blind

In past years, teams have had their seasons aided or destroyed by changes to tyre compounds. For Green, ensuring the 2017 car has enough working room to allow for the Pirelli tyres to operate at a high level, while also staying true to a defined design concept, is going to be a tough proposition. 'It's not just the tyres, the aerodynamics as well is quite a challenge,' he says. 'The aerodynamics aspect of it, even though that's in our hands, it's still a very fast moving area with development on the car moving forward at an incredible pace, and trying to feed that forward to where we are going to be towards the end of the season is quite challenging as well.

'We have to give ourselves a lot of room to manoeuvre going into the start of the season because we've really got no idea what the set-up of the car is going to be, no idea at all how the tyres are going to perform from a one-lap perspective or from a race perspective.' Green adds. 'We don't know what they are sensitive to or not sensitive to, so it's a matter of keeping everything open and that is incredibly difficult, because it means you are compromising.'

The lack of knowledge regarding the new tyres will not only increase the normal workload come the beginning of testing next year, but also severely compresses the time span in which the teams get to understand what Pirelli has delivered. This only serves to add to Green's frustration. 'We've had to make educated guesses as to what they could do. We've got three or four different tyre models that we use and we have to sweep through each one of them every time we do a development to see how the performance of the car is with these three or four different tyre models, so it's a lot more work,' Green says.

### Compromises

'Everywhere is just a little compromise to make sure we have that room to manoeuvre,' Green adds. 'It's making sure that we don't give ourselves too much room, and that we don't make too big a compromise.'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VJM09. Yet despite the familiarity of the 2015 Mercedes gearbox, Green acknowledged that importing a gearbox from a manufacturer pre-defined much of the design around the rear of the VJM09. 'The suspension pick-ups are defined for you. We do not have any say in that, and our design philosophies around the rear of the racecar, compared to the Mercedes, are quite different and it is a compromise.'

One of the compromises was the rake of the VJM09, as the Force India runs a much steeper angle of rake than the Mercedes, however, the difference was not so critical as to overly concern the Force India designer. 'We feel it's worthwhile pursuing the direction we are going in, we don't think the compromise is big enough for us to warrant changing our philosophy completely,' Green says.

## Surprise package

Green admits that Force India does not have the capacity in-house to design its own bespoke gearbox, but that this is not a new situation for a squad who have learned to minimise any losses garnered by utilising a bought-in unit. However, he also sees the positives in the new 2017 gearbox. 'Thankfully, next year's gearbox does help in that way, and the suspension pick-ups have moved to help us for 2017, but the bottom line is we have two different philosophies between the two different teams.'

Despite the large raft of updates and the improved performance of the VJM09, Green is still a touch surprised that Force India is fighting for fourth in the Constructors' Championship this season. 'Our target at the beginning of the season was to solidify fifth and move closer to Williams, and we've definitely done that. Is it a surprise that we are as close [to Williams]? It is a bit of a surprise, I suppose, that we are as close as we are right now, and we really do feel that it is potentially in our hands.'

Yet with that in mind, Green does lament lost points early on in the year and he admits that the season start was a little trickier than the team expected. 'We knew the first few races were going to be tricky, but they were trickier than we had hoped. We had hoped to have picked up more points in those first few races, so we were definitely on the back foot going into Barcelona, and we definitely needed the significant update to the car.

'We were a bit unlucky in the first few races. The car performance wasn't great, but we lost out with a few first lap incidents and some pretty poor safety car timings, which is just the way it happens in Formula 1 sometimes. So we were on the back foot going into Barcelona, and luckily the update delivered,' Green says.

## Race pace

Green contends that Force India still has room to improve its performance in qualifying, but he has been greatly impressed by the team's performance during the races, and while the main stream press may be focusing on the battle at the front of the field, Force India has made solid strides up the order, becoming semi-regular threats to the podium.

'The team has worked really hard to get where we are, to get us to this position, so it's really exciting for the team,' Green says. 'We're all up for it and the fact is we're not looking over our shoulders, which is great. We have a big buffer to sixth place now, so we can really focus on trying to get that fourth place and, if we do it, it would be amazing for the team.'

## Designing for safety

If developing the 2017 car wasn't enough of a headache for Green and his Force India team, it is looking increasingly likely that its 2018 machine will also have to incorporate the Halo device – at least some version of it or something similar – due to the push to increase driver safety.

While from the outside introducing the Halo may not appear too demanding a task, Green revealed to *Racecar Engineering* just what changes this safety device will entail. 'A completely new chassis,' says Green matter-of-factly. 'The loads that we are looking at to react to the Halo are massive. It is a significant additional structure in the chassis to withstand those loads, so it's a new philosophy, a new chassis for sure. You couldn't retro-fit a Halo to a current chassis, it just wouldn't work.'

The other headache for Green's team is that the Halo does not yet have definitive dimensions in the technical regulations. As a prototype concept, the device has been run in practice sessions by several teams this year, but its final design is still some way off, creating a delay not just for Green, but for the rest of the Formula 1 design teams too. 'We'll see how it goes over the next few months, see what the feedback is and see which direction we'll go, whether it's going to be the Halo as you see now or whether we're going to have an iteration of it going forward. We'll just have to watch this space,' Green says.

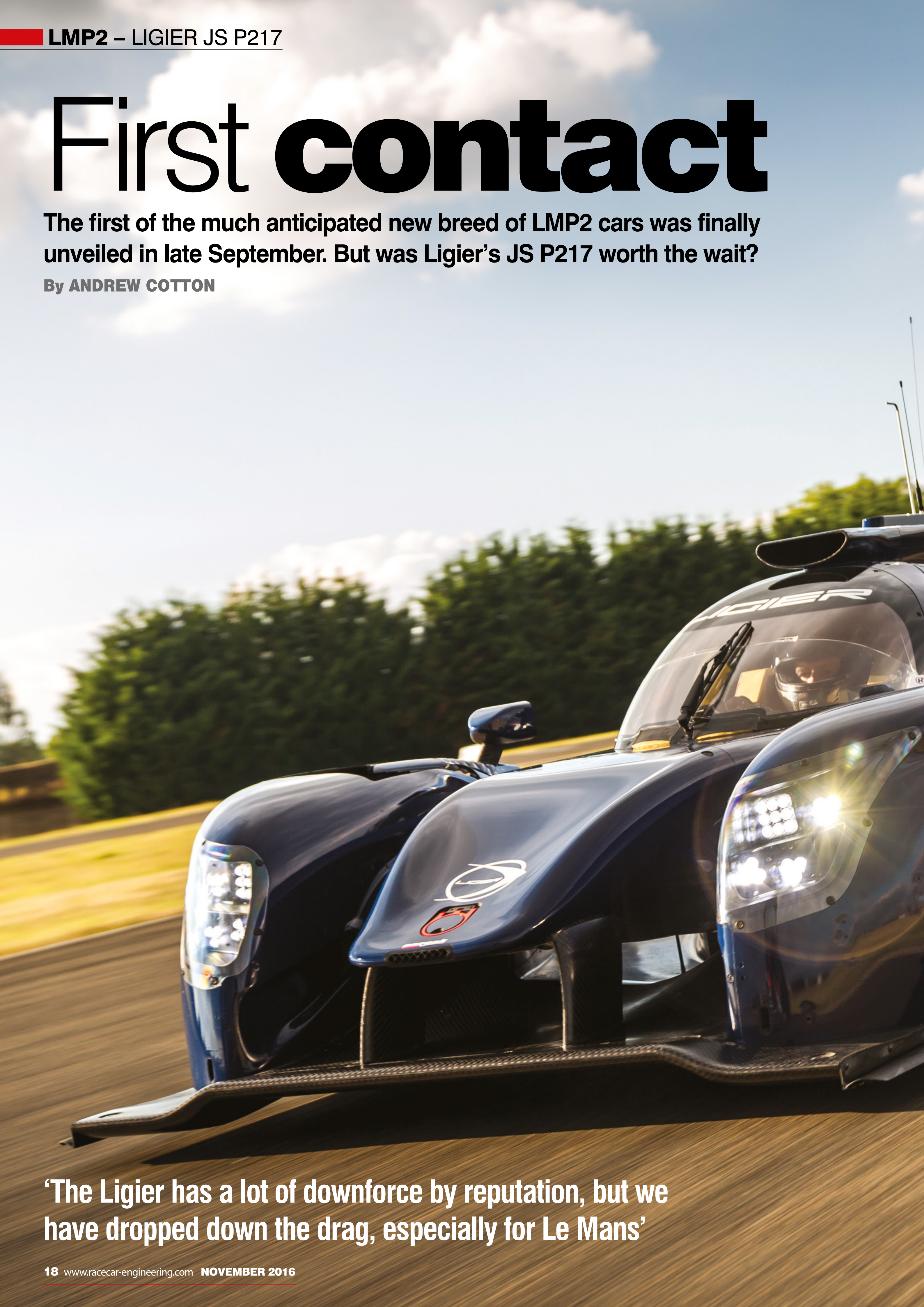

**In the interests of driver safety Halo, or some other form of cockpit protection, looks set to be a part of F1 from the 2018 season onwards and many of the teams, including Force India, have run in practice sessions with such devices fitted**


**Force India's technical director Andy Green says that to fit the Halo device will require the construction of a completely new chassis, due to the loads it will have to withstand, and that Halo could not be retro-fitted to an existing monocoque**

# First **contact**

**The first of the much anticipated new breed of LMP2 cars was finally unveiled in late September. But was Ligier's JS P217 worth the wait?**

By ANDREW COTTON



**'The Ligier has a lot of downforce by reputation, but we have dropped down the drag, especially for Le Mans'**

The new 2017 LMP2 regulations have been a long time coming, but mid-2016 they were finalised and at Spa in September, Ligier became the first of four manufacturers to launch its new challenger. The JS P217, which will be campaigned in Europe and the US from next season, also tested in the week prior to the launch, and its initial speed was encouraging.

The new LMP2s are aerodynamically more efficient and the Gibson engine produces 600bhp, around 100bhp more than the 2016 P2s. At its first test at Magny Cours, the Ligier was reputed to be three seconds faster, and the team believes that with development there could be further significant improvement. At Le Mans, the P2s will likely travel down the straight at more than 330km/h, putting pressure on the LMP1 privateers in terms of top speed.

However, prior to the launch, the ESM Tequila Patron team also announced that it would run two Onroak Automotive Ligiers in the US IMSA WeatherTech Sportscar Championship, powered by NISMO-prepared Nissan engines taken from the GT-R. To say that this racecar has to be versatile, then, while also meeting a strict cost cap, is a bit of an understatement.

The LMP2 regulations were first announced at Le Mans in 2015. Four chassis manufacturers were selected to provide cars – these turned out to be Dallara, ORECA, Onroak Automotive [Ligier] and in the US, Riley-Multimatic. The cars are cost capped at €490,000, and the running costs will be tightly controlled.

The tender for the engine supply for the European series was won by British company Gibson (see *RE* V26N8) and running costs for this are are also limited. The engine is a 4-litre V8, stressed and weighing 140kg, and the ancillaries, such as the oil tank, also come from Gibson, which caused a late design change for the Ligier team. Electronics are provided by Cosworth, and are also cost limited. There was an initial plan to limit the gearbox supply to a single supplier, although that was later opened up, so manufacturers can now select their own. Late on in the process, an air conditioning system was made mandatory, leading to another late change for the design teams.

Interestingly, with all the cost-capped parts, the majority of the suppliers of the major components (engine, gearbox, electronics) are based in the UK, which, after the Brexit vote has made guessing the correct price something of a challenge for the largely French manufacturers.


**The new Ligier JS P217 has already lapped Magny Cours seconds faster than it predecessor and the team behind the design believes it has huge potential after development**

## TECH SPEC

**Ligier JS P217**

**Chassis:** carbon monocoque by HP Composites

**Bodywork:** Carbon, HP Composites

**Dimensions: length:** 4745mm, **width:** 1900mm, **wheelbase:** 3010mm

**Weight:** 930kg

**Suspension:** double wishbones, pushrod and torque rods at the front and spring at the rear; latest generation of 4-way dampers;

**Engine:** Gibson Technology GK428 V8 4-litre, 600bhp

**Transmission:** Hewland TLS-200 6-speed sequential gearbox with magnesium casing specific to the Ligier JSP217

**Fuel Tank:** ATL, 75 litres

**Rims:** magnesium, diameter:18in, front width, 12.5in, rear width: 13in

**Brakes:** 6-piston calipers, 15in carbon discs front and rear

Ligier has used new materials in the JS P217 chassis, such as T1100 carbon, which has allowed it to absorb the extra weight of the Zylon panel that is part of the new rules package

In Europe, the category is for the privateer driver, but in the US, it is the premier class, engine supply is free, consumables are freer, and the bodywork is different too. Due to politics, the Daytona Prototype International (DPI) racecars will not race at Le Mans, a decision that also came late in the process, and this was frustrating for the manufacturers, as the decision had already been taken to increase the minimum weight to 930kg to accommodate the American cars in Europe.

The cars are narrower, down from 2000mm to 1900mm, the front wheels are bigger in diameter, and the rear wing is wider, leading to more efficient aero potential. In the US, the cars will compete for overall victory at iconic races such as Daytona, Sebring and the Petit Le Mans.

## First blood

But one race that has been won already is the race to build the first new P2. Ligier was the first to test the car, was the first to launch, and the first to start outlining the problems from the manufacturers' point of view through the design process. 'I think even normally you would think a difference of five seconds at Magny Cours is a lot, it is a huge performance step,' says Onroak's Le Mans site director Sebastien Metz. 'The car by rules has a chord [changed] from the 250mm to 300mm which has given more efficiency on the wing, less drag because the size of the car has gone from two metres to 1.9m, so we did a great deal of work on the aero and specifically on the cooling side because we can speed up the airflow on the top, and so then you have a better airflow to the radiator.

'We use a new technology of cooler for the LMP2 which is used by LMP1 and F1, which is the Mezzo technology,' Metz adds. 'That means that we can drop the size of the exchanger, give more efficiency to the cooler and reduce drag, so the car has a nice potential.'

The previous incarnation of LMP2 cars used LMP1 regulations in a bid to keep costs down, but the 2017 regulations are completely new. And Ligier has made very good use of them to introduce new materials into the monocoque and the bodywork.

'We can use new materials, [such as] T1100 carbon which allows us to absorb the extra weight of the Zylon panel requested by the FIA, which is not a small step,' says Metz. 'That means that this is the first time the material is used for the monocoque. You have a lot of simulation on the composite side, it is a new material so there is a lot of work to do it, but we have increased the overall stiffness of the monocoque, and dropped the weight.

'On the bodywork side we moved from T700 to T800, which is a step in the same way, trying to make the bodywork a bit stiffer so we can really play with the weight balance,' Metz adds. 'The regulations say you have to fix the weight balance by homologation, and you have one per cent of freedom, so we have the chance to test the different ratio; so it is always good to have a light car because you can play with it. You have an advantage of the weight distribution for the DPI. The overall weight was done for the DPI, so to get the weight down it gave us more freedom for the cooler, the turbochargers or whatever. It was a nice challenge.'

**The team worked hard on the efficiency of the JS P217, but it ultimately also produced a good-looking car, too**

The team worked hard on the efficiency of the JS P217, but it ultimately produced a good-looking car, too. That came after two weeks in the wind tunnel, more than 220 configurations of the bodywork, and 40 CFD runs, too. 'For sure we want to have a nice car, but when you develop the car it is not the priority. The first is efficiency, and after that you try to get something nice looking,' says Metz. 'When I say that we are working a lot on the aero, it is a hard job.'

## Super market

None of this seems to fit with the cost-cap imposed on the class, but Onroak Automotive owner Jacques Nicolet is not concerned about that. The regulations are fixed for four years, and with eligibility in the WEC, IMSA USC, the ELMS and the Asian Le Mans Series from 2019, the belief is that there is enough of a market to sell the cars, and crucially the spare parts to make the business case. 'We have not just started with this car,' says Nicolet. 'We have started in 2012 with the Morgan and don't forget that the Morgan won Le Mans, so it was a very good car. We accumulated a lot of knowledge, we have worked with the same partners since the beginning, we have a lot of correlation between

The car has been the subject of 40 CFD runs and has spent two weeks in the wind tunnel – but aero development never stops

Ligier has optimised the cooling on the JS P217 by turning to Mezzo technology, as used in Formula 1 and LMP1. This meant that it could drop the size of the exchanger, make the cooler more efficient, and reduce drag

The spec engine for LMP2 is this Gibson 4-ltre V8 unit which produces 600bhp – a cool 100bhp up on 2016 P2 powerplants

the wind tunnel, the CFD, the track, and so it is easier to design the car.'

One of the challenges of that design process was the need to race on very different circuits, on very different tyres. In Europe, Michelin and Dunlop provide non-confidential tyres, while in the US, a single tyre supply deal is in place with Continental. The designers also had to make the cars adaptable, able to be worked on by privateer teams and professional teams, so suspension design was critical.

'We had to keep something simple and have different options,' says Metz. 'We wanted to find a way to get a car that is efficient in all configurations on the tyres and circuits, but you want a car that is easy to set up because you have high level teams, but you also have teams that are just starting. We found out that it was nice to have an easy car to set up, but overall the racecar has to be simple to adjust and set up. We worked with the damper and rocker, third elements front and rear, and with pullrod front and rear.

'I hope that the three tyre suppliers will be close to keep the performance windows as small as possible,' Metz adds. 'Dunlop and Michelin are already close, and Continental is pushing to get to that same level. They have different sizes, the warm up procedure is different, the construction is different, but they want to be able to compete with Dunlop and Michelin in terms of efficiency. I think that they have the potential to make it.'

## 'Boxing match

Although there was a plan to have a single gearbox supplier in a bid to reduce costs, apparently behind the scenes there were arguments aplenty. ORECA worked with Xtrac, Dallara was happy to go with the decision, and Riley knew the company from its dealings in the US. However, Ligier wanted to go with the its own option, and selected Hewland instead.

'That was better for us because it was a casing that was dedicated to the car, the pick up points exclusive to the Ligier, and a it had a warranty of 8000km on the gearbox, the first time I've seen this since I have been working in racing,' says Metz. 'The cluster was already running in the BR01, the drivers that have been running the cars this week, are happy with the gearbox and shifting. It is smoother than the previous system, so everything for us is great.

'It is dedicated to the car, it is cheaper, Hewland is pushing and the customer support is there,' Metz says. Even after that decision, however, there are differences between the European and American specification. 'The gear ratio is free, and the final drive is free in America with the engine installation,' says Metz. 'By law, they cannot make a cost cap regulation, so it is a different story than in Europe. At some stage it is a bit of a strange strategy because you have a cost capped car for gentlemen in Europe and the in the US with no cost cap for pro line up, so that is why it is quite important to have a good base [in the US].'

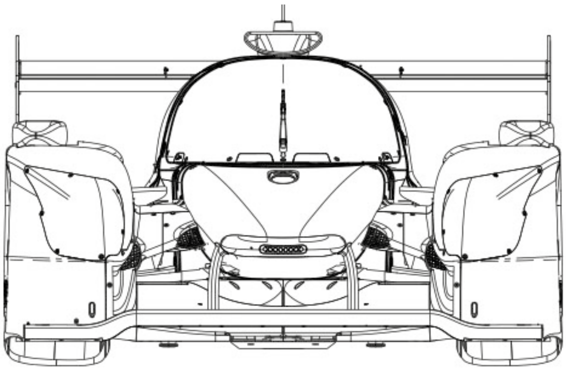
## IMSA test

Some of the DPI bodies have been in the wind tunnel for performance balancing against the European spec car, but the big test will happen in December. Then, the DPI cars will be prepared for the IMSA season, which starts with the 24-hour race at Daytona at the end of January. So the pressure is on – not only for the constructors, but also for the organisers – to get this right pretty much first time.

However, there is a change in the regulations for the North American race, where in 2016 the cars were allowed to run with the Le Mans low-downforce bodywork. With no Le Mans kit necessary for the DPI cars, due to the decision not to allow them to race there, the cars will have to race with low downforce sprint bodywork. 'The Ligier has a lot of downforce

**'We can use new materials on the car, such as T1100 carbon, which allows us to absorb the extra weight of the Zylon panel'**


Ligier has worked hard on reducing the drag, especially on its Le Mans spec. P2s are expected to hit 330km/h at Le Sarthe



New P2s are narrower, from 2000mm to 1900mm, wheels are larger and rear wing is wider, so there is plenty of aero potential

by reputation, and we have dropped down the drag, especially at Le Mans,' says Metz. 'The four will be close. They all know how to build a racecar, but this is even more challenging to get a car that is efficient. For us, it is definitely a challenge, and to be there first with the car running in Magny Cours with high potential gives us encouragement for the future.

'In the JS P2 we had the middle and the high downforce kit, and one for Le Mans. With the JS P217, we have three steps in sprint and one for Le Mans, which is important. At Daytona, we will run with the low downforce sprint package, so for sure we need to have this configuration as well. We dropped massively the drag on the Le Mans kit, so it is a compromise of the Le Mans kit from last year and the sprint package,' Metz says.

The narrower car has led to a slight reduction in space for the engine and ancillaries, and, as mentioned earlier, the Ligier crew has turned to advanced cooling technology to keep down the running costs and the efficiency.

'This technology allow us to drop 15 per cent the overall size of the cooler, but [have] a bigger window or operation,' says Metz. 'For us it was really important to give the maximum efficiency to the engine. With this technology we were able to drop the size and give more thermal efficiency to the cooling system.

'For the teams, it is important because it is multi tube technology so they can clean up the cooler without damaging the mesh,' Metz adds. 'This kind of technology has been used in Indycar as well for years, and some teams are using the same cooler for four years. It is quite an investment, but if you make the long-term calculation you have the same efficiency, the same product, the reliability, and so it was a big decision to put it on the car, [which is why] we dropped the price on the gearbox [by switching] from Xtrac to Hewland.'

## Not so cool

Into that space, the Ligier was also forced to introduce an air conditioning system, which was bit of a shame as the design team had already used what it had learned in the design and development of its LMP3 racecar to make sure there was good airflow in the cockpit and it believed that it did not need an air conditioning system. One wasn't stipulated either, until part-way through the design process.

'We knew during the discussion over the design that it was mandatory to use a common system for air conditioning, but that was not even on the first draft, [of the regulations]' Metz says. 'So, we had to install a compressor, a link between the inside of the monocoque and the outside, and there was the extra weight, and that kind of stuff looks like a little problem, but it is a major factor in designing the car. That's why the price rose a bit.'

On that point Metz says: '[Pricing] is a big matrix, because we know that we don't know whether or not we will make a business from the sale of the car, because such efficiency and performance with the cost cap is difficult, so we will try to make the money with the spare parts, so you make a co-efficient from the normal price and the spare parts, having a 1.4 co-efficient, so to get all of this in the matrix is challenging. It was fixed in Euros, but that is another story.' As for the new P2, the story of the 'global prototype' has now, at last, begun.

## The LMP1 conundrum

In a bid to reduce costs, the old LMP2 chassis regulations mirrored those of LMP1. That allowed the Rebellion team to run its ORECA chassis in the LMP1 privateer category. But the P1 privateer class is to be overhauled in a bid to keep the cars ahead of the new P2 machines. A faster fuel flow, less weight and even DRS have been discussed seriously. But Onroak Automotive team owner Jacques Nicolet actually believes that the Ligier JS P217 and its like could simply replace the LMP1 privateer cars.

'We don't understand ourselves what we can do with this,' says Nicolet of the potential to run the car as a P1 privateer. 'The monocoque maybe could be the same and we don't know for the rest of the parts for the moment. It is a pity, but it is like that. We are waiting for some information because I really would like to be in P1 privateer in the future.

'But there is not only a problem of rules,' Nicolet adds. 'We need to know clearly that the LMP1 privateer is a complete category with a normal podium, a normal title, and so on. It is for me not only the technical rules, it is the complete package that we have to know before we decide to go. If we can go with some parts of the JSP217, we will have won time.

'Normally, this monocoque meets the LMP1 requirements,' Nicolet adds. 'We have to wait for the new rules for the global LMP1 for 2018. For me, it is a pipe dream to want to try to have the P1 privateer closer to the LMP1 hybrids. The budgets are completely different. It is a dream and we have to see the reality of the situation.

'I know that we have support from the manufacturers who are not in the four [approved LMP2 builders], like SMP, Strakka, and Gibson, but I don't know about ORECA, Dallara and Riley,' Nicolet says.

**The belief is that there is enough of a market to sell racecars, and crucially the spare parts to make the business case**

# Indy future

**With IndyCar freezing its manufacturer-produced custom aero kits what does the future now hold for the USA's premier single seater category?**

**By MARSHALL PRUETT**

The sun is setting on the 2015/16 'open' body kit regulations and IndyCar is now looking at next year, 2018 and beyond

Faced with the need for wholesale changes and improvements to its 2012 Dallara IR12 chassis, the IndyCar Series has now formulated a far-reaching plan to address its wish list in the coming years.

The first confirmed step involves switching from Brembo's carbon brake package after a series of blind tests, and using PFC to outfit every car starting in 2017. But the relative ease of swapping brake solutions pales in comparison to the unwinding of IndyCar's problematic aerodynamic situation.

The series' brief flirtation with engine manufacturer-generated bodywork spanned two seasons before a decision to freeze development was made in September. Those custom Chevrolet and Honda aero kits, which feature low-drag superspeedway and high-downforce road course/short oval packages, helped teams to destroy tracks records at most stops on the IndyCar calendar.

But with the flagging interest from new manufacturers attributed to the need for engines and bodywork to field a competitive effort, an aero kit freeze for 2017, followed by the creation of a new, universal aero kit for 2018, has been set in motion to attract new OEMs.

Enhanced cockpit safety is another pressing topic for IndyCar, and unlike the FIA's well-funded exploration into solutions for F1, the American open-wheel series is facing a longer gestation period due to fewer resources.

## The plan

IndyCar's approach to its current needs has revolved around extracting the greatest amount of usefulness from the IR12 (often also referred to as the DW12) chassis. Owing to the lingering downturn in available sponsorship, the most obvious solution, to commission a brand-new chassis with all of the desired updates and improvements, is not a realistic option.

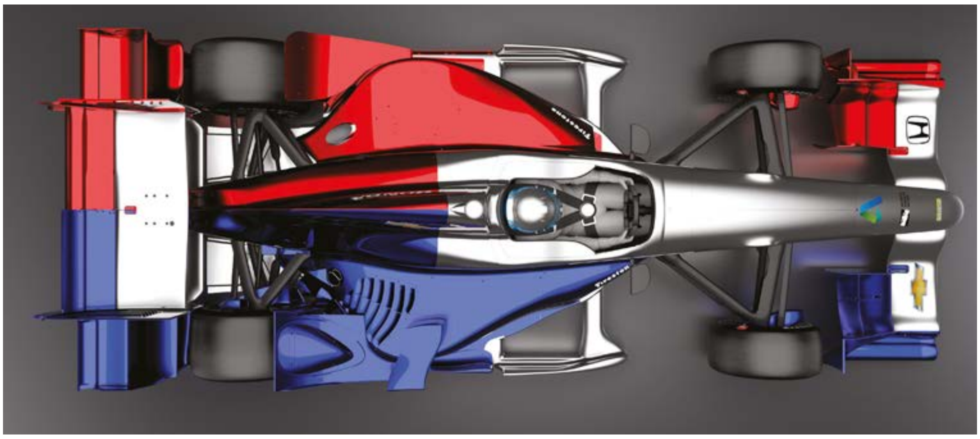
'If we talk about a plan with this car, I would say the shelf life for sure is another four years,' IndyCar president of competition Jay Frye says. 'There have been evolutions to the safety aspect of the car, and it has been a workhorse. We are comfortable with the car for sure for the next four years. And then, what happens in 2021? Is that where we come out with a clean sheet approach to the car? We think so, but it's too early to make that call.'

Frye has been hesitant, in a general sense, to define too many fixed dates in the future while the series deals with moving targets. With the universal aero kit in place, and a new cockpit safety device installed, the IR12 could go past that four-year window. However, if a new OEM enters the frame and all parties agree on a new engine formula for example, sticking to the 2021 new-chassis plan would fit those needs.

'We've tried to line up the plans for the car and the engine programmes to match with where we're heading,' Frye adds. 'There are

**The most obvious solution, a brand-new chassis with all of the desired updates and improvements, is not a realistic option**


**A lower, wider and cleaner over-body than the current racecar is central to IndyCar's plans for its future regulations**



**IndyCar was determined to have some form of open competition and so allowed Honda (top) and Chevrolet to design their own body kits for each type of track. The aero kits have now been frozen for 2017 and a new, single kit will come in in 2018**

opportunities starting in 2018 for new OEMs to come in, and we are making the point of entry easier with them not having to do an aero kit. A big part of it is to take into account what our current OEMs want and what new OEMs might ask for. That's why we're doing the things we can now that won't require a new chassis.'

Thanks to aero kits, road course downforce levels surpassed the 5500lb mark, and with the tarmac-shredding forces channelled through Firestone's red-banded slicks, IndyCar drivers began reaching their physical limits at circuits like Mid Ohio and Watkins Glen.

Given the freedom to pile wings upon wings from nose to tail, Chevy aero kit provider Pratt and Miller and Honda's in-house Honda Performance Development (HPD) team (along with residual aid from Wirth Research) made the most of the topside aero development boxes defined in the rulebook. Counter to those freedoms, IndyCar banned underwing development, and with the IR12's comparatively weak underwing and diffuser profile, the series will now look to invert the universal kit's downforce production profile.

## Downforce reduction

'Going forward, the downforce levels are already pushing the limits,' Frye says. 'The car, tyres, everything. We have to stop and reset, to go back to where we were a few years ago on downforce. These aero kits cause a huge amount of turbulence so it's hard to pass just because of the way we make our downforce.

'So if we can just enhance that, move a lot more downforce to the bottoms of the cars, make it so they are more drivable and less turbulent to follow, we'll be in good shape.'

The universal bodywork project, which will go out for bid in coming months, will also involve a re-imagining of the overall shape and appeal of the car. The tub will remain, but everything that envelopes the driver cell will be subject to a beautification and weight saving.

'Cosmetically, they are going to be good-looking, clean cars, Frye says. 'The universal car should be lighter – there are different things that will be done, so the power-to-weight ratio will improve. There's a lot of weight up top on these cars. This will be removed, cleaned up. A lot of these parts and pieces have created a lot of debris issues. Safety wise, the aero guys have done a great job but we basically stitched this whole car together with tethers. That is a good and bad thing. So with the universal kit you won't have to do that as much because there will not be as many hanging parts.'

## The '90s look

Stripping the extraneous aero pieces from the topside will help to reduce weight, and it's believed the unsightly rear wheel guards will also be downsized or lost altogether. For those who've disliked the look of the IR12, and questioned the need for an overhead intake to feed low-mounted turbochargers, the 2018 kit could also bring back fond memories of former CART and Champ Car silhouettes.

'We want the low engine cover just because we want the car to look more like a traditional IndyCar from the '90s,' IndyCar aerodynamic director Tino Belli says. 'The whole airbox thing is really left over from a normally aspirated engine, which we had had for so long. It's good at creating positive-pressure so the turbos work less hard, but it isn't the only option available, so we will be moving the [turbo] inlets to the sidepods. The advantage of that is that it makes the engine cover look a lot more sleek. We want a sleek, low, wide look.'

Moved by the helmet strike that killed Justin Wilson in 2015, and the helmet impact-related death of Dan Wheldon in the previous chassis in 2011, IndyCar is aiming for an aeroscreen-style device for 2018. The IndyCar-developed unit will likely feature different versions to suit the different viewing requirements for ovals and road courses. 'I don't think a Halo is something we could do because of the banking and looking through it,' Frye says of the options considered before deciding on an aeroscreen.

Belli adds: 'With the universal aero kit, number one, we are going to try and introduce a windscreen for the 2018 car as well for driver protection. From an aerodynamic point of

**'There are opportunities now for new OEMs to come in, and we are making the point of entry easier with them not having to do an aero kit'**

## Chevrolet has expressed its reluctance to take on the costs involved with ERS. However, Honda has been open to the concept for years

view, we have evaluated its impact and it's not something that would worry us. The windscreen that we are using so far is optically correct. We're talking about fighter plane quality materials here. When you are flying those fighters, which don't have flat sections, they are completely curved and they are optically correct. We've got to worry about rain and coatings and tear offs. It will obviously have an edge. Whether that will be disturbing the air or not – hopefully we will find that out in the simulator first,' Belli says.

## Smooth flow

The removal of the overhead airbox will smooth the trailing airflow behind the cockpit and windscreen, which, Belli anticipates, will require a solution to minimise a vacuum effect. 'We have looked at it from a head buffeting helmet-lift type point of view, [but] we are pretty sure we will not suffer from buffeting,' he said. 'We have some concern about the head lift; we are going to be pushing the air over the top of the driver's head so that will be sucking up. That needs some work, and that can be done in CFD. It can be done in full-size wind tunnels, too. The final sign-off will be at Windshear [wind tunnel in North Carolina]. Windshear really has not lied. It is the true sign-off. I am 100 per cent sure that if we [hit] our targets at Windshear we will be fine at the track. But we will track test, too.'

But because there is the longer time-line to work from, Frye also hasn't ruled out a canopy for the IR12's replacement. 'In a full canopy, it creates a lot of things that would have to come along with it, so it wouldn't be ready for 2018,' he said. 'Having said that, if you are looking at 2021, when the next car comes in, then could that be considered? Sure.'

## Side impact

A significant amount of effort is being expended on protecting the front and top of the cockpit opening of the racecar, but that aperture isn't the only focus for IndyCar's competition department for 2018. With a total bodywork replacement in the works, the series is considering two forms of improved side impact protection for its race drivers.

Additional Zylon anti-intrusion panelling has been added since the IR12 debuted, and the upper cockpit ring has also been retrofitted with strengthened materials, but with the aft-mounted radiators leaving a narrow sidepod profile alongside the drivers, more can be done to cushion a side impact.

To achieve this goal, the new universal body kit will very likely push the leading edge of its sidepods out to the edge of the floor, to allow the IndyCar series to use the internal space for crushable structures.

'We have two supportive schools of thought on that,' Belli says. 'One of them is to put the radiators there, to provide side impact. The other is to keep the radiators in about the same position that they are now but create a crush structure on the side.

'Imagine a big flattened nose; take a nose and stretch it out. That bodywork will be

**Following a spate of high profile accidents at 2015 Indianapolis 500 practice sessions the IndyCar series introduced a number of aerodynamic measures designed to slow a car and stop it becoming airborne during a high speed gyration**


**One of the by-products of the more open body kit regulations were complex road course front wing arrays which were apt to break and cause yellow flag periods**

**While the top surfaces of the wings became more complex IndyCar banned underwing development. The series will now look for more underwing downforce with its universal kit**



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## The universal bodywork project, which will go out for bid soon, will also involve a re-imagining of the overall shape and appeal of the IR12

properly laminated to crush. Those are the two ways we could go,' Belli says.

The outer edges of the floor are also up for revision during the side impact overhaul. The IR12's anti-wheel interlocking fin, dubbed the 'sponsor blocker' by the paddock for covering part of the sidepod, is on its way out when the universal kit arrives. 'Yeah, the "sponsor blocker". that piece would be gone,' Frye confirms.

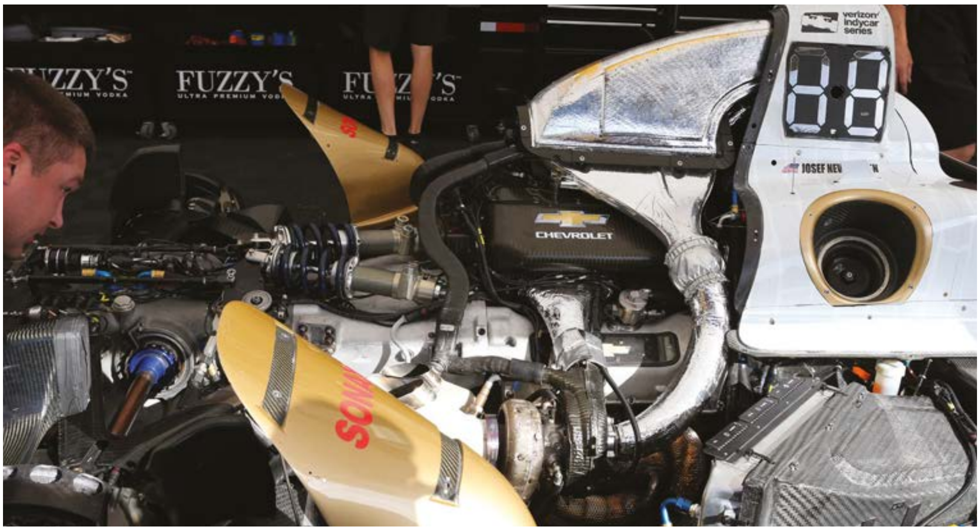
Belli and IndyCar made significant strides with superspeedway aerodynamic stability updates leading into the 100th Indy 500 this year. Dome-shaped skids, capped rear wheel pods, and rear beam wing flaps prevented the scary flights that marred the 2015 event, and through numerous spins in May, the new pieces kept each car firmly planted by piling on downforce or preventing lift.

## Flip flaps

The universal kit will carry over some of those innovations, but some changes are also in order. 'So far, we have been very happy with everything we have done for 2016,' Belli says. 'All of our cars have done flat spins. We have seen the high downforce at 90-degree of yaw from the dome skid, which is slowing the cars more, so when you have an impact with the walls it is a slower speed. For 2018, with the universal aero kit, we will not give one inch on the stability calculation we do now.

'We do calculations with CFD at 90-degree of yaw, and we want the new kit to have the same downforce at 90-degree of yaw. Typically, the car will never flip at calculations of 90-degree yaw, and we want it pushed into the ground so the car gets slowed down quicker, because that was one of the issues we've had. We will have to be at least as good, 180-degree of yaw tail up, three and a half degrees tail up. Those are our stability calculations for the superspeedways. So the new kit will have to meet all of those criteria, plus we do straight to head, 5-degree nose up, which is the Mario Andretti Indy flip [in 2003].

'We are going to try and achieve that without a dome skid. Our target is to remove the dome kit but keep the benefits the dome kit gave us. That seems to be possible. On the superspeedways, we will probably need some sort of a rear wheel guard, but it will be a lot more stylised,' Belli says.




**IndyCar has been under the current 2.2-litre engine formula for five seasons and many believe there is little room for innovation in this area now. It hopes its new 2018 universal aero kit will attract new engine manufacturers to the series**

## Power hungry

Beyond the aerodynamics, IndyCar is about to embark on its sixth season with the 2.2-litre turbocharged 6-cylinder engine formula. The E85-fueled powerplants produce something over 700bhp in road course trim, and with 2500-mile rebuild regulations keeping power figures in check, the easiest route to adding more grunt could come from an energy recovery system.

Chevy has expressed its reluctance to take on the costs involved with ERS, Honda has been open to the concept for years, and in the middle, IndyCar has been rather quiet on the subject.

With innovation having all but stalled after five years of the same engine formula, and both drivers and fans pleading for more power, Frye was asked if a spec ERS system – commissioned by the series to push the combined output to 850bhp or so – was possible in the future. 'It's something that we need to make sure we put on the table at some point shortly,' he says. 'We are not where we need to be to do anything at this point, but we need to look at that, yes. We talk about the Indianapolis Motor Speedway, and it has been doing the same thing for 100 years. So what is going to happen in the next 50 years? I don't know, the last hundred years they have done the same thing, but that was a whole different time with cars being introduced and the evolution of cars, so now what is next?

'Again, the more OEM partners we have and the more ideas that they bring – and each one will have a different idea or goal – then there's a lot of opportunities at that point to look at things differently than we currently are. And we certainly will.'


**The triangular aero device ahead of the sidepod was designed to reduce air pressure in the event of a high speed spin. This year cars have been far less susceptible to flipping while the aero measures have also slowed them before they hit the wall**

# Sand blaster

**Peugeot has committed to its cross country programme for the long term with the launch of the 3008 DKR – a car bristling with developments and optimised for the Dakar**

By ANDREW COTTON

## With a top speed of 200km/h on the sand, aero stability is just as critical as at 300km/h down the Mulsanne Straight at Le Mans


**The 3008 DKR is an evolution of the Dakar-winning 2008 DKR+. Peugeot has worked on the cooling and the aerodynamics of the DKR and the body shape has changed, giving the dune Pug a purposeful new look**

Peugeot has committed its medium term future to off road racing with the launch of the 3008 DKR, an evolution of the 2008 DKR+ with which Stephane Peterhansel won his 12th Dakar rally in January 2016. The 3008 is a development of its predecessor rather than an all-new car, but apart from the clear marketing reasons for switching to the product due to be launched at the Paris Motor Show in October, there has been a lot of development work under the skin.

The car has been on the drawing board since the start of 2016, with improvements identified throughout the car, primarily weight saving, improving cooling and drag figures, and also with the suspension, where the company has targeted better handling characteristics. Peugeot says that it has worked intensively for eight months creating the 3008 DKR at its base in Velizy, Paris, ahead of its October launch.

'The model is different, but not completely because we have to capitalise on what we have done during a successful 2016,' says Peugeot Sport's technical director Bruno Famin. 'It would have been wrong to change everything. The chassis is very similar, we just improved some points to make it a bit stronger in a couple of points. We had to change the fittings of the suspension because we have a new geometry suspension, but basically the chassis is not very different. As we have got something quite satisfactory with the 2008, we kept that.'

Already in 2016, the team had increased the width of the chassis by 20mm in order to improve lateral stability, and had also increased the wheelbase accordingly. With a spaceframe chassis this was less work than it might otherwise have been, but the team didn't feel the need to make any further changes. That the 3008 is longer than its predecessor is simply due to the length of the bodywork.

Meanwhile, a contentious change in the regulations has meant Peugeot has had to work on engine mapping, as well as its innovative and production-based twin turbo system.

## 3-litre power

Starting with that engine, Peugeot Sport continued with the 3.0 litre V6 turbodiesel engine for the 3008, but as mentioned above, there was a lot of work to do on it as a rule change means that the team will have to run


The car has a new suspension geometry, partly due to the updated chassis. It features double wishbones, plus twin dampers on each wheel. Suspension travel is a whopping 460mm

## Rough justice?

The FIA announced a reduction in performance for the Peugeot 3008 DKR through a smaller air restrictor, but although Peugeot says that the analysis was correct, it argues that the penalty is not.

'The decision taken by the FIA and followed by the ASO to reduce the air restrictor for us is not very logical,' says Bruno Famin. 'The analysis of the FIA was very well done, but the conclusion was not. Now we can see it. The conclusion was not good because they did not split what level of performance comes from the two-wheel-drive or the turbo diesel engine. Now we see that Toyota is coming with a gasoline engine, two-wheel-drive, and they have 1mm more air restrictor, and I think that is not fair at all.

'It would have been good for the FIA to go deeper into the conclusion, but they are the ones that decide. It is a pure balance of performance, but to apply this change is not fair. When you make a good analysis of the data in 2016, we won a lot of stages but the gaps were not big. What was the big difference was that we had three cars fighting for the first place, Mini only one. The Mini in one race was 15 minutes behind, which is nothing on a rally like the Dakar. At the end of the story, there was no big difference, but when you see the difference of the level of performance, it is not big. You can lose a lot of time getting lost, and [with] reliability, [with] no mistake from the crews, the co-driver and the driver.'

with a smaller air restrictor, down from 39mm to 38mm, a change that Famin believes is worth 20bhp. However, there is more to it than that. Famin believes that the FIA's analysis of the performance of the 2008 by the FIA was just and accurate, but the judgement of the performance was not, and that the reduction was not justified (see sidebar).

'The engine, the base is still the same, but we have worked on the turbo, on the turbocharging system to achieve the two targets,' says Famin. 'We had to adjust with the new FIA rule which saw the air restrictor change from 39 to 38mm, so that's 20bhp less, so we have to re-optimise the system. And the second point was to give the drivers some improvement with the driveability of the engine for this kind of car, cross country. Where the driver does not know the road, he needs to have always a very good level of torque and power every time he needs it [so as not] to get stuck in the dunes or to lose time in the curves.

'The turbo is still the same, but we improved the system. It is not complex, but we have one turbo working at low revs, and two at high revs, so we worked mainly on mapping.'

Weight is the traditional enemy of any racing programme, but the Peugeot team decided to *add* weight with a 10kg air conditioning system that it believes will help the drivers over the long stages of the Dakar and other events.

On cross country rallies there is also fuel consumption to think about. The 2008 was able to carry a 400-litre fuel tank that was good enough for 800km between refills. Now, with the Dakar organisers announcing stages of more than 600km for the 2017 event, that will play into the hands of Peugeot.

## Weighting game

'We were happy to see the long stages on the Dakar 2017, because we have lower fuel consumption than the gasoline engine, that is one of the reasons why we chose the diesel,' confirms Famin. 'The organisers have announced more than 600km stages, and that could be good for us for the weight. We added some weight, so had to reduce it elsewhere.

'We tested the air conditioning on the Silk Way rally, and it was appreciated by the drivers so we added it in the 3008. To compensate, we have saved the weight on the bodywork, on the chassis, the engine environment, the gearbox environment, everywhere we could.

'You have two ways to improve the performance,' Famin says. 'You can work, which is our way, or you do nothing and complain to the FIA Technical Working Group that the

**'We have one turbocharger working at low revs, and two at high revs'**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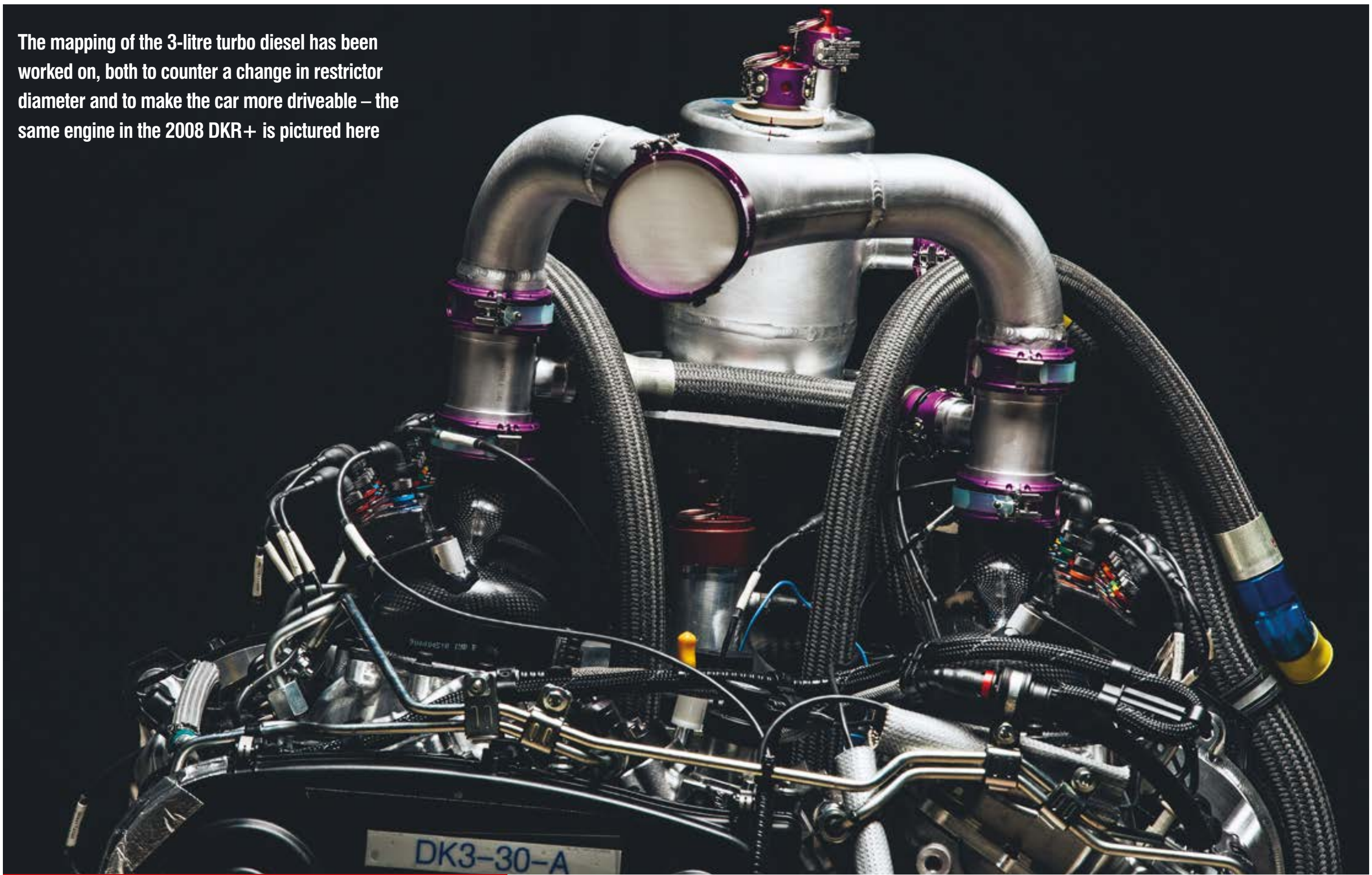



The mapping of the 3-litre turbo diesel has been worked on, both to counter a change in restrictor diameter and to make the car more driveable – the same engine in the 2008 DKR+ is pictured here

## TECH SPEC


**Peugeot 3008 DKR**

**Chassis:** Tubular, with carbon bodywork

**Dimensions:** Length 4312 mm; Width 2200mm; Height 1799mm

**Engine:** V6 bi-turbo diesel, 2993cc, 24 valves. Mid-rear positioning; 60-degree angle to V6
**Maximum power:** 340bhp (with 38mm diameter restrictor – previously 39mm restrictor)
**Torque:** 800Nm
**Max revs:** 5000rpm
**Top speed:** 200kp/h
**Lubricant:** Total Quartz 10 W 50

**Transmission:** Two-wheel-drive; longitudinally mounted 6-speed manual gearbox
**Lubricant:** Total 755 HPX 80 W 140

**Suspension:** Double wishbones, front and rear. Coil springs (one per wheel). Adjustable dampers (two per wheel). Suspension travel: 460mm. Anti-roll bars front and rear

**Steering:** Hydraulic power steering

**Brakes:** Front and rear vented discs. Hydraulic dual circuit. One-piece light alloy 4-piston calipers. Front and rear discs (diameter): 355 mm

**Wheels and tyres:** Rims: magnesium one-piece wheels (17 x 8.5). Tyres: BFGoodrich All-Terrain T/AKDR2 (37/12.5 x 17)

BoP [Balance of Performance] is not fair. And we prefer to do it the first way'

Famin would only confirm that weight was saved 'in the gearbox environment' and refused to say any more on the matter, suggesting different materials were used in the gear ratios and the gearbox casing.

## Suspension

The 2008 was conceived with two wheel drive, which allowed for larger wheels, with a diameter of 940mm compared to 810mm for the four-wheel-drive cars, and longer suspension travel, up from 250mm to 460mm. It was a concept that was continued in the updated 2016 version of the 2008 DKR+, having proven to be successful, and that same philosophy has continued into the 3008 DKR. The branding of the tyres has switched from Michelin to BF Goodridge, although the two are in the same family and the technology of the rubber on the car is much the same. The one-piece wheels have also been carried over.

The 3008 has also been developed to further improve stability and weight transfer, particularly under braking and acceleration. This meant a new suspension geometry for the car, partly due to the updated chassis.

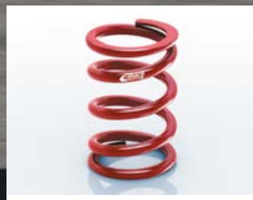
The carbon bodywork also underwent significant changes, with a lot of work done to improve cooling and reducing drag. With a top speed of 200km/h on the sand, aero stability is just as critical as at 300km/h down the Mulsanne Straight at Le Mans.

'You always need more cooling,' says Famin. 'Cooling is performance and it is reliability. The turbocharged air through the intercooler and for the water radiator. It is going in a good way. The difficulty is to improve the cooling without having the drag worse. We wanted to have better drag and better cooling. We used Peugeot's wind tunnel again, but we were running more with CFD.'

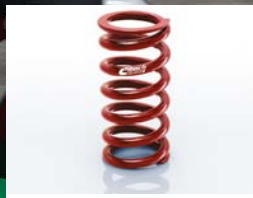
The fact that the Dakar programme has continued suggests that Peugeot is achieving its goals with visibility of the SUVs, and Famin confirms that it has been signed off for up to three years. 'I think that we are still working with two to three years visibility,' says the Argentinean. 'That does not mean that the Dakar programme will stop after three years, just that we have more years on this programme. We are starting with the 3008 for marketing reasons, which is obvious, but we wanted to work with the aerodynamics on the car, and cooling as well as balance, reducing the drag as much as we can, and we had to re-work the bodywork. Then with the new bodywork we switched to the new car,' Famin sums up.

The 3008 DKR was due to make its competitive debut on the Morocco Rally at the beginning of October.

**Stages of more than 600km for 2017 will play into the hands of Peugeot**

IMPERIAL RANGE



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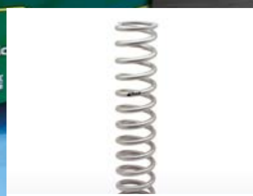

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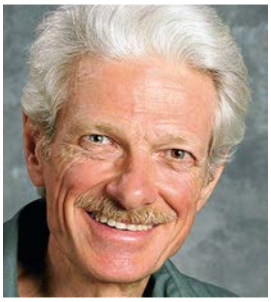

# Calculating rates for multiple springs

How to work out the rates for springs in series or in parallel

## QUESTION

How do you calculate the rate of two or more springs acting together?

## THE CONSULTANT

First of all, it matters whether the springs are acting in parallel or in series. If we have two springs side by side and we apply force to both of them so that they both deflect equally, then they are in parallel. If we have two coaxial coil springs, one inside the other as with a dual valve spring, they are also in parallel. If we have two coil springs stacked one on top of the other, they are in series. And with more than two springs, it is then possible to have series-parallel arrangements.

If we have a moving element with a spring above it and a spring below it, and both springs are active, the springs are in parallel. Examples of this in vehicle suspensions would include the sliding pillars in Morgans, some motorcycle springer girder forks, and the roll springing in monoshock car suspensions.

In some cases, two springs can be either in series or in parallel, depending on what aspect of the system's dynamics we're considering. For example, every car suspension actually has at least two springs per wheel; the main ride spring and the tyre. As far as the sprung mass is concerned, the springs are in series, with the unsprung mass situated between them. However, the ride spring and the tyre act on the unsprung mass in parallel.

When two or more springs act in parallel, the rate of the combination is simply the sum of the individual rates. That is, if $K_{total}$ is the rate of the combination of springs having rates $K_1$, $K_2$ … $K_n$, then:

**Equation 1**

$$K_{total} = K_1 + K_2 + \ldots + K_n$$

When the springs act in series, then the reciprocal of the rate of the combination is the sum of the reciprocals of the individual rates: **Equation 2**

$$1/K_{total} = 1/K_1 + 1/K_2 + \ldots + 1/K_n$$

For two springs, solving for $K_{total}$ then we get **Equation 3**

$$K_{total} = (K_1 K_2) / (K_1 + K_2)$$

For three springs, we get

**Equation 4**

$$K_{total} = (K_1 K_2 K_3) / (K_1 K_2 + K_1 K_3 + K_2 K_3)$$

The above equations work for both English or SI units.

Unless we are trying to create a spreadsheet to automate the calculation, for three or more springs it's usually simplest to just sum the reciprocals of the rates and then take the inverse of that. It will be apparent that when springs act in parallel the rate of the combination is greater than the rate of any of the individual springs, and when springs act in series the rate of the combination is less than the rate of any of the individual springs.

If you don't remember the equations or rules for springs in series, you can reason out what the combination would do. Just figure out what the deflection of each spring would be under a particular load, add the deflections, and divide that sum by the load.

For example, suppose we had a 100lb/in spring, a 200lb/in spring, and a 1000lb/in spring acting in series. If we put a 100lb load on that stack, the springs would deflect an inch, half an inch, and a tenth of an inch, for a total of 1.6 inches.

The rate of the combination is then 100/1.6 or 62.5 lb/in.

Or, using **Equation 4** above, we get:

$$\begin{aligned} K_{total} &= (100*200*1000) / (100*200 + 100*1000 + 200*1000) \\ &= 20{,}000{,}000 / (20{,}000 + 100{,}000 + 200{,}000) \\ &= 20{,}000{,}000 / 320{,}000 \\ &= 62.5 \text{ lb/in} \end{aligned}$$

Or, the reciprocals of the rates are .01, .005, and .001 in/lb. The sum of those is .016 in/lb. The inverse of that is 62.5 lb/in.


**A relatively conventional twin damper set-up on a Formula Student car. This month The Consultant ponders suspension approaches that see multiple springs working together on one wheel, whether they are arranged in parallel or in series**

**Every car actually has at least two springs per wheel: the main ride spring and the tyre. As far as sprung mass is concerned, the springs are in series**

# Figuring out Figure 8 cars

Could there be more to US Figure 8 racing than just avoiding the shunts?

## QUESTION

How can I improve the Outlaw Figure 8 racecar that I run with my father at the Evergreen Speedway in Washington state?

## THE CONSULTANT

For those who are unfamiliar with this little corner of the motorsports world, Figure 8 racing is a variation on oval track racing, generally done on specially adapted oval tracks, usually pavement. Instead of going down the straightaways in the usual manner, the cars cut diagonally across the infield twice each lap, so that the track has a figure 8 shape, with a crossroad in the middle. You just try not to crash. One thing that makes it a bit easier is that the infield is generally completely paved, and you can go outside the marked edge lines to evade crossing traffic.

The rules at Evergreen are relatively open. There is no minimum weight, no displacement limit, no restrictions on bodywork. Any kind of transmission is allowed. However, for some reason all the cars look pretty similar. They are basically bodied as Modifieds, but noses vary a lot. So do wings and spoilers. Practically all the cars have huge side plates at the outside edges of the rear of the body. Some have sidepods that look designed to create downforce.

There is no ground clearance rule. There is nothing about powered downforce or movable aerodynamic devices. There is nothing about engine location. You can use any kind of suspension. So, there isn't anything explicitly preventing you from building a sucker car with a rear engine, or a car with a passively movable or driver-controlled wing, or a car with more than four wheels.

However, there is this in the Evergreen Speedway rules: 'All rules are subject to the interpretation of track officials. Any equipment that the officials consider exotic or not in the interest, or intent, of the rules will be considered not legal for competition.'

## Domin-eight

Therefore, although you could build something dramatically different that could dominate, if you are too obvious about it they probably won't let you run at all. What's allowed is as much a matter of show business psychology as anything else, then.

But what could you do that would realistically be allowed? What could you have on the car that might not be allowed but could easily be removed if necessary without destroying the car's competitiveness?

**There isn't anything explicitly preventing you from building a sucker car with a rear engine**

Big wings, sideplates, sidepods, and spoilers are evidently tolerated. These are powerful cars on short, flat tracks, so downforce is crucial and drag doesn't matter much. There are no dimensional limitations on the cars. You can run wings that extend long distances ahead of and behind the axles. You can run sliding skirts. Anything visible that doesn't cost a lot has a decent chance of being allowed; your competitors can do it too, so it won't destroy the racing. It will just give you an edge until the others catch up. I wouldn't be shy about escalating the downforce arms race.

I'm not sure what sort of rear ends people run, but since the car has to turn both ways I'd definitely run a limited slip, not a spool diff. That would be a significant advantage if the competition hasn't figured that out already.

Independent suspension might be considered exotic and prohibited, or it might not. It does cost money, and you couldn't easily remove it from the car. If you want to run a beam axle in the back, it should have linkage that compensates for driveshaft torque, as detailed in some of my earlier pieces. When you only turn left, torque wedge helps the car on the exit. In a right turn, it hurts. Therefore, when the racecar turns both ways, you want to eliminate torque wedge.

## Motive-eight

There would be a good case for beam axles at both ends. Camber control is good, cost is low, and the suspension can be soft in warp without any exotic diagonal interconnection. That would be useful for negotiating the transition from the straight to the infield.

If I were setting up a class and wanted to keep it interesting both from a technical standpoint and from the standpoint of preserving the show, where the winner is not a foregone conclusion, I would try very permissive design rules, but with a penalty ballast rule: if you win, you get ballast added to your car for the next race. And if you win again, you get some more.

This proceeds until you don't win anymore. Once you have gone long enough without a win, you get some ballast off. This will let the innovators be rewarded with success, and gives the spectators the chance of seeing something technically new and interesting at the track, without allowing some technical wizard to dominate indefinitely.

Figure 8 cars look very much like Modifieds (pictured) and there is a lot of scope for subtle development in the category

**CONTACT**

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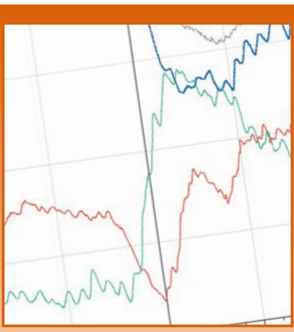

**Databytes** gives you essential insights to help you to improve your data analysis skills each month, as Cosworth's electronics engineers share tips and tweaks learned from years of experience with data systems

# Wheel speed data for real speed gain

By studying and correctly interpreting wheel speed traces you can discover a great deal about the virtues and vices of your racecar

Following on from the previous instalment, where we explained some of the ways to ensure your wheel speed traces are displayed and scaled suitably, we will now go into a bit more detail about the sort of information we can gather from the data.

We previously looked at a brake locking example with quite a major lock-up of the front left wheel, as can be seen in **Figure 1**.

As you can see, this is a fully locked up wheel which results in zero wheel speed of the front left. The flat line at 26kph is due to the way the logger samples and averages the wheel speed triggers.

Something to look out for is the differences in wheel speeds in the braking zones throughout the lap, and across different laps. If you can see a trend where one axle, or one wheel speed, is consistently slower, then this could affect performance. There could be a number of causes, such as general tyre wear, brake wear even track conditions or gradients. One way to counteract this might be to adjust the brake bias.

In **Figure 2**, you can clearly see that the driver is struggling with traction, particularly under braking. You can see that generally the rear wheel speeds are starting to lock up, identified by the downwards spikes in the blue and yellow traces.

## Braking bad

The driver may benefit by adjusting the brake bias more towards the front, so that the front axle does more of the braking than the rear, which may improve the overall braking performance.

However, it can be seen in this image that there is a small lock up of the front left wheel speed identified

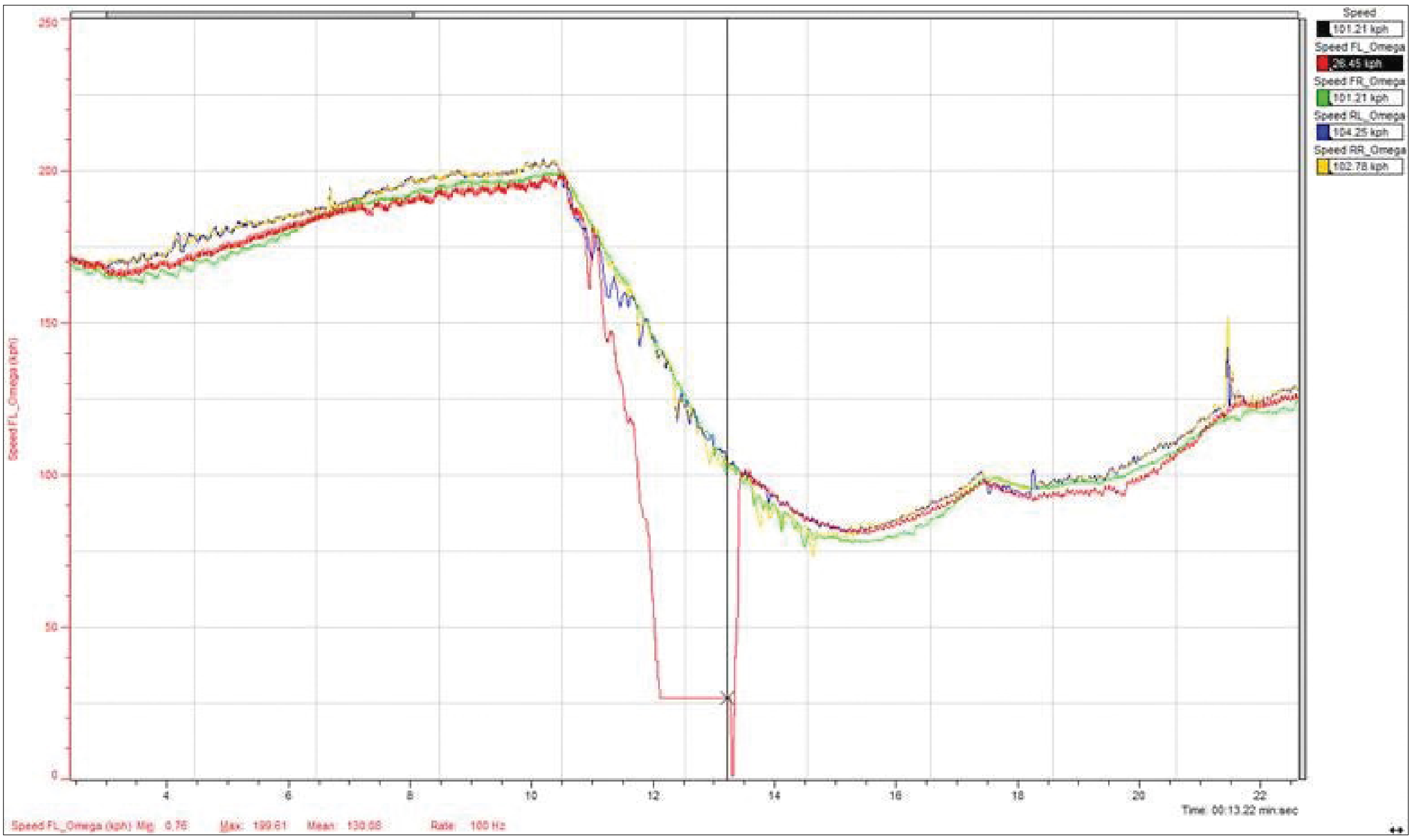


**Figure 1: Locked wheel which results in zero front left wheel speed. Flat line at 26kph is due to the way the logger samples and averages wheel speed triggers**

**Something to look out for is the differences in wheel speeds in the braking zones throughout the entire lap, and across different laps**

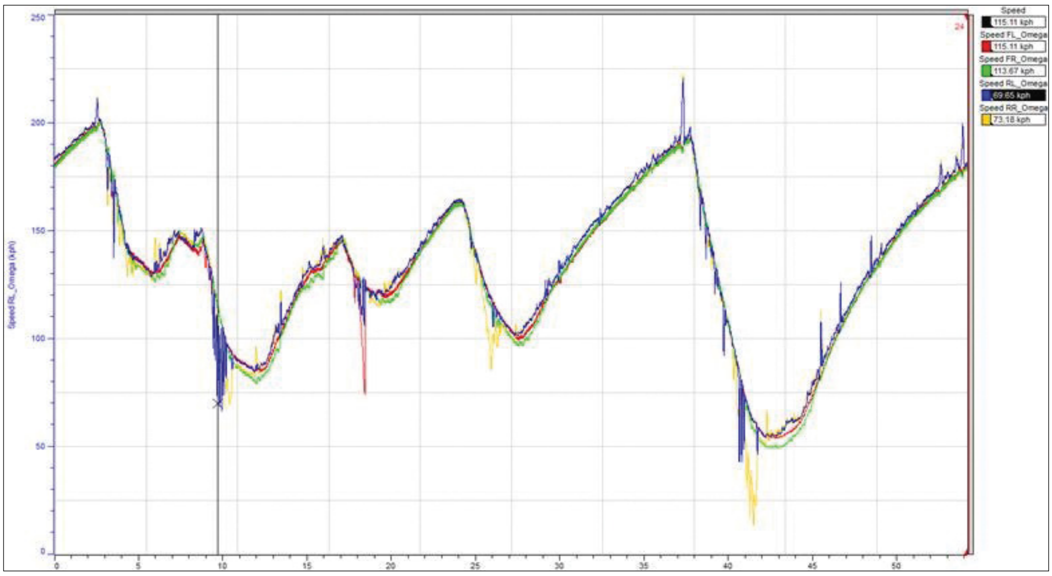


**Figure 2: It's clear here that the driver is struggling with traction, especially under braking. Rear wheels are locking**

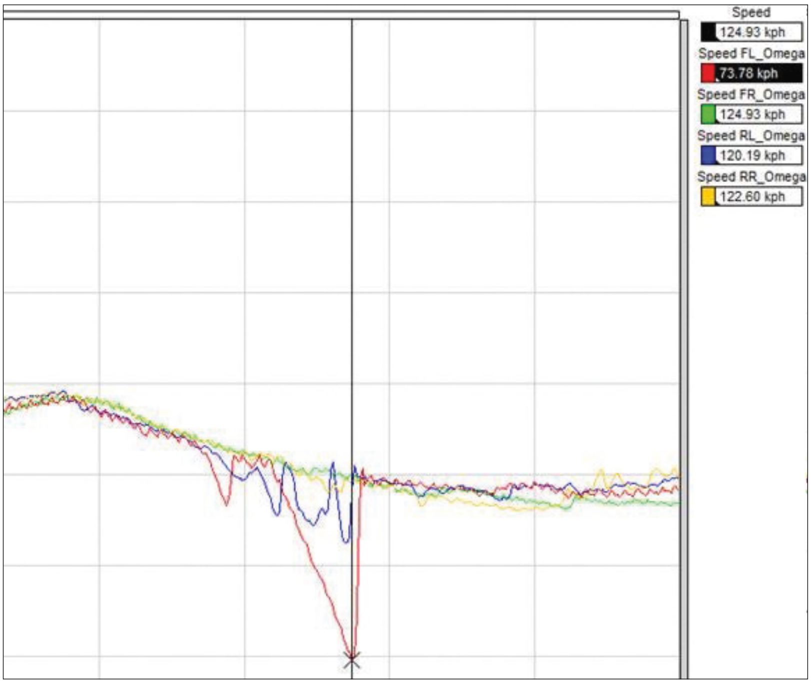


**Figure 3: Looking at the red spike from above in more detail shows different characteristics to the other wheel lock-ups**

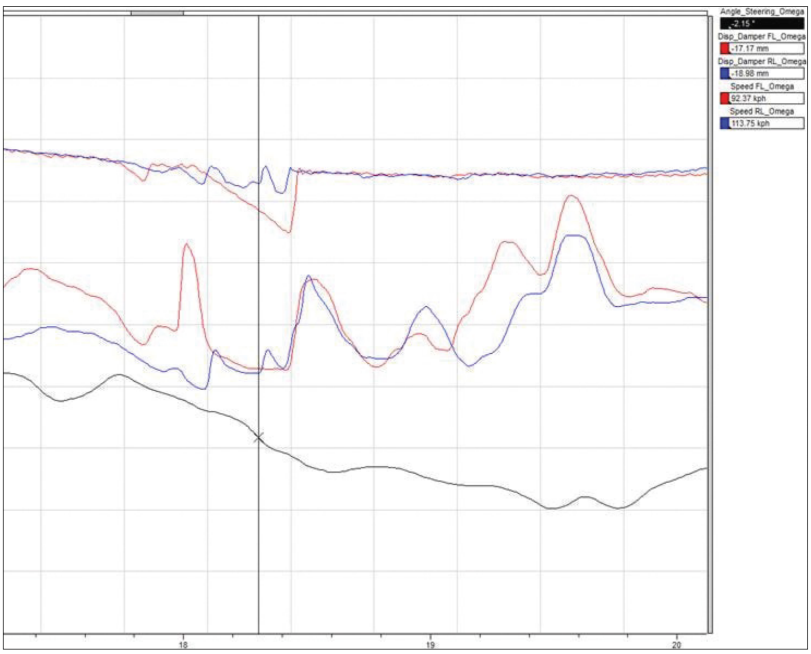


**Figure 4: The steering trace and the damper displacements clearly show that the wheel lock-ups happen as the driver transitions from one steering direction to the other**

by the downwards spike of the red trace. If this is frequently occurring, more front brake bias may actually make this even worse.

But if we analyse this more thoroughly it is actually more likely to be due to running over the kerbs at the apex of the corner.

Looking at this area of the data in more detail (**Figure 3**), it shows different characteristics to the other locks. Whereas previously the rear wheel speeds would lock simultaneously, here the front left and rear left start to lock instead.

If we also look at the steering trace and then the damper displacements (**Figure 4**) you can see that the locks happen as the driver transitions from one steering direction to the other. There are also spikes from the damper displacements that correspond.

Therefore it is safe to say that these locks happen as the driver runs over the kerbs from a right to left turn, where the left wheels are unloaded and lock as they run over the kerbs at the apex of that particular corner.

## Speed data

We have now covered some of the aspects in terms of viewing the data and what the data actually tells us. We have also highlighted how the circuit characteristics may influence the data traces and things to watch out for, such as a kerb strike. This illustrates the importance of putting yourself in the driver's shoes and thinking about the behaviour of the car as it transitions around the track.

In the next issue we will have a look at wheelspin situations, and also take what we have learnt a step further and think about how this information can be used to assist the driver and provide feedback as he is going around the circuit. This information could allow the driver to make small changes to the racecar or adapt his driving style accordingly, so that over the course of a race it could pay dividends and even make a difference to the final result.

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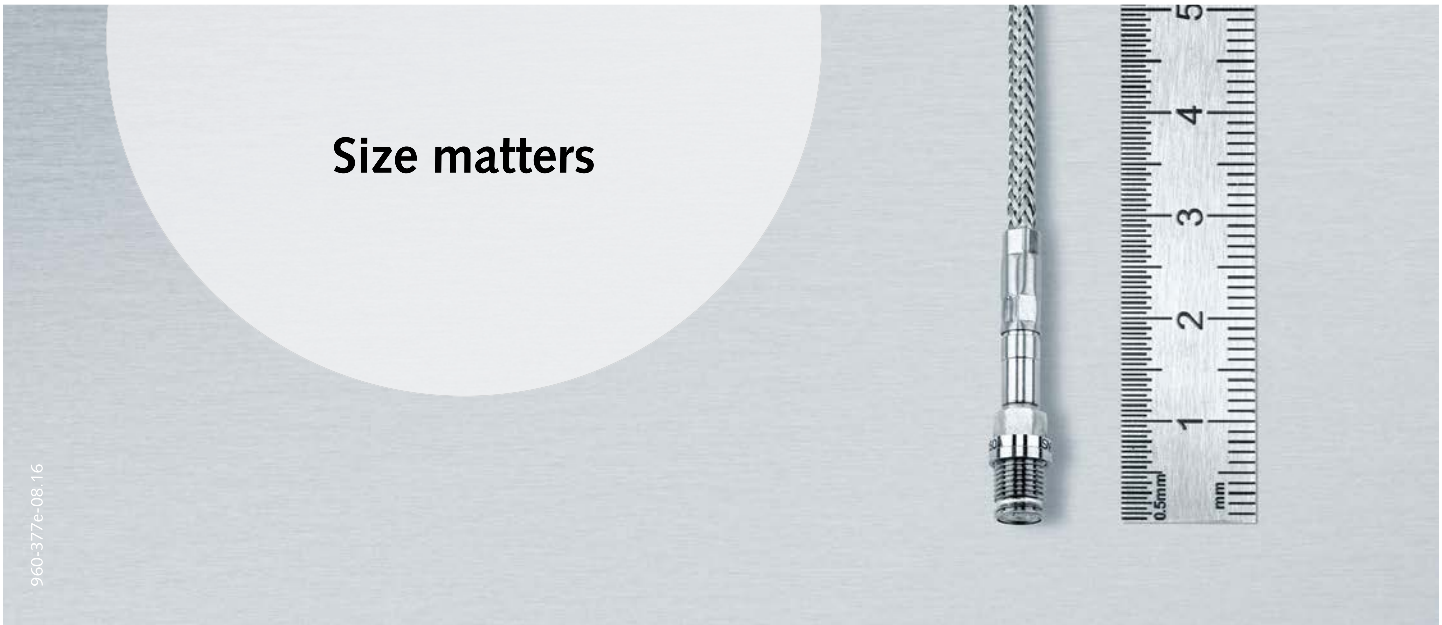
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# Taping up the BTCC Subaru Levorg GT

It's race tape time in part three of our Levorg BTCC aero study

In this final instalment of our study of the Team BMR Subaru Levorg GT BTCC racer we are going to revert to an old favourite, a roll of race tape, to find some more worthwhile aerodynamic gains. This time, though, we can also quantify the theoretical lap time benefits. First, let's briefly recap what we've learned about the BTCC Subaru so far.

Team BMR designed and built the squad's four racecars in a very condensed 87-day period that left no time for aerodynamic development. The cars thus took to the track with an aero package based on their experienced chief designer Carl Faux's previous knowledge, with development ideas due to be introduced during the season using the BTCC's development joker process. Our wind tunnel session between meetings three and four of the 2016 season (where the team scored its first win) was therefore handily timed.

In our September issue (V26N9) we saw the aerodynamic numbers from the baseline run **(Table 1)**, and learned how Faux's 'lap time delta calculator' spreadsheet could quantify the theoretical lap time benefits from changes to the drag and downforce coefficients.

This lap time delta calculator is, in essence, a lap time simulation programme that enables different overall drag and downforce numbers to be entered, and which then calculates a theoretical lap time difference over the average BTCC circuit lap time relative to baseline data. It does not take aerodynamic balance into account, but it does enable the relative effect of changes to drag and total downforce to be quantified in a meaningful way.

Modest changes to the front airdam that yielded equally modest-looking changes to the CD and –CL actually produced a theoretical 'half a tenth' lap time advantage because they reduced drag slightly. And drag was apparently much the more important aerodynamic parameter in gaining lap time on a BTCC car.

This point was reinforced in our October issue (V26N10) when we saw that a chassis rake sweep produced significant and reasonably efficient downforce increases yet achieved *only* another half a tenth lap time benefit. However, the combined tenth of a second gain was certainly worth having in a close category like the BTCC. A rear wing angle sweep showed that device, in its BTCC-controlled location, to be an effective balance adjuster but that it had little effect on lap time because the downforce increments were not efficient enough in downforce to drag ratio terms.

## Cooling drag

The final few runs in our half day session focussed on the judicious application of race tape. First, the bonnet scoop, which was being used to supply the oil cooler on the racecar, was taped over, with the changes to the aerodynamic parameters shown in **Table 2** as 'delta' (Δ) values in counts, where 1 count is a coefficient change of 0.001.

These changes would ordinarily be interpreted as a useful increment of extra front downforce along with a small drag reduction and a forwards shift in downforce balance. In

**Early running had been done with half the radiator blanked off, so it was interesting to see the effects on the aerodynamic numbers**

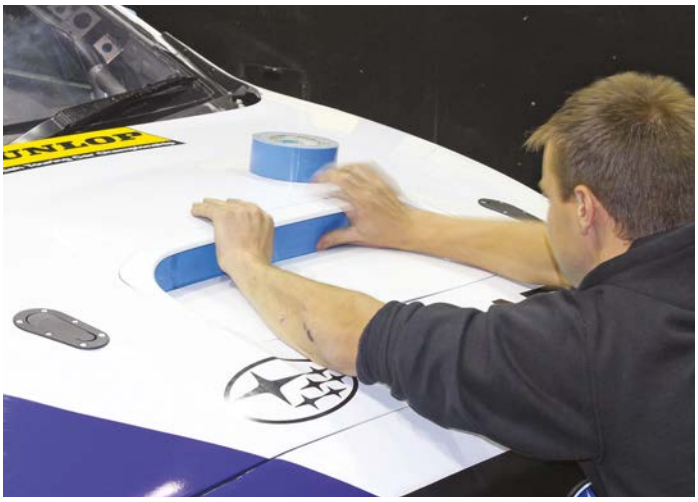
**Table 1 – Baseline aerodynamic coefficients of the BTCC Subaru Levorg**

| | CD | -CL | -CLfront | -CLrear | %front | -L/D |
|---|---|---|---|---|---|---|
| Baseline | 0.441 | 0.200 | 0.084 | 0.116 | 42.0 | 0.454 |

**Table 2 – The effects of taping over the oil cooler inlet (bonnet scoop)**

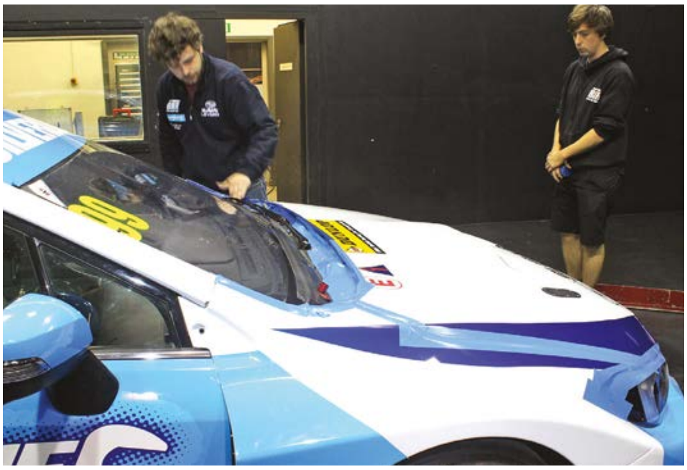
| | ΔCD | Δ-CL | Δ-CLfront | Δ-CLrear | Δ%front | Δ-L/D |
|---|---|---|---|---|---|---|
| Taped over | -4 | +11 | +16 | -5 | +3.6% | +31 |


Team BMR's Subaru Levorg touring car has caused a stir in the BTCC in its first season



Half a metre of race tape found half a tenth of lap time – which sounds like good value!


Even with very well-designed air ducting the management of the cooling flow is crucial



The bonnet and scuttle sealing taping exercise yielded some useful aerodynamic gains

**Table 3 – The effects of taping over the lower half of the radiator**

| | ΔCD | Δ-CL | Δ-CLfront | Δ-CLrear | Δ%front | Δ-L/D |
|---|---|---|---|---|---|---|
| Taped over | -2 | +8 | +8 | 0 | +1.0% | +21 |

**Table 4 – The effects of taping over the gaps on the bonnet sides and rear**

| | ΔCD | Δ-CL | Δ-CLfront | Δ-CLrear | Δ%front | Δ-L/D |
|---|---|---|---|---|---|---|
| Taped over | -2 | +9 | +11 | -2 | +2.1% | +23 |

**Table 5 – The effects of taping over gaps in the rear inner arches**

| | ΔCD | Δ-CL | Δ-CLfront | Δ-CLrear | Δ%front | Δ-L/D |
|---|---|---|---|---|---|---|
| Taped over | 0 | -2 | +1 | -3 | +0.5 | -4 |


Once again we found it is slightly better to leave rear wheel arches open at the rear

# Could the Subaru Levorg cope if the oil cooler inlet was taped over?

lap time delta terms the spreadsheet calculator predicted this most simple of modifications would yield another very useful half a tenth benefit. Could the car cope if the oil cooler inlet was taped over, if only for a short qualifying run? Or did this test simply suggest that looking for a more efficient oil cooler location was the way forwards? We will see in time how Team BMR responded to this finding.

Next, the team moved to taping over the bottom half of the water radiator, which was fed by the lower of two inlet ducts at the front (the upper one feeds the intercooler). Early season running had been done with approximately half of the radiator blanked off, so it was interesting to see the effects on the aerodynamic numbers. **Table 3** summarises the difference between the fully open radiator and the half-covered radiator.

It appeared that the response this time was more modest than that achieved by taping over the bonnet scoop, but was in a similar direction in that there was a small front downforce increment obtained along with a very small drag decrease.

The calculated lap time benefit, as might be expected, was smaller than from taping over the bonnet scoop as well, at around a quarter of a tenth per lap.

Finally, at the front of the racecar, the tape was applied to the gaps along the bonnet sides and over the gap between the rear edge of the bonnet and the windscreen scuttle – the changes to the numbers are shown in **Table 4**. The response was very similar to that obtained by taping over half the radiator, and the calculated difference in lap time was also very similar.

So, while the aerodynamic gains achieved by taping over the coolers and panel gaps at the front were individually modest, their combined effect on the Subaru was theoretically worth around a tenth of a second per lap on the average BTCC circuit. The grid for race one at Croft saw second to seventh places covered by two thirds of that time increment!

There remained just enough time to look at the effect of taping over apertures left in the rear of the rear wheel inner arches. The results are shown in **Table 5.** The effects were clearly small and, in fact, the car was very slightly better with these apertures left open, as a small increment of rear downforce appeared to accrue. This tallied with similar modifications we have seen on racecars in the past. Whereas a drag benefit might be expected from having these open apertures in the back of the rear inner arches, none seems to arise here. But what does seem consistently to accrue is this small rear downforce gain.

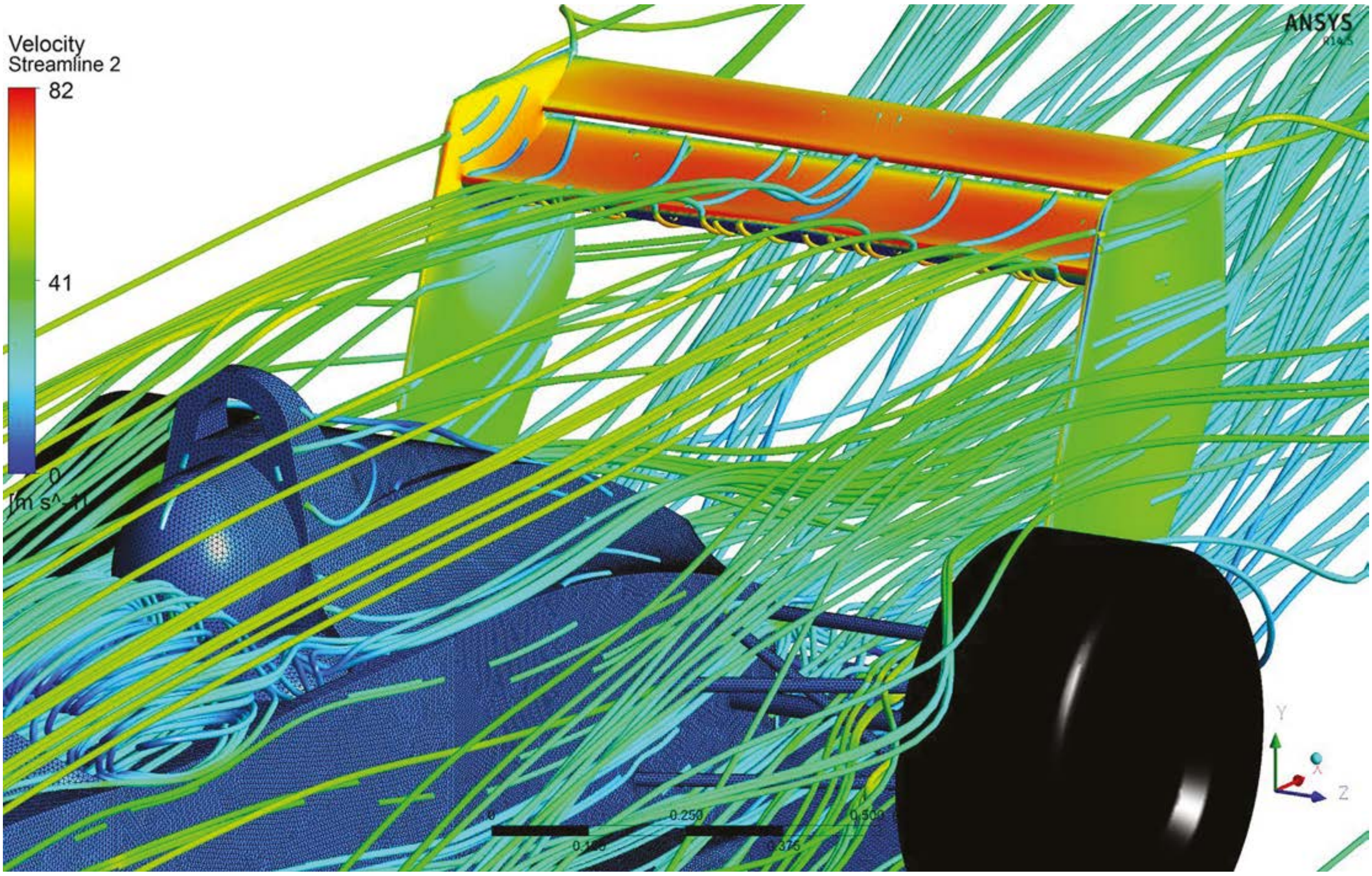
Over the course of this half-day session in the wind tunnel Team BMR found aerodynamic advantages on the BTCC Subaru Levorg GT amounting to roughly two tenths in lap time benefit. A significant gain, then.

**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

# Wings and things

**In the third instalment of our CFD study on the aerodynamic basics of single seater rear wings we look at the cluttered environment they have to work in**

By SIMON McBEATH



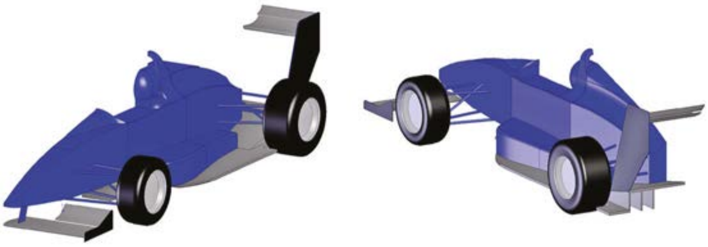

The rear wing on any racecar, but especially on a single seater, has to function in a highly compromised environment. The influence of all the upwind components, from the front wing, the open wheels, the sidepods and cooling systems, the cockpit opening, the driver, the roll-over protection system and various other necessary (and in some cases, optional) protuberances, all conspire to ensure that rear wings do not work the same on the back end of a car as they would in clean, freestream air.

This month we have used the marvels of flow visualisation in ANSYS CFD Flo to take a closer look at the rear wing's operating environment, and we've also looked at a brief sample of measures that can be taken to alter the rear wing's performance.

## The model

The first two instalments of this occasional series on the aerodynamics of a simple single seater model looked at a range of parameters in the deployment of a high downforce single element wing (December 2015, V25N12) and then at a number of variables on a high downforce dual-element wing (June 2016, V26N6). For the current study we begin with the same single seater model with a baseline dual-element rear wing. To recap, our simple model (see image **CAD 1**) featured a flat underside between the wheels, a V-divider and tea tray splitter beneath the chassis at the front of the underbody, and a simple rear diffuser with the transition from the flat floor in line with the front of the rear wheels. The front wing was a 1400mm span device with a part span flap either side of the nose and a simple, flat end plate. The rear wing was supported between tall end plates and had a span of 960mm, fitting between the end plates that connected at the bottom to the outside of the rear diffuser. This wing mounting method was found to be the most aerodynamically effective during our earlier CFD studies. The fore/aft and vertical location of the wing was kept constant through the current exercise, and again at the most effective location determined in earlier runs. The top of the end plate was set at 900mm above the ground plane, matching the regulatory limit in many single seater series, and the rear wing's trailing edge was kept close to this height throughout.

As usual, your writer has been consistent with his inconsistent use of SI and Imperial units (not to mention improper orientation of the global coordinate axes y and z), air and ground speed being set at 100mph with forces reported in Newtons, N (divide by 4.459 to obtain pounds, lb). The meshing incorporated refinements around the wings and wheels to improve the capture of flow



CAD 1: The single seater model used for our rear wing studies

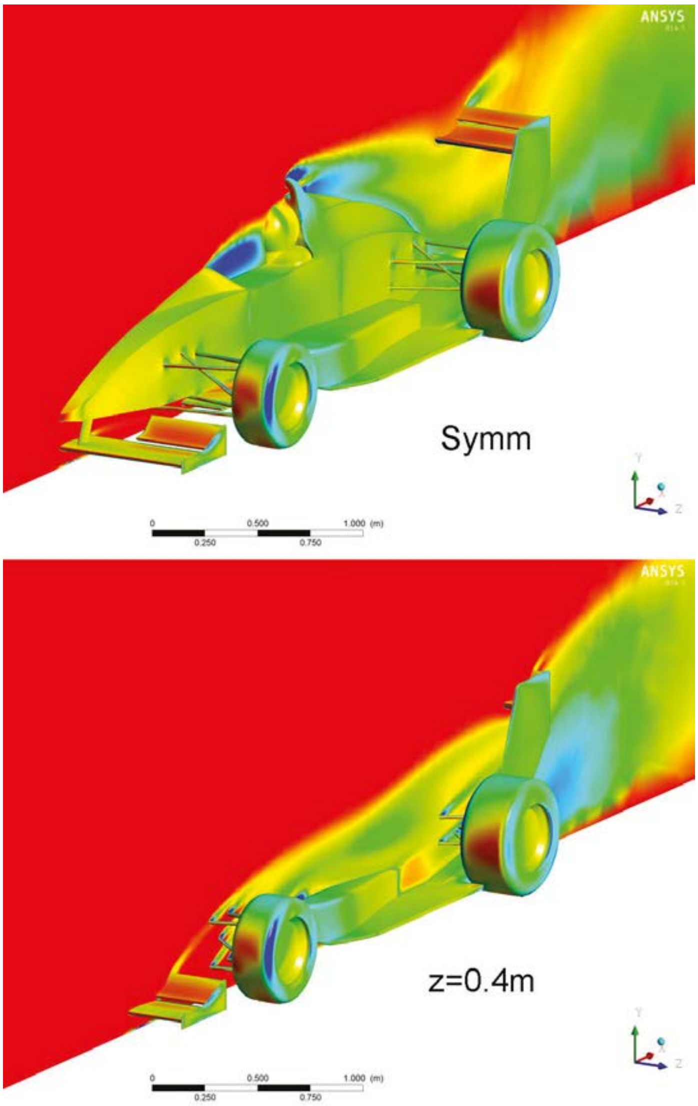



Figure 1: Total pressures on the symmetry plane (top image) and at 0.4m outboard (the bottom image) show reduced energy reaching parts of the racecar's rear wing

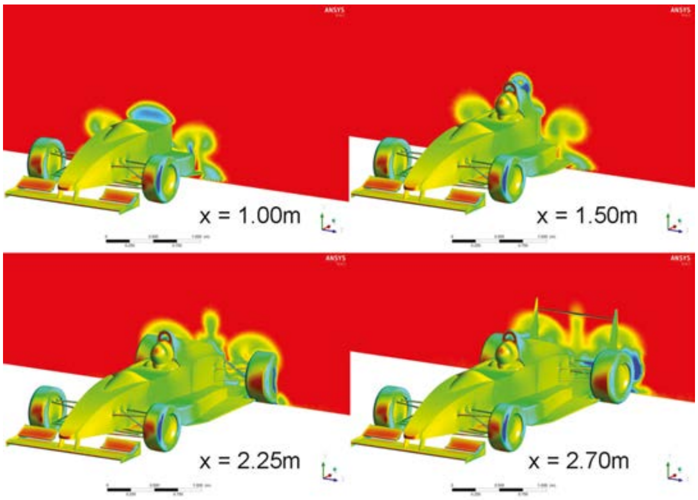



Figure 2: Total pressures on a set of transverse planes cut aft of front axle and before wing's leading edge give a different view on the air quality reaching the rear wing

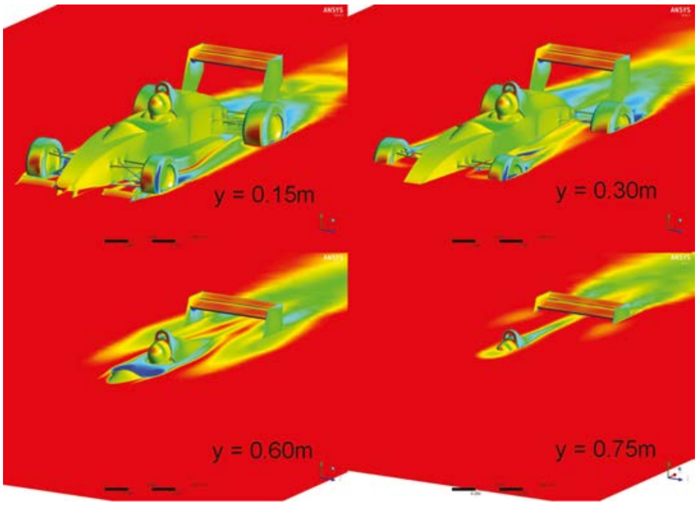



Figure 3: Total pressures on a set of horizontal planes cut at increasing heights above the ground plane provide yet another view of the flow field around the car

separations on those bodies. Moving ground and rotating wheels were utilised, and the K-epsilon turbulence model was invoked. The simulations were run until the calculated forces on the monitored bodies were deemed satisfactorily steady.

## Wing environment

Our lead image illustrates some of the complexity in the flows reaching the rear wing. In this case streamlines were projected upwind and downwind from the car and from the wing itself to give an idea of the flow directions and velocities that reach the wing. The varying onset flow angles at the wing's leading edge are apparent, with the flow coming slightly downwards from above the roll hoop in the centre, but approaching more or less horizontally to the outer ends of the wing's main element. And the downwash at the leading edge is quite clear. Another flow feature to highlight here is shown by the cluster of streamlines emerging from the corner of the cockpit next to the driver's shoulder; note how these initially progress rearwards more or less horizontally but then they became entrained in the wing's downwash and turned downwards to pass well below the wing itself. We will return to this characteristic later.

Another way to visualise the flow fields around the car, and how they impinge on the wing, is to use slices on specified planes coloured by total pressure. Vertical and horizontal longitudinal planes and vertical transverse planes yield different information, but collectively they help to visualise the overall 3D picture and give a clearer impression of the air's fluid movement around the car. Looking first at the vertical longitudinal planes in **Figure 1**, the losses in total pressure (flow energy) are shown by colours other than red, where red represents freestream energy. We can see in the upper image how the roll hoop on this model caused losses on the symmetry plane so that the flow that encountered the centre of the rear wing was at reduced energy. However, moving 0.4m outboard (lower image) the air encountering the wing's main element was at freestream energy, although not far below that the flow was at reduced energy. Contributors to these energy losses, and to the direction in which they travelled,

**Varying onset flow angles at the wing's leading edge are apparent, the flow coming slightly downwards from above the roll hoop in the centre**

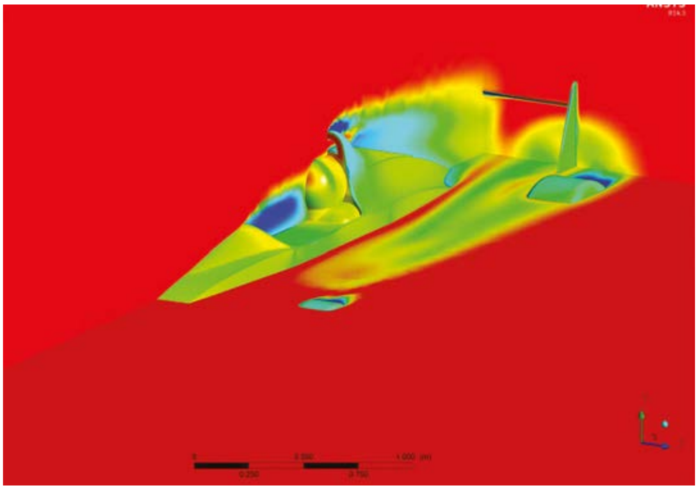


Figure 4: Combining three planes helps with 3D perception of the flows to the rear wing

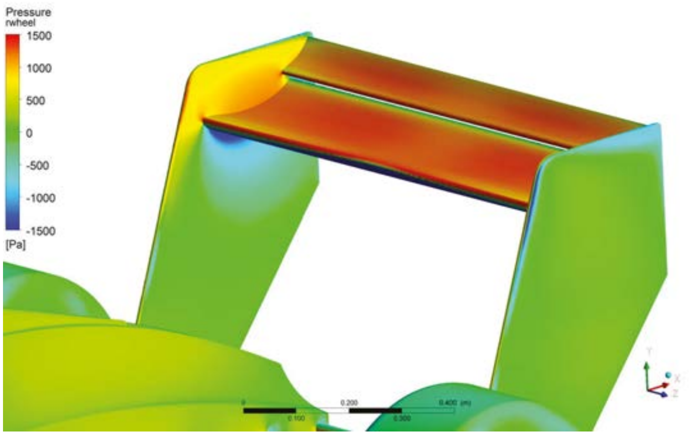



Figure 6: Static pressures on the wing's upper surface show more subtle variations; note the curved stagnation line, shown as the most vivid red strip at the leading edge

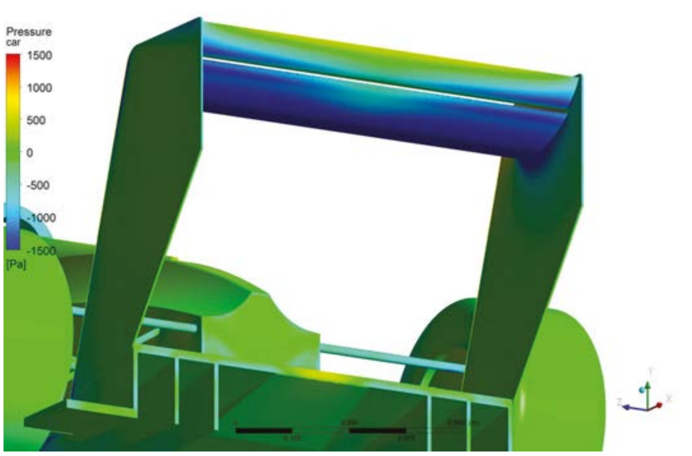



Figure 5: Static pressures on the wing's lower surface shows a central 'dent' in suction

**Table 1: The effects of modifying the roll hoop and sidepod leading edge; forces in Newtons at 100mph**

| | Drag | Downforce | %front | -L/D |
|---|---|---|---|---|
| Original | 954.5 | 2484.3 | 38.4% | 2.603 |
| Modified | 940.3 | 2508.8 | 37.6% | 2.668 |

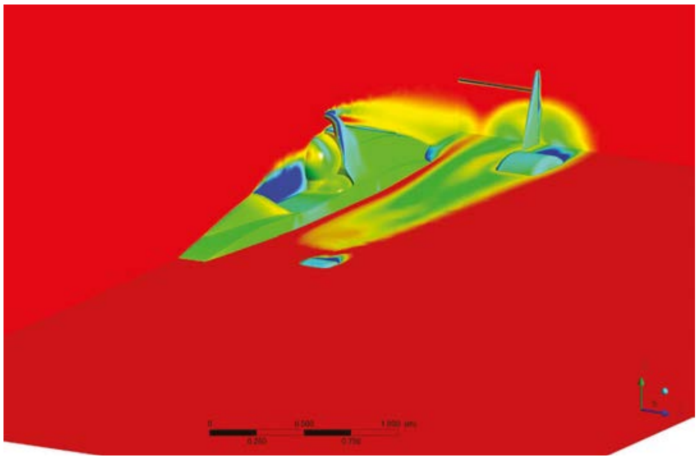


Figure 7: Total pressure losses reduced after detailed improvements to the roll hoop

include the front wing, which caused small losses but significant upwash, the front suspension and the leading edge of the sidepod, which on this iteration of the model triggered flow separation on part of its leading edge and created more widespread losses that were caught up in the flow heading rearwards.

Looking next at transverse vertical planes, **Figure 2** shows a sequence of plane cuts aft of the front axle line to just in line with the rear wing's leading edge. In the first image at x = 1.00m (the front axle was at x = 0m) we can see losses in the flow's energy above and outboard of the sidepod; the former were triggered at the sidepod leading edge while the latter primarily represent the wakes of the front wheels. At x = 1.50m these features were still present but the front wheel wakes had moved inboard slightly, but more noticeable in this image are the losses in the wake of the roll hoop and cockpit. At x = 2.25m the sidepod separation wake and front wheel wake had moved inboard of the rear wheel, while the roll hoop and cockpit wake was still clearly defined. At x = 2.70m, in line with the wing's leading edge, we see the transverse confirmation of what Figure 1 told us about the centre of the wing, and that there were also energy reductions just beneath the outer parts of the wing.

**Figure 3** shows horizontal plane cuts at increasing heights above the ground plane. At y = 0.15m we see the energy losses arising from the front wing tip that passed inboard of the front wheel, but the predominant feature is the front wheel wake. At y = 0.30m the standout features are the front wheel wake and the losses caused by the flow separation on part of the sidepod leading edge. At y = 0.60m we can see the effect of the cockpit and the engine cover and also, further outboard, that the front wheel wake had risen to this height and encountered the rear wing end plate further aft. At y = 0.75m the most noticeable feature is the roll hoop and engine cover wake encountering the centre of the rear wing, and also outboard that the upper part of the front wheel wakes were still just in evidence. **Figure 4** is a composite of three planes; two longitudinal planes that give a combined view of the flows that reach the transverse plane level with the rear wing's leading edge.

The effects can also be seen in the surface pressure distributions on the wing itself, and **Figure 5** shows how the pressures on the underside of the wing have been affected, with the 'dent' in the low pressure in the centre of the wing being caused by the reduction in total pressure alluded to above. **Figure 6** shows quite subtle variations in the raised pressures on the wing's upper surfaces, and it is also possible to see the effect of the differing onset flow angles at the leading edge, as evidenced by the upward curvature in the 'stagnation line' in the centre of the wing, which can be seen as the most vivid red (highest pressure) strip along the leading edge.

It would seem that our rear wing was being compromised not only by its fundamental location but also by some details on the model which could be improved. For example, the keen-eyed reader will have spotted the simplistic, sharp edged roll hoop in the lead image, and as no self-respecting roll hoop would be manufactured in box-section, a

**Our rear wing was being compromised not only by its fundamental location but also by some details on the model which could be improved**


Figure 8: Surprisingly the mirror streamlines did not impinge on the rear wing

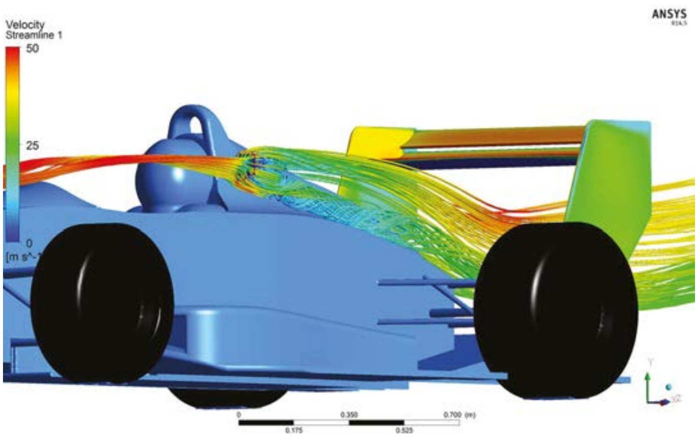



Figure 10: The camera generated more disruption but its wake passed below our wing. If their had been a lower wing tier it might well have been adversely affected by this

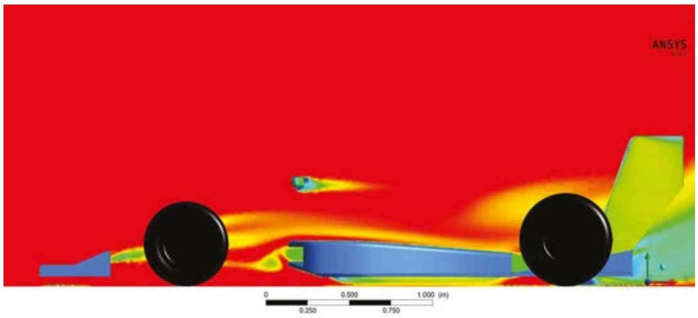



Figure 9: Total pressure losses caused by the mirrors were relatively short lived

Figure 11: Rear wing Twist 1. Angle of attack at centre was increased by four degrees

**Table 2: The effect of Twist 1 on the overall aerodynamic data of our single seater model**

| | Drag | Downforce | %front | -L/D |
|---|---|---|---|---|
| With original wing | 940.3 | 2508.8 | 37.6% | 2.668 |
| With Twist 1 wing | 942.1 | 2473.4 | 38.5% | 2.625 |

generous radius was applied to the roll hoop's leading edges. Clearly this modification was not one that would be necessary in the real world of round steel tubing, but the benefit of the unrefined CAD in this instance was to highlight and amplify the potential effect of this region on the wing. And in a modest first attempt at reducing the flow separation on the sidepod's leading edge the radius on this feature was increased. There was a tangible effect in the force data, as **Table 1** illustrates, and the total pressure plots in **Figure 7** showed reduced losses compared to those shown in **Figure 4** in the flows encountering the rear wing, especially from the roll hoop.

By examining the force distributions on the individual component groups it was evident that most of the extra downforce came from the rear wing, while most of the drag reduction was from the chassis/body, which of course included the roll hoop.

A feature absent from our model was mirrors, so mirrors of representative size were modelled onto the car to examine what effect they would have on the rear wing and the overall aerodynamic data. The result was very interesting, because although the mirrors added about 9N, or just less than one per cent extra drag, there was no appreciable effect on the downforce numbers whatsoever. So while some effect might have been expected on the flow field encountering the rear wing, this was not the case, on this model and under these test conditions at least. **Figures 8** shows that the streamlines leaving the mirrors travelled a similar route to those that emanated from the cockpit sides, alluded to earlier, in that they were turned downwards by the rear wing's downwash and passed well under the wing's elements. Had a lower wing tier been in use here then the effect on downforce might have been different. However, **Figure 9** also suggests that the total pressure losses caused by the mirrors were relatively short lived, freestream energy air filling in the wakes not far downwind, well ahead of the rear wing.

An object frequently seen these days clamped to roll hoops is the onboard video camera, and while the professionals in the top echelons house their onboard cameras in aerodynamically streamlined pods, the camera of popular choice used elsewhere is shaped like a small house brick, albeit it with filleted corners, and attached with (necessarily) bulky brackets. Once again then a 'camera' of representative dimensions was modelled on to one side of our car and attached to the roll hoop base, and again the result was perhaps not as expected. There was an additional drag increment of around 0.6 per cent but, within the margin of error arising from computational fluctuations, there was no significant change to the downforce numbers. **Figure 10** shows the streamlines projected upwind and downwind from the camera, and although the camera was evidently more disruptive than the mirrors, its wake passed well under the rear wing's main element and, according to the data, it did not materially affect the wing's performance. Again, had there been a lower wing tier then potentially there may well have been an effect.

## Winging the changes

It's always risky trying to mimic a design characteristic, and that is certainly true when copying features from a car designed and highly developed to a unique and specific rule set. However, when it comes to rear wing designs it's tempting to try

**Mirrors of representative size were modelled onto the car to examine what effect they would have on the rear wing and the aerodynamic data**


McLaren F1 rear wing from Spa 2014 was the inspiration for our Twist 1 wing – shown in Figure 11

XPB

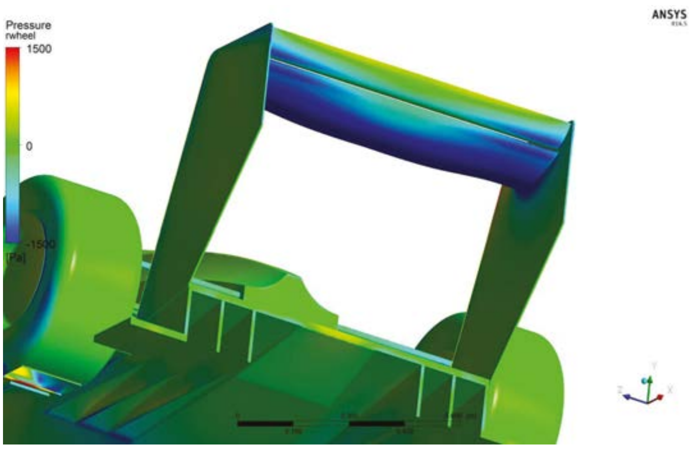



**Figure 12: The dent in the suction on the McLaren-inspired Twist 1 rear wing's lower surface seemed to be larger than that shown with the baseline rear wing**

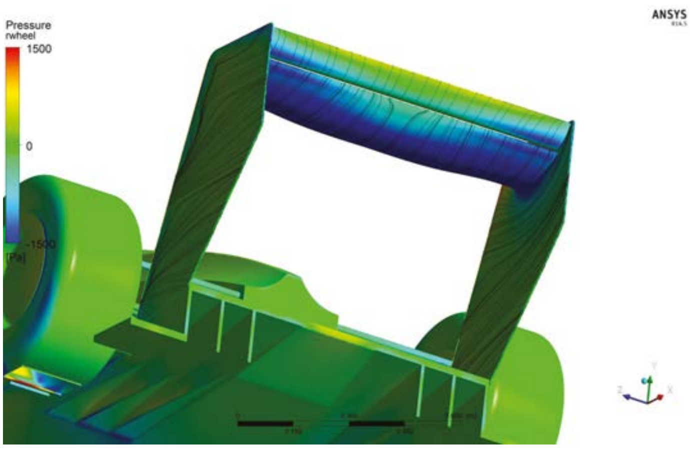



**Figure 13: Surface streamlines showed that flow separation almost occurred near the trailing edge of the centre of the main element of the Twist 1 rear wing model**

out a couple of features seen on F1 cars to see if they might be generically useful and thus beneficial on our single seater model. With our simple model and the limited resolution of the resources on which the CFD was being run, it would have been pointless making small changes and expecting to see their effect, so a small selection of reasonably significant changes was made so that the results could be viewed with a certain amount of confidence.

The first change that was made was to the main element of our rear wing, and the inspiration for this was a wing that McLaren ran at Spa in 2014. In order to obtain a main element approximating this shape (**Figure 11**), the angle of attack at the centre of our wing was increased by four degrees, while that at the outer ends was decreased by two degrees. The flap was left exactly as before, whereas the McLaren's flap featured small V-notches in the centre and near the tips, and the whole wing assembly sported the usual myriad details. The purpose of our trial was to see if twisting the main element (Twist 1) produced a different result on the car, and the results are shown in **Table 2**.

There was very little difference then with the Twist 1 wing installed on our model, drag barely changing and downforce dropping by about 1.4 per cent, with the net result that efficiency (-L/D) dropped by 1.6 per cent. So while one would have expected that McLaren fitted their 2014 Spa wing to either decrease drag or increase efficiency, or both, simply applying a similar-looking twist to our wing's main element didn't appear to provide any benefits at all.

However, looking at the pressure distribution on our wing's lower surface in **Figure 12** it is apparent that the increased angle in the centre of the wing was possibly slightly excessive in that the 'dent' in the low pressure in the centre of the wing was somewhat larger than on the original wing (Figure 5). **Figure 13** shows the surface streamlines were almost on the point of separating near the main element's trailing edge, confirming that this wing may have performed better with some further optimisation of the angle at the centre, although nothing in the data suggested that there would be worthwhile gains from this twist concept.

The second modification to the wing was inspired by the 'spoon' shaped device that Mercedes have run at low downforce tracks like Spa and Monza. In the F1 team's case the flap also incorporated span-wise variations in chord and angle, but in our case the flap was kept as per the original wing and the main element

**There was little difference with the Twist 1 wing installed on our model, drag barely changing and downforce dropping by about 1.4 per cent**


The Mercedes low downforce rear wing, as used at Spa and Monza

Figure 14: Twist 2 is based on the Mercedes low downforce rear wing

**Table 3: The effects of Twist 2 on the overall aerodynamic data of our single seater model**

| | Drag | Downforce | %front | -L/D |
|---|---|---|---|---|
| With original wing | 940.3 | 2508.8 | 37.6% | 2.668 |
| With Twist 2 wing | 932.4 | 2470.9 | 38.8% | 2.650 |

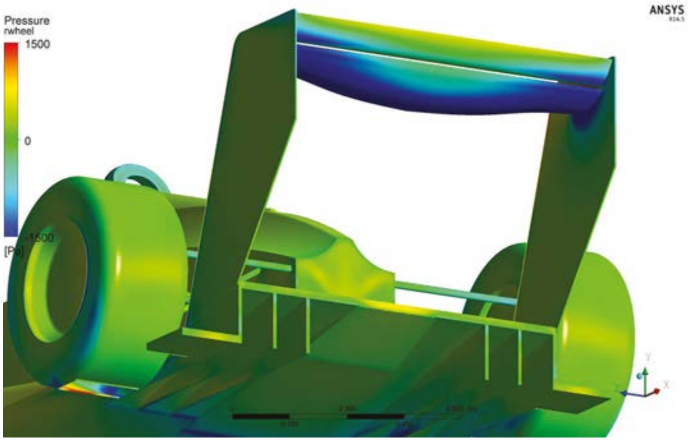



Figure 15: Twist 2 exhibited a slightly wider dent in its underwing suction

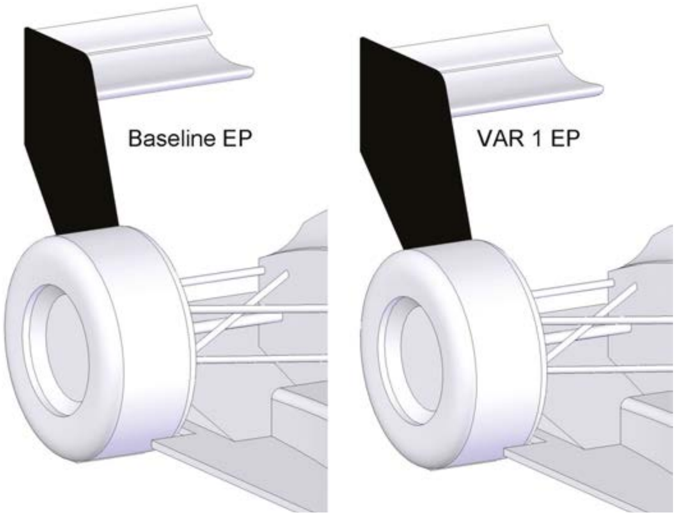



Figure 16: End plate was extended 100mm further aft of the wing (VAR 1)

**Table 4: The effect of end plate VAR 1 on overall aerodynamic performance**

| | Drag | Downforce | %front | -L/D |
|---|---|---|---|---|
| With original wing | 940.3 | 2508.8 | 37.6% | 2.668 |
| With VAR 1 wing | 940.0 | 2524.9 | 37.6% | 2.686 |

only was modified. The angle of the centre of the main element was increased a further two degrees on the Twist 1 wing, and the outer ends had their chord dimension reduced by 70 per cent, with a gradual taper from the centre to form our Twist 2 wing (**Figure 14**). **Table 3** gives the data compared to the baseline car.

In this instance there was slightly more than a 0.8 per cent decrease in overall drag together with a 1.5 per cent reduction in overall downforce, leading to just under 0.7 per cent reduction in efficiency. So although the wing could not be said to have helped with aerodynamic efficiency, it did generate less drag. Of course it would have been possible to have achieved a comparable result by simply backing off the angle of the flap or of the whole wing assembly, so it would be fair to assume that Mercedes achieved rather better than this with the complex shaping of its spoon wing. In reality it may not have used such a steep angle at the centre of its main element, but rather reduced its overall height in the centre so that it could interact more strongly with the devices below it, including the small central monkey seat wing and the rear diffuser, and these may have increased overall efficiency.

But the reduced chord near the tips would have contributed to reduced downforce and drag, as seen with our Twist 2. **Figure 15** shows once again the dent in the surface pressure near the centre of the wing, and this is now slightly wider than on the Twist 1 wing, so optimisation may yield improvements in efficiency.

Another aspect of F1 rear wings that might have generic applicability was the front to rear depth of the end plates. Ignoring the complex shapes, louvres, notches and vanes on current F1 rear end plates, fundamentally the rear edges extend further past the wing elements than is usually the case. Although this is at least partly driven by the technical regulations, end plate overhang is a parameter this writer has not specifically investigated where technical freedoms exist and the dimensions are optional, so a quick look-see with an additional 100mm of end plate aft of the wing elements was run as VAR 1, **Figure 16**. The data is shown in **Table 4**.

In this instance drag did not alter but downforce increased by just over 0.6 per cent, taking efficiency up to the best value in this trial. Clearly in the context of, say, a club or national category, a relatively very cheap modification like slightly bigger end plates to achieve the kind of modest aerodynamic performance increases we have seen in these trials would be much better value than tooling up for an entirely different shaped rear wing main element. End plate overhang is a parameter we may come back to in a future issue, along with other end plate modifications yet to be tried.

## Summary

Having examined the environment in which the rear wing on a single seater has to work, we have also seen that significant changes to wing shape made small differences to overall aerodynamic performance. The quest for effective gains will continue …

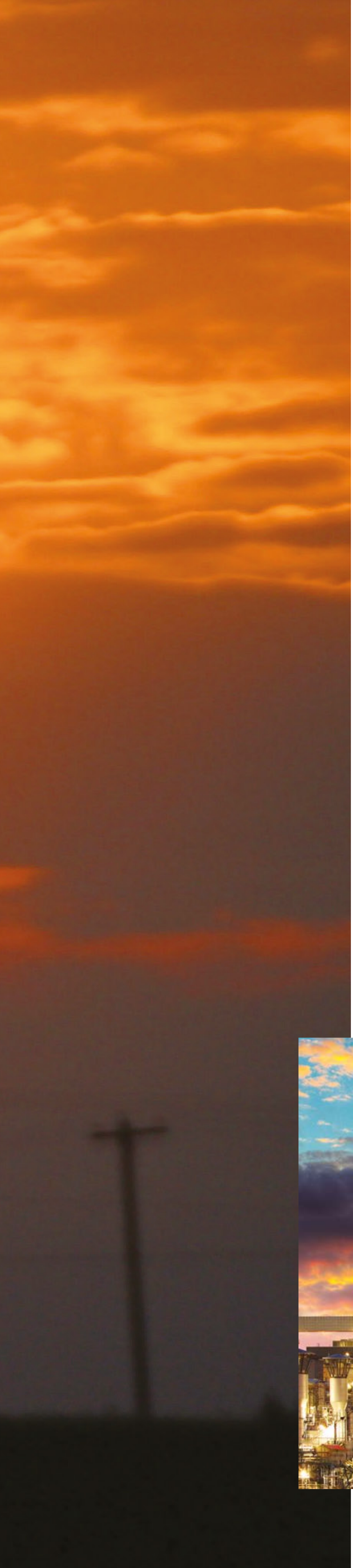
*Many thanks to ANSYS UK for providing the CFD software.*

# Mercedes may not have used such a steep angle in its main element

# Carbon dating

**As the focus starts to switch from engine efficiency to emissions, could the fuels used in F1 change dramatically, and might we be approaching the end of the fossil fuel era? *Racecar* investigates**

By SAM COLLINS



With the introduction of F1's new chassis and aerodynamic rules fast approaching, attention is beginning to turn to what comes next for the power unit. The current 1.6-litre V6 hybrids are mandated to be used in the sport until at least 2020, but beyond that point the future is not entirely clear. Many in the sport and wider industry are calling for an increase in the potency of the hybrid systems, while many others feel that emissions control must feature in the new regulations.

At the heart of these potential future developments, and indeed the substantial increases in efficiency achieved though clever combustion techniques, are the fuels used by the teams. Shell, Petronas, Total and Mobil 1 all supply into Formula 1 and are constantly developing new formulations to allow combustion development to increase.

## Neutral friends

But what's the future? One man who thinks he knows is Audi Sport's Ulrich Baretzky: 'The future is further increased efficiency and CO2 neutrality, we have to take care of the emissions, that's the future. It's as simple as that, diesel or gasoline it does not matter. What does it mean? Well at first it's the reduction of consumption compared to the power we are creating, but you also have to take car of environmental things because this is what the world asks of us. As you know, there are new laws in Europe that means that the fleet average must be below 95g/km CO2, I think motorsport could contribute a lot to that, but it's not down just to engine technology, you also have to look at the fuel.'

Indeed, the type of fuels used in future will play a key role in defining what that future actually consists of, and there seems to be a consensus that the current fuel used will not meet the demands of the future. And there are those who firmly believe that the F1 fuel of the future should be used to improve the production car. 'We need to develop solutions to increase the knowledge of mechanical engineers to try to reduced CO2 emissions,' Philippe-Franck Girard, Total's scientific delegate says. 'For the engines that means increased efficiency, and that means work on all areas of the engine. A lot of work has been done in marine diesel applications, for example, and the efficiency of those is huge – more than 50 per cent (52-53 per cent); that is really impressive. In comparison if you look at Gasoline engines on the road it's like 25 per cent. The beauty of the FIA rules today is to push the efficiency of the engine, and that is key.'

## Road relevance

Increased efficiency and reduced emissions is, of course, a core aim for most of the major car manufacturers as well as the fuel suppliers, and many want to make the link between motorsport and mainstream automotive production closer than is the case at present. Shell's Wolfgang Warnecke says: 'I truly believe that we do motorsport for the track to road. We believe that all of the industry together needs to have an innovative environment where we can test and prove things which if they are successful will eventually enter the market. Whatever we do in motorsport should reach the road. So, the starting point when thinking about the future of motorsport should be; what is the future of what is on the road in the next 10 years? We need to look at the challenges of mobility and use motorsport as a testing ground for that.'

The current fuel used in Formula 1 is loosely based on the EU EN228 specification and adapted to the demands of F1 motor racing. But this specification is expected to be changed in the not too distant future and racing fuel may have to also change accordingly, but here you start to perhaps find some dissatisfaction

# 'To take care of the emissions, that's the future. It's as simple as that'

about that new specification being adapted for competition. Girard says: 'The new EU rules will be focussed on increased bio-content in the fuel, but I don't think this is the right way to go. When you are calculating the CO2 emissions of bio-components fuels, depending on how they are produced, the result is not that good. Very often you have the same emissions levels in a traditional fossil fuel. Bio components that come from sugar for example, the farming and agriculture to produce these is not good.

'The CO2 output for bio components right now is very high, too high. It's a poor compromise. I would prefer to have an increase in the octane number, I think 98 to 100 as a minimum standard would be much better on the road. If you increase the RON to 100 minimum across the board then you will have a real reduction in CO2 emissions. I hope that the FIA can push the sport and the EU in that direction, because that is the correct way to go. We need to go to lighter fuel and higher efficiencies. It is difficult because we need to push the calorific content of the fuel, so that means lighter components in the fuel, and we need to compromise to give good anti-knock properties. The rules now are not good for anti knock. If you are developing new engines with higher compression ratios then you create more risk of knock, so you need the fuel to suit those conditions. The solution is that the rules must change at the EU level. I hope that in the next few years we get new rules to allow us to develop new types of high efficiency fuel. That is my dream,' Girard says.

**Ethanol based fuels such as E85 have always been popular in motorsport in the US due to their combustion characteristics and high thermal efficiency. Bio-fuels of all types are now being investigated for future use in international motor racing**

**Shell has played a major part in combustion advances and in driving engine efficiency in Formula 1 through its technical tie-up with Scuderia Ferrari. Could fuel development in F1 also focus on the control of CO2 emissions in future seasons?**

## Alternative fuels

Some companies have already started to explore the development of alternative fuel types, some for production car use, but also some for competition, though their use would in most case require a substantial loosening of the regulations in both Formula 1 and LMP1.

Baretzky says: 'The way fuel is produced can be very environmentally friendly, like the E-fuel we are doing at Audi. We have a plant in the east of Germany which is producing E-gas and E-fuel, the electricity for the process comes from excess electricity created by wind turbines and not needed elsewhere, or you do it with Algae, bacteria or wood chips. You take CO2 out of the environment and so when you burn it you either have an overall reduction or neutrality.

'You have advantages with this fuel in terms of combustion because it's a synthetic fuel so you can kind of design it for what you want, either gasoline or diesel. This allows you to make a cleaner more effective combustion process, you have less particulates, less emissions. It means you can advance the combustion to much higher pressure and not have the negatives that brings. By using this type of fuel you make the combustion even more efficient.'

## Bio logical?

But synthetic fuels are not the only area of research. Despite the concerns surrounding some of them, bio-fuels are also a key area of investigation, not least due to the incoming change in EU law. 'We are already looking at bio fuels,' Warnecke says. 'We are thinking about what to do with natural gas, use that and the CO2 is immediately far better, perhaps a 20 per cent improvement tank to wheel. We are doing a lot on decarbonised fuels'.

But the relaxation of technical regulations, even just those relating to fuels, is likely to be problematic with many organisations extremely concerned about rising costs. Indeed, because of this fear, in 2017 F1 fuel suppliers will be limited in the number of different specifications of fuel they can use during a season. 'It does not save much money for us,' Girard says. 'I would prefer multiple fuels at Le Mans, and in F1 I would also like a system where you are free to use whatever engine you want with the freedom to use the fuel type you like. But I'm not certain it is realistic for Formula 1. I think the cost is the limit. Actually, in future I think that the best thing is a compromise between LMP1 and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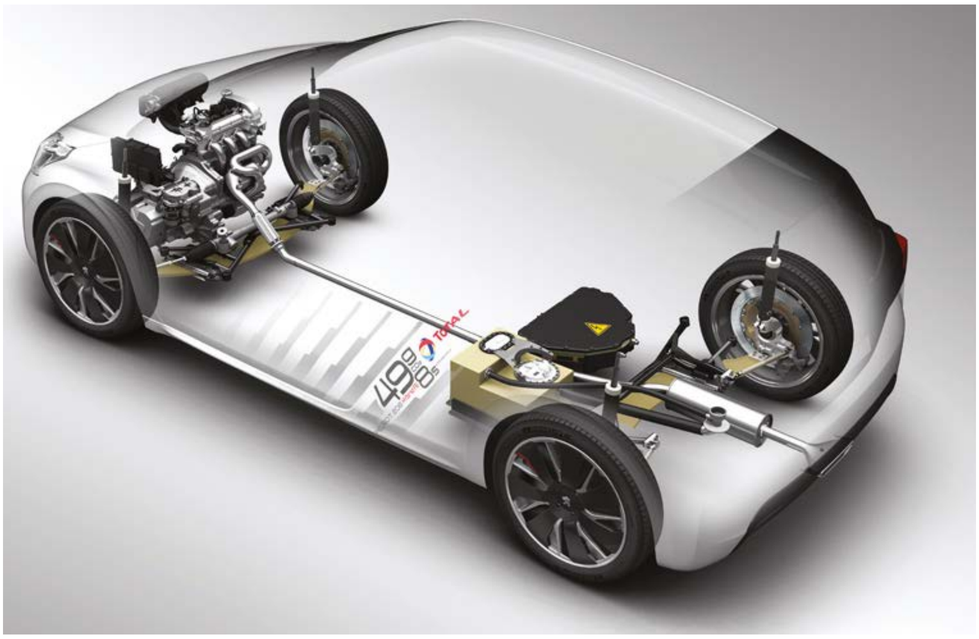

**Formula 1 fuel producer Total has worked with Peugeot to develop the 208 Hybrid FE. It features a completely new type of engine with a very high but also variable compression ratio. Could this sort of thinking find a place in high-end motorsport?**

F1. But I fear that it could be very costly because there would be an engine development arms race with people studying different engine types in parallel, and we as the fuel suppliers will have to meet the needs of those engine types. If we could have that, the knowledge and the value of that research would be huge, really huge. But I don't know where the compromise is. If you look at WEC and you compare the results of Audi and Porsche to that of Toyota, you can see that the results are directly related to the budgets. Audi and Porsche are pushing the marketing hard, in order to sell more production cars. It's no longer pure racing, it's a marketing war. If you open up the fuel then you could see Toyota improve as they have a partner which would be focussed on them, developing a fuel for the engine they use. Opening up the fuels in LMP1 will not increase the cost that much, as the fuel suppliers will limit themselves to developing with just one partner.'

## Emission control

If the focus of F1's new rulebook follows the lead set by the ACO and does indeed contain a significant element relating to emissions, then Girard is confident that the current fuel is already up to the job. 'Actually, even if emissions control comes into F1 I'm not sure the fuel will be an issue. Our fuel is really, really good quality in terms of pollutants, sulphur metals and so on. Perhaps a few ppms of sulphur, not really metals apart from a few additives to clean the combustion chamber. I'm sure we can guarantee it's good,' he claims. However, Girard also believes that it is not fuels that need to change in order to meet the dual goals of reduced greenhouse gas emissions and also a reduction in pollutants, but in fact it is the engines which may need to change. But other changes which may be on the horizon may have aerodynamic and packaging implications too.

**Opening up the fuel specification could also open up some other interesting avenues for motorsport R&D**

'We have to think always about the whole system,' Girard says. 'Not just the fuel and engine in isolation. So we do greases, lubricants, all the small things which are sliding, but it makes tiny differences and they all add up and make a quicker car. If F1 adopted a catalyst, for example, it would have a big impact on the aero, the flow rate of gas is still very important, you have a high compression ratio, turbo, etc., the speed of the gas is really high. To treat those gasses you need a certain size of catalyst, but where do you put it? We could already do it on endurance cars as we already have a particulate filter on the diesels, so it's possible, it's just mechanical engineering and electronic control. Using new catalysts in lean conditions is not a great challenge today, the challenge is one of temperature to avoid the fusion of the catalysts.'

## Lean machines

Opening up the fuel specification could also open up some other interesting avenues for motorsport R&D, some of which are now outside the regulations, but seemingly very pertinent for production car development as manufacturers begin to experiment with lean burning high compression gasoline engines. 'Road cars need to follow the lead of F1,' Girard says. 'To have very lean burning engines, with an excess of air. With this type of engine you could reduce NOx and CO2, that's a key point for the future. But perhaps the technologies of the engine will change. We have developed the 208 Hybrid FE with Peugeot. We developed a new type of engine with this car with a very high compression ratio but it is also a variable compression ratio. We used an interesting valve control system so the connecting rod remained the same length but other things changed under different RPM and load conditions. We could move from 11:1 to 16:1 compression ratio depending on the demand. The performance was really strong for a production car. If this was allowed, I think variable compression ratios would be very useful in racing, to reduce knock and increase efficiency.'

## Cost concerns

But the concern over cost is a serious one and something that is hard to overcome, though many are looking at seemingly unlikely avenues to make Formula 1 and LMP1 both financially sustainable, and still relevant for automotive R&D. 'Perhaps one way to move the rules would be to take a production car engine and push it to the limit for F1 or endurance,' Girard says. 'LMP1 and F1 are two extremes at the moment. In the past at Le Mans there was the index of thermal efficiency. It was very interesting because the idea was to go as fast as your rivals with less fuel. Perhaps that is also one solution for the future of endurance.'

Right now the negotiations and discussion about the regulations for 2020 and beyond are only just beginning, but while the introduction of a new fuel or type of power unit may seem to be far away discussions, talks about the introduction of the current power units began in 2007, and they were introduced in 2014. In other words, it could be argued that Formula 1 is falling behind schedule somewhat.

'We have started to discuss the future,' Girard says. 'We have to try to give the FIA the right ideas, and get them to raise those suggestions with the teams. If you leave it up to the teams to find a direction it will take far too long. Mercedes, Honda, Renault, they all have different objectives. But for us now it is a question of how do you change peoples mindsets – it's tricky. If you give the FIA the idea but they are not convinced you need to show them a demonstrator, and that can be difficult. But I'm ready to discuss the future with the FIA in a very open fashion, we have developed some engines. We know how to do it, and we have some ideas.'

While the ACO has already stated that it is looking toward emissions control and CO2 reduction in LMP1, there is to date no announcement of the detail or concepts being considered for Formula 1 fuels and power units beyond 2020. But when those details are released, do not be surprised if it marks another major departure for the sport.


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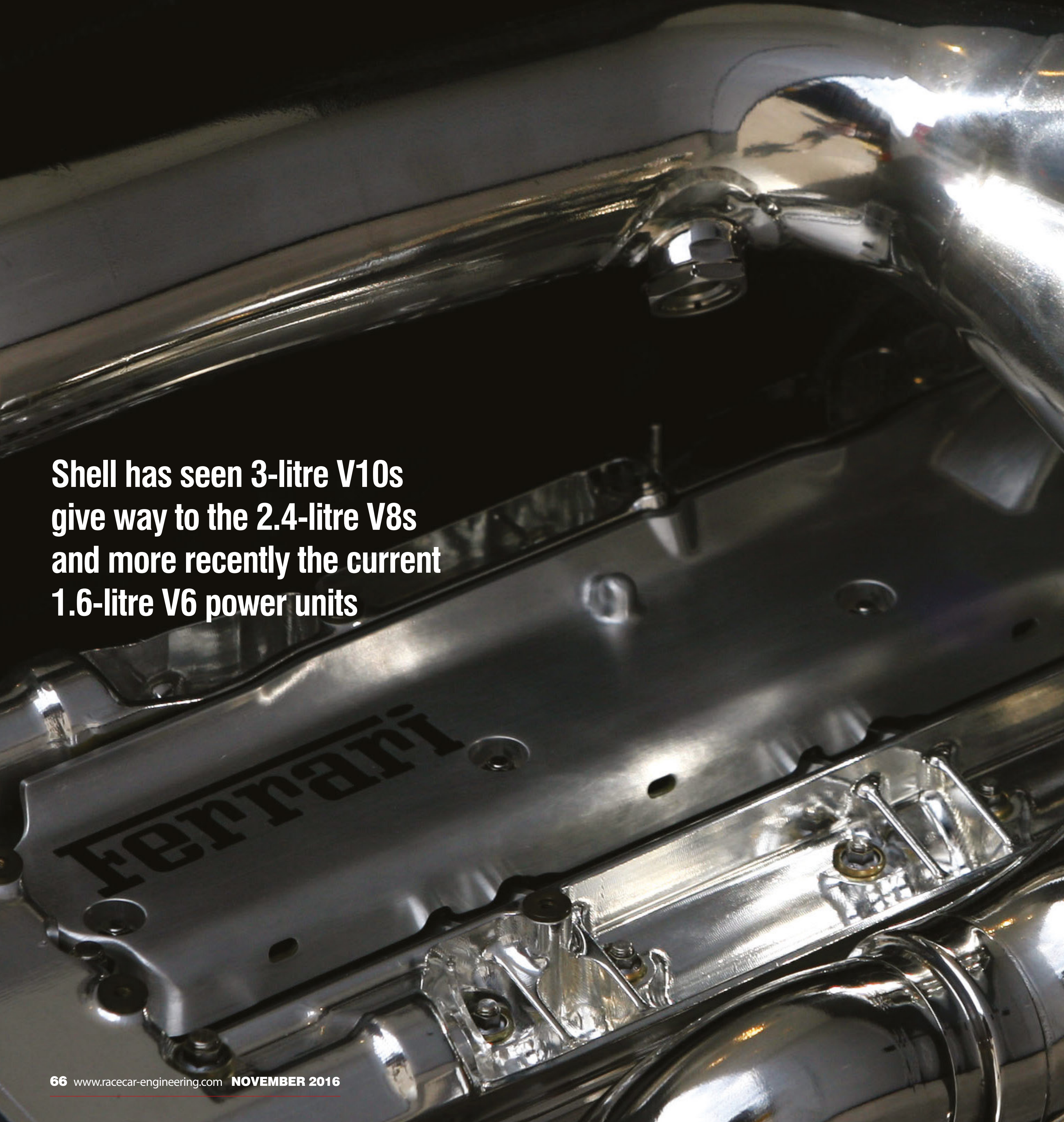
# Shell fire

**Shell has been Ferrari's fuel and lubricants supplier for over 20 years and has played a vital role in the Scuderia's engine development during that time. Here's the inside story**




**Shell has seen 3-litre V10s give way to the 2.4-litre V8s and more recently the current 1.6-litre V6 power units**

For the 1996 Formula 1 season Ferrari dropped its distinctive V12 engine in favour of a 3-litre V10, and began working extremely closely with technical partner Shell on engine development. What resulted was a fascinating period of co-development which continues to this day. It has seen various 3-litre V10s give way to the 2.4-litre V8s and more recently the current 1.6-litre V6 power units. This article sums up the development of Ferrari's engines throughout that period from a unique perspective, that of co-development between engine designers and petrochemical scientists.

Up until the early 2000s the design and development of F1 engines was not restricted in terms of thermo-fluid dynamics, the main constraints were essentially the engine size (limited to 3000cc) and the number of cylinders.

## V10: complete freedom

In all F1 engines the performance is primarily represented by the maximum power or more specifically the average power in the useful range, which is approximately the range of 3000rpm around the engine speed which gives maximum power. Targets of maximum torque or torque at low revs are of secondary importance; in essence a Formula 1 engine is characterised by its maximum power level. The brake engine power (PB) can be expressed from first principles as a function of the air flow rate, the corresponding energy from fuel and the thermal efficiency: see equation below.

The relationship in this equation states that for a given fuel and engine thermal efficiency, maximum power can be obtained by maximising the air flow rate to the engine, that is, by increasing the mean piston speed, bore and volumetric efficiency.

The mean piston speed is limited to values in the region of 24m/s due to the thermo-structural capacity of the piston. Consequently the equation shows why the evolution of naturally aspirated engines has been that of a gradual increase in the bore, with a corresponding reduction in stroke (for given displacement) and a consistent increase in engine speed. So when the mean piston speed reached 24 to 25 m/s, the bore was increased to allow further increase in rpm.

During the period of free thermo-fluid engine development in the V10 era the main engine design objectives focused on maximising the engine speed to increase the air flow rate and consequently the fuel flow rate consumed by the engine, and therefore the energy available for combustion.

Maximisation of the engine's volumetric efficiency was achieved through the reduction of pressure losses in the intake system and mainly the optimisation of the dynamic effects in the intake and exhaust ducts. As turbos were banned this was achieved through exploiting the pressure waves present in intake and exhaust systems. With this in mind the main design objectives were: maximisation of the pressure in the intake duct close to intake valve closing (IVC) to exploit the so called ram effect and increase the density of the charge; and tuning of the intake duct which was optimised using variable trumpet length. Variable inlets were permitted on V10s; the length of the trumpets decreased with the engine speed to ensure the correct tuning of the pressure waves.

Additionally, the timing of intake and exhaust cams were characterised by elevated valve overlap. Optimising the overlap allowed the proper exploitation of the wave in the exhaust duct necessary to scavenge the combustion chamber from the burned gases and to maximise the depression in the cylinder to increase the ram effect. High valve lifts even during the overlap period were also used. This required deep pockets on the piston crown, which was facilitated by not maximising

### The Shell equation

$$P_B = \left(\eta_{VOL}\frac{\rho Z S V_p}{4}\right)\cdot\left(\frac{Q_{FUEL}}{\lambda\cdot AFR_{ST}}\right)\cdot\ \eta_{TH}$$

**Air flow rate** — **Energy flow rate per unit mass of air**

where:

$\eta_{TH}$ = engine thermal efficiency, i.e. the ratio between the effective power at the crankshaft and the thermal power introduced in the engine cycle.

$\eta_{VOL}$ = engine volumetric efficiency, i.e the ratio between the air mass induced within the cylinder and the theoretical swept volume

$\rho$ = air density

Z = number cylinders

S = piston surface, i.e. $\frac{\pi}{4}B^2$ where B is the bore diameter

$V_p$ = mean piston speed

$Q_{FUEL}$ = fuel heating value

$AFR_{ST}$ stoichiometric ratio air/fuel

$\lambda$ = relative air-fuel ratio

# External parts also played a major role, with the intake of key interest

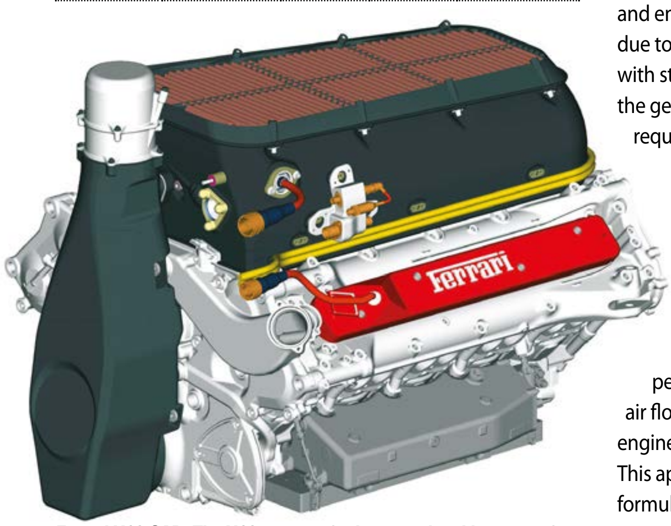
the compression ratio. Ambitions towards compression ratio increases to improve the thermodynamic efficiency clashed with the limitations of volumetric efficiency, with the later inevitably prevailing.

The designs of the valves themselves, then, was important, with the intake valves being typically larger than the exhaust; the ratio between exhaust and intake valve diameters was in the region of 0.8.

Rich mixtures were used with relative air-fuel ratios between 0.8 and 0.9 in order to achieve high flame speeds, but also the optimum

**Table 1: Typical values for certain Ferrari V10 engine parameters over the years**

| Bore (mm) | Stroke (mm) | Max.rpm | Vp (m/s) | Stroke/Bore |
|---|---|---|---|---|
| 94 | 43.2 | 16,500 | 23.8 | 0.46 |
| 96 | 41.5 | 17,250 | 23.8 | 0.43 |
| 98 | 39.8 | 19,000 | 25.2 | 0.41 |




Ferrari V10 CAD. The V10 era was far less restricted in terms of thermo-fluid dynamics than is the case with the current formula


The Ferrari V10 engine pictured in 2004. During the period of free thermo-fluid engine development in the V10 era the main engine design objectives focused on maximising the engine speed to increase the air flow rate and hence fuel flow rate too

mixture was rich in order to provide a necessary cooling function to some critical components of the engine, in particular the exhaust valves.

While much of the focus was understandably in the combustion chamber itself, external parts also played a major role, with the intake of key interest. Snorkel designs were constantly optimised in order to maximise the charge air density by transforming the kinetic term of the speed of the car to gain pressure at engine inlet with an increase of the latter of approximately 30mbar and as a consequence an increase in power output in the region of 30bhp.

Of course, this has a direct relationship with the flow into the cylinder on a port injected engine, so there was a focus by the Ferrari engineers on maximisation of inlet port flow coefficients at high lifts without compromising the organised fluid motion within the combustion chamber to increase the turbulence and enhance the combustion velocity. This was due to the fact that the shape of the chamber with stroke/bore ratios less than 0.5 prevented the generation of ordered forms of tumble that require ratios close to 0.7 to 1.

Performance development was also pursued in the following areas, albeit with lesser impact: Injection systems and friction reduction.

## Fuel and oils

One of the key parameters for engine performance was the maximisation of the air flow rate, achievable through increasing engine speed and/or volumetric efficiency. This approach had a number of impacts on formulating the optimum fuel for Ferrari engines of the free thermo-fluid dynamic era.

Higher air mass flow to the combustion chamber through fuel cooling effect was one area of focus. The fuel formulation was targeted to have a high capacity to evaporate quickly under the prescribed engine conditions, especially because inlet ducts were designed to maximise the flow coefficient at high lifts, without any compromise in the creation of air turbulences which would have helped the fuel to evaporate. The ability to evaporate quickly and fully is positive, because seen from a thermodynamic point of view it cools the air in the inlet ducts, increasing air density (the mass of air trapped in the cylinder).

## Flame speed

The ability to increase engine revs through fuel formulations to advance flame speed was also key. There were numerous hardware challenges with increasing the engine speed, including the ability to enable complete combustion of the air fuel mixture in the shortest time (the available time being shorter as the revs increase). By selecting molecules with the highest flame speed, combustion velocity and completeness could be positively influenced.

These parameters were key for the prime focus of gaining absolute power. Fuel consumption was also of importance, though to a lower order based on the effects to vehicle mass, packaging and race strategy.

As a consequence of the above and the fact that the engines were not knock limited, the fuel formulations of the V10s and V8s often included high levels of paraffin and olefin components.

The main development target of the engine oil formulation is, of course, to reduce friction. This can be achieved via surface active chemical additives that form films between moving parts, or by reducing the viscous friction in the oil film by reducing the viscosity of the oil. Against this, the oil must also protect the moving parts of the engine from wear, by maintaining a suitable oil film thickness between them.

In times of relatively fixed engine specifications, the trend of lubricant development has been to reduce the viscosity in order to minimise viscous losses. In the period covering the V10 through to the V8, this has seen a reduction in high-temp high-shear viscosity of 70 per cent, kinematic viscosity at 100degC of 80 per cent and kinematic viscosity at 40degC of more than 90 per cent.

In order to accommodate such reductions in viscosity, the most heavily loaded parts of the engine, such as the valve train, gear chest and piston ring/ liner contact were coated in extremely hard and wear-resistant ceramic and DLC coatings. These allow the oil film thickness to be very low between moving parts without excessive wear or an increase in friction.

One other aspect of the oil affected by changes to the viscosity and engine architecture

# Fuel was formulated to have a high capacity to evaporate quickly

is unwanted aeration, and the pumping losses and cavitation-erosion of bearings that can result. This is particularly prevalent with the use of scavenge pumps in the engine sump that introduce a high amount of gases into the oil circuit returning to the oil tank. Design changes to the oil system, oil tank and oil pump aimed at removing the air from the oil, and changes to the oil formulation to promote air release have been made in all iterations of the F1 engine over the past decades to reduce this problem.

When the engine regulations require an increase in the lifetime of the engine, the general trend has been to reformulate the oil to a higher viscosity in order to provide higher levels of protection, at the expense of some performance. However, in each case changes to the formulation and engine hardware in subsequent years can reclaim this performance while maintaining the higher level of durability.

## V8 restrictions

Between 2007 and 2013, F1 engine development became severely restricted in terms of thermo-fluid dynamics, so this type of development was not the central focus. The main areas of performance development in the engine departments extended to: development outside of the regulatory perimeter, e.g. exhaust and snorkel design; fuel and oil development to address potential reliability concerns caused by them; minimising engine performance degradation over mileage; design of engine auxiliaries for easiest installation without compromising functionality; the extension of an engine's operating range to allow the design of a more compact vehicle; and the focus on dynamic strategies and optimum engine utilisation at the track and, later, the use of the engine for aerodynamic purposes.

## F1's new V6 era

Formula 1's current power unit regulations mandate a 1.6-litre V6 engine using direct injection and, from 2015, variable inlets. Crucially, there is also a 100kg/h fuel flow limit as well as a maximum consumption of 100kg during a race. This imposed a significant change in the thermo-fluid dynamic development of the engine in comparison to the V8 and V10 engines for a number of reasons:

Firstly, the limitation of the fuel flow rate means that performance increase cannot be obtained by increasing the air and fuel flow rate but must be obtained by maximising combustion efficiency: this is the key point of the new technical regulations and the main changes compared to the previous generation of Formula 1 engines.

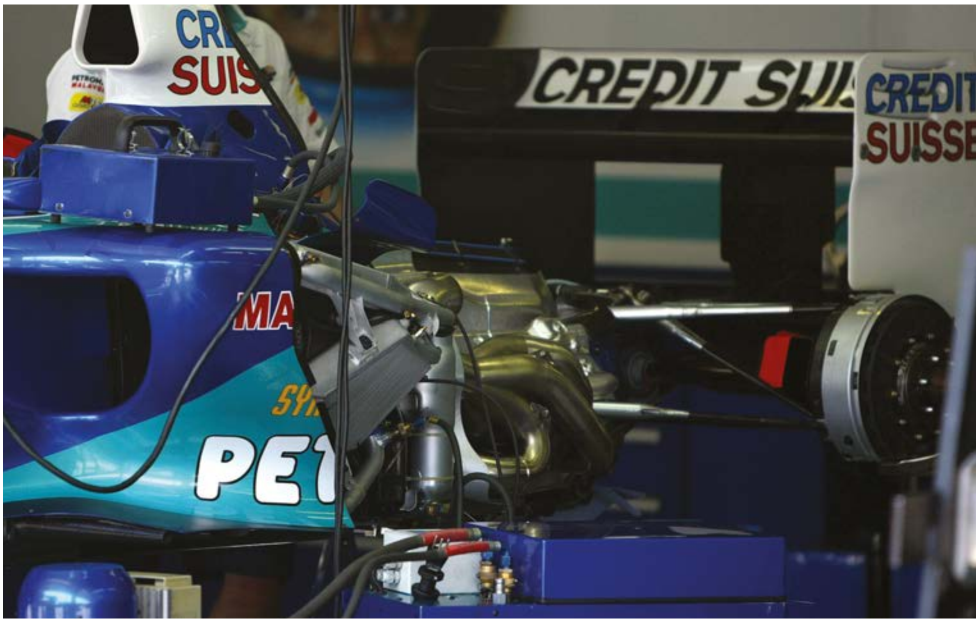
The turbocharging and the reduction of the engine speed mean knock is the main limitation of the development of such engines: anything that lessens the tendency to knock (i.e. the increase of burning rate) and the reduction of the temperature of the charge at IVC has a positive impact on performance because it optimises the combustion of the engine and allows increase of the compression ratio.

Maximising the volumetric efficiency assumes a secondary importance since the pressurisation of the compressor can compensate lower flow coefficients of the intake system or poor dynamic effects on the ducts if such approach helps the combustion.

Moreover, high flow coefficients could reduce the turbulence and hence the combustion velocity, and so volumetric efficiency is these days a compromise between MGU-H recovery (required compressor power) and knock tendency.

A compromise exists between optimising engine performance while ensuring energy of exhaust gas to the turbo and the MGU-H recovery. The goal, then, is not only the performance of the engine but the whole ICE and MGU-H to minimise the lap time of the car.

In particular, at the design level this results in the absence or different use of dynamic effects in the intake ducts: the main objective moves from volumetric efficiency to the reduction of all methods which reduce the tendency to knock. Even for the overlap between intake and exhaust cams the main purpose is proper combustion chamber scavenging. The value




**The Ferrari V10 in a Sauber in 2005. The external features of the engine were also heavily developed during this halcyon period of F1 engine design. Snorkel inlet designs were constantly optimised in order to maximise the charge air density**

**There was a concerted effort to focus on optimising inlet port flow coefficients at high lifts at Ferrari during F1's V10 era**

# The fuel for the V8 and V10 would not perform in the V6 turbo engine

of this overlap is, however, compromised to prevent unburnt fuel entering the exhaust duct because this would represent a decrease of the performance of the power unit.

Compared to the V8 and V10, the diameter of the intake valves is not as great and the ratio between the diameters of intake and exhaust valve is now closer to 1; the influence of exhaust pumping now is at the same level of importance as the volumetric efficiency.

## Combustion speed

The combustion chamber is now designed to maximise the speed of combustion. The increased stroke to bore ratio improves the evolution of the flame front and reduces the heat losses to the walls due to the more compact combustion chamber. The reduction of the valve diameters and depth of valve pockets allow the flame front to develop more quickly and efficiently. The increased bore stroke ratio (almost 0.7) gives the possibility to exploit organised motion fields such as tumble with the associated benefits this gives in turbulence and combustion speed.

This optimisation of flow coefficient of the intake system to increase the volumetric efficiency does not have a direct impact on engine performance, partly because the air flow required by the engine can be compensated by the boost pressure. As stated above, an increase in the volumetric efficiency does not directly affect engine performance, though does influence the MGU-H recovery as a consequence of the minor work requested to the compressor to boost the air. The level of MGU-H recovery is important for lap time, but is not the only factor.

At the inlet ducts it is also required to generate some tumble motion, needed to increase the turbulence at the end of compression and the combustion speed. In terms of the air/fuel ratio, the situation is completely the opposite to the old Formula 1 engines, with values in the maximum power conditions greater than 1.1 for two reasons: the abundance of air to burn all the injected fuel, avoiding CO/HC and partial combustion, and reducing the tendency to knock.

Last of the Ferrari V8s, the 056 of 2013. Fuels for both V10s and V8s often contained high levels of paraffin and olefin components

## V6 fuel and oil

As previously stated, the performance increase of the Formula 1 power unit now comes from the ability to increase the power output from the 100kg/h fuel flow through optimised combustion efficiency. In terms of fuel formulation, the anti-knock properties are now very important. With improved anti-knock properties of high octane fuels, the spark advance can be increased (up to MBT), leading to a better combustion phasing and hence better engine efficiency. The flow restriction means that the fuel itself must be made up of compounds with higher energy per mass, that is, providing more energy with the same given flow. In fact the energy density of the Formula 1 fuels has increased by approximately two per cent since 2013.

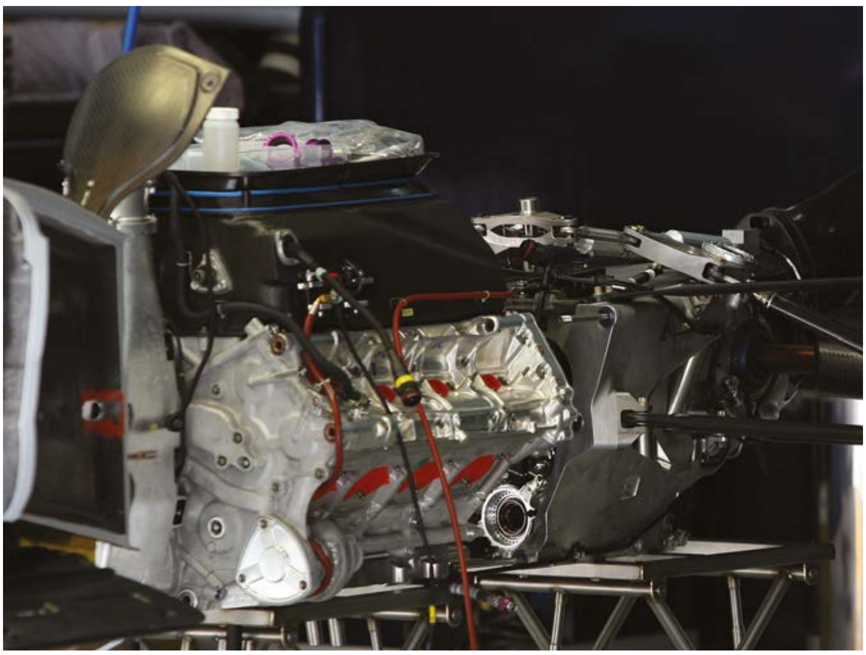
Additionally the speed and completeness of combustion through higher flame speed formulations is a constant target, as these items are having a direct impact on the combustion efficiency of the IC engine.

## Knock need

Clearly, based on the above, Formula 1 fuel formulations for the NA V8 and V10 would not perform in the V6 turbo engine, because with a lower RON value, this fuel would not have been able to cope with the highly knock sensitive engine conditions of the new V6, and as a result the spark ignition would have needed to be set as an absolutely non ideal value for combustion efficiency. The fuel was neither optimised for its energy content and its value was clearly not optimal to get the maximum energy out of the 100kg/ h fuel flow rate.

With the introduction of the 2014 power unit, the engine oil had to face a number of extra challenges. Not least of these was the high temperature and high stress placed upon the oil by the turbocharger. Under these considerations the oil was reformulated to avoid excessive oxidation, evaporation and deposit formation.

The demand for a further increase in engine lifetime to five races in 2015 also skewed the balance to a more protective oil than in the



Ferrari 056 V8 in a Red Bull RB2 in 2006. The thermal efficiency of the V8 engines was able to reach 30 per cent by the end of their development due to their high compression ratio, without the knocking phenomena

Performance of the current V6 PU comes from the ability to increase the power through optimised combustion efficiency


LEON
HISCOX
JOTA
serco
EPSRC

**Figure 1: Evolution of typical combustion chamber parameters**


**Figure 2: Evolution of engine and mean piston speed at maximum power**

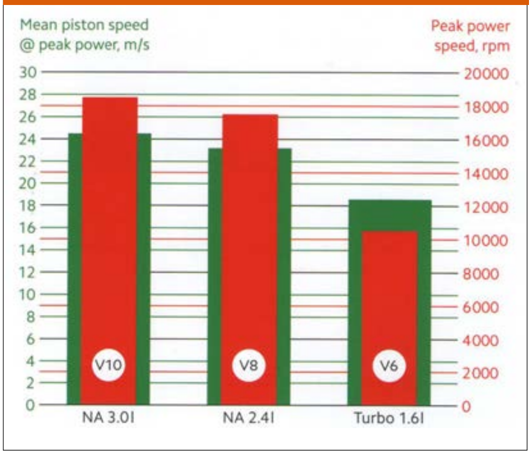



**Figure 3: Evolution of relative AFR and volumetric efficiency**

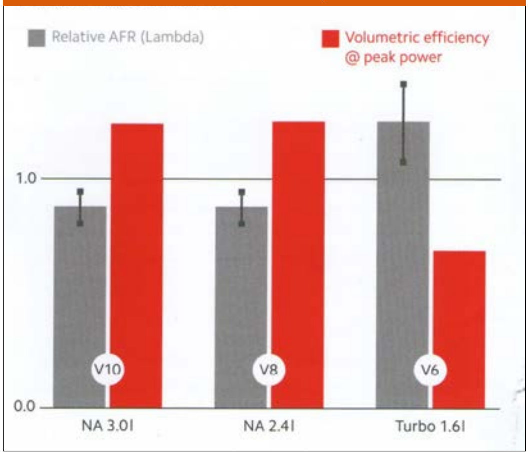
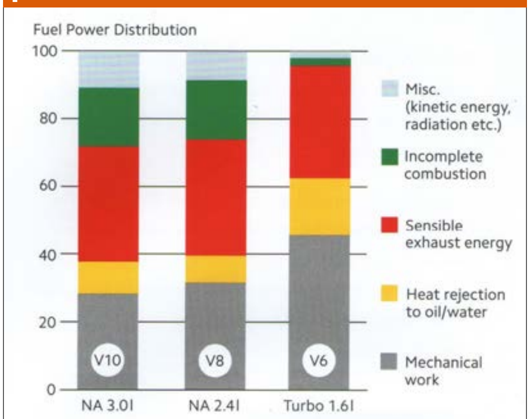



**Figure 4: Evolution of fuel power distribution**




past, without compromising the outright friction reduction and performance.

## Comparing engines.

The passage from V10 to V8 had only minor differences in engine design terms, and the biggest differences were as a result of rule changes more than anything else. In **Figure 1** and **Figure 2** the evolution of some of these parameters are reported. The increase of the stroke to bore ratio from 0.41 to 0.66, and the increase of exhaust to intake valve diameter from around 0.8 to 1.0, highlights the focus switch from airflow to combustion.

The compression ratio rise of around three from V8 to V6 proves the importance of thermal efficiency in more recent years. The compression ratio of the V8 engine was compromised compared to the V10 due to the need of even higher volumetric efficiency.

The mean piston speed has dropped for the V6 as **Figure 2** suggests but to a lesser extent than the drop of speed due to the stroke increase. The V6 engine still reaches occasionally mean piston speeds similar to V8 or V10 since it is revving at speeds higher than peak engine power as opposed to its predecessors, for the benefit of the entire PU performance.

## Efficiency gains

The evolution of typical performance indices captures more specifically the switch of the design focus from the V10/V8 era to more recent years with the V6 PU. **Figure 3** depicts very accurately that volumetric efficiency is compromised in view of the indicated efficiency and from figures in excess of one, it does not even need to reach values close to it. The relative air-fuel ratio trend demonstrates the importance of combustion efficiency and knock resistance as opposed to flame speed and extreme air utilisation over the years.

The normalised fuel power distribution among the different engine concepts, as shown in **Figure 4**, attempts to quantify the efficiency gains with the V6 PU. The thermal efficiency has seen a significant step from around 30 to more than 45 per cent by utilising almost perfectly the chemical energy of the fuel. The heat rejection, even though similar in absolute terms, it is higher in relative terms to the fuel energy for the V6 due to the extra needs of the inlet air intercooler. The sensible exhaust energy share remained roughly the same, while the kinetic energy in the exhaust of the V8 and V10 was significantly higher in the absence of a turbine.

## Conclusion

During the first period, the maximum performance was not necessarily linked to maximum efficiency. The focus was given on engine's breathing capability and all critical engine parameters were designed along these lines: minimum possible stroke/bore, maximum possible mean piston speeds, low exhaust/intake valve diameter, elevated overlap and highest possible volumetric efficiency.

Even if the combustion efficiency was not much greater that 80 per cent and the frictional losses at such high speeds were significant for V8 engines, the thermal efficiency of these engines was able to reach 30 per cent primarily due to their high compression ratio without knocking phenomena, and excess turbulence generated by such high speeds and sophisticated oils and materials/coatings.

The 2014 PU focused on efficiency since the fuel flow rate has been regulated and as a result maximum performance was completely linked to efficiency. The combustion chamber design became more compact, the intake port design focused on combustion and less on airflow, further increase of compression ratio was necessary, while fuel-air mixtures were selected to favour efficiency and knock resistance rather than total air utilisation and flame speed. The contribution of fuel properties, especially the heating value and anti-knock tendency, became fundamental. The PU of this period exhibits thermal efficiencies over 45 per cent, with almost perfect combustion efficiency.

One of the interesting consequences of the new F1 PU is the increased relevance and interaction with road car development, where the key driver is also efficiency, though primarily to control fuel consumption and emissions. Even if the fuel consumption reduction is researched in different operating regions – high load and engine speed in Formula 1 to increase the power, low rpm and low load for passenger cars to reduce the emissions – the design of the intake ducts and combustion chamber and all innovations to reduce the tendency to knock are areas of common interest for the two different applications.

### Thanks to ...

**This feature is an edited version of a presentation written by Lorenzo Sassi and Ioannis Kitsopanidis of Scuderia Ferrari; as well as Guy Lovett from Shell. The original paper was titled *Evolutions in Formula 1 Engine Technology: Pursuing Performance from Today's Power Unit through Efficiency*, and it was presented at the 2016 Vienna Engine Symposium**

# Time machines

## *Racecar's* numbers man explains how simulation has brought the science of aerodynamics to the no-holds-barred world of Australian Time Attack

**By DANNY NOWLAN**

One of the untold stories of ChassisSim is how it has been used as a racecar design tool. In particular, over the last seven years I have been working very closely with an aerodynamicist, Andrew Brilliant of AMB Aero, as he has been applying his skills to the World Time Attack category. It's been a fascinating story because this remains one of the last bastions of technical freedom in our sport. This, plus the lessons we have learnt using both CFD and vehicle dynamic simulation together, makes this a very worthwhile discussion.

World Time Attack Challenge revolves around taking a standard road car and modifying it beyond recognition to make it as fast as possible around a circuit.

The event is held at Eastern Creek raceway Australia in October, annually. In a motorsport era dominated by oppressive regulation World Time Attack has gone in completely the other direction. Yes, the cars look like the love child of the Batmobile and a drag queen fully dressed up for Mardi Gras. However, you can do anything you want to the car and it is for this very reason it is worthy of discussion.

Where ChassisSim was first used in this category was with the modified Evo 9 Nemo that won the 2012 event. Nemo was the first time that CFD and lap time simulation was used in concert to define what you were looking for as an L/D target. One thing that needs to be understood about the Time Attack category is its origins was with a bunch of street drag racers who decided to go circuit racing. Consequently the focus was on hitting max speeds. Grip was not even thought about. The simulation shown in **Figure 1** changed all that.


**World Time Attack is one of motorsport's last bastions of technical freedom and as a result is home to some radical machines**


**Nemo was the first car on which the science of ChassisSim was brought to bear. Before this it had been all about top speed**

The coloured trace was no downforce. The black was with CLA and CDAs north of seven and 1.5 respectively. In terms of lap time the high downforce package is significantly faster. For those of us who have done this professionally we take this for granted, but this was very much a light bulb moment for the category. Particularly when the speed differential was 248km/h for the downforce configuration, against 274 km/h for the no downforce configuration.

## Binding Nemo

However, the real benefit of using both CFD and lap time simulation together was quantifying what was going on with tyre loads. When you are talking CLAs that are north of seven, if you want a hope of appropriately designing a car (that is not falling apart) ignorance of the tyre and suspension loads is not an option. One of the great things about the work we were able to do with both ChassisSim and CFD is that we could quantify this. The results of this are illustrated in **Figure 2**.

As can be seen, in Turn 1 the front tyre loads are in excess of 1000kgf and the suspension loads are in the order of 600kgf. Due to customer confidentiality I have deliberately blanked out this information. However, the take away from this is that it allows you to appropriately size your structural members.

The other consequence of using simulation and CFD together is that you can now be very deliberate about specifying bump rubbers. If you have come from a street racing background and you see big downforce your automatic instinct is to crank on more spring. But an astute race engineer will know that this is what the bump rubber is for. As a case in point my US dealer John Hayes uses ChassisSim extensively for just this purpose when he engineers the

# The real benefit was in quantifying what was going on with tyre loads

PR1 Motorsport LMPC entry. This was also used extensively for the Eclipse car when we had to determine bump rubber gaps, see **Figure 3**.

As can be seen, you can clearly predict how to set your bump rubber gaps and how to refine them. It may be a little thing but knowing what attitudes and gaps to run can make your life infinitely easier. Particularly when you are dealing with high levels of downforce.

The other ramification of using CFD and simulation together is nailing down the attitudes and downforce levels you want to achieve. This became particularly apparent with the Scorch entry in 2014. Given that this car was rear-wheel-drive and going toe to toe with the likes of the 1000bhp Tilton all-wheel-drive Evo, AMB Aero had to be very deliberate about what to target to get the best result. The reward was coming within 0.004s of the Tilton lap time. This is even more impressive given that the driver, Tomohiko Suzuki, is an amateur.

## Wacky racers

However, in a category that has no technical regulations a key question to be asked is is it actually worth increasing the downforce *ad infinitum*? The answer is no, because the limiting factor with these cars is the tyres. In particular in the pro class they barely stand up for a full flying lap. So how do we quantify this? This is where the ChassisSim tyre force modelling toolbox is worth its weight in gold.

The model presented in **Figure 4** was reverse engineered from race data. At the request of AMB Aero I have deliberately blanked out the tyre loads. However, you can clearly see you get to a certain load and the tyre becomes saturated. This can be used to further refine the required aero targets. Yet the most interesting aspect of all this is using the ChassisSim simulated data to define the regions you want to solve for using CFD. As anyone who has worked with CFD will know, it is very computationally intensive. Consequently you need to be very deliberate about where to put your numerical resources.

ChassisSim will return a plethora of channels about the car's performance and AMB Aero was very deliberate about making the best use of them. In particular, it returns damper positions and wheel movements. What this means is that for any given point of the simulation ChassisSim will return not just the ride height of the vehicle but its roll angle as well. It is well worth spelling this out because you can use this as a maths channel.

For any given returned damper displacement and wheel movement the movement of this bit of the car is shown in **Equation 1**. For any given corner of the car the ride height of that particular point in the car is given by **Equation 2.** So here is the key takeaway. Andrew Brilliant from AMB Aero was using this data to nail down where to do his CFD solving. While totally simple, this is nothing short of genius, and I just about fell off my chair when Andrew explained the method. Also, to roll this out is not as onerous as you may think. Here is a suggestion for the solution procedure:

- **Use ChassisSim and the tyre model to establish a CLA and CDA target.**
- **To keep it nice and simple use a unity or a very simple aeromap.**
- **Once this has been established then run the simulation.**
- **Using Equations 1 and 2 establish the ride**

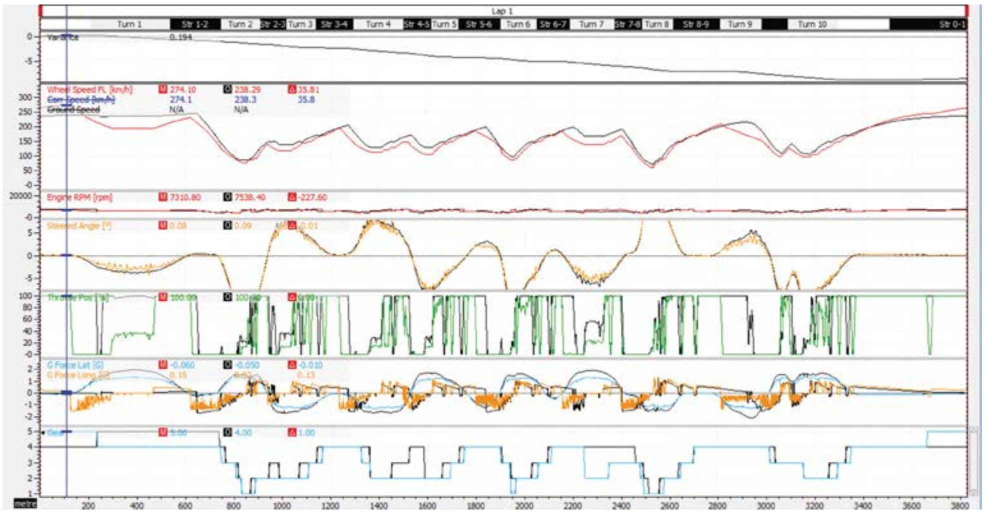


**Figure 1: The Nemo L/D simulation for Eastern Creek. The 'light bulb moment' that showed that high downforce was faster**

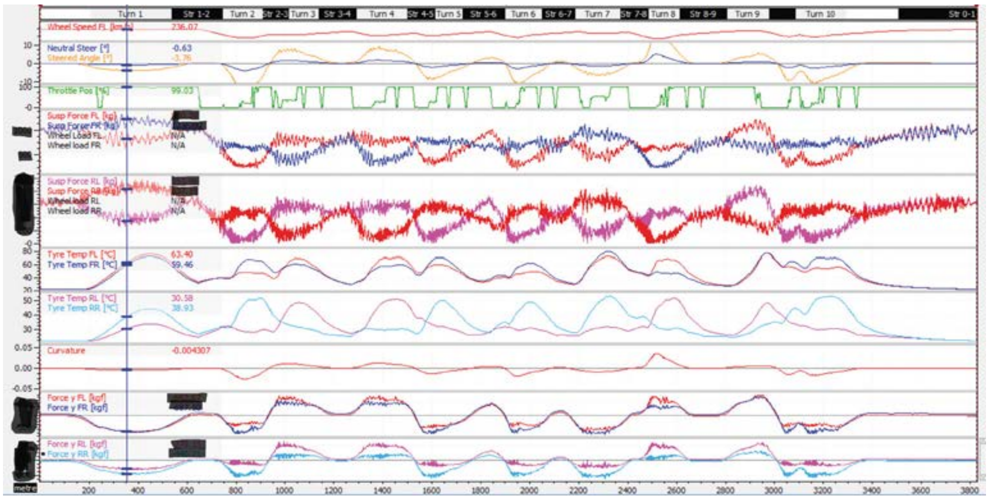


**Figure 2: Nemo tyre loads. Turn 1 front tyre loads are in excess of 1000kgf and suspension loads are in the order of 600kgf**

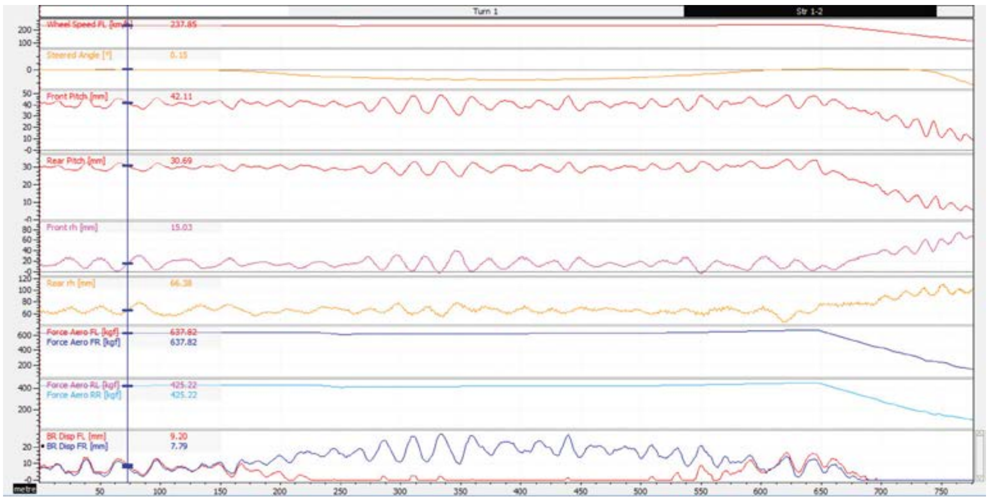
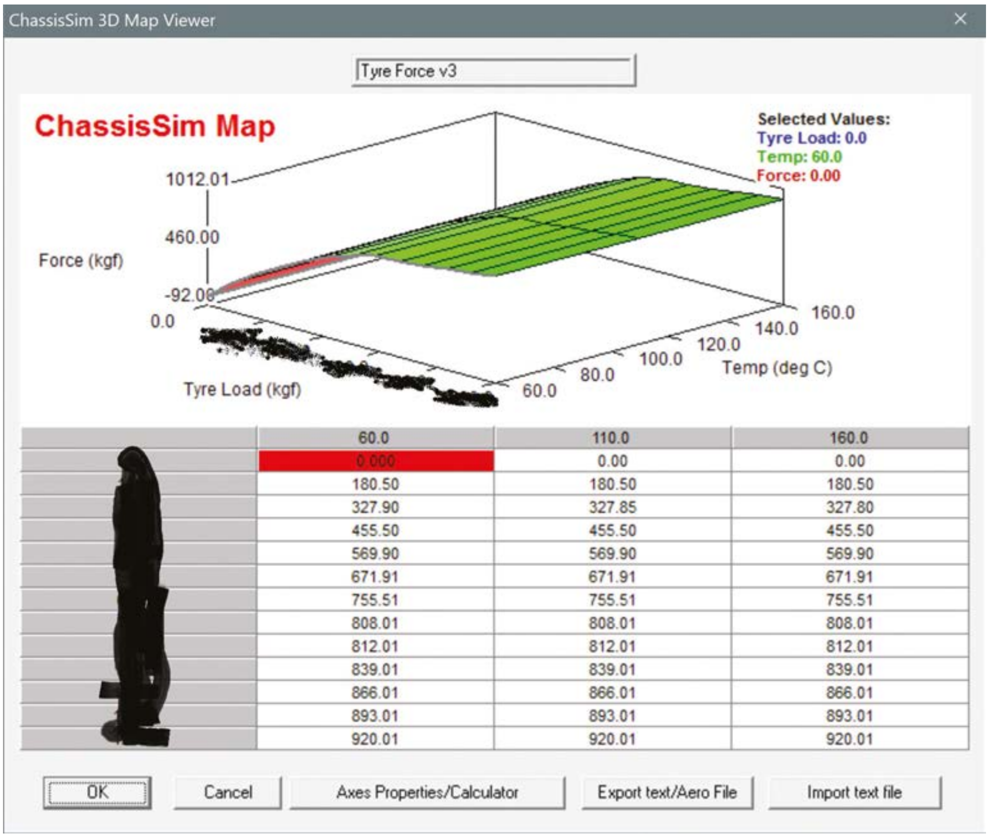


**Figure 3: With ChassisSim you can predict how to set bump rubber gaps and how to refine them. This is for the Eclipse car**

Downforce levels on the rear-wheel-drive Scorch were arrived at through a combination of CFD and simulation techniques




| | 60.0 | 110.0 | 160.0 |
|---|---|---|---|
| | 0.000 | 0.00 | 0.00 |
| | 180.50 | 180.50 | 180.50 |
| | 327.90 | 327.85 | 327.80 |
| | 455.50 | 455.50 | 455.50 |
| | 569.90 | 569.90 | 569.90 |
| | 671.91 | 671.91 | 671.91 |
| | 755.51 | 755.51 | 755.51 |
| | 808.01 | 808.01 | 808.01 |
| | 812.01 | 812.01 | 812.01 |
| | 839.01 | 839.01 | 839.01 |
| | 866.01 | 866.01 | 866.01 |
| | 893.01 | 893.01 | 893.01 |
| | 920.01 | 920.01 | 920.01 |

Figure 4: A World Time Attack two-dimensional tyre model generated from the ChassisSim tyre force modelling toolbox.

## EQUATIONS

### EQUATION 1

$$d_i = \frac{x_{s_i}}{MR} + w_{m_i}$$

Where:

$d_i$ = Combined axle movment

$x_{si}$ = Damper movement zeroed at the ground.

$w_{mi}$ = Wheel movement zeroed at the ground.

### EQUATION 2

$$rh_i = rh_{i0} - d_i$$

Where:

$rh_i$ = Current ride height for this particular corner at the axle.

$rh_{i0}$ = Static ride height for this particular corner at the axle.

$d_i$ = Combined damper and wheel movement.

**heights and roll angles of interest.**

- **Use the CFD Solver to define what aero you need to be looking at.**

While simple this is also very effective. It also illustrates just what you get from the vehicle modelling process and how you can use it to devastating effect.

In closing, World Time Attack Challenge provides a great case study in how CFD and vehicle dynamics simulation can work together to produce race winning results. Both the Nemo and Scorch entries show what can happen when you get very deliberate about using lap time simulation to specify what targets to aim for when doing CFD.

Determining your spring and bump rubber packages becomes very straightforward and you can use simulated data to see how far you need to go with downforce. However, what is even more significant is that you can use very simple simulated data to be specific about what ride heights and roll angles to put in your CFD solver. What is more, both of these tools are very cost effective. Consequently you would be crazy not to use these tools if you ever have to design and run a car in the Time Attack category. But for the final word on this, let's hear from Andrew Brilliant himself.

## Brilliant's mind

'We had a few core uses of ChassisSim that I believe either helped us keep ahead in the field, or avoid pitfalls. As Danny mentioned, we were simulating to know we were on the right side of the drag compromise. Alongside of that, though, we also do risk analysis for various power levels. Our customers have various settings that they can choose from, so the data has proved valuable to them. They can tune the aero package alongside the engine, knowing what to expect,' Brilliant says.

'After we modelled the tyres we started looking at what was going on in specific corners. Whenever we saw something come out of CFD or the wind tunnel that looked good on paper we carefully analysed how that played out on track. We kept growing downforce, but we knew that we would load-saturate in more and more corners as a result. We optimise for a cornering attitude, so we depend greatly on knowing which corners the downforce would help, and by how much.

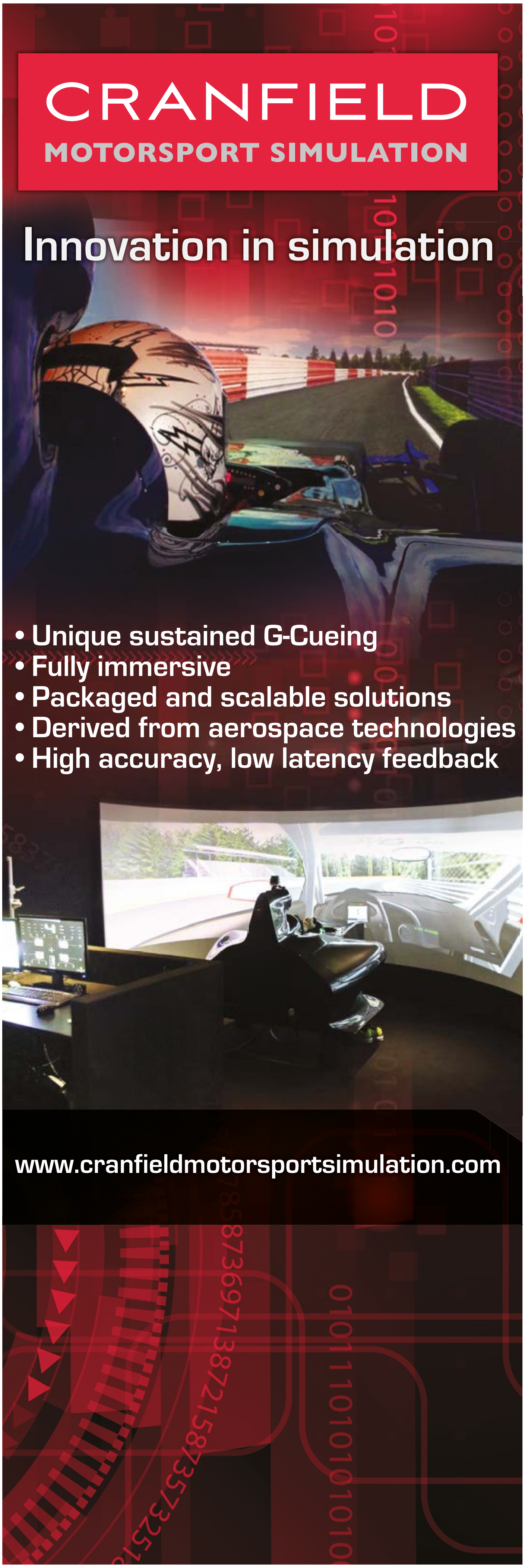
'That data let us get more grip out of any given peak straightline downforce value by focusing our efforts on specific attitudes. We could also make cars that were easier to drive as a side effect. We tried to move further away from dictating the aero to be in a tight window of attitudes and more towards trying to make the aero operate better everywhere.

'We also created a mathematical system to quantify the vehicle dynamics compromises. If you simply add downforce you might have to make a car so stiff to handle the loads you don't actually get any quicker in the real world. We used our way to model bottoming and then derived what sort of ride rates you might need.

'Nemo had kicked off an aerodynamic war and some tried to stay on top by growing the aero size,' Brilliant adds. 'We were able to accurately predict the point where compromises go too far. We limited the size of the aero and then concentrated on making it more effective in a smaller package.

'One team went over the edge, their corner speeds had gone down even though they reported an increase in wind tunnel downforce. We were able to predict and avoid that by using simulation. In our latest technology we are actually shrinking the aero.

'We are working to build tech to let us make it more compact without sacrificing downforce. ChassisSim will play a valuable continued role in this work,' Brilliant says.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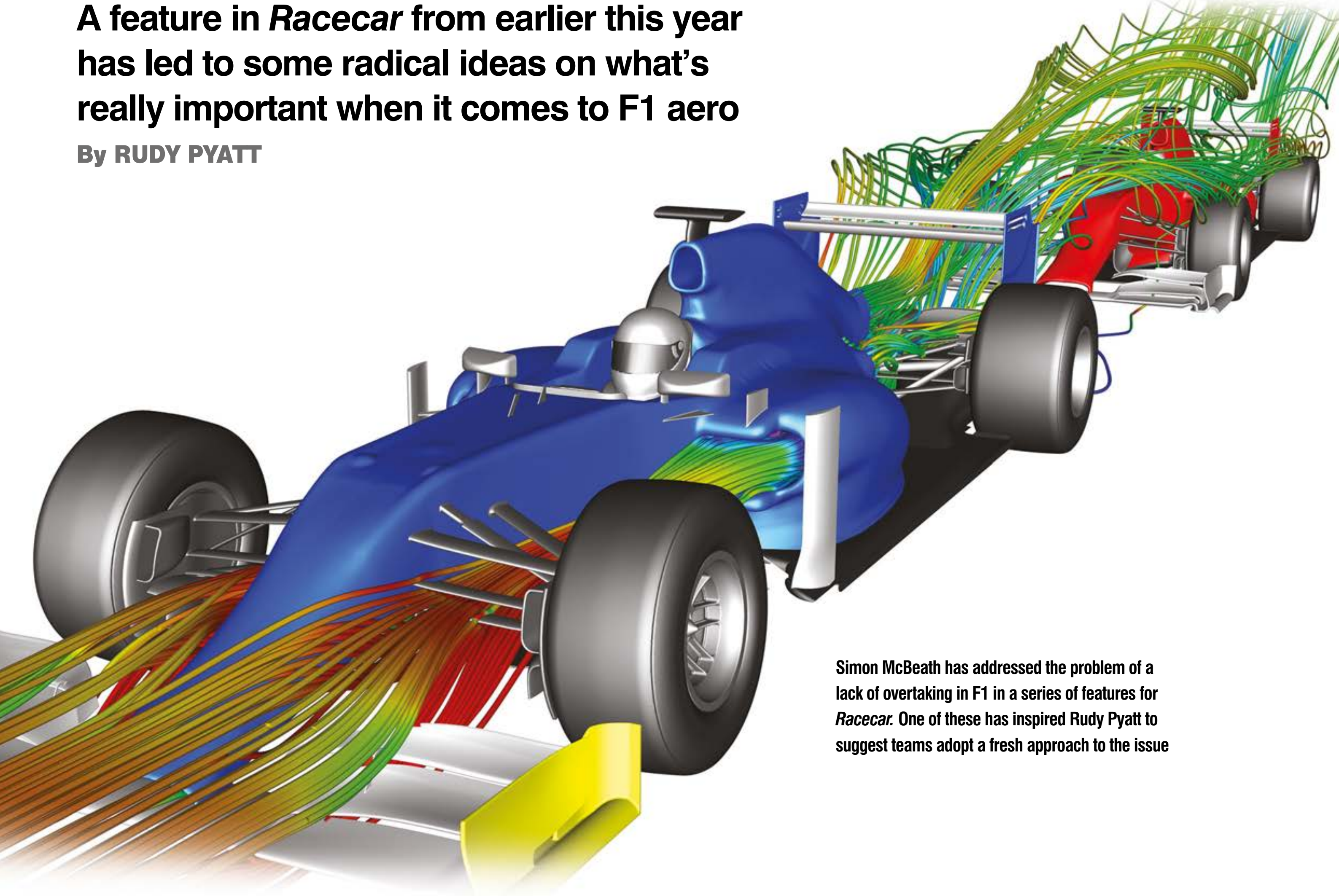
# Clear the air

## A feature in *Racecar* from earlier this year has led to some radical ideas on what's really important when it comes to F1 aero

By RUDY PYATT



Simon McBeath has addressed the problem of a lack of overtaking in F1 in a series of features for *Racecar.* One of these has inspired Rudy Pyatt to suggest teams adopt a fresh approach to the issue

Simon McBeath's piece in the February issue of *Racecar Engineering* (*Follow Closely*, V26N2), which was produced in collaboration with Miqdad Ali and Dynamic Flow Solutions, refers to the Purnell-Wright paper of 2007 and reproduces a graphic included in that paper (see p82). At minimum, McBeath and Ali have raised questions worthy of additional computer simulation and experiment, an idea for which I present here.

All told, McBeath's article and the Purnell-Wright graphic present enormous opportunities for a team of sufficient boldness and ingenuity to exploit. Simulation will be necessary simply because real world empirical data will be difficult to obtain, at least via F1 teams. The inertia of received wisdom, standard practice, and frankly, ego, prevents the F1 establishment from assuming that aerodynamic downforce creates the fastest car. But the way remains open for lesser categories that permit teams to build their own chassis, such as Formula 3, to put ideas to the test which, if successfully implemented, can reset the concept of what is the most effective open-wheeled racecar.

### Time for change?

This has happened before of course: then-lesser teams Cooper and Lotus so effectively demonstrated that the long discredited rear engined layout, allied to light weight and effective, though not overwhelming, engine power had sufficient advantages over the then prevailing practice as to usher in the so-called 'rear engine revolution' (see page 85). I believe that we are at a tipping point in F1, much as in the 1950s, when current practice will give way to a demonstration of the effectiveness of a simpler approach. The demonstration this time will be success through aerodynamic efficiency.

Ask most teams and engineers what they mean by aero efficiency and you'll probably hear something along the lines of 'the greatest amount of downforce for the least amount of drag'. As proven time and again in the last 20

**A car with high RaE is one that is the least sensitive to wake turbulence and other effects and it can follow the racecar ahead of it more closely**

# Are there Formula 1 tracks with characteristics such that the RaE versus the LaE balance point can be reached over the course of a lap?

years, whoever gets this combination right, at least if they have an appropriately powerful engine, will have a car that produces the fastest lap possible in qualifying. Pole position, or at least a spot on the first two rows, usually comes with that performance. For the reasons outlined by McBeath, cars outside the first two rows often find that lack of qualifying pace to be an insurmountable obstacle. They cannot closely follow, let alone overtake, the cars ahead of them because of aerodynamic effects. For these reasons, I believe that the correct measure of aerodynamic efficiency is what I call 'racing efficiency' or RaE. So measured, efficient aerodynamics are those least affected by other cars. In other words, a car with high RaE is one that is the least sensitive to wake turbulence and other effects and can follow the car ahead of it more closely – closely enough that the driver can overtake without the racecar's handling deteriorating in bad air.

## Downforce issues

This is why the Purnell-Wright graphic is so significant. It shows the aerodynamic continuum from 'racing efficiency' to what I'll call 'lap time efficiency,' or LaE. Quite plainly, cars optimised for LaE (high downforce) cannot follow each other closely and passing is difficult to impossible. More interesting still, the Purnell-Wright graphic shows the point at which LaE and RaE balance out such that a car with high RaE (low downforce) will have an advantage down the straights over a high LaE car, with the reverse being true around corners. And therein lies the rub, leading to the following questions with respect to F1 especially: In what kind of corners does a high LaE car excel? Are corners with such favourable characteristics uniformly present at all F1 tracks? Are there F1 tracks with characteristics such that the RaE *v* LaE balance point can be reached over the course of a lap?

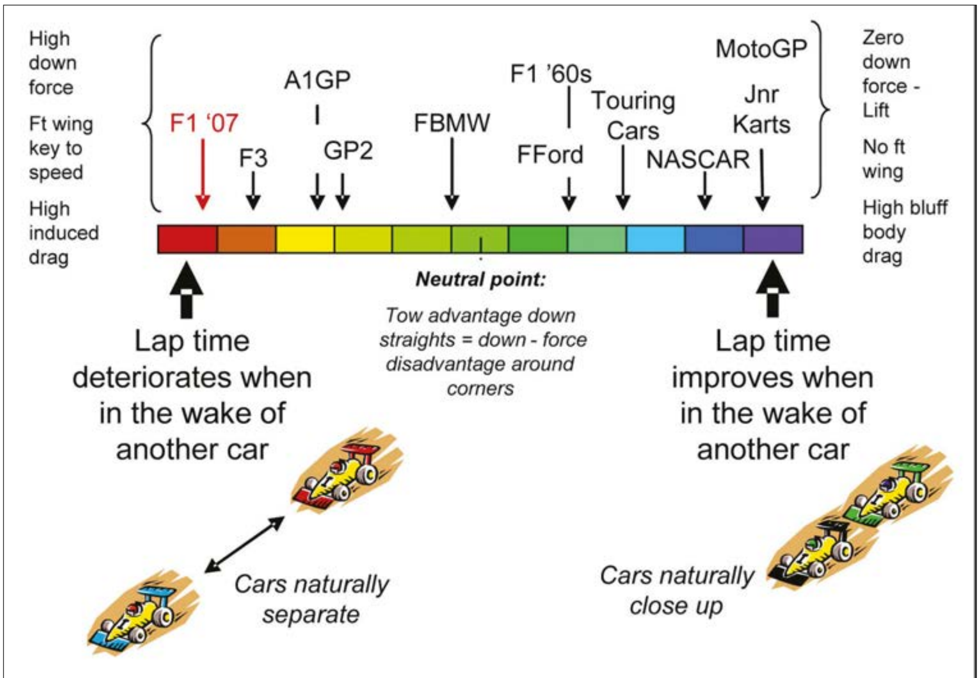
Intuitively, it seems that high LaE works to best advantage on tracks with lots of high speed corners. Those conditions allow downforce to maximise and maintain speed through corners that would otherwise require deceleration (via lifting or braking) to safely and effectively negotiate. Conversely, RaE seems best suited to long straights and slower corners – conditions that allow an advantage gained on the straights to be sufficiently large to fend off opponents despite having to corner slowly.

Let me attempt some maths here (I'm a lawyer and former journalist, and members of both professions are stereotypically bad at mathematics. I am not the exception to prove the rule, but bear with me) to the extent of defining some fairly obvious terms and equations for present purposes to illustrate. Let (fc) = fast corner and (sc) = slow corner. Let Ad (like I said, I'm being obvious here) = Advantage, Tr for track. The foregoing intuitive conclusions would be expressed as:

Ad[LaE] @Tr if (fc)>(sc) and Ad[RaE] if (sc)>(fc).

But, from the Purnell-Wright Continuum, this implies that where:

Tr(sc) = Tr(fc), then Ad[LaE] = 0 and Ad[RaE] = 0.




**This graphic was included in a paper from 2007 by Peter Wright and Tony Purnell. It suggested that a lack of overtaking in F1 was due to high downforce, a dependence on the front wing, and the drag produced by downforce-generating devices**

In other words, where (fc) and (sc) are approximately equal, Tr will be 'Balanced' (BTr) and LaE has no advantage over RaE. You can take this as a 'track corollary' to the Purnell-Wright Continuum.

So, in theory, we have a continuum of tracks and a continuum of cars running – Ad[LaE] – BTr – Ad[RaE] – and the question becomes: just how close do the values of (sc) and (fc) have to get before reaching BTr on a given track? And are there any existing race tracks on the calendar that allow both RaE and LaE to thrive without one dominating the other?

But let's go back to the cars, because here's where the simulation comes in. Let's take a CFD model of an ordinary non-wing, non-diffuser Formula Ford, and give it the same 900bhp as the average F1 car as the stand-in for RaE.

Now let's take the McBeath *Racecar Engineering* 2013 Formula 1 model as LaE and assume the same horsepower. To eliminate the influence of tyres, assume they both have current F1-spec hard compound tyres.

## Simulated duel

Now, pick some set of tracks from the current Formula 1 calendar – let's say Silverstone, Monaco, Dubai and Sepang – and run some simulations. Start with simulating a qualifying lap. What lap times do the cars produce when alone on each track? What about together, in a simulated duel for the lead? What about expanding the simulation to include a complete grid using a mix of our two CFD models: does starting grid position correlate closely with finishing position for RaE?

Based on every description, the 2017 F1 rules have aimed to increase LaE: the explicit goal was to reduce absolute lap times. This should make for an excellent time trial car; but it seems that making a good racing car – a car that maximizes RaE – is at best a hoped-for by-product of the new rules.

On at least some tracks, my fear is that close racing, with genuine (non-DRS) overtaking, will in fact be rare. My hope is that an analysis of the kind I have outlined here will show that a race team can succeed with a radical approach that doesn't sacrifice all other considerations on the altar of absolute lap time.

Of course, these considerations are not confined to Formula 1. It may take successful teams in other categories to show the way forward. After all, Formula 3 doesn't have to be what amounts to a Dallara spec-series. Perhaps analysis as outlined here will prompt a team to take up Formula 3's standing invitation to design and build its own car? If that happens, and succeeds? *Vive La Revolucion*!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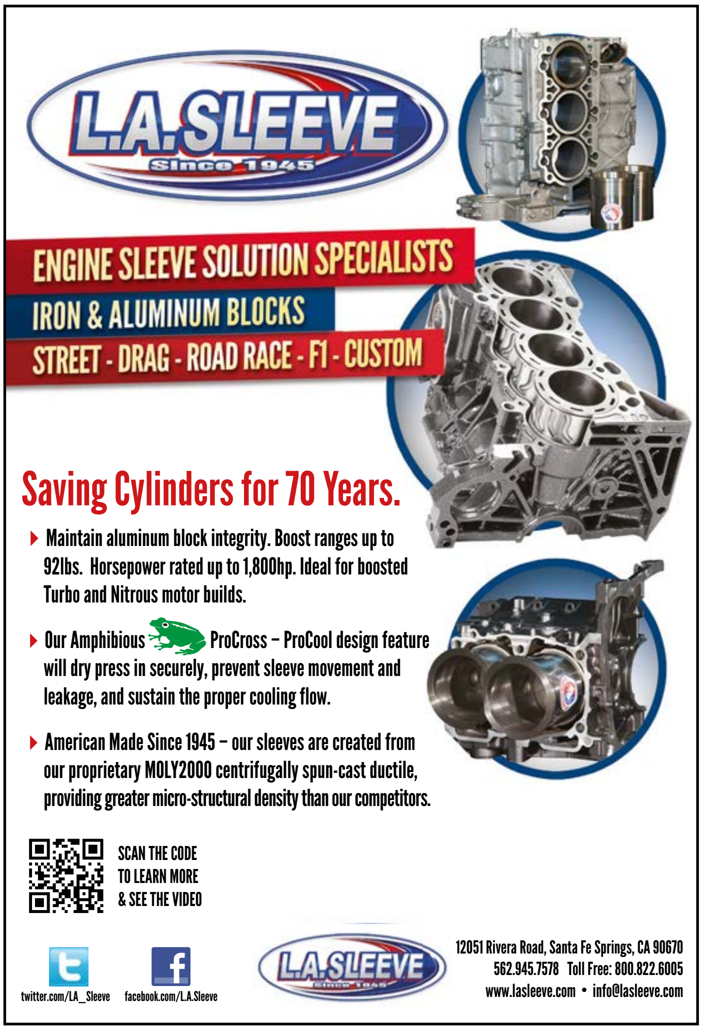
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# Back to front

**Was motor racing a little too quick in dumping front-engined racecars, and is it now time to look again at putting the horse before the cart?**

**By RUDY PYATT**

For 45 years now, conventional wisdom has had it that the best racecar designs have the engine behind the driver. Specifically, F1 and IndyCars *must* be rear-engined. The reasons given for this, repeated over the years, are familiar to anyone with an interest in motorsport: rear-engined cars are smaller, lighter, handle better, with better weight distribution and driver position.

When examined closely, however, none of these contentions holds up. All of them are now merely received wisdom. To the degree they were once true, modern regulations, materials and construction techniques have erased the supposed advantages of this *definitive* layout.

When Cooper first arrived on the F1 scene of the late 1950s, its cars were indeed smaller and lighter than the other cars on the grid, and so they should have been. They were actually F2 cars, inherently smaller and lighter to begin with, and easily so given the materials and construction techniques then common. Simply put, they used less stuff. Lotus illustrated the point even better than Cooper. Once Colin Chapman went to the rear-engined Lotus 18, superseding the front-engined 16, the difference was obvious: the 16 weighed in at 1080lbs, the 18 at 100lbs less. But the 18 had another advantage over the front-engined 16: an extra 300cc and roughly 40 more bhp of Coventry-Climax FPF, an advantage also enjoyed by Cooper as it won the last two championships of the 2.5-litre formula.

That they were smaller, lighter and therefore more nimble came naturally from the fact that they were already smaller lighter and more nimble. Dropping a bigger engine into a smaller car would automatically give better performance. And exactly this cemented the rear engine layout when F1 returned to power in 1966 after the 1.5-itre formula (itself derived directly from the 1957 to 1960 F2 regs) expired.

But consider this: modern F1 and IndyCars have wheelbases of the order of 120 inches with lengths to match and indeed greater. To put that into every day terms, the current Dodge


XPB

**Ferrari's Dino 246 was one of the last of the front-engined GP cars – note that the powerplant sits behind the front axle line**

Charger has a 120-inch wheelbase. In terms of yesterday's racers, a Watson Indy roadster had a wheelbase of only 96 inches, a Maserati 250F, about 90 inches. Even the GP racers of the '30s, so often considered huge, were nothing of the sort in modern terms, a Mercedes W125 or W154 having a wheelbase of about 107 inches.

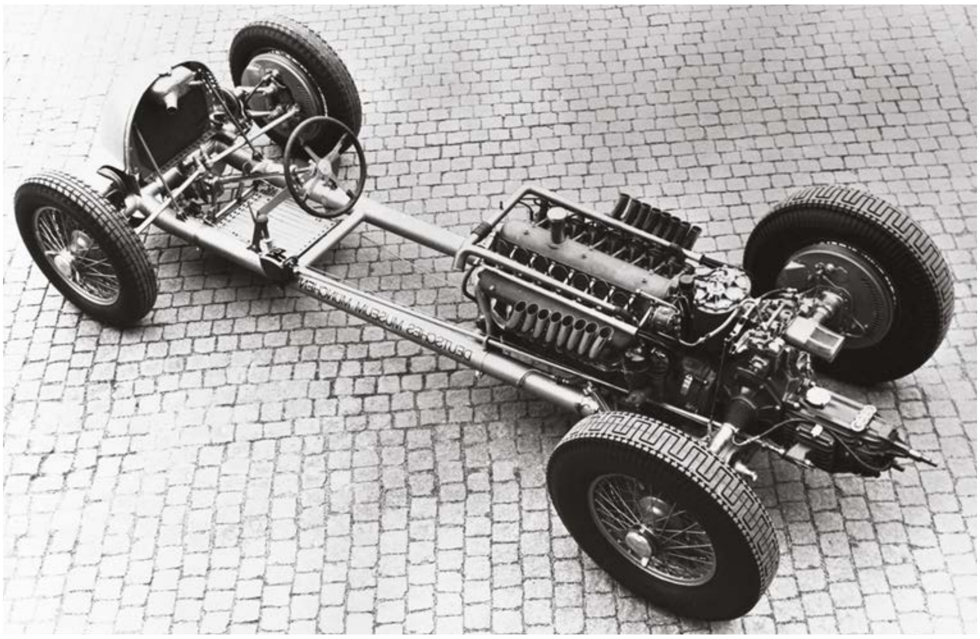
## Rearguard action

Yet modern F1 cars need up to 100kg of ballast to reach their 550kg minimum kerb weight. Their American open-wheel counterparts, heavier primarily because of the need for greater impact protection, still only weigh about 700kg, less than a W125 but roughly the same as an old Watson. And contemporary F1engines produce more than three times the power of their 1.5-litre ancestors but are smaller and lighter despite greater displacement.

Big (light) cars, little (powerful) engines then. If racecars this big can be built this light and if their engines can be so compact and powerful, does it really matter where the engine sits relative to the driver? Take a good look at a a front-engined Indy roadster; any Kurtis-Kraft, Watson or Epperly will do. You'll see the engine mounted almost exactly in the middle of the car, and well behind the front axle line. Likewise, examine the last front-engined GP cars and you'll see the same thing, in a Ferrari Dino 246 for instance. So, despite the implied claims of 'the rear-engine revolution,' front-engined racers of the late 1950s to mid-1960s should be considered 'front-engined' solely in the sense that their drivers sat behind the engine.

Now consider the following observations by FIA Technical Consultant and former Lotus engineer Peter Wright. In the March 2000 issue of *Racecar Engineering*, (V10N3), Wright examined why the Panoz LMP Roadster made sense under then prevailing ALMS/ACO rules. A major impetus for the layout, that less than optimal rear tyre sizes were permitted under the rules and the resulting need to get more weight forward in order to balance front and rear grip, applied not only to sports racers, but to F1 cars

**Does it really matter where the engine sits relative to the driver?**



An undressed 1936 Type C Auto Union. The German marque was the first to have grand prix success with rear-engine layout


Cooper was at the vanguard of the rear-engine revolution in Formula 1 at the end of the 1950s. This is its 1960 car, the T53

as well. Wright explicitly connected the two: 'The only way to put more rubber on the car, and keep it balanced, is to increase front tyre width and make the front axle do more work (in other words, move weight forward). Exactly the same problem has confronted Formula 1 since rear tyres were limited to 15 inches and then grooved. Formula 1 racecars are now running around 45 per cent or more weight on the front axle, exact figures being closely guarded secrets. The last front-engined GP cars achieved about 47 per cent front axle weight. With modern materials and construction methods, therefore, 45 per cent lies just about at the watershed of what can be achieved with the engine mounted either in front of or behind the driver. The reason for putting it behind the driver is only to put more than 55 per cent of the weight on the rear axle. Of course, there is the issue of practicality in a single seater: the difficulty of transmitting the drive from the front engine, past the driver and fuel tank, to the rear axle. But this is not an obstacle in a 'two-seater' sports prototype.'

Another defining characteristic of modern racers, aerodynamic sophistication, does not derive automatically from the rear-engine layout, as Wright also pointed out: 'Aerodynamically, engine position has little effect. There is a small advantage in the front position in that the ram-air to the engine does not have to find its way past the driver. Indeed, achieving full ram-air pressure to a rear engine requires the intake to be well above the driver's head, increasing frontal area and hence drag, and disturbing the airflow to the rear wing. However, the greater front weight distribution achievable with the front engine does lead to a potentially better L/D,' Wright said.

## Frontal assault

Thus the aerodynamic disadvantages of the rear-engined layout appear to be at least as great as the packaging (i.e., driver and drive line position) issues attributed to the front-engined layout. Overcoming either set of problems requires only wrestling the details into submission; getting the best compromise with the resources available, just as for any engineering problem in general, and for any racer in particular. With respect to deciding whether or not to go with a front-engine layout, Wright posed the following: 'The three key questions are: Is there anything about the engine position that is detrimental to the structural stiffness of the chassis? Is there a loss of traction due to less weight being on the rear axle? And does the position of the driver affect his ability to control the car?'

It goes without saying that careful use of modern materials and construction techniques will ensure adequate stiffness regardless of layout. Rear traction likewise poses no insurmountable problem, particularly with modern tyre compounds. Certainly the Panoz LMP 01 showed no disadvantage here. As stated earlier, balancing traction front to rear within the constraints of the permitted tyre sizes was the major advantage of the car's design.

## Popular front

The effect of driver position on control of the car has been addressed in part above. But, as Wright also points out, in terms of driver control, sitting on or just in front of the rear axle provides him with the best chance of sensing what the rear axle of the car is doing. Not only can he sight the racecar along almost its full length, but also, any tendency to oversteer results in a change of lateral acceleration in the logical direction, giving him the best opportunity to control the yaw rate.

Of course, to Wright's list must be added: can a front-engined car meet the relevant safety regulations? Obviously, yes. Panoz did it, and on a budget far short of even the poorest F1 team. Similarly, the new generation USAC Silver Crown racers have been rigorously crash tested and, like their more exotic counterparts, use a safety cell that incorporates the cockpit and fuel tank within the same structure.

So the case for the rear-engined single seater racer is not as clear as received wisdom paints it. Modern materials and construction methods, as well as minimum weight, dimension, and safety regulations, prevent cars with this layout from being arbitrarily smaller and lighter than a front-engine equivalent.

And modern materials and construction methods mean that weight distribution will be in the same range regardless of layout. In any event, owing to other design and performance considerations, modern GP cars are much longer than even their pre-war counterparts. Size and weight therefore may be ruled out as favouring the rear-engine layout. Similarly, there is nothing inherently superior aerodynamically in a rear-engined car. Moreover, positioning the driver behind the engine presents no insurmountable problems in packaging or safety but does provide advantages in driver feedback and therefore control. Therefore driver position may also be ruled out as favouring the rear-engine layout. Maybe it is time to put the horse before the cart once more?

# It also provides advantages in driver feedback and therefore control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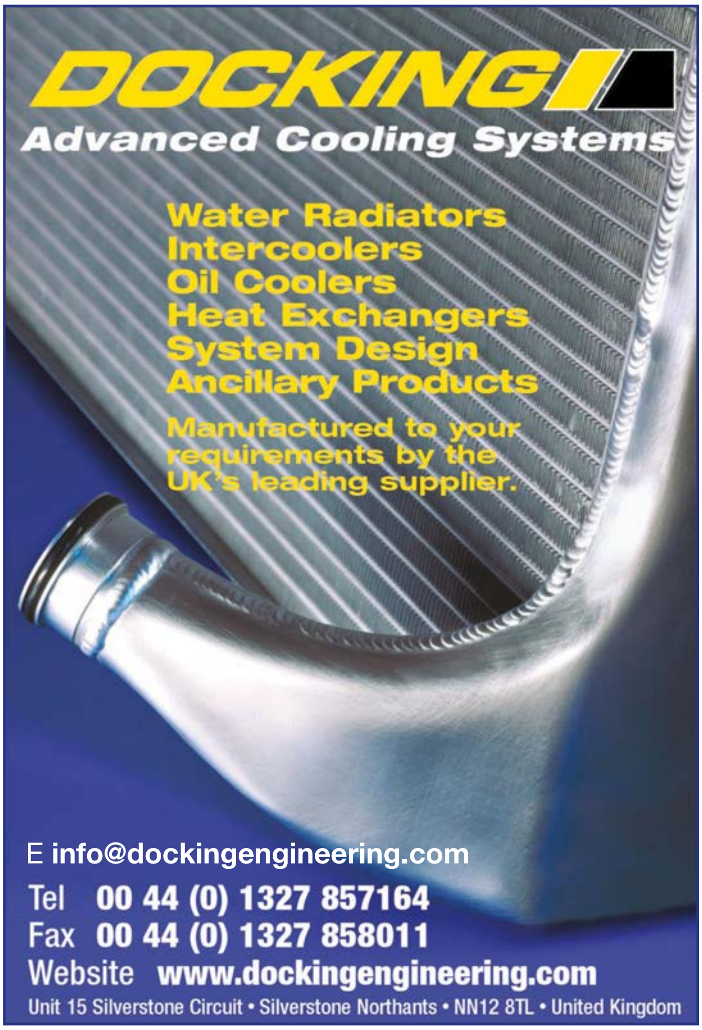
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# US conglomerate Liberty Media takes first steps in purchase of Formula 1

**Liberty Media Corporation has agreed to buy Formula 1 from its group of owning companies, which is headed by majority shareholder CVC Capital Partners.**

Liberty Media (see panel) will acquire 100 per cent of the shares of Delta Topco, the parent company of F1, and it has already purchased an 18.7 per cent minority stake for $746m.

CVC will continue to be the controlling shareholder in Formula 1 until Liberty has completed its takeover of Delta Topco during the first quarter of next year, when it will then become the largest shareholder in F1 with a 35.5 per cent stake. CVC will still retain a 24.7 per cent share after selling off 13.4 per cent.

Liberty said in a statement: 'After completion of the acquisition, Liberty Media will own Formula 1 and it will be attributed to the Liberty Media Group which will be renamed the Formula One Group.

'The consortium of sellers led by CVC will own approximately 65 per cent of the Formula One Group's equity and will have board representation at Formula 1 to support Liberty Media in continuing to develop the full potential of the sport,' the statement added.

Chase Carey, currently the executive vice chairman of 21st Century Fox, has now been appointed chairman of F1 by Delta Topco, taking the place of Peter Brabeck-Letmathe, who stays on the board as a non-executive director. Bernie Ecclestone will stay on as Formula 1's CEO.

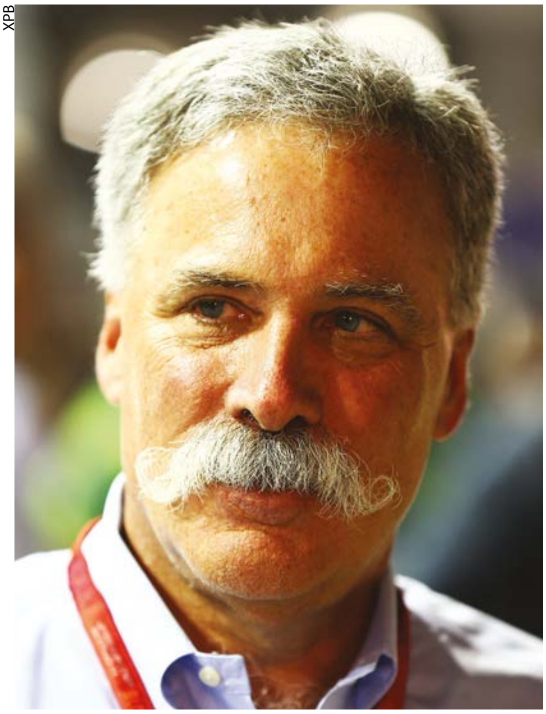
While it is not known exactly how much the deal will cost Liberty, the company has declared the value on the sport and it has also said that it is taking on Formula 1's current debt which is over $4bn.

'The transaction price represents an enterprise value for Formula 1 of $8bn and an equity value of $4.4bn,' Liberty Media said.

Carey said: 'I greatly admire Formula 1 as a unique global sports entertainment franchise attracting hundreds of millions of fans each season from all around the world. I see great opportunity to help Formula 1 continue to develop and prosper for the benefit of the sport, fans, teams and investors alike.'

There are still some hurdles that the deal will need to clear to go through, however, including the European Commission's ongoing anti-competition investigation and possibly similar antitrust tests in the US.

Recent company filings for Luxembourg-based Delta Topco reveal that Formula 1's parent company saw its operating profit rise by $76.3m to $329.9m in 2015.



XPB

**Chase Carey will move from 21st Century Fox to become the chairman of F1 following Liberty Media's announcement**

## Who is F1's new owner?

Liberty Media is a US media giant with a major presence in several sports and entertainment businesses.

The organisation, owned by 75-year-old billionaire John Malone, has stakes in US cable TV firms, plus various entertainment and ticket sales companies.

It also owns satellite and online radio company Sirius XM plus the Atlanta Braves baseball team and event promotion company Live Nation.

The company is one of three media and telecoms businesses owned by Malone – Liberty Interactive and Liberty Global are the other two; he is chairman of all three.

Liberty Interactive's subsidiaries include the home shopping channel QVC while Malone also has a large stake in Barnes and Noble, the biggest bookseller in the US. In the UK, Liberty Global owns Virgin Media and has a 10 per cent stake in the ITV television group.

Malone started his career at AT&T in the 1960s and is now said to be worth around $7bn. It is said that he is not a typical media billionaire in that he shuns the limelight, while he has a reputation for taking a long view of markets.

Malone is also the largest private landowner in the United States, owning 2.1 million acres, much of which is in New Hampshire and Maine.

## Formula 1 team reaction

### Monisha Kaltenborn
Sauber

'From what we've read so far and heard in the statements made I hope that they see that the sport has to be looked at from the inside and that they will take steps to ensure a certain competitive parity. That's for us equally as important as looking towards the outside, how the product is going to be promoted.'

### Christian Horner
Red Bull

'They are obviously part of a very serious group and I can't believe a company like Liberty would buy into Formula 1 at the value that it is rumoured to have been purchased at without having a long-term game plan, and rather than having a venture capitalist or a financial institution buying into the sport I think it's far better that a company like Liberty has bought in and hopefully that will address some of the areas we have been weak in previously.'

### Guenther Steiner
Haas

'What I would like to say is being an American company, I hope, there is big potential in the States, so we being an American team we hope they bring that to fruition, that market, and that we can all have gains on it. We are more than happy to help them to do anything they need to do in the United States.'

# Williams group delivers strong results for first-half 2016

**The company behind the Williams Formula 1 team, Williams Grand Prix Holdings, has published much-improved financial results for the first six months of 2016.**

Williams Grand Prix Holdings says that group revenue has increased to £80m for the period, compared to £63.1m in the same period in 2015, while EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization) improved from a loss of £1.4m in 2015 to a profit of £7.8m in 2016. The group generated operating free cash flow of £13m for the six-month period (this was £7m in the same period 2015).

As far as the Formula 1 business is concerned, it generated revenues of £51.3m (slightly down on £51.4m in the same period in 2015) with an EBITDA of £4.1m (£1.6m last year), while Williams Advanced Engineering (WAE) – the division that sells F1 technology to wider industries – generated revenues of £20.6m (£10.8m in 2015) with an EBITDA profit of £3.5m (£0.1m in 2015).

Williams Group CEO Mike O'Driscoll said the latter was thanks to WAE branching out into new industries, particularly defence and health. He also said that WAE started the year with over 40 ongoing projects, adding that many of these are long-term.

Williams will again receive prize money for finishing third in the 2015 constructors' championship next season, but more long term it could be hit by disappointing results this year – it is currently in fifth. It is also now spending heavily on developing a car for the new 2017 regulations, which could also hit future profits.

O'Driscoll said: 'The evolving Formula 1 regulations dictate a significant change in car design for the 2017 season, which we embrace enthusiastically as an opportunity to make a step forward in our track performance.

'There are headwinds that we must face in the second half of 2016 and into 2017, notably the increased costs that are incurred during a period of regulatory change in the sport, and predicted uncertainty in many world economies, and this will impact our near term results,' O'Driscoll said.

XPB

The Williams group has posted good half year financial results

# Holden and Nissan commit to Australian Supercars

**Both Aussie V8 stalwart Holden and Japanese motor giant Nissan have committed to continuing their campaigns in Australia's premier race series, Supercars.**

Holden, the GM brand in Australia, which was said to be close to leaving the championship just two years ago, has now signed a deal with Triple Eight Race Engineering which will see that outfit race as Red Bull Holden Racing Team (HRT) for the next three years at least. The former official HRT team, Walkinshaw Racing, will no longer be a works Holden operation.

Meanwhile, Nissan will remain with current works outfit, the Kelly family-run Nissan Motorsport team, which will field a squad of four Altimas through 2017 and 2018.

Holden has seen a surge in car sales in Australia in recent months, as has traditional rival Ford, at the expense of Hyundai, though it still lags behind Toyota – the latter sold 18,650 cars in Australia in August of this year, while Holden sold 7667. Nissan sold 5616 in the same period.

Holden chairman and managing director Mark Bernhard said of the new deal: 'Motorsport has played a significant role in Holden's heritage and we're proud to be carrying on that tradition with the new Red Bull Holden Racing Team, while reshaping our brand and presence in the market and in motorsport. We're taking our company forward.'

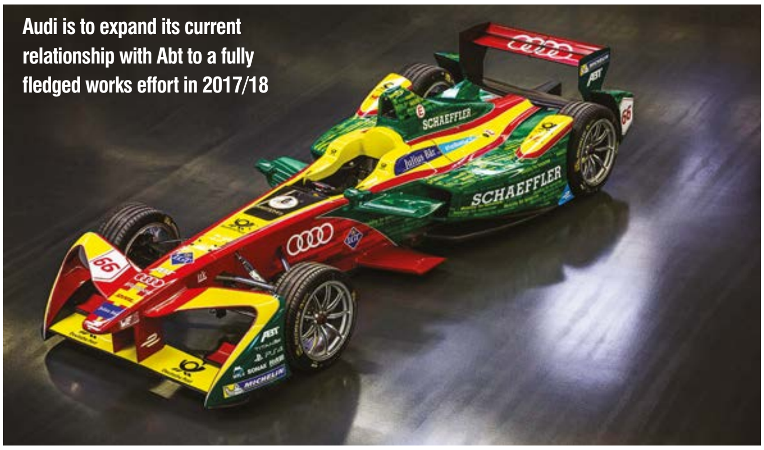
Bernhard also made it clear that Holden would not be completely abandoning Walkinshaw Racing: 'We'll continue to help Walkinshaw wherever we can,' he said.

Nissan Motor Co (Australia) managing director and CEO Richard Emery, said: 'We are very proud of our global approach to motorsport.

'The Supercars Championship is one of the most high-profile sporting events of any kind here in Australia and Nissan has tremendous heritage and also a huge fan base in this series,' Emery added.


Both Holden and Nissan (pictured) have committed to a future in prestigious Aussie tin top series Supercars

# Audi to field works entry from season four of Formula E




Audi is to expand its current relationship with Abt to a fully fledged works effort in 2017/18

**Audi is to compete in Formula E as a full works team from the 2017/2018 season.**

The German manufacturer intends to expand its partnership with the Abt FE outfit – which it has backed since the inception of the electric racing championship – during the next season of FE with both financial and technical backing. Abt will then become a full works Audi team in season four and the manufacturer will also play a role in developing the powertrain alongside existing Abt technical partner Schaeffler.

This marks Audi's first venture into single seater racing, disregarding the part it played in Auto Union in the 1930s. Its other main sporting programmes are currently LMP1 in WEC and the DTM.

The Formula E move is in line with Audi's long term strategy of making a quarter of its models EVs. Dr Stefan Knirsch, an Audi board member who has responsibility for technical development, said: 'Electric mobility is one of the key topics in our industry. We intend to evolve into one of the leading premium car manufacturers in this field. By 2025, every fourth Audi should be an electric vehicle.

'In the light of these plans, adapting our motorsport programme and taking up a commitment in a fully electric racing series is only a logical move,' Knirsch added.

Head of Audi Motorsport Dr Wolfgang Ullrich said: 'Audi has consistently been using motorsport to test and develop new technologies further for subsequent use in production. Now we intend to repeat this in fully electric racing. Formula E with its races being held in the hearts of major cities is an ideal stage for this purpose.'

# Nashville Superspeedway sold to real estate company

Nashville Superspeedway looks set for a future as a logistics and distribution park

**The company that owns the Nashville Superspeedway has said that it's entered in to a 'definitive agreement' to sell the former NASCAR and Indycar track.**

Dover Motorsports, which owns the Nashville facility through one of its subsidiaries, is to sell the superspeedway to Panattoni Development Company, an international commercial real estate firm that specialises in industrial, office and build-to-suit projects.

Under the terms of the agreement Dover Motorsports and its wholly-owned subsidiary, Nashville Speedway USA Inc., will sell the facility, related equipment and assets for $27.5m.

Panattoni now plans to build a logistics and distribution park on the 1400 acre site and intends to start work on two speculative developments on the land some time next year.

The part of the property the race track occupies will initially not be built upon or cleared, with the developer keeping the door open to possibilities that might emerge. But Panattoni had made it clear that it 'isn't in the motorsports business'.

The sale is expected to be completed during the first quarter of 2017. It comes on the back of a failed purchase by global technology company NeXovation for $46m, that was announced back in 2014. This fell through after at least seven deadlines for finalising the deal failed to be met.

The Nashville Superspeedway opened in 2001 and the 1.3-mile oval was designed to be used for both single seater and stock car competition – it hosted IndyCar in 2008 and a number of sub-Sprint Cup NASCAR races. However, spectator attendance proved disappointing and Dover Motorsports called an end to racing at the track in 2011.

Last year former Bristol Motor Speedway owner Gary Baker said that he considered the hybrid layout a liability. 'It's impossible to build a track that's suited for both stock cars and IndyCars. The only way to fix it, in my opinion, it to totally re-configure it. If they did that, and a few other things, it might have a chance to succeed,' Baker said.

# UK testing business snapped up for £122m

**Vehicle testing business the Millbrook Group, which includes the well-known testing facility of the same name, has been acquired by global precision instrument and controls supplier Spectris.**

The FTSE 250 listed concern has bought Millbrook Group for £122m, and it will now join Bruel and Kjaer Sound and Vibration, HBM and ESG Solutions in Spectris' Test and Measurement business segment, a division that is heavily involved in the motorsport business.

Spectris has annual revenues of over £1.2bn and now employs around 8700 people in more than 30 countries, but the acquisition will not result in any job losses at Millbrook, it tells us. The Millbrook Group is a leading independent vehicle and tyre test, validation and engineering service provider, perhaps best known for the proving ground of the same name, which is set in a 700 acre site in Bedfordshire and includes a number of test tracks including a high speed banked bowl. It also has outdoor testing facilities in Finland. Millbrook was previously acquired by Rutland Partners from GM Holdings in 2013.

Eoghan O'Lionaird, Spectris Business Group director, said: 'Millbrook represents our largest purchase to date of a pure testing services business. It is closely related to our existing instrumentation businesses and, as such, the acquisition is an important step forward in the realisation of the group's strategy to provide our customers with differentiated solutions that incorporate a combination of hardware, software and services.

'We believe that there is a significant opportunity for Millbrook to strengthen its market position and accelerate its growth through continuing its recent capital investments and making bolt-on acquisitions to expand internationally and broaden its service portfolio,' O'Lionaird added.

Alex Burns, CEO, Millbrook Group, said: 'There are many advantages to becoming part of this global group, which will underpin our investment plans. Spectris' other portfolio companies will bring us expertise and capabilities so we can offer our customers innovative solutions. We will retain all jobs in Millbrook and we will have the opportunity to accelerate Millbrook's growth through investment and expansion into key international markets. We will remain independent and impartial and benefit from the stability that this change brings to Millbrook.'

Millbrook's high speed bowl – the well-known test venue has been bought by Spectris

## IN BRIEF

### Funding opportunities for SMEs

A £1.25m pot of funding has been secured for businesses in the South East Midlands – which includes the heart of Motorsport Valley – that are seeking to expand, invest and recruit. There are two types of grants available, the Velocity Growth revenue and the Maximum Velocity capital grants. Velocity Growth revenue grants (£1000 to £10,000) will support specialist consultancy, projects, goods and services related to increasing sales, improving productivity and profitability and improving business processes. Maximum Velocity capital grants (£5000 to £50,000) will fund investment in technology or processes that facilitate growth and create jobs. For more, contact the Velocity Growth Hub on 0300 01234 35 or by email at enquiries@VelocityGrowthHub.com.

### Casting further afield

Grainger and Worrall (GW), the UK high-precision casting technologies concern, has completed the purchase of a castings facility in Worcester. The facility, which will be known as GW Coscast, will see GW expand the scope of its low pressure sand casting operations, allying its use of digital technology with its special Coscast process, to create high-performance castings for the motorsport, automotive and structural castings markets, GW tells us. The Worcester operation was previously owned by Mahle Powertrain.

**INTERVIEW** – Yves Matton

# New year's Yves

## The boss of Citroen Racing gives us the lowdown on the French firm's push for 2017 WRC glory and reflects on its hugely successful spell in the WTCC

**By MIKE BRESLIN**

XPB

**'We intend to win some WRC events next year, and will then try to win the titles back in 2018'**

As sabbaticals go, Citroen's has been remarkably successful, the French manufacturer scooping two wins in the World Rally Championship during its year off as it prepares for the new regulations in 2017. Of course, there's a bit more to this than meets the eye, as the cars are run by semi-works team Abu Dhabi Total WRT, and the wins have had – just perhaps – a little bit to do with the controversial running order used this year, which benefits part-time competitors.

Still, it will have done Citroen Racing no harm to get used to the feeling of winning rallies again. But however enjoyable it's been for Citroen to watch its crews spay champagne from the bonnet of victorious DS3 WRC cars this season, the serious business has been all about testing for 2017 – when it's all change in the WRC with a new more powerful engine (thanks to a larger restrictor), and fresh eye-catching body shapes

Citroen Racing's 2017 car will be based on the new Citroen C3 and testing has been going very well, says its general manager, Yves Matton, the Belgian who has been in charge at the organisation since 2012: 'I would say that we are quite happy. We have had no major problems, and we have been able to run all the days testing as planned. We have had no major incident like a crash or something like that, and so we have been able to do a lot of mileage. For sure, we still have a lot to do, but I think we will see in Monte Carlo that it is good.'

It's not all been plain sailing, though, and the new aerodynamic parts allowed under the 2017 regulations have proved to be a little problematic, on a quite fundamental level: 'The main concern we have had is to do with the new body parts, that have to be able to stay on the car in rough road conditions,' Matton says. 'To get these [aerodynamic] parts to stay fixed on the car on gravel, it is something new. We have the same kind of car, but these parts are not the same, and we have had to find some new solutions to make them stay on the car, but also to stay as flexible as they need to be to work properly. We do not have this problem so much in touring cars.'

## Aero experience

Yet Citroen's WTCC experience has actually helped it with the WRC C3's aerodynamics, says Matton: 'When we went to touring cars we had no knowledge of aerodynamics, we learnt a lot. If we did not have the experience with the touring car I think it would have been one of the major areas on the car which we would have had to have worked on a lot more.'

That said, the WTCC experience can go only so far, and rallying throws up its own peculiar problems: 'It's not only [about] downforce, we have some other problems in rallying, and I can give you a good example,' says Matton. 'As you will see on rallies like Finland, the car is leaving the ground [flying over jumps]. This is something that you do not have in touring cars and it is an aspect that we have to work on.'

Talk of Finnish 'yumps' is a reminder of what makes rallying special, yet some have said they are worried that the new cars will not be spectacular. But Matton – who as a driver peddled beasts of yore and yaw such as Ford Sierra Cosworths and Opel Manta 400s, so should know a bit about sideways action – says these concerns are unfounded. 'We will never now have a car that is spectacular on asphalt, because we know that to be fast on asphalt, the only way is not to slide. But on gravel, from what I've seen, the car is really spectacular, and I think it will be much more spectacular than the car we have now. One of the things is that it's possible to maintain the drift for a long time [with the new car]. Sometimes [with the current car] the drivers complained that due to the engine it was not very easy to maintain the slide, but now it will be easier.'

## Mission accomplished

That new engine is very similar to the one Citroen has used to such good effect in the WTCC – which it has won for the past three years now, including 2016 – and Matton concedes the rally engine will benefit from this experience. But now that programme has come to a close, what are his reflections on Citroen's circuit racing adventure? 'We were able to follow the plan and achieve the targets. We went there because we wanted a global approach to the market. It was important to go to China, and we were able to do it, and for the marketing aim and the racing aims, we were successful.'

It's not been quite perfect, though, and Matton says he has been particularly vexed at the enormous success ballast

Citroen has had to work with this season, with an 80-kilo upper limit, while the way the WTCC has changed the rules over the past few years has also been frustrating, he says. 'If I have to complain about something of our three-year experience of touring car, [it] is maybe a lack of stability during that time. But at the end it's very positive and personally [I enjoyed] the experience last year to manage four drivers and three world champions [Yvan Muller, Sebastien Loeb and Jose Maria Lopez].'

While the works team will not be on the grid next year Citroen will still have a presence, with two private teams running its Citroen C-Elysees including Sebastien Loeb Racing. 'It will not really be a semi-official programme, it will be more a technical support programme,' Matton tells us.

## Rallying focus

As far as other racing involvement is concerned Citroen has no plans to expand its customer programme to TCR, but it will be pressing on with its highly successful R5 rally customer activities and Matton says that there is beginning to be a certain specialisation within the sporting divisions of the PSA Group, now made up of Citroen, Peugeot and DS. 'We have decided that we have a plan for the next five years, with each year a new customer product. Citroen will be more focussed on rally products. Peugeot will be more racing.'

With Citroen fully-focussed on WRC next year it would be foolish to bet against it winning a rally or two at least, though it will be up against strong opposition from the current top performer Volkswagen, plus a returning Toyota and regulars Hyundai and Ford (M-Sport). Matton has no doubt which car will start favourite when the WRC kicks off in Monte Carlo in January, though. 'For sure, it's Volkswagen, who is the leader of the championship now for three years. They have started their test programme with the new car a long time ago, and they will be the manufacturer to beat. But people will expect from us a high level of performance due to the fact we are the manufacturer who has won the most championships [with nine drivers' titles]. The target for us is to be at least second in the manufacturers' championship [in 2017]. We intend to fight to win some events next year on a regular basis, and try to win the titles back in 2018.' If its 'sabbatical' year is anything to go by, it has every chance of doing just that.


**The Citroen C3 WRC test programme has been a success but it has had some issues with aero parts coming adrift on rough surfaces**

## RACE MOVES

XPB

Former IndyCar president of competition and operations **Derrick Walker** has resigned from his post as president of SCCA Pro Racing, the Sports Car Club of America's for profit-run business subsidiary. Walker joined the SCCA last autumn, after he left the IndyCar series, and was tasked with getting the F4 United States Championship off the ground, as well as overseeing other SCCA series.

Sauber has appointed **Xevi Pujolar** as head of track engineering. The post has been vacant since **Tim Malyon** left the Swiss team back in April, just three months after he replaced **Giampaolo Dall'Ara**. Pujolar began work at Sauber's base at Hinwil immediately after F1's summer shutdown at the end of August. The move is part of a concerted recruitment effort by Sauber (see below).

**Nicolas Hennel de Beaupreau** is now head of aerodynamics at the Sauber F1 team, a position he formally held at Lotus – now Renault. Before Hennel de Beaupreau's arrival at the Swiss team, head of aerodynamic development **Mariano Alperin-Bruvera** and **Seamus Mullarkey** – who is responsible for aerodynamic research – had split the head of aerodynamics role between them on an interim basis.

The Sauber Formula 1 team has signed up former Ferrari and Haas strategist **Ruth Buscombe**. Buscombe worked as a simulations development engineer at Ferrari before taking on the role of race strategist, based at the factory. She then joined Haas, first working at the track then back in the factory. She left after eight months with the new US-owned team.

There has been a shake-up in the management structure at NASCAR outfit Richard Petty Motorsports with **Philippe Lopez** and **Scott McDougall** now overseeing all the duties and roles previously held by **Sammy Johns**, both at the race track and the workshop.

**Betty Jane France**, the mother of NASCAR chairman and CEO **Brian France** and International Speedway Corporation CEO **Lesa France Kennedy**, has died. She was the widow of the late NASCAR Chairman and CEO **William C France**, who passed away in 2007, while she was also executive vice president and assistant treasurer of NASCAR, and the chairwoman of the NASCAR Foundation.

**Matt Mindrum** is now the vice president of Marketing and Communications at the Indianapolis Motor Speedway. Mindrum comes to the fabled race track from Butler University, where he held a similar position, and before that he worked in PR at Eli Lilly and Company.

Formula 3 impresario **Barry Bland** has stepped down from his long-held position as organiser of the Macau Grand Prix, the blue riband F3 season closer. Bland, along with his company Motor Race Consultants, has been looking after the race since 1983 and is widely credited with the success of the annual event. The FIA Single Seater Commission has now taken on the responsibility for organising the showpiece street race.

Well-known US race team owner **Fred Opert** has died at the age of 77. Opert started out as a driver on the back of his successful New Jersey motor trade business, and then went on to become an agent for Brabham and Chevron, and others, in the United States. He also run cars in Formula 2 and Formula Atlantic in the 1970s, and is especially well-known for the part he played in **Keke Rosberg's** racing career.

**Mike Collins** is the new president of SCCA Pro Racing, filling the post left vacant with the departure of **Derrick Walker**. Collins, a veteran of the United States Marine Corps, brings over 20 years of experience in the motorsports and event industries to the role. He has also raced with some success, most recently in the highly competitive Mazda MX-5 Cup in the US. He has been a member of the SCCA for 15 years.

# Teams concerned about tech specialisation in F1

XPB

Aldo Costa says increasing specialisation in F1 could mean future tech directors might not have a complete knowledge of the racecars

**F1 bosses have said increasing specialisation could make it harder to find technical chiefs with a full overview of the cars within F1 in the future.**

With more and more specialised roles in Formula 1 it is now difficult, some say, to gain an overall expertise on all facets of the F1 car, and they believe this might have an impact on future generations of technical directors.

Aldo Costa, engineering director at Mercedes, said: 'It's a big problem that all F1 organisations have got at the moment. People like me, I changed in a team many different types of job to try to understand as much as I could everywhere. Now, these days, the young guys get employed and they become specialists and they don't grow up with a general knowledge of the car.'

Gunther Steiner, team principal at Haas F1 Team, said: 'I think it's difficult to find, like in the old days, one leader who knows it all which itself is getting more and more difficult because the cars are getting more and more complex.'

But Luca Furbatto, chief designer at Manor, said such specialisation is more of a problem for the bigger teams: 'I think the biggest difference with a top team is the size of our design office which is much smaller, about a third or a quarter of what [Mercedes] has got and as a result, engineers are actually not that specialised, but they need to deal with different parts of the car which they find very motivating, very rewarding.'

Costa said that Mercedes is now addressing this issue. 'We're trying to do a programme for development of students [and engineers] … trying to get them to understand a bit more widely around the car, to hopefully become the next generation of technical directors,' he said.

# Volkswagen Motorsport appoints new director

Sven Smeets is the new boss at Volkswagen Motorsport

**Volkswagen Motorsport has a new boss in the shape of Sven Smeets, who takes over from Jost Capito, now at McLaren.**

The appointment of Smeets as director comes as part of a restructuring of the management team at VW Motorsport, which also sees Lukasz Urban take over as commercial managing director from Kirsten Zimmermann, who has now moved into a new management role at Volkswagen AG.

Meanwhile, technical director Francois-Xavier Demaison, and director of engine development Dr Donatus Wichelhaus, have both been promoted on to the VW Motorsport Management Board.

Smeets is now responsible for all of the brand's motorsport activities, including its involvement in the World Rally Championship (WRC). The Belgian has been with Volkswagen Motorsport since 2012. He joined the organisation as team manager in the WRC and took on the role of sporting director in the middle of 2016.

Demaison also joined Volkswagen in 2012, and since then has been responsible for the technical development of the Polo for the WRC. As technical director since June 2016 he is now also responsible for all of Volkswagen's other motorsport programmes.

Wichelhaus has been a member of the management team since 2005. He took over as director of engine development in June, meaning he is now responsible for the development of all Volkswagen motorsport powerplants.

Andre Dietzel (head of Communications and Marketing), Matthias Meyer (manager of workshop) and Eduard Weidl (head of Customer Sports) continue in their current roles within Volkswagen Motorsport.

## RACE MOVES – continued

XPB

Former high-profile Williams and McLaren F1 engineer, sporting director and technical director **Sam Michael** has been given a position on the board of the Australian Institute for Motor Sport Safety. The Australian, who left the McLaren Formula 1 operation in 2014, will join **Dr Michael Myers**, **Dr Michelle Gatton**, **Dr Michael Henderson**, **Mark Larkham** and **Andrew Papadopoulos** on the restructured board. **Garry Connelly** is its new chairman.

The new MIA School of Race Mechanics, which is run in partnership with the Motorsport Technical School (MTS) of Monza, is to open on 19 November at Donington Park and will run for 10 weekends. The hands-on, pit-garage practical and classroom courses will be led by current racecar and race bike mechanics. Those wishing to attend the school should check for further details on the website: www.the-mia.com/education

**Roger Curtis** has left his post as president of Michigan International Speedway. Curtis started at MIS in 2006 and has spent more than 30 years in the race circuit business, including spells at California Speedway, Richmond International Raceway and Watkins Glen.

NASCAR's track operator International Speedway Corporation has signed up **Rick Brenner** as the new president of Michigan International Speedway, filling the role vacated by **Roger Curtis** (see above). Brenner was previously president of DSF Sports and Entertainment, the company that owns the New Hampshire Fisher Cats baseball team.

**Cameron Waugh** has left NASCAR Sprint Cup operation Hendrick Motorsports, where he was the front tyre changer on the No.48 Chevrolet driven by **Jimmie Johnson**. His position on the car has been taken by **Kevin Novak**.

**Patrick Allen** is no longer the managing director of Silverstone Circuits Ltd. Allen was placed on a leave of absence in August (see V26N10) because he was said to be too close to parties involved in the deal to sell the British Grand Prix venue, allegations that have since been retracted. Circuit owners the BRDC now intend to appoint a permanent management team – Allen was employed on a consultancy basis.

**Antonio Spagnolo**, the former head of tyre performance at Scuderia Ferrari, has joined the Williams F1 team's operations group, where he will work as competitor analysis and performance concept team leader. Spagnolo spent 11 years with Ferrari in a number of roles.

NASCAR Sprint Cup outfit Furniture Row Racing has hired **Chris Gayle** to work as crew chief on rookie driver **Erik Jones**' Toyota in 2017. Gayle will move from another Toyota squad, Joe Gibbs Racing, where he has worked for the past 14 years.

NASCAR Sprint Cup outfit Richard Petty Motorsports has assigned **Drew Blickensderfer** to the position of crew chief on its No.43 Ford. Blickensderfer replaces **Trent Owens** in the post, the latter taking up a new role within the RPM organisation. Blickensderfer most recently served as director of Research and Development with RPM and has been with the operation for the last four years.

◆ 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**

AUTOSPORT INTERNATIONAL
ENGINEERING SHOW 2017
IN ASSOCIATION WITH
Racecar engineering

# The fast show

## The big event is a matter of months away – here are a few good reasons why you should make sure you're there

The world of motorsport is entering a significant period of change, especially with wholesale rule changes governing Formula 1 and the World Rally Championship set to come into place in 2017. New rules mean teams must now also find new solutions to meet the regulations, while at the same time, developing innovative ways to gain that all-important competitive advantage.

And Autosport International and Autosport Engineering, in partnership with *Racecar Engineering*, still remains the place to witness these new developments for the first time ahead of the new season.

Also, the world's leading suppliers and buyers of cutting-edge motorsport tech, such as AP Racing, Hewland Engineering, McLaren Applied Technologies, Eibach – currently celebrating 65 years in business – and Young Calibration will be present on the two dedicated trade days between 12 to 13 January.


ASI is the perfect start to the motor racing season and a must-attend event for all involved in the trade

## Networking

Beyond the amazing variety of exhibitors and as part of an extended range of networking events and business-focussed activities, the organisers have also created an all-new space within Autosport Engineering for buyers and suppliers of motorsport technology to meet and discuss new opportunities. This new business hub complements the Motorsport Industry Association (MIA) International Business Lounge, and numerous workshops running throughout the four days, in providing unrivalled networking opportunities for exhibitors and business professionals.

While attending Autosport Engineering, visitors get the added benefit of access to the Trade and Technical area within Autosport International. Building on the success of the inaugural Tech Talk in the Trade and Technical area, organisers will continue to offer exhibitors the opportunity to present to other like-minded professionals.

The Tech Talk segment of Autosport International was seen for the first time at the 2016 show. The all-new insightful and specialised Engineering feature was considered a huge success. Tech Talk gives important members of the engineering world, and significant contributors to the industry, the opportunity to discuss innovative, topical and important subjects in the motorsport, automotive and performance engineering sectors to an audience of engaged, knowledgeable and, of course, enthusiastic professionals. The overwhelming success and positive feedback from the first Tech Talk means ASI has decided to continue this event at Autosport International in 2017. If you would like a company representative to present a Tech Talk about your product or service, send an email to: autosportinternational@haymarket.com

## Tech trade

In addition, the Trade and Technical area within Autosport International will run over all four days between 12-15 January with well-know companies such as Nicky Grist Motorsports/Stilo SRL, Ohlins Racing and Schroth Racing all confirmed for next year's show.

**There's a new space within ASI for buyers and suppliers to meet and discuss business**

### Lifeline Firemarshal

Following the successful introduction of the Lifeline Zero 3620 fire suppression system, the well-known company, which will be exhibiting at ASI, has now launched the new Zero 3620 Firemarshal – an approved system that meets FIA 8865 suppression standard and has been tested and developed for use with unleaded petrol, diesel and E85.

Housed within a single fabricated aluminium cylinder, it discharges into both the engine and cockpit. The engine side of the system discharges 1.0kg of 3M Novec clean agent suppressant through one high discharge outlet, which is then supplemented by two further coolant outlets, utilising Lifeline's patented dual discharge technology. The cockpit side of the system discharges 3.0kg of 3M Novec through two cloud burst outlets, developed specifically to disperse the suppressant efficiently throughout the entire cockpit, quickly putting out the fire.

The MAT bicycle is typical of the sort of Formula 1-inspired hi-tech products McLaren Applied Technology produces

## AUTOSPORT INTERNATIONAL

**12 to 15 JANUARY 2017**

**OPENING TIMES:**

**Saturday: 9:00am to 6:00pm**

**Sunday: 9:00am to 6:00pm**

**TRADE TICKETS**

| TRADE | Advance Price | Door Prices |
|---|---|---|
| Adult | £28 | £30 |
| MSA members | £23 | £25 |
| BRSCC members | Free | Free |

Tickets do not include access to LAA (Live Action Arena ), which is sold separately at £11 (advance and on-site) Each ticket includes a Trade Directory (value £10), collectable on the day.

**STUDENTS**

Ticket type Trade days (12 and 13 January)
Public days (14 and 15 January)

| | | |
|---|---|---|
| Student 1 day entry pass | £28 | - |
| Student 1 day entry pass + LAA | £33 | - |
| Tutor 1 day entry pass | £28 | - |
| Tutor 1 day entry pass + LAA | £33 | - |

**How to book**

Trade Days.
To register visit www.autosportinternational.com or call 0844 335 1109
(BRSCC Members should contact the BRSCC directly)

**CONSUMER TICKETS**

| CONSUMER | Adult | Child (6-15yrs) |
|---|---|---|
| Standard | £35pp | £23pp |

## Recruitment drive for McLaren Applied Tech

One prominent exhibitor at the show in 2017 is McLaren Applied Technologies (MAT). The British firm is currently undergoing a massive recruitment drive aimed at offering the opportunity for 'creative and technically excellent people' to work and collaborate across specialist fields.

MAT prides itself on applying disruptive thinking to solve important challenges, whilst taking insights from the race track to improve performance across a range of sectors from healthcare and transport to consumer brands, and even financial products. 'Solving problems that might otherwise remain unsolved', it says.

It does this by taking advantage of the natural convergence between data management, predictive analytics and simulation, MAT tells us.

As part of the McLaren Group, MAT is uniquely positioned to capitalise on progress made within the broader business. This means it can solve a wide range of challenges through the interplay between high-performance engineering and advanced electronic technology. 'Whether supplying existing or derivative electrical components, or designing wholly new solutions to as-yet unsolvable challenges', it says.

In its current vacancy drive, there is scope to work with a wide range of clients in a variety of sectors, it says, adding: 'ensuring the employee gets exposure to a wide variety of technologies, industries and processes is very relevant for anyone considering working at McLaren Applied Technologies'.

MAT says that if you have a strong analytical mind and are inquisitive then it may well be worth you checking out the company's website at: www.mclaren.com/appliedtechnologies.

## Bend it like BTB

Even though the name 'BTB Exhausts' indicates a speciality in exhausts, it could also stand for 'Brilliant Tube Bending', the company tells us. This is because BTB has an in-house CNC tube-bender which has, over the years, been used for a wide range of projects. As a result, BTB staff have built up extensive experience on the fine art of bending. Geometry data can be put directly into the CNC tube bender, allowing for unrivalled accuracy and precision.

This versatile machine can bend tubes from 12mm diameter up to 70mm in a variety of materials, including stainless steel, aluminium and titanium, and it is equally adept at one-off or repeat batch work.

Over the years, BTB Exhausts has not only bent tubes for all manner of exhaust applications, but fluid pipes for all kinds of automotive applications, and structural tubes for chassis components and rollcages, and also many non-car jobs, BTB tells us.

All bent parts are checked on BTB's FARO coordinate measuring machine to ensure that they are delivered right first time, and with the right tools, and with the BTB team of expert fabricators and welders always to hand, all manner of complex tubular assemblies can be completed, the company says.


Factory R&D



# The ICE man speaks

While Formula E is preparing for its third season, the argument surrounding efficiency, and more specifically where to achieve the greatest gains, continues. Audi announced that it would be increasing its involvement in Formula E this season, and there was some disquiet at the WEC race in Mexico as to what effect this would have on the Le Mans programme, but we will simply have to wait and see.

Meanwhile, at the Low Carbon conference at Milbrook mid-September, a round table discussion was had regarding hydrogen fuel cells. It is known that BMW is looking to introduce this technology into the LMP1 category at Le Mans, probably through a change of regulation in 2020-2022. The problem, it was explained, is that the renewable energy is created in the north of Germany, and it's required in the south. Transporting it has always been an issue, but BMW believes that hydrogen is the way forwards, not only for its cars, but also for German industry.

As LMP1 and Formula 1 continues to evolve battery technology, there are clear gains coming there, but in Mexico Audi Motorsport's head of drivetrain, Ulrich Baretzky, in typically ebullient form, said that he believes that, with a more open set of regulations, gains in efficiency from the internal combustion engine could be increased by between six and eight per cent from where it is now. Already, the Bavarian says, the racing engines are far more efficient than the mass-produced production engines, so such a gain would be incredible.

'This would really be a benefit, [the production car team] can use it immediately, we just have to do it,' said Baretzky, while we were discussing the increase of stored energy from 8MJ to 10MJ, and the introduction of another hybrid system – for Porsche and Toyota three, for Audi potentially two. Typically anti-electric, Baretzky pointed out that three ERS in a car is not road relevant, and set his stall firmly against his friend and colleague, Thomas Laudenbach who heads up the hybrid department within Audi Sport.

'The reality of physics cannot be cheated,' says Baretzky. 'We are between the hammer and the hard place. We don't want the costs to explode, but if you restrict it too much then companies like Audi will lose interest. They are here to make technology which they can use later on. This is not possible anymore because the rules are so restrictive. What I say is that we should a little bit change the orientation to what we have now to what we need in the future; that would be quite helpful. I told [the ACO] that they are about to kill the spirit of the 24 hours. It will go for another 10 years, or 15 years, but it is no longer what it should be. It is a race like all the others, but longer. The spirit that was behind it has disappeared.'

It's a shame that Laudenbach was not there to continue the discussion, and hopefully when the two are in the same room, I can set the recorder, ask the question, and let them go. If nothing else, it would be highly entertaining.

Baretzky's argument carries weight; the spectators will not see a change in performance, and will not care whether or not there are three ERS in the car. Toyota, however, was slightly annoyed that the issue had come up now, and not a year ago, when it proposed that on grounds of cost control the limit remained at 8MJ and gains in efficiency were explored instead. The rise to 10MJ, and potentially an extra ERS, means more weight, and that leads to more weight saving throughout the car, starting with the monocoque, and that is not a cheap part to develop.

> **'At the end of the day the car will be slower, but more expensive'**

There is, apparently, no possibility now to rescind what is laid out on the road map. In 2018, the maximum electrical energy able to be delivered at Le Mans will be 10MJ, at other tracks that will be reduced according to circuit length. For the LMP1 cars, that will mean an extra ERS, as laid out in the pre-agreed road map. Toyota has already started to recruit personnel and has secured the funding to develop a third system for its next car, presumably the TS060.

'I don't think it is a big chance [to delay the introduction of the 10MJ class],' says Baretzky. 'From my understanding, the others have already developed or are about to develop their systems. We have one that we have already made, so the technology is there, Porsche will add one on the rear axle which is easy, while Toyota has to develop something like Porsche or us, so we will have more or less the same systems, so it will be a bit boring. But expensive! Expensively boring. At the end of the day the car will be slower, but more expensive. We have reached a level so that every newcomer has to spend a lot of money and hopefully become competitive, and how should he explain this to the board when he is always fifth, or sixth or seventh or whatever? It will be difficult. This is a big danger. If the system collapses one day then they are standing with empty hands. For the spectators I don't see the benefit and I don't see the benefit for road cars.'

The argument will continue for many a year and I hope that Baretzky is wrong; and that racing in all its forms has a long term future as a testbed for technology.

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