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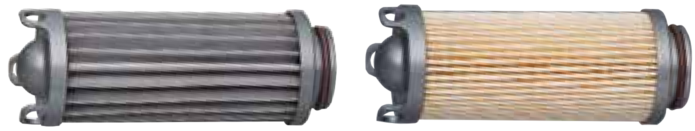

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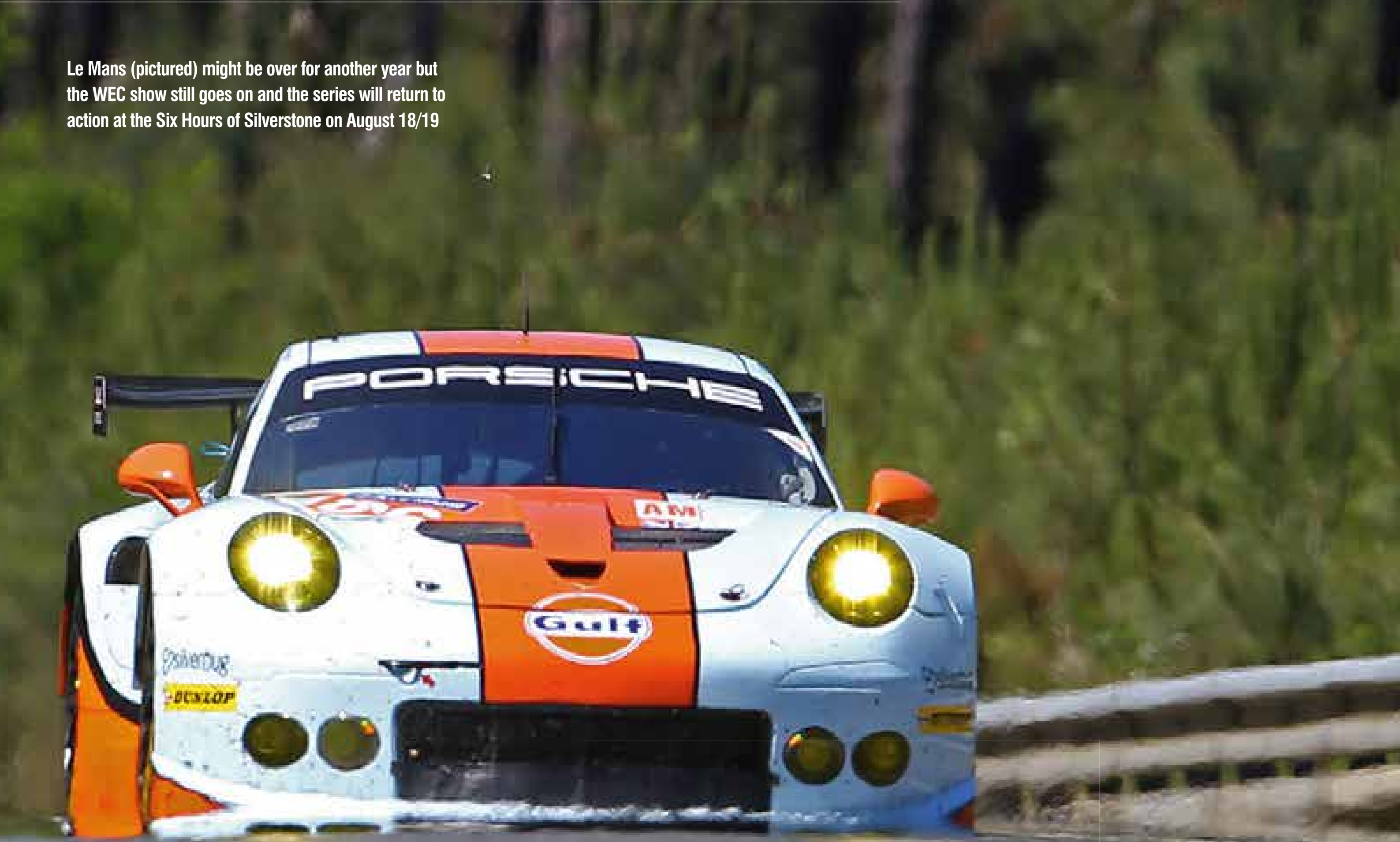

Le Mans (pictured) might be over for another year but the WEC show still goes on and the series will return to action at the Six Hours of Silverstone on August 18/19

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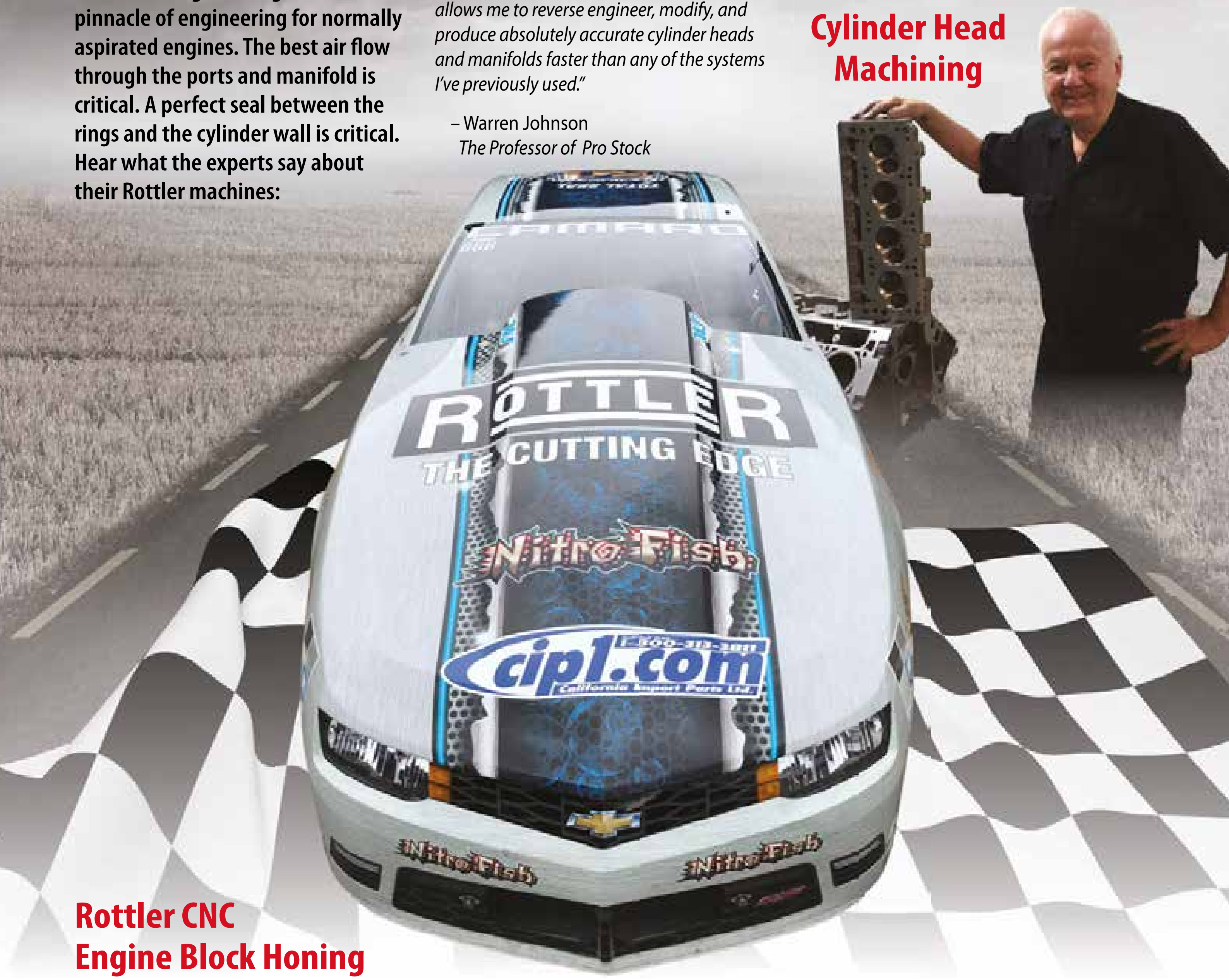
Pro Stock drag race engines are the pinnacle of engineering for normally aspirated engines. The best air flow through the ports and manifold is critical. A perfect seal between the rings and the cylinder wall is critical. Hear what the experts say about their Rottler machines:

"The Rottler P69 with its advanced software allows me to reverse engineer, modify, and produce absolutely accurate cylinder heads and manifolds faster than any of the systems I've previously used."

– Warren Johnson
The Professor of Pro Stock

Rottler CNC Cylinder Head Machining



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"We have spent countless hours using the Rottler CNC Vertical Honing Machine in the hunt for the proper surface finishes required to achieve perfect ring seal.

Until recently we have been limited to using vitrified or diamond abrasives.

The vitrified stones gave us nice clean cuts and make it easy to hit the target surface finish numbers but consumable costs are much higher compared to diamond stones.

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CBN honing stones are a real game changer."

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The fan zone

Motor racing spectators are a dedicated yet unfathomable breed, argues our columnist

Being on the working side of the track, one gets used to the rhythms of the race. The early start, arriving at least two hours before any session, then settling down to the familiar routines. The day passing in the bowels of the pits, if you are the main event, or tucked away in the backwaters of the support race paddock.

But one tends to forget the spectators, who not only brave the traffic jams and queues to get to the track, but probably leave their homes much earlier than the circus members and then *pay* to get into the circuit. There might be a psychological name for their peculiar derangement, for surely no one in his right mind would do it. Formula 1 events or major iconic races bring their own denizens, and each nation has – or had – some particular loonies.

Bog standard

'The Bog' at former US GP venue Watkins Glen was a no-go area with marauding gangs of drunk spectators, easily identified as such by having bottles or beer cans in both hands. You had to beware of the wielders of a single can, for these were the ones inciting minor riots – escalating on a memorable occasion when a bunch of Brazilian race fans returned to their bus and found it had been burnt down, with their luggage inside. The Bog epithet was a fair description of this wild-cat parking on the infield, by Saturday morning the muddy and crater-covered area could have been used to film a WW1 battle scene, but it wasn't as safe as Ypres, say, in 1915. Rumour has it that one year a police car mysteriously went up in smoke, when the occupants dared to enter The Bog.

Osterreichring, now much changed and known as the Red Bull Ring had it's own version of The Bog, but with less rioting and just possibly more beer. Try to visualize an area roughly the size of two football fields, but with the crowd actually on these fields, rather than stood at the edges. As it usually rained at some time during the weekend, this meant that any grass had been totally wiped out, leaving a brown 10-inch deep muddy swamp. Everything was brown, including the crowd, a good percentage of them actually lying down in the mud, one arm in the air to stop the beer steins from sinking in the mire. By the time the teams were leaving most of the singing had died down, but one could always hear the odd discordant strains wafting over.

XPB

Ferrari fans horsing around at Suzuka. Japanese spectators are very committed and will always go the extra furlong to show their support

Silverstone always brought out the Blitz spirit, no more so than when trapped in the infield with the surrounding countryside a sharp example of what gridlock does to a B-road network. It has improved since, but last century you were aware that from the paddock there was no way you would be out before midnight, hence the tradition of having a picnic with some music being played by members of the teams, notably Eddie Jordan.

NASCAR races have tailgate parties where there seemed to be no alternative to beer. Just walking under the grandstands required an umbrella, for the passageways under the jerry-built bleachers had its own weather, a misty rain constantly dripping in the gloomy depths. This was hopefully beer, at least it smelled of it. There would also be a rabble of strange haircuts; like having the number of your favourite driver cut into your buzz cut. Many caps, too, a fair number worn backwards, presumably to keep the sun off the already very red necks.

Draft beer

Indianapolis was another version of the NASCAR mob, but with a Hoosier tinge. The same queues to get into the venue, but rather quick if you consider that there were nearly a third of a million souls. Silverstone should take note. One just imagines the quantities of corn dogs consumed on race day could probably stave off famine in a middling sized third world country. And the beer downed could alleviate a drought in that same country. Funny, isn't is, this recurring beer theme?

Suzuka and Fuji were the polar opposite. Well-groomed orderly people, but they could put the English to shame in the sceptred isle's favourite sport – queuing. We would leave the track at 1am after finishing the car preparations for the morning warm-up and find the serried rows of cars queuing up for the next day's event. The pit walk queues were rank upon rank of quiet people waiting for a couple of hours, which would then part like the Red Sea in front of Moses as you came up to them, and as your team gear was recognised. A very strange phenomenon, really, as most of them were also wearing team gear – *voluntarily*.

This team gear thing still has to be properly explained to me. Spending a considerable amount of my time dressed up in strange colours, plastered with adverts, it escapes me why people will dress up that way out of choice; and pay for the privilege. Perhaps it fulfils a deep atavistic necessity to belong to tribe and show their colours?

Cooling fans

There were often peculiar customs at circuits. At Interlagos the fire department hosing down the crowds under a blazing sun ended up as a tradition, as it was always sunny and even though the crowd was used to heat, being in the packed grandstands was quite a different story from sipping coconut juice at the beach.

In Buenos Aires they always had a thing where the crowd were whipped into a frenzy by pounding drumming, the perpetrators set high up on the grandstands. A local explained to me once that this sort of thing was traditional, but was usually reserved for football matches.

Then there was Monza. Human traffic jams going through the tunnel under the track to the paddock, not to mention the track invasion after the race, perilous enough usually, but if Ferrari won it went a couple of notches higher. The imperative was to begin barricading the pits and putting as much of the equipment as possible into the trucks before the last couple of laps to avoid being looted of everything, like a field overrun by locusts.

The Nurburgring Nordschleife is an even stranger affair, with the whole forest filled with a massive crowd, barbecues with pork and wurst featuring heavily – and beer, of course – and some of those fans might even watch the race at some time during the 24 hours. Lederhosen might be involved, too. Football crowds? Pah! They can't hold a candle to race track spectators.

There was a memorable occasion when a bunch of Brazilian fans returned to their bus to find it had been burnt down, with their luggage inside

Recovery position

How might Williams and McLaren regain their winning ways in Formula 1?

McLaren and Williams are in dire trouble, and this shouldn't please anybody who genuinely recognises the value to the sport of their names and achievements, and the dedication and loyalty of their employees. This is not just sentiment, there's little room for it in F1, but fans identify with certain teams. Losing them may also lose some of the interest and support that is essential if Liberty's plans to expand race coverage in areas including social media are to be realised. All sports need recognised star names to attract followers who will know that they are engaging with the best in their chosen sphere.

It is immensely hard when down and being kicked to pick oneself up. It is difficult to step back from the inevitable daily fire-fighting to really assess the reasons for being in the situation and then to identify and implement ways out of it. Clarity is essential, but far from easy to achieve. Humble pie has to be eaten.

Reality check

If either team is to recover and reach anything like their previous status, they need to re-think themselves without the baggage of trying to live up to their successful pasts. Comments such as 'we know how to win' are just hubris – very clearly they no longer *do* know. Kidding yourself over the performance of your racecar and talking it up, as McLaren's Zak Brown has frequently done, only confuses and obfuscates the real picture. So does Claire Williams' use of semantics to avoid the term 'pay driver'.

The relentless pace of Formula 1 guarantees that rapid obsolescence is built-in and it is easy to assume that design processes, including tools which were state-of-the-art when quite recently installed, remain fully effective. While certain aspects of a design brief are red lines that simply cannot be compromised, for example driver safety and product quality, establishing the right first-order priorities other than these is essential. But it takes a strong and clear-visioned technical director to see beyond all the 'fluff'.

McLaren has not been benefiting from this and it remains to be seen if recent acknowledgement will create the step-change required. Williams has similarly not benefited. In particular the organisation has to adopt the mind-set of a start-up team; it needs to be lean and hungry and open to new and innovative operating practices. Pride in its history, while important, has to be subjugated to the needs of today and tomorrow.

Non-core activities that bleed focus and resources from the sole task of getting to the front half of the grid should not be countenanced. In the near future Williams doesn't have a chance of winning races, so only realistic objectives should be established, not too far removed from those of an outfit fresh to the battle, however hard to swallow. The team's steadfast refusal to go along with proposals a few years back of permitting a limited number of customer cars to be run always smacked to me a little of hypocrisy, given that this was Sir Frank's original way into F1. It also reflects dogged ideology and a refusal to face facts, the results of which have sadly come home to roost.

Williams has now to accept that the only advantages it has are an annual $30m historical earnings budget contribution and a substantial, skilled workforce. The vast database of technical information built over time ought to be an additional plus, but there's no sign of this being so, judging from the team's woeful situation.

XPB

McLaren and Williams have struggled in recent years but could a change in management culture put both back on the road to Formula 1 success?

Firing line

Head of aerodynamics Dirk de Beer 'stepped-down' after only a little more than a year since, with great play on his abilities and Ferrari knowledge, he was recruited. Every designer gets it wrong from time-to-time; Adrian Newey was responsible for a couple of howlers during his time with McLaren. The key is to learn quickly from the mistakes. Personality clashes and poor management skills aside, only if a technical head is dogmatically following a certain design philosophy that is not delivering should he or she depart with such speed.

Regarding former Williams technical director Sam Michael in 2011, this was evidently the case, despite his commitment and hard work. Since then there have been a number of senior engineering director appointments and departures, actions which can have a negative effect on ongoing good work. No consistent upward movement in results has ensued, aside from positive blips in 2014 and 2015. These occurred partly from the advantage of having Mercedes power when their PU was hugely dominant – this actually a good leadership decision – partly due to driver quality and also to the intervention of Pat Symonds before he, too, abruptly departed the scene. The team principals therefore have to hold up their hands and admit responsibility.

Winging it

There seems to be an ongoing weakness in Williams' engineering processes. Fitting development rear wings to the FW41 cars at Silverstone caused a so-called 'phenomenon' of stalling the underbody when the DRS closed. Thorough assessment of the overall aero effect of the wing assembly – essential, surely, with a change of this magnitude – should have revealed the problem. If such a process was short-circuited then it smacks of desperation to find some kind of quick-fix improvement. If the process was followed, then there is something seriously wrong with Williams' aero tools, or with the analysis of the results. Perhaps both.

Paddy Lowe, despite his abilities, is discovering that being in overall technical charge is different from being just one member of a senior group, especially in a depressing non-performing situation. He, too, maybe needs time to shape up to this role, even though Formula 1 doesn't permit much in the way of learning on the job. However, an honest and detailed appraisal of what's gone wrong must extend beyond the technical shortcomings that Lowe was hired to address. Some serious self-analysis is needed at the very top to regain effective direction.

Williams has to adopt the mind-set of a start-up team; it needs to be lean and hungry and open to new and innovative operating practices

Indy **900**

With a step-up in power to 900bhp set for 2021 and a new chassis arriving a year later IndyCar's gone some way towards mapping out an exciting technical future – but will this be enough to entice new manufacturers into the series? *Racecar* investigates

By ANDREW COTTON

A new body kit has transformed the ageing DW12 IndyCar, seen here in super speedway spec, and it will continue to race for the next four seasons

IndyCar has laid out the path that will take it through the next eight years, with new engines due in 2021 leading to an increase in horsepower to 900bhp, and a new chassis due in 2022, but perhaps mostly with the hope that a third engine manufacturer will take a shine to these new regulations and join Honda and Chevrolet in the US series.

The step-up in horsepower will come via more boost and an increase in engine capacity, from 2.2 litres to 2.4, and the series will stay away from intercooling systems while also maintaining the ban on technology such as fuel flow meters – a ban which was introduced this year – to keep the costs for the teams under control. IndyCar's engine currently hits 750bhp and the rise will be about 100bhp, with the extra 50bhp to get to the 900 attained with push to pass.

IndyCar has also discounted rumours that it will switch to methanol fuels – the regulations will stay with E85 based on pump fuel available to the consumer – or that it will introduce a new aero concept that will see high noses and more air flow through the underside of the car. Not only is seating position an issue with the raised nose, but risk of penetration into the cockpit of a car that is sideways on the track, particularly the super speedways and short ovals, is also cited as a reason to stick with its low nose.

Step by step

The changes are limited in their scope for 2021, but this is deliberately so. The decision not to introduce a new chassis at the same time as a new engine is based on the teams' resources. IndyCar simply does not want to have the paddock full of engineers trying to fight fires while spending lots of money making the

It was originally planned that the 2.2-litre engines would run for just four years, but they are now in year seven and the manufacturers felt it was time to change

The UAK18 kits were a result of wind tunnel work in the first half of last year. This set the downforce at roughly the same level as when the DW12 was first introduced back in 2012

racecars reliable during the first year or two of the new engine regulations.

The headline 900bhp is based on the push to pass system that is already in place in the series, and is there because drivers want to have something potent to play with, and to help with overtaking on the US circuits that rarely have straights long enough to allow for a pass. 'A big part was to give the drivers something that was more challenging, says Bill Pappas, vice president competition, race engineering, at IndyCar. 'They were screaming that they don't have enough power and as the current engine formula life is coming to a close, for the next generation we wanted to target something that was an experience for the drivers.'

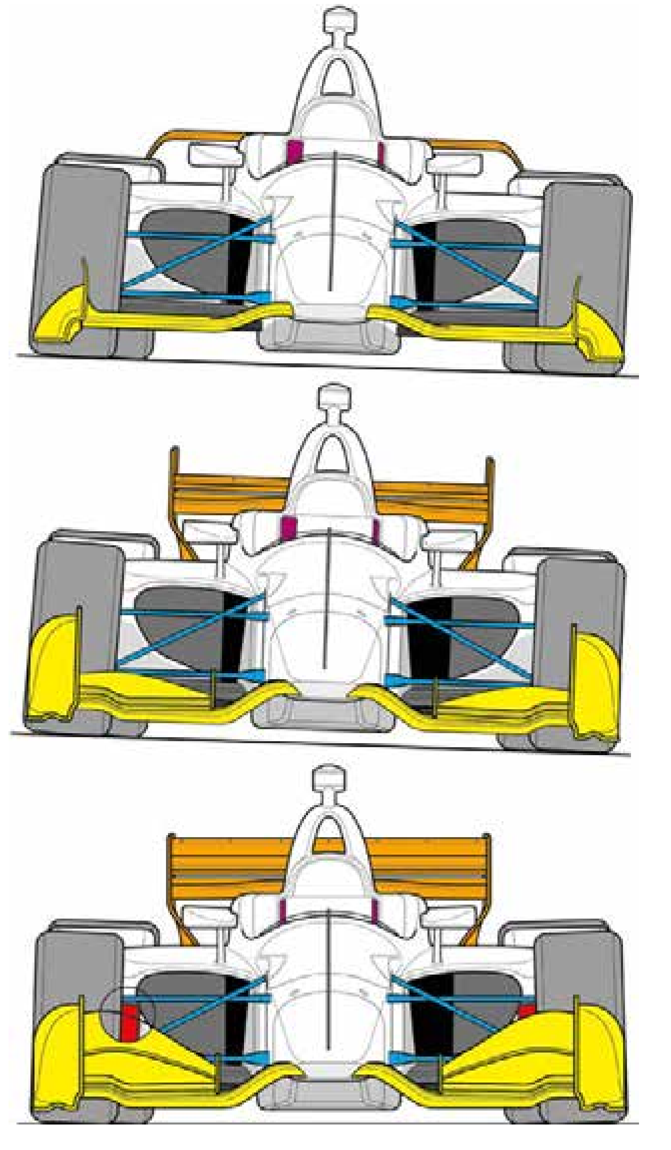
Old faithful

The decision to delay the introduction of the replacement for the Dallara designed and built DW12 chassis – 'DW' for Dan Wheldon who was killed in 2011 before the car was introduced in 2012 – to 2022 means that the current chassis will have had a shelf life of around 10 years before it is replaced. IndyCar and Dallara are therefore looking at the safety implications of continuing to race this car. 'This is the longest that we have ever run a chassis,' says Tino Belli, director, aerodynamic development. 'We are in the fact-finding stage to see if there should be a maximum life on the super speedways. For the road courses and street courses we don't really care [are not concerned], but the super speedways and short ovals are the ones

Launch of the UAK18 aero kit. Aesthetics were a major design consideration and this is the first IndyCar since 2007 to run without an airbox. IndyCar is also looking at a screen rather than a Halo for its cockpit protection

Road course kit being put through its paces in testing. The new aero has lessened the loads which means the more powerful engines can be introduced without too much concern about the suspension and tyres coping

Change of kit



One of the things that has always set IndyCar apart from European style racing on the one hand and NASCAR on the other is its embracing of a mix of different circuits; from full-on super speedways such as Indianapolis to short ovals like Iowa, and classic road courses such as Road America to street circuits like St Petersburg. This year the 17-round series visits 10 road and street tracks and six ovals and it is a challenge to make a car, or in this case a set of body kits, that will suit all of these. It was a challenge that's been met this year with the UAK18 kits.

Track specific

The UAK18 has three different configurations, according to what's demanded from these circuit configurations. There are significant detail changes between the super speedway kit (**top left**) and the short oval car (**middle**), both with single element front and rear wings. Cockpit padding for both versions of the car is more built up on the right hand side to counter the force for the drivers' heads, and in case of accident where impact is expected to be on the right hand side against the SAFER barriers and the walls.

Minimal brake ducting is also used on these kits, while the tyre camber is towards the right to allow the car to sit more balanced on the banked tarmac of the ovals.

But, as might be expected, it's the road course configuration which sees the biggest changes (**bottom**) from the speedway set-up. For road course and streets there's a multi-element front and rear wing and larger brake ducts to allow for more cooling. Camber is set on both sides to allow for both left and right hand turns, while the cockpit padding is also equal left and right.

This year the 17-round IndyCar series visits 10 road and street tracks and six ovals

where we have to do due diligence and be comfortable and use the same tubs. Some teams are still running with their 2012 tubs. These are strong cars, but this is a new area, so we have to do due diligence.'

The economic argument for not introducing the new tub takes some explaining. The engines are leased and cost capped for the teams. However, it is the ancillaries around the engine not included in the lease agreement that would cause the issues economically. 'Any time you do a new engine, there are always significant costs of the ancillaries that you need to run an engine,' says Belli. 'It is also, from a team point of view, easier to introduce things in stages so you don't have to debug everything at the same time. If you do a new tub, with a new fuel system and a new oil system and a new transmission, and bellhousing, and cooling system, and the engine is not running right, you have to trouble shoot the clutch and gearbox and so on, if you do your job well as we did with the UAK18 [the new aero kit], you don't have many problems.

'But we are not used to, as a paddock, a whole new car in one step,' Belli adds. 'We feel that it is better economically and practically to introduce things in stages, to bring the technology up in stages. Right now, the plan with Honda, Chevrolet and ourselves is that we don't change the cooling system. [We will] take an engine out of the box, put it in, turn the key and it will start.'

Aero worship

The series introduced its new aero kit in 2018 to bring the teams into line after some years of Chevrolet domination. The DW12 was first introduced with a Dallara-designed aero kit, but that was then opened up to allow manufacturers to develop their own kits. The downforce levels increased incredibly and Honda teams struggled with performance.

Work to bring the aero back under the control of the series started in 2016, and the first wind tunnel model was ready for January 2017. By May of that year, the tunnel testing programme was complete. Downforce levels were slightly higher than they were in 2012, but significant amounts had been shaved off. 'We have actually built in a bit extra because it is much easier to take downforce away than to add,' says Belli. 'If you add, it is really expensive. If you design the wings nicely you have a range, so for the road courses and street courses the wings have a large range of adjustment. For the short ovals we go to a single flap front and rear.'

The introduction of the UAK18 and the reduction in downforce brought the suspension back into a comfortable working range, so the increase in power will not necessarily

'We feel that it is better economically to introduce things in stages'

An IndyCar in its natural environment; Indianapolis. This year there were a number of spins when cars were running alone at the Brickyard

The DW12 runs on E85 pump fuel and rumours that it intends to switch to methanol when the new powerplant formula arrives in 2021 have been dismissed by IndyCar's engine development team

After such a long and successful project with Dallara it seems highly likely that the Italian company will be in the running to build the new chassis

cause IndyCar to look at a redesign. But with the higher speeds the series will be looking at improving the braking. 'We are already working on the brakes in anticipation of the new package,' says Belli. 'Our preference is to stick with the same size brakes if we can get the cooling we need. It should be possible; F1 has a 13in wheel, we have 15in. The starting weight of an F1 car is pretty close to what we have.'

Indy spins

The Indy 500 in May was notable for a number of single car spins, which happened while they were running out of traffic, which pointed to a problem with the set-up of the car. IndyCar had targeted qualifying speeds of 230mph and achieved that with one lap, and for the cars to race with the same maximum downforce as the faster cars could race with the manufacturer aero kits. That was not universally popular; the midfield teams struggled to create the downforce that they needed to be competitive in the pack, but IndyCar had increased the cars' ability to run with space between them and a car in front without a major loss of performance, reducing the possibility of contact.

'The only slight unexpected situation was the talk of more understeer in traffic,' says Belli. 'The drivers were having to use their tools to take out all of the understeer and then if they got to clean air they had to go all the way back to stop it oversteering, and I think that was part of the problem that we saw with drivers spinning on their own. They have a lot to adjust; two anti roll bars, and a weight jacker, a diagonal crossweight, so when you want the car to understeer less you put left front right rear weight in the car so it turns in, and they had to wind that backwards and forwards. That's our target for next year, to reduce that.'

The PPG-developed aeroscreen, which is IndyCar's more elegant cockpit safety solution compared to F1's Halo, has yet to be introduced but the IndyCar team says that it may be fitted to the DW12 if testing goes well. 'We have quite a bit of engineering to do with it, and we are not going to introduce it until we have signed off on those specifications,' says Pappas. 'We will test it on another circuit with another race driver, but it won't be introduced until we are comfortable with it. We are always looking at safety, and we will get through this year, see where we want to lay out the design parameters for the new car, which will be paramount.'

Power boost

In order to keep the development programme and base DW12 tub, the new engines will have to have the same mounting points to the chassis. But beyond that there will be opportunities for improvement. For Honda, for instance, the change in regulations gives it the chance to fix a lot of the issues that it has found with its current IndyCar powerplant. Originally, it was planned that these 2.2-litre engines would run for four just years, but they are now in year seven, and the manufacturers felt it was time to change anyway.

'We targeted eventually 900 horsepower, so the easiest way is displacement and boost


brembo

The 2.2-litre Chevrolet, and its rival engine from Honda, are set to become relics in 2021 when they will be replaced with 2.4-litre units that will be capable of producing an impressive 900bhp in push to pass mode

without changing completely the architecture,' says HPD race team leader Allen Miller. 'We could have done it [achieved the power] with what we have now, but it would have been more stress than what we have now, and the engines are at the limit of their development, so it gives us the chance to fix some of the things that we would like to have fixed anyway. We will have some new turbochargers, but it is not clear what they will be yet.

'We would like to start over,' Miller adds. 'Last year we struggled with bottom end failure, bearings, castings breaking, and so now we can do more to fix that.'

Push to pass

For Chevrolet, the new engine is all about improving the racing – passing should be easier with the increased boost. 'The problem with push to pass is that if you don't have enough power, it is ineffective,' says Paul Ray, president of Ilmor Inc. 'You have to have enough additional grunt from the engine to go from behind the car in front to in front of it. If you don't have the power you can't do that. Where we are today is marginal on some tracks whether you have enough time to come through the corner preceding the straight, both accelerating together, and then to have enough extra power to get in front of the car. To be effective, it has to have a big enough delta.

'The cars are too efficient now in terms of being able to create significant downforce and minimal drag,' Ray adds. 'Just look at the evolution and see the size of the wings that allow us to go the speeds that we are going. Smaller cars, and we are way faster, and that is tyres, aero, and floor. IndyCars used to have big tunnels that produced immense amount of downforce; we don't need them anymore.'

'We have actually built in extra downforce because it is much easier to take it away than to add it'

Road relevance

IndyCar actually originally planned to introduce a 2.4-litre engine, but it decided on 2.2 when the regulations were introduced. 'Indycar deserves a lot of credit for the downsize displacement [as it] did nail the relevancy to OEM,' says Rob Buckner, Chevrolet Racing's engineering programme manager for IndyCar. 'The 2.2-litre [replaced] the 3.5-litre engine in 2011. If you look at a typical car that had a 3.5-litre engine it has a 2 to 2.5 litre engine in the showroom 10 years later. [But] Instead of adding the cost and weight complexity of intercoolers, [there is] a slight displacement increase. You can't just add boost pressure if you have to stay with non-intercooler. That would be a bad scenario for all of us in terms of temperatures. With an increase in displacement and boost, you get to that 900bhp that the drivers were after.'

Fuel for thought

The decisions not to go with either methanol, which would be a fuel that could reduce temperatures, or intercoolers, which would increase power, were purely economical. The intercoolers would require a new chassis, and a move to methanol would make the engines non-road relevant. Although there has appeared to be some hints within the IndyCar hierarchy that methanol is still under consideration, this is refuted by the engine manufacturers and indeed by the IndyCar engine team itself.

'E85 works well with the non-intercooler concept because the flow rate is very high,' explains Buckner. 'You couldn't stay committed to non-intercooled and then change paths on the fuel. The groundwork, the first thing you need to lay out, is the fuel type and the fuel density and octane and all that.'

Darren Sansum, managing director engine development at IndyCar, adds: 'We are not changing to methanol, we are sticking with E85 because it has relevance to what is available as pump fuel, so that is a main driver for that.'

Turbo charge

There will be a new turbocharger under these new regulations – it is not clear who will supply this package – but the series will stick with the twin turbo layout that it says is better for racing and more road relevant. 'There will be a new turbo package to go with the new engine,' Sansum confirms. 'It's a complete new powertrain. The turbo package is still something that has to be decided, where they will come from and exactly the configuration of them.'

Also still to be decided is the supplier for the chassis, although after such a long and successful project with Dallara it seems highly likely that the Italian company will be in the running again. IndyCar went through the tendering process before for the Indy Lights category, and found that the best organisation for design and, critically, for support and stability, was Dallara.

With the future so clearly laid out, and with the teams' economics at the heart of it, IndyCar seems to have the clearest of visions. It is not concerned with hybrid tech and has actually taken steps to avoid a large reliance on engineering staff to run cars. But will these regs prove popular enough to attract new manufacturers? There are other car makers around the table, as would be expected when discussing new rules, but none has so far committed. For the moment it remains a two-horse race between Honda and Chevrolet.

Super hero

With lap times close to Formula 1 and an aero package that should ensure on-track action could Super Formula's new Dallara-built SF19 be the most exciting and relevant single seater to be unveiled this year?

By ANDREW COTTON

It has been five years since the premier single seater category in Japan, Super Formula, last introduced a new car. But the long wait is now nearly over and in July the new design from Dallara hit the Fuji circuit in Japan for the first time and the plan is to deliver cars at the tail end of 2018, in time for testing for its debut season in 2019.

The targets for the SF19 was that it should be up to two seconds faster than the previous model while facilitating overtaking, therefore providing spectators with more entertainment. With this in mind the car has larger wings, designed to maintain aero balance while following another car, more underfloor aero, while with a push to pass function the drivers should be able to make passes on track.

'When I made my initial visit to Dallara, they asked me "what are you looking for from this car? To be able to do more overtaking manoeuvres, faster lap times or make the top speed faster? Because these are all different things,"' says JRP President Akira Kurashita. His reply to Dallara was: 'Top priority should be given to allow more overtaking.'

Super aero

Other aerodynamic changes include a third flap that was added to the front wing, while a 'chassis wing' has been fixed to the front of the sidepod, Formula 1-style, to direct air into radiators, while also providing more downforce as a secondary function. The shape of the rear wing is slightly more open as well, swept back and incorporating rain lights in the upright elements, LMP1-style, as well as a central rain light on the rear crash structure. Larger front tyres were incorporated into the design to give more front grip while emphasis for downforce was placed on underfloor aero rather than the bodywork. The engine cover carries a rather elegant shark fin, too.

Electronics are by Cosworth, the fuel tank is from ATL, while the gearbox is carried over from the SF14, the current Super Formula racer, and is supplied by Ricardo. The decision to stick with the gearbox, made for cost reasons, also means that the rear suspension wishbones can be carried over onto the new racecar.

Under the JRP regulations that govern the category engine manufacturers are free to design their own units for the car and Honda and Toyota use their 2-litre, single turbo layouts from the current Super GT formula in the SF14 and SF19 cars. Nissan also has a compatible engine, but does not race in the category.

First run

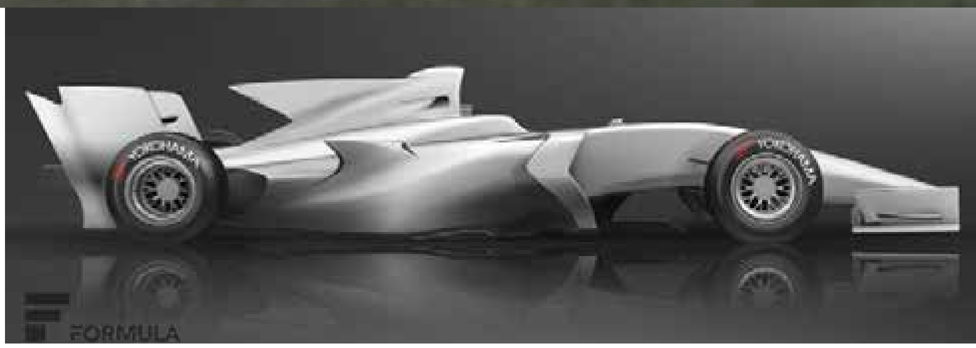
The public unveiling of the car, at a cold and wet Fuji Raceway early in July, was also the first time that it had turned a wheel, other than a small systems check back in Varano, Italy, before the cars were due to be shipped to Japan.

The SF19's first test at Fuji was hit by adverse weather. It's expected it will lap at close to F1 speeds when it's tested at Suzuka in September

> 'In Japan there is a different spirit, a bit more of a pure racing approach, and so we tried to keep this in mind when designing this new car'

Beneath leaden skies the SF19 completed its first laps, but the rain became so hard that even straight-line aero testing along the start finish straight was hard to complete, and eventually the test was curtailed on day one. The second day produced more of the same, although drier weather in the afternoon meant that the SF19 could run with slick tyres, albeit on a track with wet patches that meant it could not show its full performance potential.

Driver Tomoki Nojiri set a time of 1m26.173s in the shakedown test, three seconds slower than pole position in 2017 due to the weather. Further testing was planned in July, also in Fuji, but the key test is in October, in Suzuka, where the hope is that the car will run two seconds faster than the SF14, and that puts it close to F1 pace. The record for the class with the SF14 is 1m35.907, while Lewis Hamilton's F1 pole in 2017 was a 1m27.319s and Fernando Alonso lined up last in the McLaren with a 1m30.687.



The SF19 is especially striking in profile thanks to its low nose, neat dorsal fin and the steeply raked rear wing assembly

Engineers are hoping that they will have found a second in the SF19 chassis, while the development Yokohama tyres will also yield a second of performance gain, they say.

Super model

From the outside, this is a good-looking car. The most striking aspects of it are its swept back wings and the low nose design, which looks set to become an FIA standard under the new aerodynamic regulations, with driver positions having been analysed closely.

Dallara also designed and built the outgoing car, the SF14, which was originally designed to accommodate a KERS behind the driver seat. But in five years that plan never reached fruition. The space for this is now used for electronics, and has made the new car shorter overall, and so it features a shorter wheelbase than its predecessor.

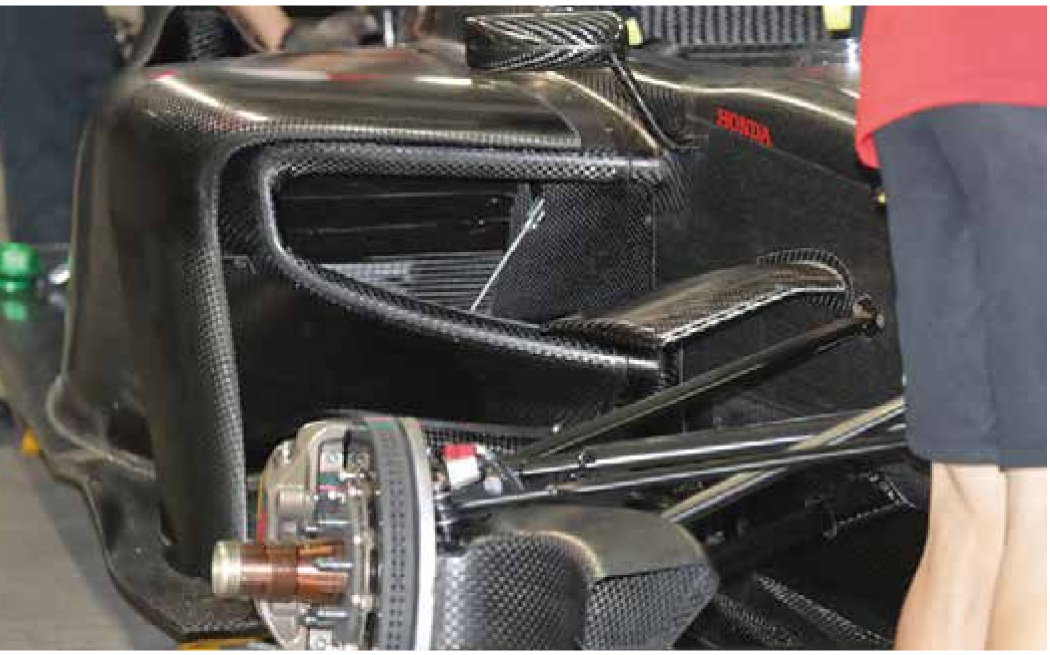
One of the major aspects in the design brief for the SF19 was that the car should not cost more than the outgoing model

That has all led to a reduction in weight, a necessary point of order for the Dallara design team as they incorporate all the latest safety technology, including the provision for fitting a Halo. The car has been homologated both with and without the head protection system so that it can run in either configuration, but the Japanese organising body insisted that the chassis at least had facility to adopt this safety device. The car is some kilos lighter than the SF14, even with all the latest safety equipment, although that weight advantage would be almost wiped out with the Halo in place.

'The driver position is not much different to before, but the car is ready to mount the Halo system,' says Fabio Grippa, programme chief at Dallara for the SF19. 'We had to position the driver considering the possibility to adopt the Halo, so that includes the position of the steering wheel, and the position of the head of the driver which is a bit different to SF14. It is not clear yet when the Halo will be introduced; that decision is taken by the championship organisers. JRP is thinking obviously about the Halo and have the possibility to test it on the track to get the feedback from the driver, particularly for visibility. We will test with the Halo possibly in the second test in Fuji.'

Dallara attacked the overtaking issue by actually increasing the downforce from the front wing, introducing a third flap with a view to maintaining an aero balance whilst running in traffic. 'This topic is one of the most difficult areas when developing a new car because there are several parameters which have an affect on the performance of the car,' says Grippa. 'Basically, we worked on these parameters. We can say that one important one is the loss of downforce when one racecar is following another one, and drag reduction, because this gives the possibility for the car staying close to another on the straight and therefore being close to each other on the brakes.'

The aero work has been focussed on overtaking. At the rear of the car one of the carry-over parts from SF14 is the gearbox


The Formula 1-style chassis wing drives air into the radiators while it also has a secondary function of increasing downforce

Underfloor aero

'Another important parameter is the aero balance shift,' Grippa adds. 'When you have the aero balance change a lot when you are following another car, you can have big understeer or big oversteer and this does not give the drivers the confidence to follow the car in front. To do all these things, we had to do a lot of work on the underfloor of the car to get the maximum downforce. In this way we can increase the overtaking capability because the effect of a car following another one is less.'

The wider front wheels, still 13in diameter similar to Formula 1, allow for more front grip, and that also changes the wake pattern. But tyre supplier Yokohama has yet to start tyre testing with the SF19, which was only finished in June, and the wet weather Japan suffered during July didn't give it much chance to evaluate anything other than a wet tyre.

From the front, the wings are designed to be less potent to reduce the impact of following another car, but the most striking thing here is that low nose. This was by regulation from the Japanese organisation, rather than from the FIA, but it has had a significant impact on the airflow to the underfloor and the radiators.

Nose blowing

Despite the low nose the front of the monocoque is actually higher than it is on the SF14. 'Adopting the new nose, we have new aerodynamic performance and downforce because with the very high nose it is possible to direct flow from the nose to the underfloor of the racecar, so when adopting the new lower nose that was simply not possible anymore,' says Grippa. 'If you look to the side of the monocoque, the front section is higher and it is really smaller than before. For this reason, I think the racecar looks different and the installation of all the mechanics, suspension,

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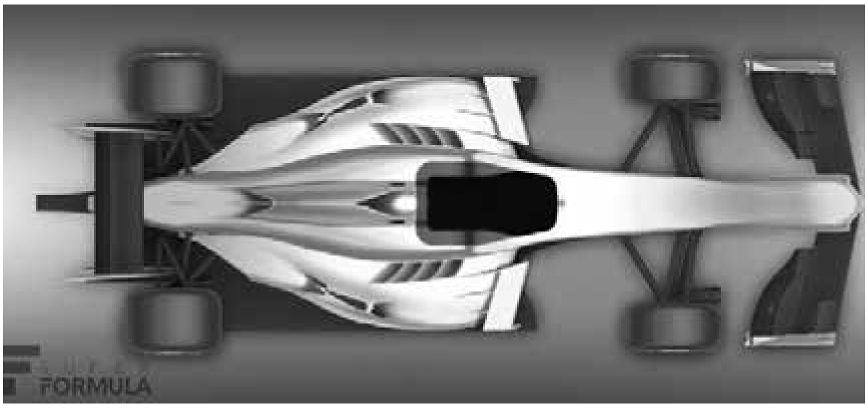
The elegant cooling system on the SF19 has been carried over from the SF14 – although like other parts of the car it has needed a rework as a result of the new low nose design

The car has been homologated both with and without the Halo head protection system so that it is able to run in either configuration



SF19 conforms to all FIA crash tests. This clean design could be cluttered up with a Halo by the time it races

dampers, steering column and so on is more tight and more difficult with this car.'

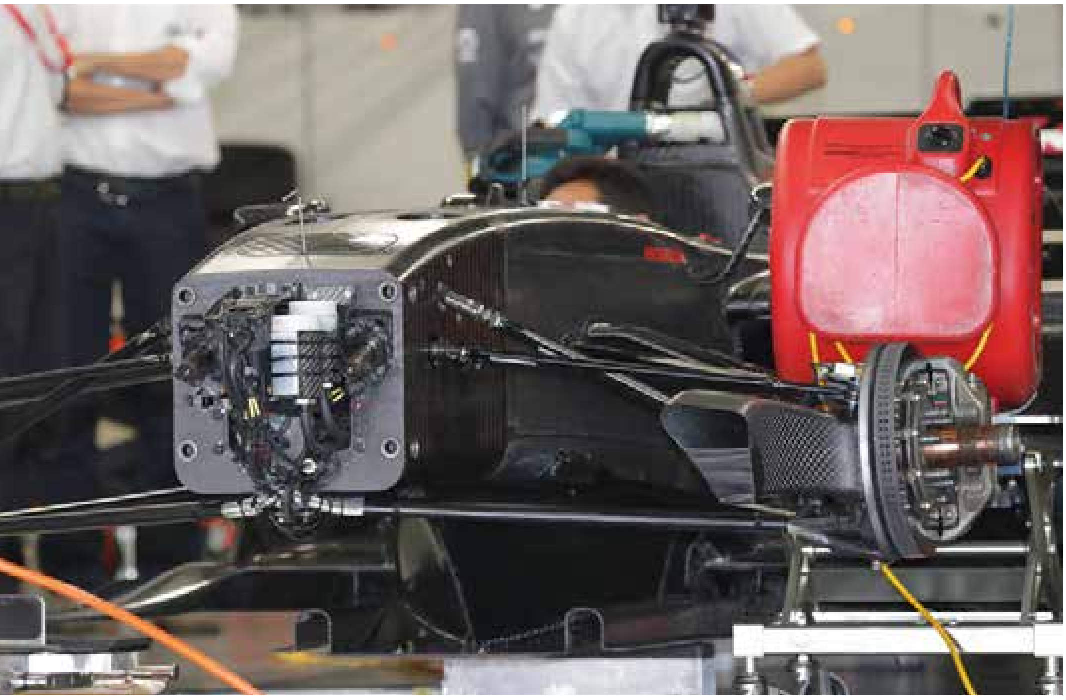
Not only is the monocoque raised compared to the SF14, it is also therefore smaller as the top surface is a similar height, presenting a challenge to designers, in how to squeeze all the necessary fluid bottles, braking system and pedals into the small area. 'We had to fit in everything, and this was one of the most difficult jobs we have done on the car, to put the front suspension on the monocoque which is smaller than before,' says Grippa.

That front suspension is new, although some suspension parts including wishbones are carried over from SF14. Because they have stuck with the Ricardo gearbox the rear suspension and rear tyre sizes stay the same. Incidentally, with free damper choice there is plenty of room for car set-up, which is also a positive point for the Japanese race engineers. The cooling system has also been carried over from the SF14, although it has been redesigned as a result of the new nose. In order to drive air into the radiators a 'chassis wing' has been introduced to the front of the sidepods, F1-style. Despite all this talk of Formula 1-style aero one of the major aspects in the design brief was that the car should be in the region of the outgoing model, and if possible the cost of the new car needs to be decreased.

Super safe

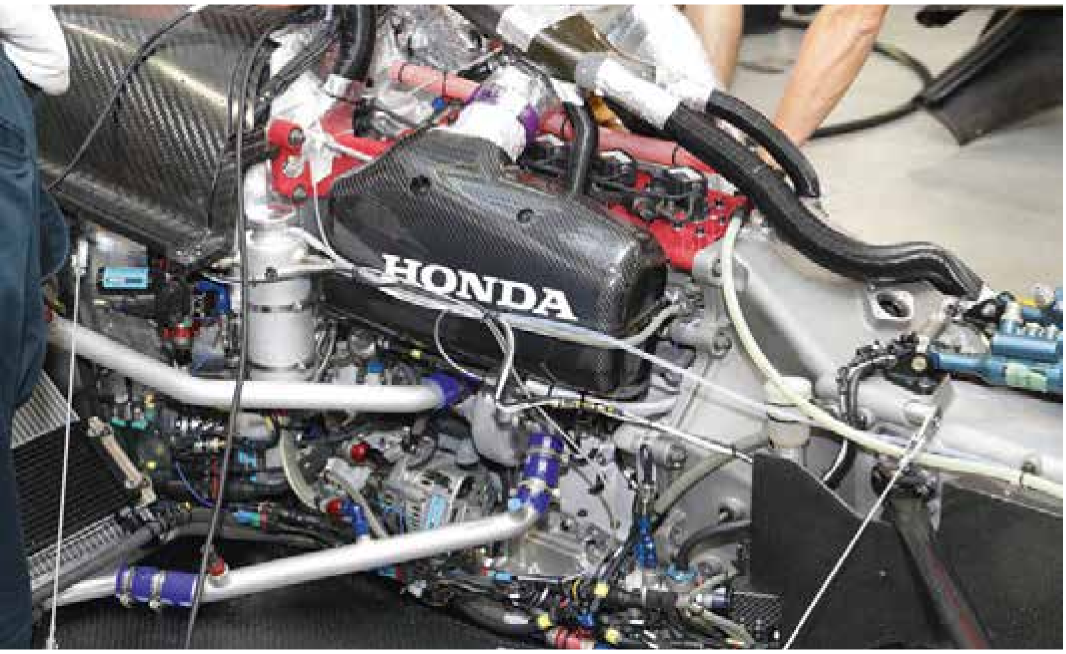
From a safety standpoint, the SF19 conforms to all the FIA crash tests, which is no mean feat in a single seater. That said, Dallara has plenty of experience, having built chassis for Haas in Formula 1, the Audi R18 LMP, as well as its IndyCar and Indy Lights, not to mention Formula 3. Still, meeting the crash test criteria with the Super Formula SF19 was challenging.

'The requirements on the safety regulations are more demanding than before and to be honest, they set the homologation to be more difficult now,' says Grippa. 'We have the new side impact structure from the FIA and there are a lot of homologation tests that have to be done on the monocoque, more than before, and they are more demanding. We perform two front crash tests, and static tests and this kind of stress [on the racecar] is really crazy. We did a big job because we decided to update the racecar with the latest regulation from the FIA, but at the same time we decided to keep the weight of the car as low as possible.



Despite the low nose the monocoque sits higher than its predecessor; this is to help increase the airflow to the underfloor

Rear suspension is a carry-over from the SF14. Dampers are free, which gives the engineers some scope to tune the cars



Both Honda and Toyota use their 2-litre turbocharged Super GT NRE powerplants for their Super Formula race programmes

'At the end, despite the compromise for the new safety regulations for Formula 1 the SF19 is a few kg lighter than the previous SF14,' Grippa adds. 'It is something like 80kg lighter than a Formula 1 car. You see a lot of changes in the aerodynamics of the car but one of the very big developments was under the skin. The monocoque design is completely new, we used different material for the wings, for the monoqocue and bodywork, just to reduce the weight as much as possible. It is not something that is so important in Europe, but in Japan there is a different racing spirit, a bit more of a pure racing spirit, and so we tried to keep it in mind when designing the new car.'

Material benefits

The Dallara design team worked with a different combination of resin and fibres to increase the strength of the monocoque as well as the rigidity, no doubt drawing from its experience on the LMP2 and LMP1 cars which were designed for the gentleman drivers in the case of the former and for the pro in the latter. These new material compounds were also used in the bodywork, saving further weight.

From the outset it was clear that the car would be powered by the 2-litre, single turbo NRE design from Honda and Toyota, despite the arguments raging over the power unit for the new Super GT/DTM/Class 1 regulations. The pick up points at the rear of the chassis were designed to be the same as on the SF14, and the engines will be a carry-over from this season, further saving costs for the teams.

Super Formula is a category that is going from strength to strength, and while there are many standard components on the racecar, there is still enough development potential that this is a proper engineering formula. 'There are a lot of possible changes to the set-up,' says Grippa. 'The set-up will be quite challenging for the engineers, which is good because in Japan there is a pure racing spirit and it makes it possible for an engineer to put a hand on the car and make a difference.'

Racecar says

From the outset this concept has been focussed on exactly what is needed to produce a successful single-seat racecar, and early indications are that this has worked. Primarily due to the speed at Suzuka, comparisons with Formula 1 are bound to be drawn ahead of the publication of the new F1 aero regulations.

The chassis and front wing are spec in Japan, which is a shame as variety and opportunity for young designers is on the wane. However, the concept of the new Super Formula car does raise possibilities for the architects of the new Formula 1 regulations. Let's hope they look east before they rubber stamp them, then …

Bake off

Formula Student teams had to battle the searing heat as well as the competition and the course itself at Silverstone this year – but it proved to be a memorable event

By GEMMA HATTON

The 2018 crop of cars at Formula Student UK covered a wide variety of designs, philosophies and technologies; demonstrating the very high level of engineering talent within the teams

Formula Student UK top 10 overall
1. Monash University
2. Oxford Brookes University
3. Monash University (EV)
4. TU Munich
5. University of Sheffield
6. University of Birmingham
7. Poznan University of Technology
8. University Of Texas Arlington
9. Queen's University Belfast
10. Loughborough University

Formula Student is arguably one of the most unpredictable forms of motorsport that exists today, and this year's UK event at Silverstone was no exception. Add to that, the 28degC heatwave that was sweeping across England and the students had a real fight on their hands – and it was a fight for survival.

The first challenge of the weekend is getting through scrutineering. Just like any other motorsport category, this is where scrutineers examine each car to ensure the designs are within the regulations and meet the necessary safety requirements. This year a higher percentage of cars passed scrutineering than ever before – so the bar was already set high.

The next major event is Design. With 150 points available it is the most important static event and equates to 17 per cent of a team's overall score. Therefore, the Design results give the first real indication of who the top runners are likely to be. Teams present, explain and justify the engineering behind their car to a panel of real-world engineering judges. This year, there were seven finalists, including teams from Munich, Monash (Australia), Rochester Institute of Technology and Rome, while the battle of the Brits continued as the three UK heavyweights: Bath, Hertfordshire and Oxford Brookes also made it to the Design final.

Design triumph

First place in Design was awarded to the Munich car, which featured a fascinating aerodynamics package as well as a topology optimised upright. Oxford Brookes came second with

This year, a higher percentage of cars passed scrutineering than ever before – so the bar was already set high

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its enhanced yet effective car impressing the judges, while Monash claimed third.

But, however impressive your car design is, if it can't deliver out on track then your Formula Student weekend is over. This is why success throughout the dynamic events, which in total accounts for 64 per cent of the overall score, is imperative in achieving a top place finish.

The first main dynamic event is Acceleration, where each car's acceleration is timed across a 75m straight and the top six take part in a final run off. Normally, electric contenders dominate this event due to the obvious advantage of constant torque throughout the speed ranges as well as only having one gear and typically four-wheel drive. But this year's top six was an interesting mix, with only the electric car from Munich making the final. Unsurprisingly, Munich still set the best time of the day, a 3.88s, followed by Poznan, Cardiff, Roma, Loughborough and Hertfordshire respectively.

Next up was the Sprint event, which features a 1km course to test the cars' speed in a straight line and during cornering. Munich topped the times with its best run clocking in at 52.16s, followed by the two Monash cars, combustion and electric respectively.

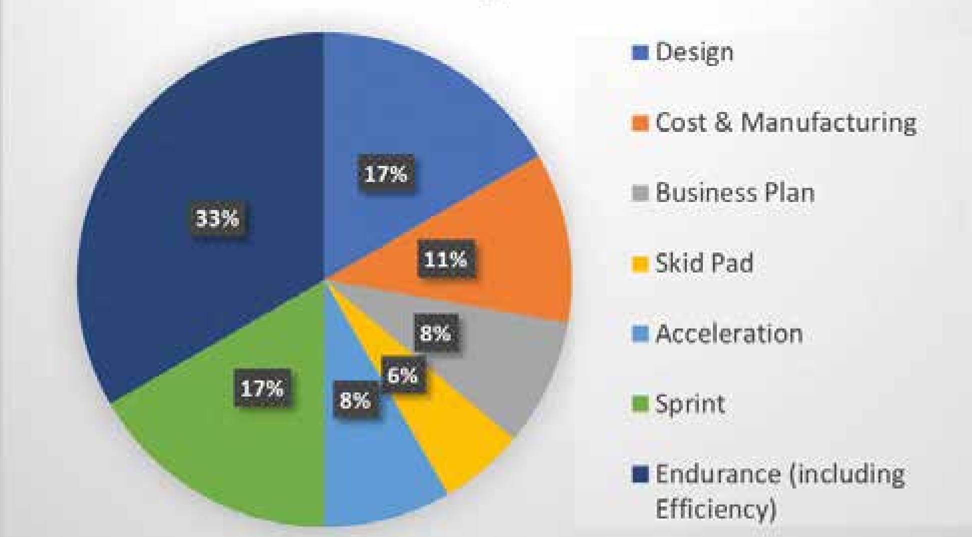
Endurance racers

The final dynamic event is Endurance, which is Formula Student's equivalent of a race. Here each car gets one chance to complete the course, with at least three cars on track at any one time. This brutal 22km circuit is a renowned car-killer and is unquestionably the teams' toughest challenge, and with a third of the overall points up for grabs the result of the Endurance test can either make or break your weekend. But it's not just about setting the fastest time – the main challenge the teams face is simply surviving. Not only does the car need to complete 22 laps, but it also has to tolerate a hot restart and a driver change, which is usually where the majority of cars fail and this year nearly 50 per cent of the teams who were at the start line did not cross the finish line.

Fall of Rome

Going into Endurance, Munich was favourite to win the overall event, with Monash, Oxford Brookes, Bath, Rome, Rochester and Hertfordshire competing for second place. Rome was one of the first to fail as its car stopped after only five laps. Hertfordshire

FSUK points breakdown



A breakdown of the percentage of points awarded at each static and dynamic event. The importance of Endurance is clear

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A certain Jenson Button was in the Formula Student UK paddock, lending his support to the teams backed by Santander

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Oxford Brookes claimed second overall, its best result in 20 years, but it was beaten to the top spot by the Monash ICE team

then experienced a sticking throttle which forced it into retirement after only six laps.

By mid afternoon only the big teams were left to run. Rochester started strongly, overtaking Loughborough, but soon after, a plume of smoke from an engine failure caused the car to stop out on track. Oxford Brookes then took to the track and was showing strong pace, although a sudden stop at the hairpin, causing traffic, suggested there was an issue, and there was. The car was stuck in third gear. But this did not stop the Oxford Brookes car and it completed Endurance whilst even overtaking its main rival, Bath, out on track.

Early Bath

Bath had been having a strong weekend, having fixed a gearshift issue the night before. However, at the restart, the car wouldn't shift into gear and the team exceeded the maximum allowable restart time, resulting in a DNF. The only teams left to run were the two Monash cars and Munich – and all three were out on track at the same time for a grand finale.

Munich, however, had problems; the initially impressive pace of its electric racer tailed off due to a lack of torque, costing it as much as 16 seconds per lap at one point. This led to both Monash cars overtaking Munich, leaving the Australians to fight it out between themselves.

Eventually, the combustion car caught up with its electric brother in the second stint and overtook it, but there were issues for the electric car as it struggled for power when accelerating out of the blue flag zone and again at the hairpin. However, that seemed to be the only issues it had, as both Monash cars completed Endurance, while Munich crawled to the chequered flag. This meant that Monash combustion topped the times, with its electric contender coming in second and Oxford Brookes finishing third. The competition favourites, Munich, finished down in 13th place.

Final result

As ever, Endurance shook up the field. Munich's issues out on track combined with Monash's strong performance meant that the Australian outfit claimed first place, making this its best result in an international competition ever. Oxford Brookes finished in second overall and was the top UK team, marking its best result in 20 years. Monash electric claimed third and Munich had to be content with fourth.

Overall, this year's competition was as exciting as ever, but more importantly it demonstrated a very high level of engineering talent that will progress into industry over the next few years – which is what the Formula Student platform is all about.

The brutal 22km Endurance circuit at Silverstone is a renowned car-killer and is unquestionably the teams' toughest challenge


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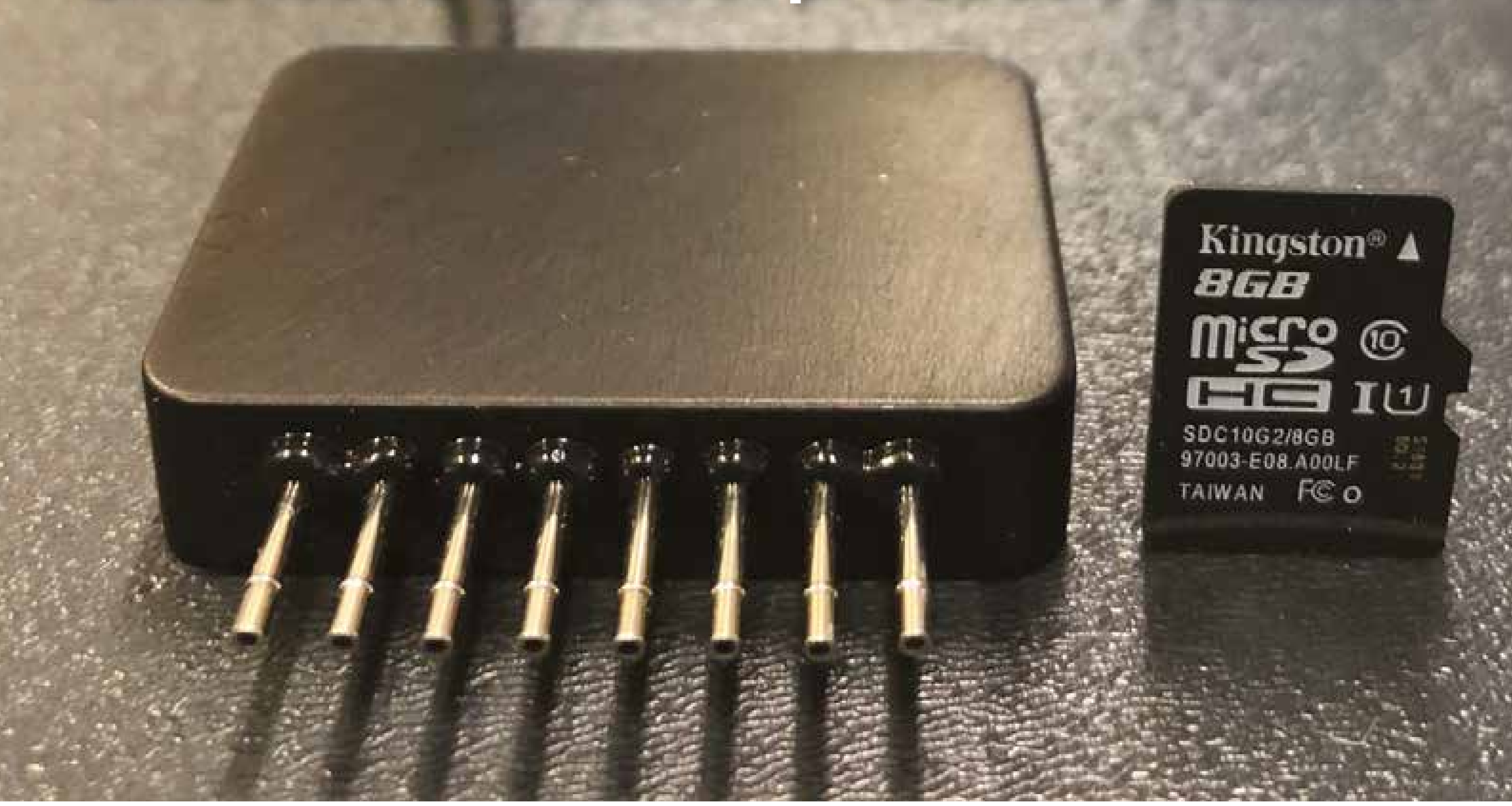

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Wizard of Aus'

Monash Motorsport brought two cars to Silverstone, one electric and one combustion, with the ICE car winning and the EV coming third. But, as *Racecar* discovered, it was testing that gave the Australian team the edge

By GEMMA HATTON

Monash Motorsport will be forever known as the team that pioneered aerodynamics in Formula Student. Its rich history of wings, diffusers and undertrays dates back to 2002, when it competed at FSAE Australia with its first aerodynamic package. That said, with it having access to a full scale automotive wind tunnel it's no wonder that Monash was the first team to not only introduce an aero package, but optimise it to prove a lap time gain. Its monster-winged car actually received a mixed response initially, but despite this Monash became a trendsetter and aerodynamics has revolutionised the competition ever since.

Some 16 years on and six UK competitions later, the Australian team was finally victorious in the UK. Its combustion car won the overall Formula Student UK competition this year at Silverstone, while its brand new electric contender came third – making this Monash's most successful international result ever.

Monash was a pioneer in the use of aerodynamics in Formula Student 16 years ago but it had to wait until this year for its first FSUK victory

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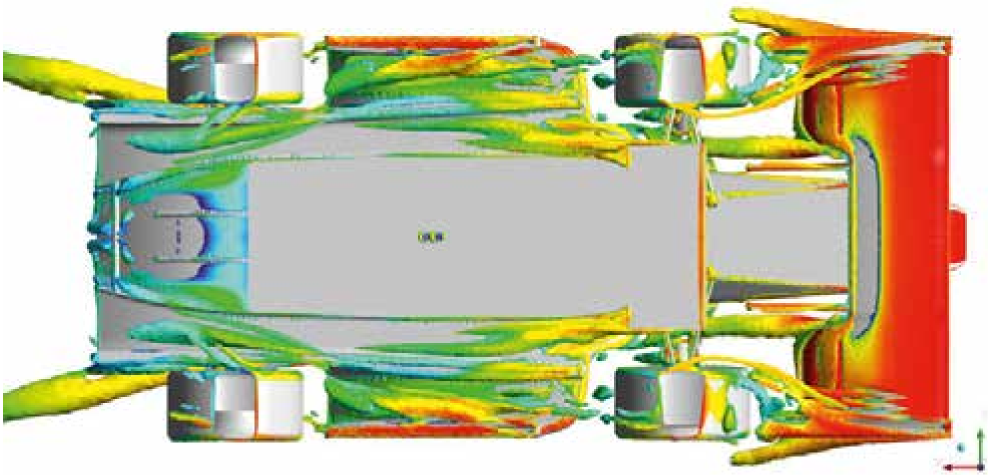
Gas and electric

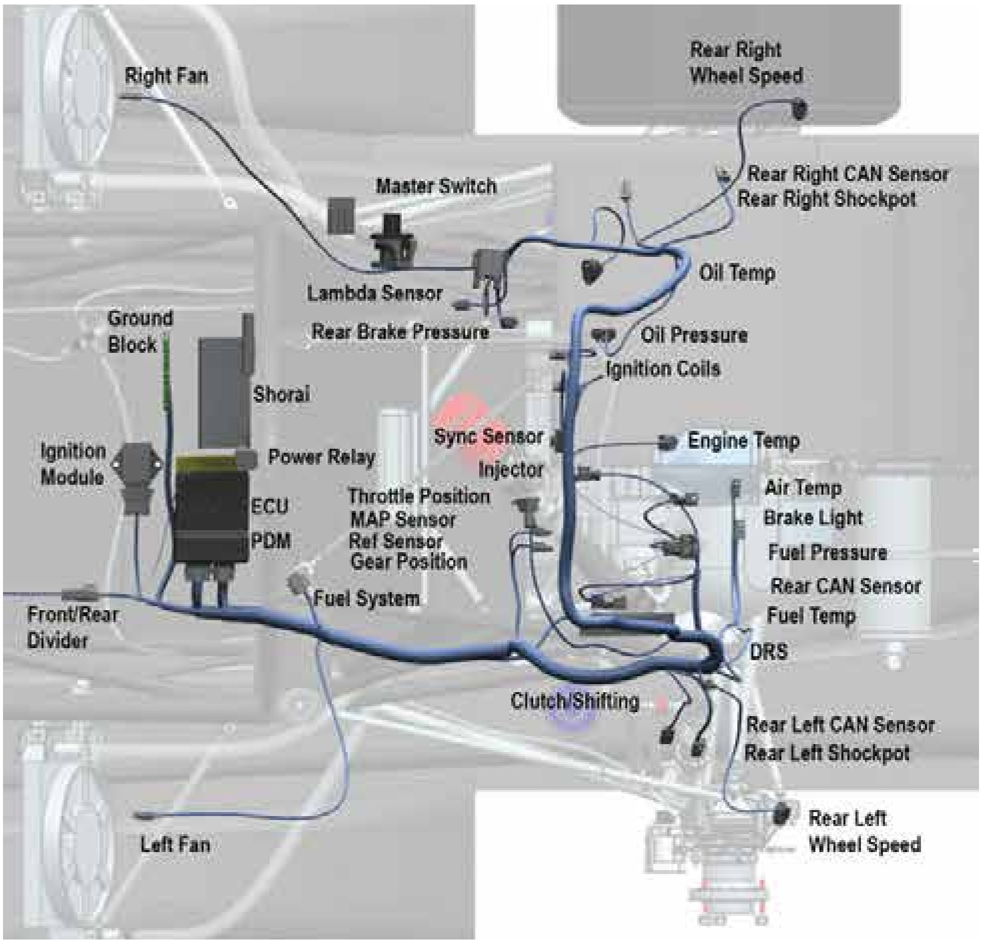
Monash took a new approach this year, flying to Europe with two cars rather than one; its M17-C combustion contender and its very first electric design, the M17-E. 'Our motto is "one team, two cars" and that is because almost everything is interchangeable between our combustion and electric car except for the powertrain packages. It's the only way we could do it,' explains Paul Hendy, lead CFD and aerodynamicist at Monash Motorsport. 'The chassis are almost identical. The only main difference is a front mount for the accumulator and the engine mounts. The engine plate has a few extra mounts on it for the electric car, but that just requires one machining operation. So we can have one spare engine plate that can go on either car, it just makes everything more efficient and we don't have the resources to split everything up and have two teams with two different cars.'

The suspension design is identical for both, then, aside from a slight variation in set-up to account for the additional weight of the electric car (273kgs compared to 208kgs for the M17-C). Both aero packages are the same, with only a few modifications to get around the rear motor



As well as spending 20 hours in the wind tunnel Monash also ran around 400 CFD simulations during development. Here we can see the Q-Criterion isosurfaces in Ansys, showing the vortices with the colour representing coefficient of total pressure

'Almost everything is interchangeable between our combustion and electric cars, except for the powertrain packages'



The M17-C's loom; this is an excellent example of the high standards of engineering required to succeed in Formula Student

Both Monash cars feature pneumatically-controlled DRS on their substantial three-element rear wings. Note large rear diffuser, too

'Our concept models were improving each year, but we were getting fewer points, so we had to revamp what we were doing, and so we focused on testing and going back to basics'

cage for the electric motor. 'However, going from a combustion only powertrain to both meant a much wider rear to the chassis. This is where we have gained a lot of aero in the past, by lifting the rear which allows for a big rear diffuser. So instead we introduced some aggressive side diffusers,' says Hendy.

The controversies surrounding Formula Student aero are twofold. First, there's the argument that on short and twisty tracks, the downforce is unnecessary due to the relatively low speeds. Second, it's said that it tempts teams with few resources to develop aero packages without fully understanding them, which goes against the purpose of Formula Student.

Testing focus

But this year it was not all about aero for Monash. 'We focused on maximising testing time because we found that our reliability and on-track performance compared to what our concept and models said we were going to achieve was declining,' says Hendy. 'Our concept models were improving each year, but each year we were getting fewer points at competition, so we had to revamp what we were doing and focus on testing and going back to basics. For example, we moved the front wing mounting from being sprung – which is complicated and requires lots of parts – to attaching it to the chassis, which is simple, stiff and ensures it is mounted at the right angle.'

TECH SPEC

Monash M17-C (combustion)

Chassis: Spaceframe with bonded composite panel floors, aluminium rear bulkhead; 1020 mild steel frame, 4130 chrome moly roll hoops; carbon fibre and Nomex honeycomb core panels.

Bodywork: Wet-laid carbon fibre reinforced polymer sidepods and nosecone, with integrated radiator ducting.

Powertrain: 2017 KTM 690 Duke-R; 102mm bore, 84.5mm stroke; 1-cylinder 690cc naturally aspirated unit running on 98-RON fuel.

Drivetrain: Spool driven differential.

Suspension: Front – double unequal length A-arm, direct acting. Rear – double unequal length A-Arm, direct acting, adjustable anti roll bar.

Aerodynamics: Double-element front wing and three-element rear wing. Drag Reduction System for rear wing, adjustable front wing.

Dimensions: Overall length, 2936mm; width, 1391mm; height 1185mm.

In terms of that testing, Monash completed 20 hours in the wind tunnel, approximately 400 CFD simulations and a total of 3400km of track running across both of its cars. Not only did this improve reliability and accumulate vast amounts of data for correlation studies, but this extensive testing programme also allowed Monash to discover a number of issues and then fix them before competition.

'We developed two pressure tapping systems, one for the track which runs about 16 pressure taps at 17Hz and another one which is still in development, so we borrowed one from the Monash Wind Tunnel which has 60 pressure taps,' Hendy says. 'We found that our CFD didn't model the radiators at all, so we put a lot of effort into using the pressure tapping system in the wind tunnel to help with the design of the cooling flow.

'We also used cobra probes to measure yaw flow angles on track,' Hendy adds. 'Throughout our cornering and straight line runs we noticed that the downforce dropped a lot during cornering as our mountings seemed to pitch the wing higher than desired. This demonstrated that the manufacturing and mounting of the wings can have a more dominant effect on downforce, and we only discovered this through testing, and not through CFD.'

Aussie rules

This ethos of maximising testing time actually drove areas of the design. For example, everything in the suspension was made adjustable such as the roll centres to ensure that the set-up could be accurately refined. Even the steering effort was designed to be low to minimise driver fatigue throughout a whole day's testing, whilst still heavy enough to provide the necessary feedback. All in all, both Monash cars dominated the UK competition because they were complex but reliable, and the approach was simple, but effective.

Technical studies

During FSUK *Racecar* patrolled the paddock to uncover the very best of the many technical innovations on show at Silverstone

By GEMMA HATTON

The designs at this year's FSUK event were as inventive as ever. Bespoke engines, dampers and uprights, and even a combustion four-wheel drive car, gave the judges plenty to consider

When you give a group of enthusiastic engineers the chance to design and manufacture a solution to win a competition, you are always going to end up with some fascinating designs, and at this year's Formula Student UK that was certainly the case.

One of the most memorable cars competing was the Sapienza Corse car from the University of Rome, scoring an impressive 142 points (out of 150) in Design. 'We are the only internal combustion Formula Student car that has an all-wheel drive transmission,' says Nicholas Longo, team leader and drivetrain manager at Sapienza Corse. 'The drivetrain was a completely unique design because we had to fit this system to a formula car. We devised a system with a central differential which is split left and right unlike the usual one which splits front to rear, and we have two propshafts; one on the left and one on the right side of the monocoque. This allowed us to use bevel gears at each end of the propshafts, so we achieved a three-to-one reduction ratio which lightens the stresses on the components, so we could use smaller and lighter parts.'

The nature of Formula Student tracks requires the cars to have good agility and fast

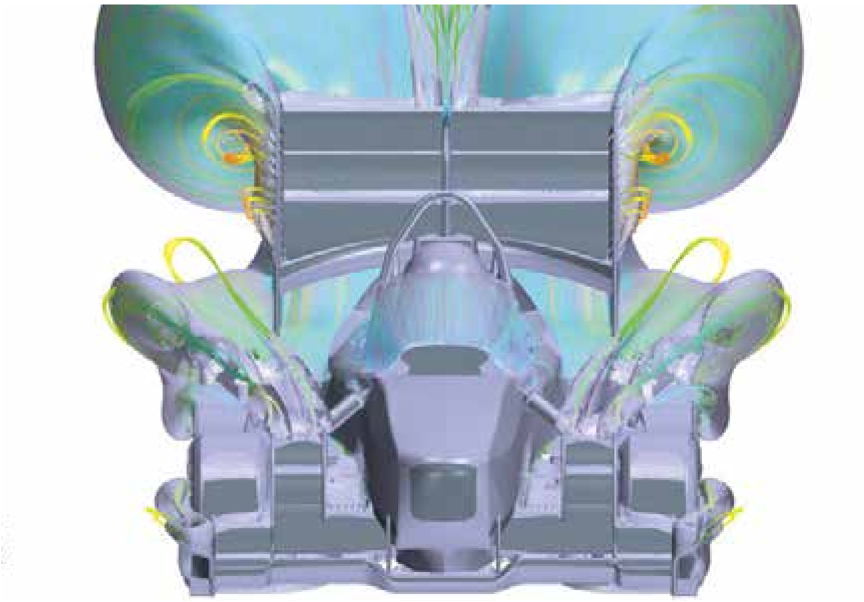
The nature of Formula Student tracks requires the cars to have good agility and fast acceleration

IMECHE FORMULA STUDENT

acceleration. The latter is optimised with 4wd, but to improve the car's agility Rome also incorporated torque vectoring. 'This is achieved through two slipping clutches, an electric actuator which actuates the disc so one clutch is connected to the right side, while the other clutch is connected to the left side,' Longo says.

Of course, with such a complex system, comes an increase in the number of

The Munich car featured plenty of advanced technology including topology optimisation to reduce the weight of its upright. It also made use of GKN metal additive manufacturing techniques to minimise the motor housing so to fit within the wheel hub



The Munich car features a very advanced aerodynamic package including DRS on the rear wing, a Formula 1-style shark fin, a monkey seat and a complex front wing and undertray

In addition to hydraulic interconnected suspension Edith Cowan's car features a beam axle and a heave spring at the rear

Edith Cowan produced many of its car's parts in-house including its own dampers, which are based on a design from Ohlins

Suspension design and set-up was yet another area which resulted in a vast array of solutions from the teams

components and therefore weight. In addition to positioning the three differentials next to the driver to minimise the effect on balance, the Rome team also used carbon fibre extensively throughout the design to try and account for this mass increase. The wheel assembly, for example, is entirely made of carbon fibre, including the uprights, hubs and rims. Carbon fibre was also used for the suspension arms which are actually flexible. The engine is longitudinally mounted while the team arrived in Silverstone this year with its first ever full aerodynamic package.

Unfortunately, a retirement during Endurance meant that Sapienza Corse finished the competition down in 20th place. However, it's car design was the talk of the paddock and even more impressive was the fact that the majority of the components were manufactured in house and by the students.

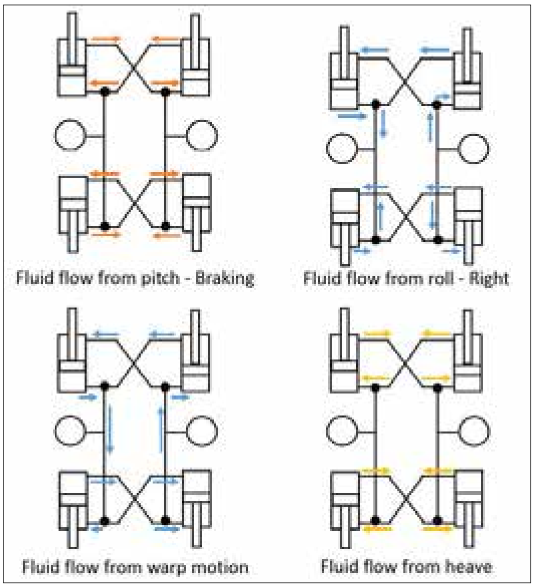
Gram prix

Another team that always arrives with a fascinating car is Munich, and this year was no different. You might describe Formula Student as 'Formula 1 cars, but made by students' and Munich's car is exactly that. This year's iteration features an impressive F1-style aero package including DRS, a monkey seat and a shark fin. The chassis is a full carbon fibre monocoque with an inventive powertrain solution and an award-winning upright design.

'We've really focused on light-weighting, our car weighs 156kg which I think is the lightest four-wheel drive electric Formula Student car,' says Julian Ratschiller, head of suspension at TU Fast from Munich. 'For example, we have built our very own silicon carbide inverter which has been a really big step for us. Our inverter weighs around 2.6kg, compared to 7kg if you were to buy one, so ours is much lighter. We also have carbon fibre rims that weigh only 800g, which is one of the lightest designs in Formula Student, and we have also changed to lightweight dampers for this year.'

Perfect package

Packaging has also been a key consideration; effective packaging of the accumulator has led to a very slim rear chassis and it's the same story for the suspension, uprights and powertrain.



A diagram illustrating how the innovative hydraulic interconnected suspension on the Edith Cowan car works for each of the modes

'At 90km/h, in theory our car will actually generate enough downforce to run upside down'

The all wheel drive wheel hub consists of an electric motor with a laser sintered aluminium body which was designed and developed by the students at Munich themselves. By using the GKN metal additive manufacturing technique, the motor housing could not only be optimised to fit within the wheel hub, but could also incorporate cooling channels to maximise efficiency. So, in effect, the electric motor is actually part of the chassis.

'In terms of overall downforce, we have a CLA of 6.8 which equals approximately 1100N of downforce at 60km/h, so at 90km/h, in theory our car will generate enough downforce to run upside down,' highlights Simon Biechele, aerodynamic team leader at Munich. 'The monkey seat we have is quite unique, it is actually part of the cooling system, so it guides the airflow coming out of the radiators and helps to create a low pressure zone on top of the radiator to help suck the air out.'

Munich, unsurprisingly, came first in the Design part of the competition, whilst winning the Sprint, Acceleration and Skidpad events. It was also awarded a prize for the most efficient car. Sadly, its Endurance event did not go quite as well and overall it finished fourth.

Interconnected

Suspension design and set-up was yet another area which resulted in a vast array of solutions. One of which was the hydraulic interconnected suspension system on Edith Cowan's car.

'The main purpose of this is to increase roll stiffness whilst reducing warp stiffness. Warp stiffness accounts for a higher mechanical grip than you might otherwise have without decoupling the suspension,' explains Bryson Murphy, head of suspension and manufacturing at the Australian based team.

'It also allows for a stable aero platform to maximise downforce,' Murphy adds. 'For example, the roll motion is governed by the pressure in the accumulators and this pressure acts as a gas spring, which enables us to tune the roll stiffness. The set-up of the lines in the system and how they are routed is what allows the accumulators to have minimal effect in warp and heave, but a significant effect in roll. Therefore, during cornering, the whole chassis doesn't roll, maximising the downforce of the aero platform in the corners.'

Custom made

The entire suspension system is made by the team in-house, including producing its very own dampers which were based on a variant from Ohlins. The only part that was carried over were the valves. This development philosophy applies to the engine too, which is a completely custom engine based on the Ducati 695.

'We carry over the heads and engine rotating assembly and the block is designed and cast by the students,' explains Murphy. 'The block is a single-speed powertrain with the ability to interchange an external gear to vary the gear ratios for each track. We decided to go for this custom v-twin because it decreased complexity and weight while maintaining torque at low rpm.'

Herts and minds

Hertfordshire turned up with an interesting rear wing design featuring DRS and an additional element forwards of the main arrangement. Simulation showed the aero package was worth a 'couple of seconds' around the Silverstone course

One of the most interesting rear wings at this year's FSUK was to be found on Hertfordshire's car. This featured three elements, DRS and an additional aerofoil situated in front of the main arrangement of elements. 'We had a target to increase the downforce by about 20 per cent on the rear end to give us a nice 50-50 balance, but we knew that increasing this would increase the drag so that's why we have implemented the DRS system,' explains Elliott Cook, team leader and drivetrain manager at UH Racing.

'The top element serves two purposes,' Cook adds. 'Firstly, it gives the rear wing more rigidity and it does actually produce a lot of downforce on its own. There's no point putting something on the car if you don't know how it works so we have tested with the aero kit on and off to see if there is any lap time advantage. Around this track [Silverstone] we gain a couple of seconds with aero. When we went out testing on a much shorter track we gained 0.8s per lap. These wings weigh about 3kg at the front and about 4kg at the rear so to be faster with that weight disadvantage clearly shows just how much downforce is produced.'

‘As a general rule of thumb the torsional stiffness of the chassis should be at least 10 times the stiffness of the suspension’

The chassis of Formula Student cars range from steel spaceframes to fully moulded carbon fibre monocoques, plus some interesting alternatives

Skeleton key

With chassis choice relatively free in Formula Student the debate over whether spaceframe or monocoque is best – or even some other solution – rages on. *Racecar* weighs up the pros and cons of each approach

By GEMMA HATTON

Humans have skeletons, and racecars have chassis. Although, unlike a skeleton, a racecar chassis can come in many different configurations and materials using a variety of manufacturing processes – this is particularly the case in Formula Student.

The regulations in Formula Student are relatively free, permitting teams to experiment with both metal tube spaceframes and composite monocoques. The only restrictions are that of the main hoop and its bracing which must be made of steel. This has led to some very interesting designs over the years, with some teams even arriving at the track with bamboo bodywork. As long as a team can prove that its material satisfies the required safety tests, and all the data is submitted to the scrutineers, it can race.

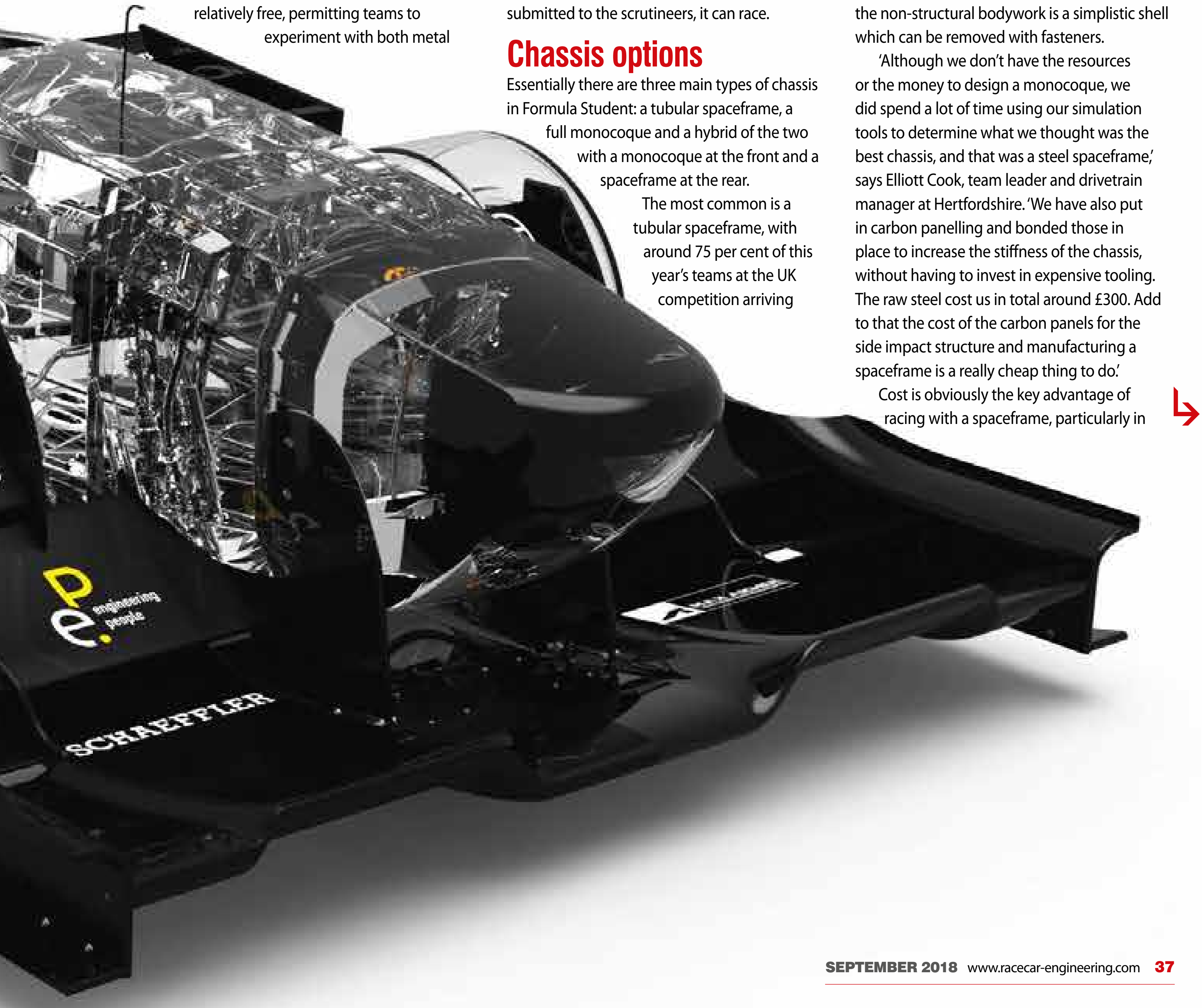
Chassis options

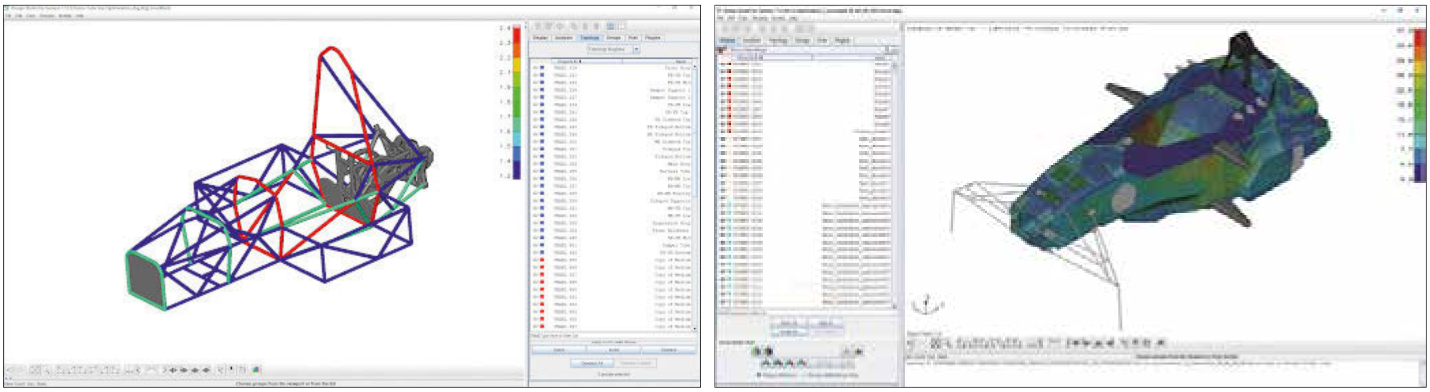
Essentially there are three main types of chassis in Formula Student: a tubular spaceframe, a full monocoque and a hybrid of the two with a monocoque at the front and a spaceframe at the rear.

The most common is a tubular spaceframe, with around 75 per cent of this year's teams at the UK competition arriving with one. This is typically made of mild steel tubes that have been welded together. The bodywork can be non-structural or structural with the latter consisting of composite panels such as carbon fibre reinforced plastic or aluminium skins with aluminium or Nomex honeycomb cores. These panels are permanently bonded to the steel tubes whereas the non-structural bodywork is a simplistic shell which can be removed with fasteners.

'Although we don't have the resources or the money to design a monocoque, we did spend a lot of time using our simulation tools to determine what we thought was the best chassis, and that was a steel spaceframe,' says Elliott Cook, team leader and drivetrain manager at Hertfordshire. 'We have also put in carbon panelling and bonded those in place to increase the stiffness of the chassis, without having to invest in expensive tooling. The raw steel cost us in total around £300. Add to that the cost of the carbon panels for the side impact structure and manufacturing a spaceframe is a really cheap thing to do.'

Cost is obviously the key advantage of racing with a spaceframe, particularly in





Steel spaceframes, such as this design from Warwick Racing in GRM Genesis software (left), are an effective solution for Formula Student. Full moulded monocoques, such as this Formula 1 example (right), are lightweight and have increased torsional stiffness. It is often the expense of the latter approach that drives Formula Student teams to opt for the former

Top: A fully moulded monocoque, shown here on the Bath car, can achieve a much smoother curved profile which can be more aerodynamically efficient. **Bottom:** A car that makes use of a folded monocoque can have a more boxy appearance

a student competition where the resources at some universities can be extremely limited. A spaceframe is also relatively simple to design and manufacture and any modifications required during testing and competition can be easily achieved through a few simple welds. A monocoque, on the other hand, requires re-manufacture if damaged.

Stiff test

Yet despite the teams' efforts of bonding composite panels to a spaceframe to increase chassis stiffness, this is by no means the optimum solution. Martin Ogilvie, former Formula 1 car designer with Lotus and the mastermind behind cars such as the Lotus 92, explained why when he visited Warwick Racing earlier this year. 'As a general rule of thumb, the torsional stiffness of the chassis should be at least 10 times the stiffness of the suspension. For a spaceframe, ideally you want 2000ft.lbs per degree and that is very difficult to achieve on a Formula Student car due to features such as the high rear roll hoop. Whereas with an aluminium or carbon honeycomb chassis you are much better off. For example, you can build the chassis up to the roll hoop, which is by far the strongest part of the car.'

Trying to increase the stiffness of a spaceframe is a challenge as it usually results in increasing the weight, which is a major disadvantage, particularly when spaceframes are relatively heavy structures to start with. Alternatively, teams can fall into the trap of focusing on a lightweight spaceframe, which can actually be designed to achieve a similar weight to a monocoque, but of course it will have compromised stiffness.

Hot tubs

This is why the teams that can afford it choose a full moulded carbon fibre monocoque, because this allows them to create a lightweight yet stiff chassis. Furthermore, teams can adjust the angle of each ply during layup, as well as the number of plies to tune the strength of their monocoque to their specific requirements.

'We have improved the layup of our carbon fibre monocoque and now we think

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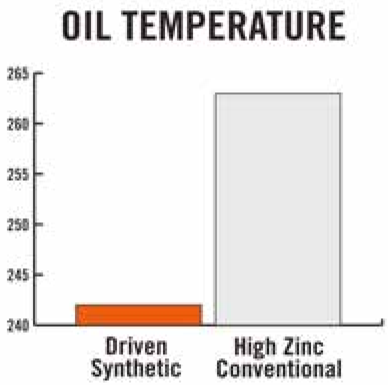

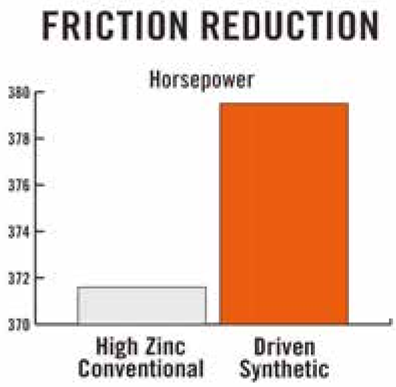

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Cost is obviously the key advantage of competing with a spaceframe chassis, particularly in Formula Student

we have one of the stiffest chassis,' says Julian Ratschiller, head of suspension at Munich. 'With a monocoque you are also more free in terms of packaging, particularly for an electric powertrain such as ours. In our opinion, if you want to manufacture a good aerodynamic car, then you have to go for a monocoque rather than a steel spaceframe.'

Cut and fold

Manufacturing methods can often play an important role in improving performance, especially when it comes to the development of the chassis. For those teams who wish to design and make a monocoque, but don't have the necessary resources to make moulds and undertake a full composite layup, there is an alternative; the cut and fold technique, which several of this year's teams have opted for.

This process starts with a large sheet of aluminium honeycomb with either aluminium or carbon fibre skins bonded on either side. A CNC machine mills out grooves corresponding to the flat template of the chassis. The width and number of these grooves dictates the bend radius and bend angle required. This machining process does not penetrate all the way through the material. This therefore allows the honeycomb to bend along these grooves, creating each side of the chassis – similar to how cardboard boxes are folded together. The assembly is then secured through a series of jigs all held together with ratchet straps. The joints are then glued and left to set. Once cured, the inside of these joints can then be reinforced with additional material such as wet carbon layup or folded aluminium sheet, depending on the skin material, for increased strength.

Cut and fold is a cheaper alternative to making moulds and doing a full composite layup. This is Edith Cowan's pattern for its monocoque. Note where the carbon fibre skins and the honeycomb have been CNC routed to allow the material to bend

Once bent into shape the material needs to be accurately jigged and held together with ratchet straps while the glue cures, otherwise the chassis can move during the curing process which could result in inaccurate suspension mounting points

'The trick comes in the actual folding,' Ogilvie says. 'Obviously you need a gap at the joint which then closes up to zero when it is folded. Therefore, each gap has to be tailored to a different width which is another challenge. The really difficult debate is how deep the groove is. If you groove it right down to the bottom and take all the honeycomb out, then it tends to kink once it has been folded, but if you leave some of the honeycomb in, then it won't fold. It is a very difficult compromise, that is even more difficult with carbon fibre skins because the carbon tends to be too stiff.'

Skin in the game

Despite this, carbon fibre skins seem to be the preferred choice for those teams exploiting the cut and fold technique. 'Our monocoque is made up of two carbon fibre reinforced skins with a Corex aluminium honeycomb in the middle and we essentially have three panels; the floor and the two sides,' explains Joseph Jones, business development manager at Oxford Brookes. 'Bending carbon fibre is not always easy because as everyone knows, it is very brittle. However, we can manufacture our whole monocoque in house, by ourselves, although it is a labour intensive and time-consuming process. We developed this technique back in 2014, where our monocoque had a carbon skin on the inside, and an aluminium skin on the outside. In 2016 we moved to carbon skins for both and have been refining the manufacturing process ever since.'

The main benefit of the cut and fold technique is that it requires minimal tooling and machining, as the jigs can be made out of MDF or metal, and there are no complicated tooling blocks. These cost savings allow teams to then pump more resources into other design areas of the car to improve performance.

Accurate jigs

On the other hand, there can be issues with the accuracy of the folds, joints and the suspension mounting points. If the chassis is not jigged effectively during the bonding process, then the joints and therefore the chassis can move around as the glue cools back down to room temperature, which is where the inaccuracies can begin to creep in. For example, this can result in misalignment of the wheelbase, track width and wheel alignment, all affecting the overall suspension geometry.

'Our jigs are made of CNC routed wood and laser cut metal, so the jigs are quite accurate,' says Ross Marais, head of manufacture at Oxford Brookes. 'Throughout the jigging process we took a lot of measurements, consistently

‘If you want to manufacture a good aerodynamic car, then we believe you have to go for a monocoque rather than a steel spaceframe’

Despite the challenges of folding carbon fibre this seems to be the preferred solution for some teams, including Oxford Brookes which uses carbon fibre skins and aluminium honeycomb as shown here: top image is front and bottom is rear

re-checked them and also compared it to our CAD data so that we could try and transfer the accuracy of the jig over to the folded monocoque. The variances in our kinematic points between CAD and the real monocoque were very small. I think our biggest difference was one point which was approximately 5mm different, but we were able to deal with that because we had good communication with the suspension team so that they could adjust the wishbone geometry accordingly.’

Mounting rescue

Another benefit to a monocoque is the freedom to mount the suspension in the optimum position. A fully moulded monocoque allows complete freedom with this, whereas a cut and fold monocoque requires the suspension to be mounted away from any folds. A spaceframe, on the other hand, is extremely limiting in terms of suspension design because there are set points, called nodes, to which the wishbones, springs and dampers have to be mounted for structural integrity. These nodes are typically the triangulation points where several bars are joined together. This therefore restricts the region on the chassis in which the suspension elements can be attached whilst maintaining an efficient design.

In terms of the actual fixtures, again this is yet another area where there are both pros and cons. Physically attaching the suspension mounting points to the middle of a honeycomb panel can be a challenge, especially if the honeycomb sheet is already bonded to the skin. This typically requires complex inserts which act as local reinforcement to avoid crushing the composite panel. These inserts again need to be accurately jigged while the glue cures in order to maintain the desired suspension geometry. A spaceframe, on the other hand, does not require any additional reinforcement, therefore the suspension brackets can be welded on at any time.

Space race

Overall the optimum chassis solution will always depend on the available resources of each team. Like anything in engineering, there is no point in doing something if you can’t do it well. Monocoques, whether moulded or folded, require an extensive amount of research to ensure the manufacture is carried out accurately to capitalise on its lightweight and torsional stiffness benefits. On the other hand, a spaceframe will continue to be a reliable, effective and cheap way of constructing a chassis, and therefore these will continue to dominate Formula Student grids.

Hot and bothered

Solving the problems of cooling a hybrid-powered car has been one of the major challenges of the current Formula 1 era, but thanks to genuine F1 team blueprints *Racecar* has been able to piece together the complex thinking, and plumbing, that goes into the design of these systems

By SAMUEL COLLINS

If you walked around to the bin stores at any F1 team's factory (and a few WEC facilities too) in late 2013 or at any point in 2014 you would have found the metal waste hoppers overflowing with scrapped radiator cores. It was a sign of the biggest shift in grand prix car cooling system design in decades, if not ever.

Today, cooling system layout and optimisation remains a crucial part of the design of every single car on the grid and is a constant area of study. The bins at the back of the F1 teams factories are still quite full, if not overflowing as they were four years ago. This article looks at the cause of those overly full bins – the process of the design, development and optimisation of a current F1 car's cooling system. It draws on two main sources of information. *Numerical Simulation of a 2018 F1 Car Cooling System for Silverstone Circuit* is a technical paper by Victor Tizon Otero and Stephen Samuel of Oxford Brookes University, which was presented at the WCX SAE World Congress Experience in early 2018. The second source of information is a set of internal design documents from the defunct Caterham F1 team, which detail the development of the 2015 Caterham CT06. This is the first time such detailed information has ever been published on a modern grand prix car.

When you look at any competition car (or indeed any car) you will quickly note that there are several sources of heat and those all need to be cooled to some extent. All of these sources can be gathered into two main categories; those that only need to be cooled, and those that not only have to be cooled but also have to have their temperature controlled and maintained between the proper operational boundaries.

One source of heat that does not need an accurate control of its temperature is the racecar's braking system. This system only needs to be cooled to keep its temperature below the operational limit of the materials in which the different components of the system have been manufactured.

But falling entirely within the category of a source of heat which needs its temperature to be controlled is a Formula 1 power unit. Every single component needs to be kept under strict thermal control. The complete power unit consists of the internal combustion engine (ICE) and the hybrid system. The hybrid system is made up of a number of core components; the motor generator unit-heat (MGU-H) and the motor generator unit-kinetic (MGU-K), an energy storage (ES) as well as control units for each (CU-H, CU-K and CU-ES).

ICE cool

The main source of heat the cooling system has to manage is the internal combustion engine. The cooling of the engine is against the thermodynamic efficiency; the cooling system extracts heat from the combustion chamber that could be used to increase the pressure within the cylinder to extract more work from the engine. However, the cooling system is mandatory in an internal combustion engine due to the limits that materials composing the internals of the engine have regarding higher temperature. Above certain temperatures, these components would fail, so their temperature has to be kept under safe conditions.

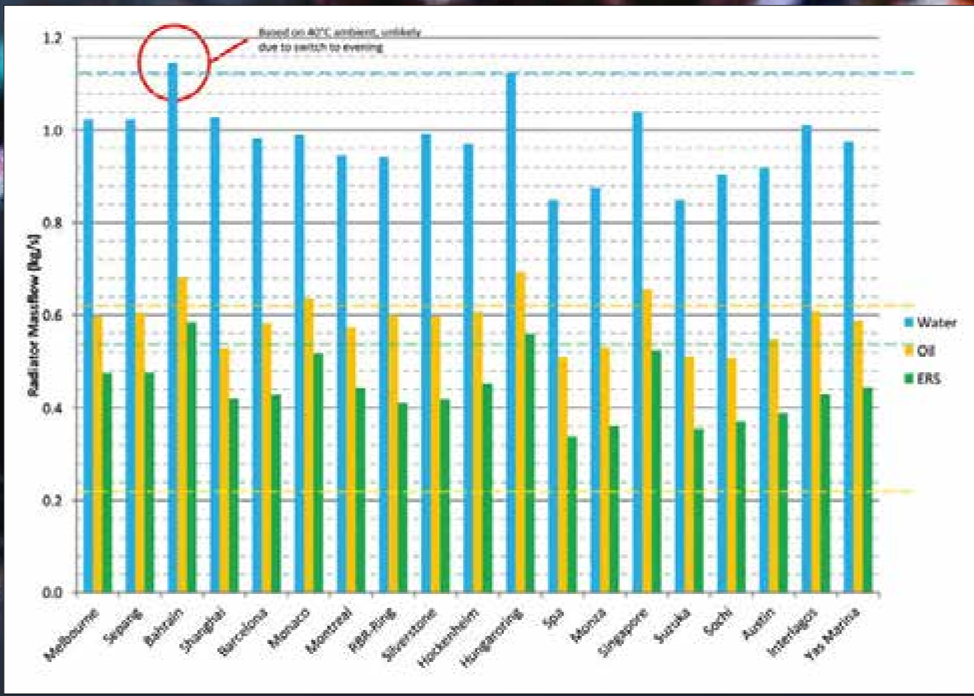


Figure 1: The first step was to map out the expected cooling demands over a season, including the extreme temperatures

While the cooling demands for a combustion engine are well understood, those for a hybrid system are far more complex

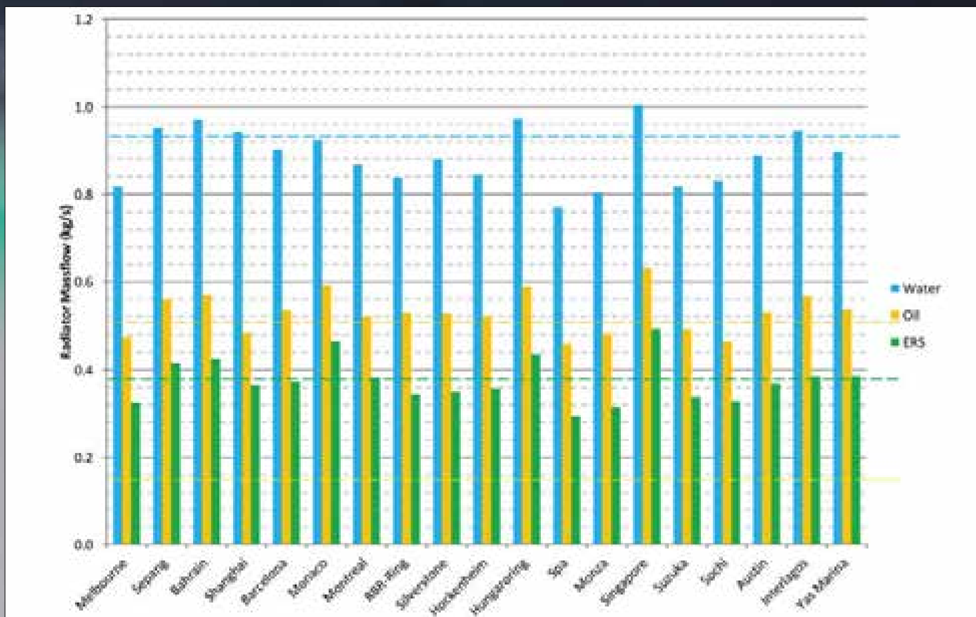


Figure 2: The average conditions were also analysed. Both sets of data were then used to create the cooling specifications

In addition, oil loses its lubricating properties when the temperature is higher than around 175degC, thus increasing wear of engine components and maybe leading to premature failure of the engine. DLC (diamond-like carbon) coatings and other treatments play a role here in reducing friction and, in turn, heat. Another area where DLCs help is in the transmission – which also has a cooling demand, though significantly lower than the power unit components.

Cool for CADs

The design of a cooling system for a Formula 1 car is a demanding task that has to be carried out following all the regulations that govern the sport. In addition to the specific regulations for the cooling package which place restrictions on some materials, for example, its design has also to take into account the regulations of other components of the car since they interact and transfer thermal energy across the systems. For instance, the maximum pressure a pump can deliver or the maximum energy that the battery can hold can change the overall heat addition or rejection quantity. So one of the first challenges is to model the associated parts and components in order to assess the thermal performance of the complete vehicle.

As mentioned, the main source of heat for the cooling system is the 1.6-lire V6 engine. The heat transfer takes place via two main fluids. The main coolant is the water, the fluid in charge of removing excess heat from the cylinder and the head. The second fluid is the oil, used mainly to lubricate engine components like the pistons, the camshaft and the crankshaft, but also to remove heat from pistons, the turbocharger and other engine components. Additionally, the fuel used also has a cooling role.

But this challenge is nothing new and combustion engine cooling systems have been refined and optimised ever since Mr Benz first fitted a reciprocating combustion engine to a car in 1886. That said, a challenge not quite as old, and very new to motor racing, is cooling a hybrid system alongside the combustion engine. This was the reason behind the piles of experimental cooler cores found in those bins mentioned at the start of this piece.

With many more sub-systems requiring cooling than before one of the first challenges that the Formula 1 teams had to understand in the run up to the introduction of the new power units in 2014 was actually working out what the cooling demands really were.

For Caterham, the starting point for this was analysing the weather data from the race circuits that are visited by Formula 1 over the course of a season, with the weather extremes mapped out **(Figure 1)** along with the average conditions

	$V_{average}$	T_{air}	W	O	E	G	T_{air}	W	O	E	G
Melbourne	53.57	36	0.994	0.647	0.410		23	0.800	0.506	0.295	
Sepang	50.85	36	0.994	0.657	0.411		32	0.928	0.604	0.367	
Bahrain	52.54	40	1.110	0.744	0.491		31	0.944	0.613	0.375	
Shanghai	51.91	30	1.000	0.567	0.373		25	0.920	0.517	0.331	
Barcelona	49.52	30	0.956	0.625	0.380		25	0.832	0.570	0.337	
Monaco	40.73	27	0.990	0.682	0.461		23	0.904	0.632	0.418	
Montreal	53.18	33	0.928	0.636	0.399		28	0.854	0.575	0.351	
RBR-Ring	56.92	29	0.932	0.646	0.366		22	0.832	0.565	0.312	
Silverstone	51.93	29	0.964	0.650	0.376		22	0.860	0.569	0.320	
Hockenheim	55.11	34	0.956	0.667	0.401		26	0.834	0.567	0.327	
Hungaroring	49.78	36	1.070	0.754	0.483		28	0.932	0.638	0.388	
Spa	60.38	25	0.798	0.534	0.301		19	0.726	0.480	0.265	
Monza	64.37	31	0.828	0.566	0.316		26	0.762	0.512	0.280	
Singapore	45.70	32	1.012	0.708	0.461		30	0.978	0.680	0.437	
Suzuka	57.50	28	0.822	0.560	0.324		26	0.796	0.539	0.309	
Sochi	53.38	26	0.882	0.542	0.333		21	0.814	0.495	0.299	
Austin	51.12	26	0.882	0.601	0.357		24	0.854	0.579	0.341	
Interlagos	53.86	28	0.960	0.654	0.383		24	0.898	0.606	0.348	
Yas Marina	50.95	31	0.934	0.640	0.397		26	0.860	0.580	0.350	

Figure 3: Flow rates. *T-air* is ambient temperature, *W* is flow rate required by water coolers, *O* for oil coolers and *E* for ERS

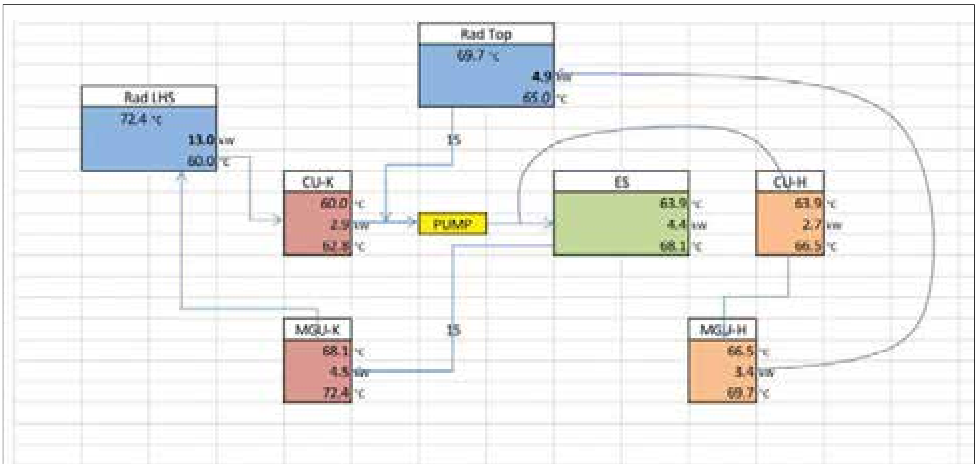


Figure 4: In first ERS cooling circuit devised by Caterham the small central cooler would feed the control unit for the MGU-K

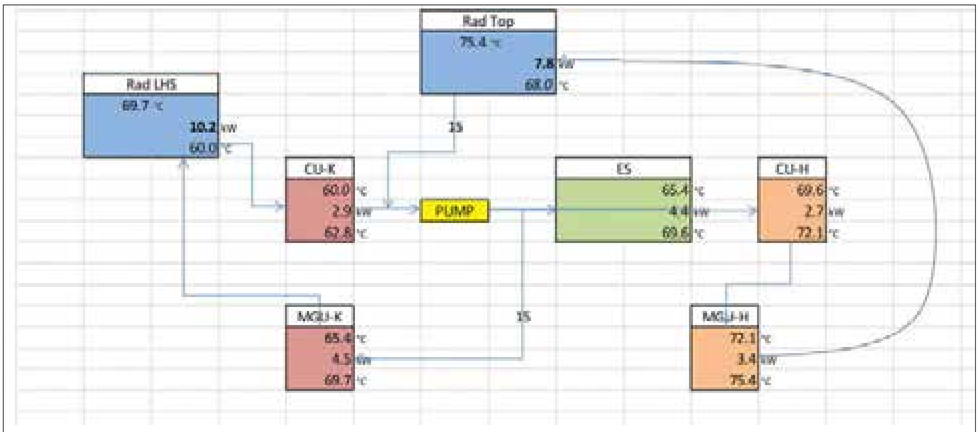
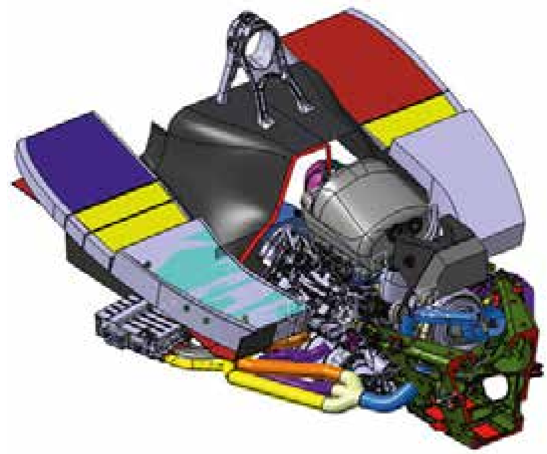


Figure 5: Team looked at integrating energy store cooling into the MGU-H circuit and making greater use of centreline cooler



The final Caterham CT06 cooler layout. Two charge air coolers with ERS and oil and water coolers are on the left side, water cooler on the right. The gearbox cooler is above the turbocharger

This is the first time such detailed information has ever been published on a modern grand prix car

(**Figure 2**). This data was then used to create both a maximum cooling specification and a baseline cooling specification, as well as the bodywork options for the racecar.

A design report on the car states: 'For the maximum cooling specification one has to look at the extreme weather predictions as well as the average and consider the likeliness of the extreme weather to be occurring and whether there are other ways of reducing temperature (at the cost of performance obviously). Once established, these massflow numbers can be used to size the radiators needed (based on expected maximum possible massflows from an aero point of view). For the baseline cooling specification one needs to consider on how many circuits one does accept an aero penalty for average conditions.'

Packing heat

Another factor which Formula 1 teams have to consider is the maximum operational temperature of various components. A typical 2015 Formula 1 power unit had the following maximum allowable temperatures for the various components in the power unit. The control units ranged from 60degC to 75degC, the MGUs around 85degC, and the energy store was between 73degC to 85degC.

Additionally, the fluid temperatures in various systems are often defined by the power unit supplier. This is all factored in to allow for a cooling circuit (or indeed circuits) to be laid out and the various coolers sized and positioned in the car, as well as the various airflow requirements for coolers within the system. Those flow rates can be seen in **Figure 3**. Here the extreme conditions are shown in red and the average conditions are in blue.

Based on the maximum flow rate for water at Singapore (1.01kg/s @ 32degC) and the Hungaroring (1.07kg/s @ 36degC) a maximum flow rate for the water coolers was set at 1.02kg/s, similarly for oil (0.71kg/s at Singapore and 0.75 kg/s at Hungaroring) a maximum of 0.72kg/s was set. In terms of the ERS the maximum was set at 0.47kg/s.

While the cooling demands for a combustion engine are well understood, the demands of a hybrid system are far more complex and required a lot more investigation than would

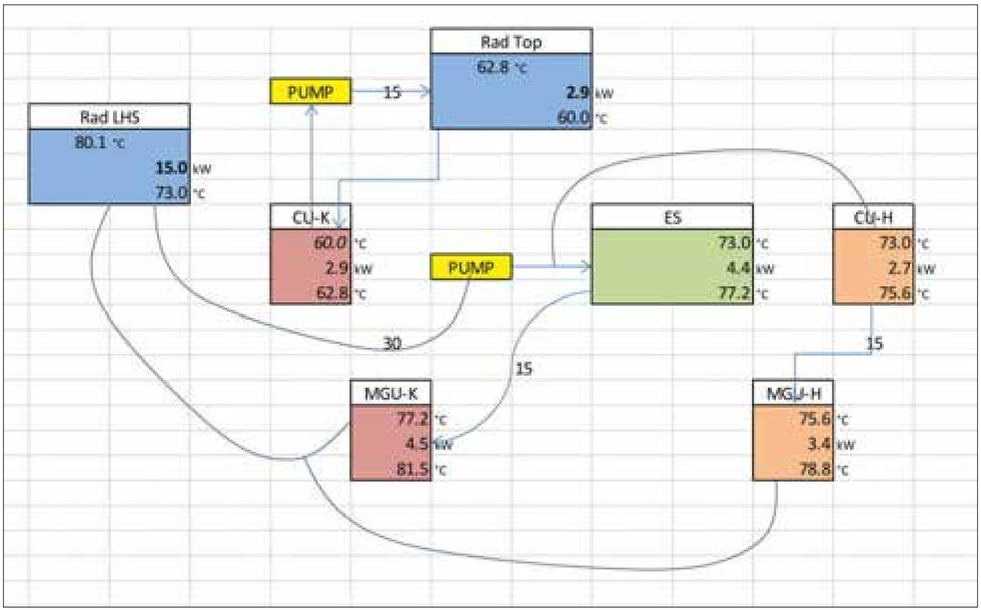


Figure 6: A second pump was added to serve the CU-K and this was to be fed via a cooler on the centreline of the racecar

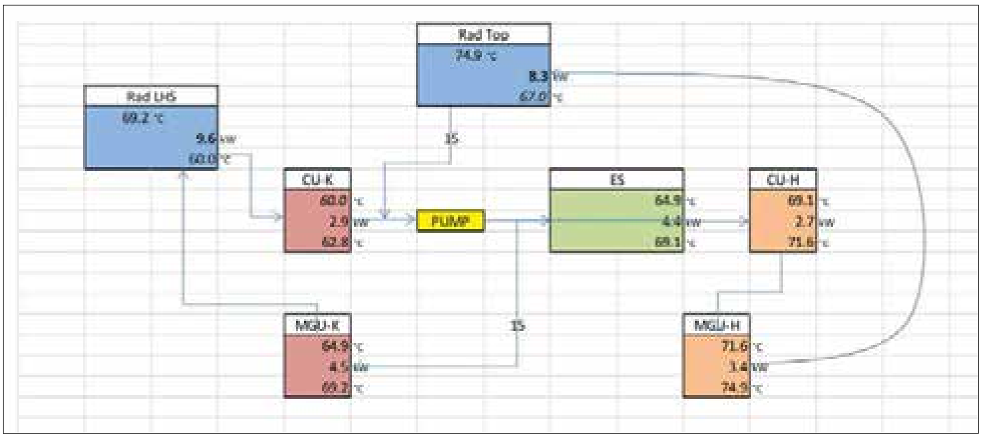
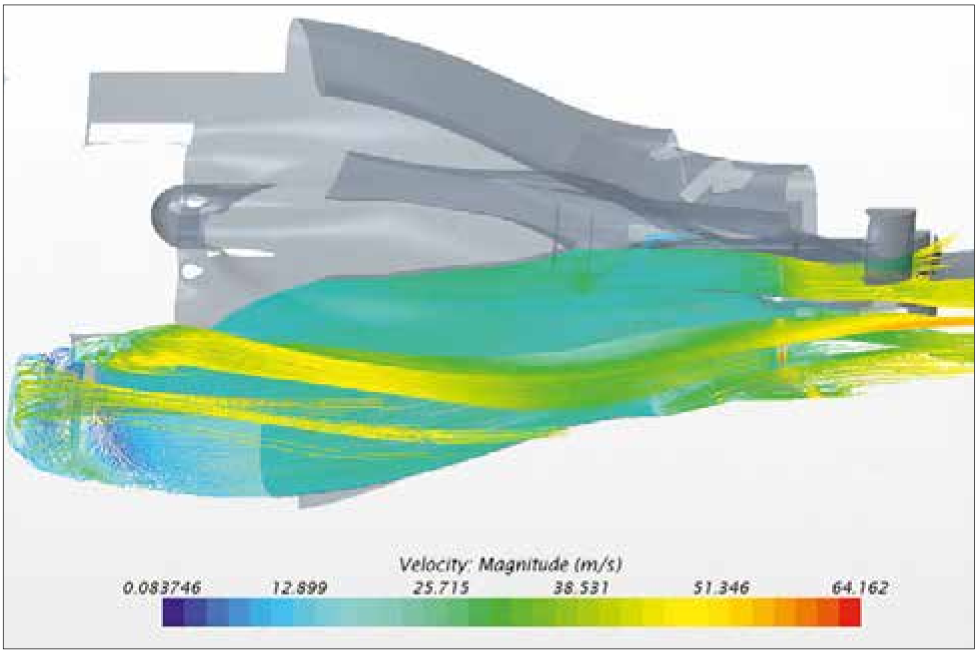


Figure 7: The single pump would have been workable but the demands of the oil system and ERS cooling counted against it



Airflow under the body and through sidepods was calculated in CFD to ensure adequate flow and a good level of efficiency

usually be conducted by a Formula 1 team. As a result, one of the first cooling circuits to be laid out was the ERS cooling, and this was to utilise a heat exchanger in the left hand side sidepod as well as a smaller centreline cooler. The sidepod duct circuit would cool the energy store, both MGUs and the control electronics for the MGU-H. The small central cooler would feed the control unit for the MGU-K **(Figure 4)**.

Chill out

However, this layout was found to place a high demand on the left hand side radiator, so to overcome this the team looked at integrating the energy store cooling into the MGU-H cooling circuit and make greater use of the centreline cooler **(Figure 5)**. But simulation suggested that while this layout would likely work for the average circuit temperature demands **(Figure 3)** it would struggle to meet the demands in the extreme conditions, it would also be a struggle to get adequate cooling from the centreline cooler. The issue was felt to be the low temperature requirement of the MGU-K control unit, which essentially caused a bottleneck in the system.

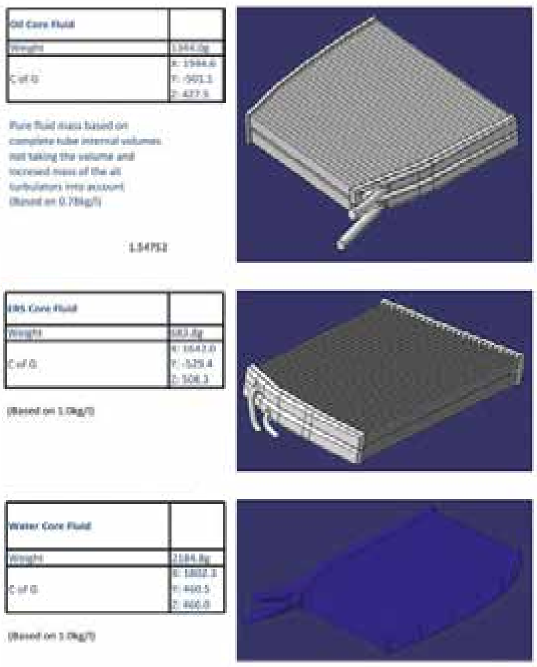
To get around this a second pump was added to the system, primarily to serve the CU-K, and would be fed via a cooler on the centreline of the racecar – the additional pump would also have the benefit of reducing the airflow requirement of the centreline cooler (**Figure 6**). This layout would allow the CU-K to run at a cooler temperature while the other components would be able to run hotter, reducing the size of cooling apertures across the racecar.

Pump action

However, there was still interest in a single pump layout and both the twin and single pump layouts were re-evaluated at a higher ambient temperature, but it was found that while the single pump solution would be workable the demands of the oil system and the ERS cooling could create a significant aerodynamic penalty **(Figure 7)**. The double pump layout was found to still require less air flow into the centreline cooling duct, but made little difference in terms of the size of the sidepod duct and ultimately this layout, the same as **Figure 6**, was adopted.

Once the layout had been confirmed the attention then shifted on to the coolers themselves. A set of design targets were established, not only based on the pure cooling demands of the power unit but also on the racecar's overall aerodynamic goals. Additionally, the weight of each of the components was also tightly monitored.

The issue was the low temperature requirement of the MGU-K control unit, which essentially caused a bottleneck in the system



A set of cooler design targets was established and this was not only based on the pure cooling demands of the power unit but also on the racecar's overall aerodynamic goals. Meanwhile the weight of each component was also monitored (above)

The final design called for the mounting of a double pass charge air cooler in the left sidepod along with a double pass oil cooler and the ERS cooler. In the right sidepod a second charge air cooler would be installed (though of different dimensions to the one on the opposite side) along with the engine water cooler.

The transmission cooler would be mounted above the turbocharger and fed from the centreline of the car. After a substantial amount of optimisation of the coolers the weight of the entire cooling system for the car was brought down to 16kg. The Caterham CT05 had a cooling system weight of over 30kg, so the 2015 Caterham would have seen a substantial saving, had it been completed.

Out in the cold

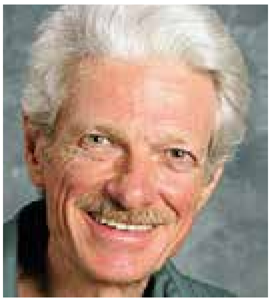
But that's the sad part. Ultimately, how effective this system would have been was never determined as the CT06 was never constructed because the team collapsed during the 2014 season. It is fair to say, however, that the complexity of cooling systems has increased substantially since 2015, with a significant shift toward centreline cooling, largely for aerodynamic reasons, and with more coolers and elements added to the systems.

Perhaps the most complex layout on display in 2018 is that of the Sauber C37 (see *Racecar Engineering* June 2018, V28N6), which is equipped with a multitude of different circuits and coolers. This has been done for one overriding reason – aerodynamic performance. Indeed, the cooling system is a major challenge for the aerodynamic performance of the car and it is constantly adjusted and optimised. It is also one of the few areas of an F1 car which can be developed outside of the perimeter of restricted aerodynamic testing, so the amount of development is substantial.

Playing it cool

The use of thermal barrier coatings on the inner surfaces of the car bodywork has seen the cars almost shrink-wrapped around the power unit at the rear, and climate specific aerodynamic packages developed. But the teams still struggle to get the heat out, scorch marks still appear on bodywork and extra ducts and outlets have to be added at hotter circuits. All of which create an aerodynamic penalty for the overall car. So the never ending cycle continues, with testing optimisation and development, and all the while cooling systems offer a significant potential performance gain.

The use of thermal barrier coatings on the inner surfaces of the body has seen the cars almost shrink wrapped around the PU at the rear



Axle of evil: taming the tail happy Lagonda

How De Dion and Mumford will help to fix our troublesome classic

In the last instalment of *The Consultant* (July issue, V28N7) I promised an actual design proposal, at least as a fairly detailed concept, to convert the swing axle suspension on the snap-oversteering late 1940s 2.6 Lagonda road and track day car we have been looking at to a De Dion system. But this proved to be a bit more challenging than I anticipated, but I do at least have something drawn now.

I wanted to make this a bolt-in conversion, so that the car could be returned to original configuration if desired. This helps preserve the resale value of a rare vintage car. I also wanted to provide at least three inches of suspension travel in both directions. And I wanted a minimum of bump steer and a low enough roll centre so that the suspension would not generate judder in hard cornering.

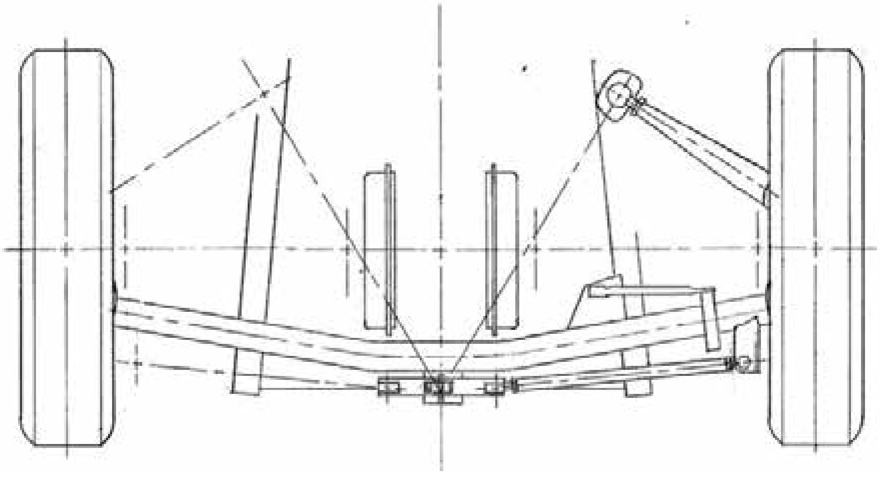
Mumford and some

My first thought was to use a Watt linkage with the rocker lying flat. However, due to the fairly tight lengthwise space that was available, the rocker would have had to lie under the De Dion beam. That would reduce the space available for the beam to move in droop. If the rocker were vertical, behind the beam, the roll centre would be higher.

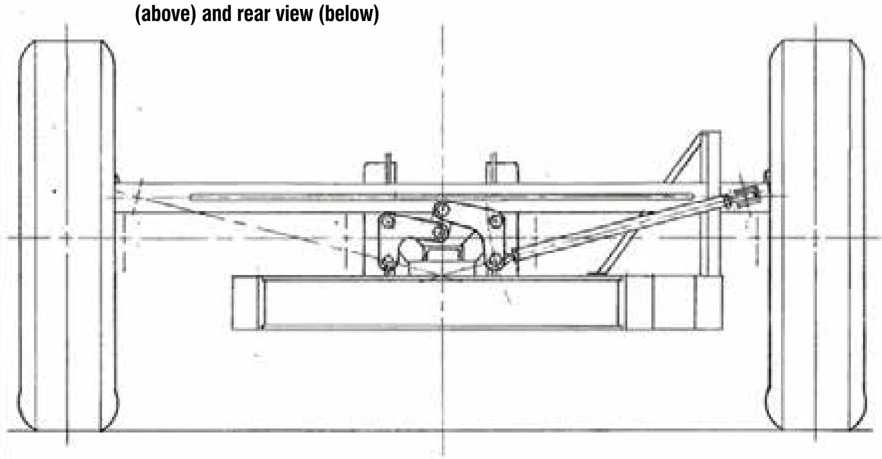
So, to get the lateral locating linkage behind the De Dion beam and at the same time get a lower roll centre, I have gone to a Mumford linkage. This is shown in top view and rear view on this page. The beam is of 2.25in outside diameter, .25in wall tubing, with a .50in wide slot milled through the back wall after bending. The tube should also have at least two small drainage holes drilled through the bottom.

The outer links of the Mumford linkage are tubular with spherical rod ends (heim or rose joints). The two rockers, the short centre link, and the stand that supports the rockers are machined from solid, in steel. Pivots are cylindrical bushings, nylon or bronze.

The rocker assembly bolts to the pedestal on the rear cross-member where the rear legs of the stock swing arms attach. There are six bolt holes there. The De Dion beam (we probably can call it a tube, per usual vernacular, since what's shown really is a tube) passes



Mumford link shown in top view (above) and rear view (below)



through the stock bump stop frame, which I have shown only on the right side; the left side has a mirror image one as well. These frames bolt to the main frame rails, so they can be slipped down over the De Dion tube.

The halfshafts are shown here only as centre-lines. The little brackets on the De Dion tube that pick up the outer points on the Mumford linkage are made from 2in x 1in, .125in wall rectangular tubing.

Tube ends

At the ends of the tube are circular flanges that mate with the stock hub carriers. These are not quite square to the ends of the tube, so if stock end lugs are used, the tube would need to be bent a bit at the ends. I think probably a good fillet weld there will be adequate, with quarter-inch material thickness for both the tube and the flange. That would eliminate the need for the lug.

The drums for the inboard brakes are shown. I have not drawn in the diff, or the lever shocks, or the torsion bars. As discussed in previous instalments, the torsion bars, which are at frame height, are basically longitudinal, but angle inward at the front and attach to a rubber mounted member that acts in series with the torsion bars for roll, providing roll-soft springing for the original suspension system. This can all be left in place.

The De Dion tube is designed to twist in roll. Slotted as shown, it should provide a reasonable amount of rear roll stiffness. If it didn't have the slot, it would be too stiff. With it it should provide an amount of roll resistance that can be balanced with a front anti-roll bar, probably selected through trial and error.

The slotted De Dion tube should provide a reasonable amount of roll stiffness

Forecasting a damper spring

What is the purpose of 'negative springs' and how do they affect a racecar out on track?

Shocks and coil springs in the usual relationship to each other. But what about springs that are placed within the dampers?

QUESTION

I recently heard that some people are building shocks with coil springs *inside*. These are designed to act in droop and sometimes they are called 'negative springs'. They go on the shaft side of the piston and are located by the shaft. What effect does such a spring have on the overall spring rate? Does it reduce it, since it acts to compress the unit, or does it add spring rate because it's a second spring acting in parallel with the main spring? And how do such shocks affect a car's behaviour?

THE CONSULTANT

In the range where it's active, a 'negative spring' *adds rate but reduces force* at a given coilover length or displacement. That is, as the coilover extends against the negative spring, the total spring force *diminishes faster*. The value of the force is less but its rate of change is greater. Therefore, then, the spring rate is greater, not less.

If we have negative springs that are just barely unloaded at static ride height, but come into action whenever the suspension extends at all, the effect is somewhat like a 'zero droop' set-up, but gentler. When the car is cornering, the inside suspension is stiffer than the outside suspension. That means the inside suspension extends less than the outside suspension compresses, and the car sits a little lower in the rolled condition. Additionally, the inside suspension is stiffer in pitch than the outside suspension. This causes the car to de-wedge some if we are decelerating while cornering, or gain wedge if we are applying power while cornering. Depending on driving style, this will tend to free the car up (add oversteer) on entry, and tighten the car (add understeer) on exit. This may very well be beneficial.

Finding a sense of proportion

Clearing up the confusion between limiting and proportioning valves in braking systems

QUESTION

I was reading an article you once wrote on asymmetrical racecars and I was particularly interested when you got to asymmetrical brakes. You were talking about shut-off valves and proportioning valves. I have a valve I have been using on cars for a few years which is supposed to be a mini proportioning valve. I am wondering if you think this valve will work correctly to proportion the brake balance or if you think it is just another type of shut-off valve that will cause the brake to be sluggish?

THE CONSULTANT

I have learned a bit about proportioning valves over the 18 years since I wrote that article. At the time I was under the erroneous impression that proportioning valves were simple limiting valves that prevent any further increase in output pressure once input pressure reaches the valve's set point. Actually, above the set point most of them transmit a percentage of added input pressure. They also have a hysteresis effect which results in higher output pressure when input pressure is being gradually released, as in trail braking.

This particular valve, however, does appear to be a simple limiting valve. That is, when the set point is reached it shuts completely, rather than transmitting a percentage of additional pressure. So it's not like putting a shut-off valve or simple restrictor like a needle valve in the line, which I discussed in the piece mentioned, but it's not like other proportioning valves either. With an ordinary proportioning valve, if you graph input pressure as *x* and output pressure as *y*, the plot has a slope of one up to the set point and a slope of, typically, .43 beyond that. This valve apparently produces a slope of one up to the set point and a slope of zero beyond that. I'm not sure if it would produce a hysteresis loop in gradual release like ordinary proportioning valves, but I would guess not; the plot has a zero slope so the hysteresis loop would have zero vertical width. I think that during gradual release it simply gives constant output pressure down to the set point and then has output pressure equal to input pressure. However, to really know you'd have to test it with pressure gauges.

The valve in question appears to be a simple limiting valve, says our man Ortiz

CONTACT

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

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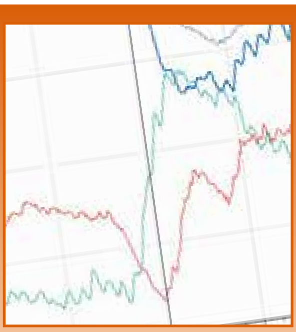


Databytes gives you essential insights to help you to improve your data analysis skills each month, as Cosworth's electronics engineers share tips and tweaks learned from years of experience with data systems

Reinventing the steering wheel

How the Cosworth CCW Mk2 steering wheel in a Super Formula car is so much more than a device for turning left and right

Super Formula uses Cosworth's FIA certified Carbon Wheel (CCW Mk2), a lightweight 280mm carbon steering wheel designed specifically for professional motorsport applications.

Incorporating a high resolution, fully customisable display this steering wheel is also used in a number of other series, including FIA LMP2 and IMSA DPi. This configurable aspect allows for individual driver needs to be catered for while adding variety to a spec formula.

The 4.3in TFT display is complemented by a row of 10 shift lights and six alarm LEDs which can be customised for optimum driver feedback from both engine and chassis parameters.

Clear display

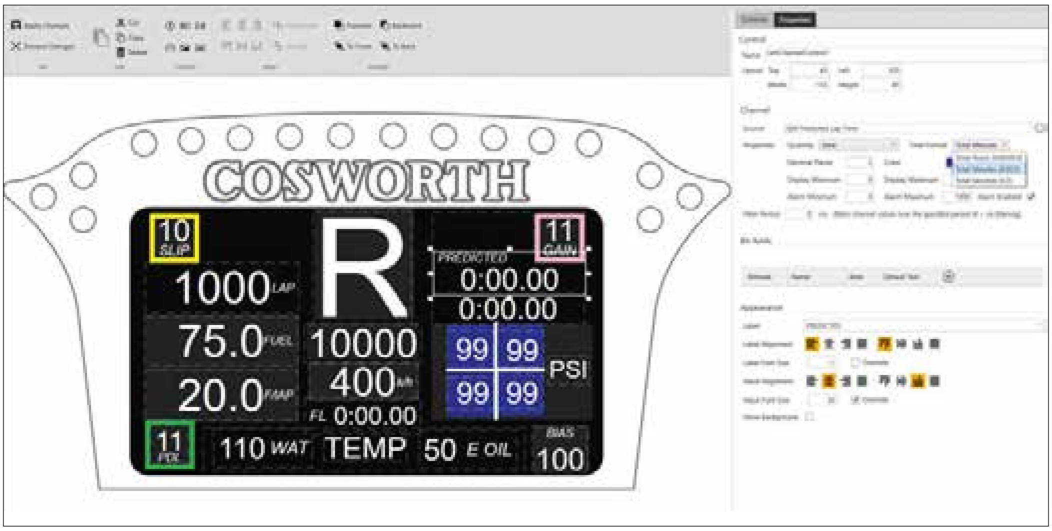
The ethernet driven display is fully customisable, allowing both race drivers and mechanics to have relevant information displayed both clearly and instantly.

Super Formula use Cosworth's configuration software Pi Toolset. The CCW is associated with a Cosworth data-logger which acts as a parent device, driving the display and shift lights. Display pages can then be created showing anything from temperatures and pressures to predicted lap times.

Overlay feature

The display also has an overlay feature which allows the user to show only relevant data at any appropriate time. This can be in the form of alarms or simply confirming any driver input.

Cosworth's CCW Mk2 is the steering wheel of choice in Super Formula and is also used in LMP2 and IMSA DPi cars



The display has an overlay feature which allows the driver to show only the relevant data at any appropriate time

The 4.3in TFT display is complemented by a row of 10 shift lights and six alarm LEDs which can be customised for optimum driver feedback

LED and display brightness are also fully adjustable and can be programmed to any of the rotary positions or buttons on the CCW

A simple drag-drop interface allows for the pages and overlays to be built up to each driver's specification, using bar, text and colour indicators to emphasise information and coloured boarders for alarms and overlays.

For example, if the fly-by-wire position switch is moved the ECU can issue a feedback to confirm that the correct map has been chosen. The screen can then have an overlay that pops up for a short time to show which map has been activated.

Map values

This overlay is driven by one user-configurable math channel which is written within the Pi Toolset interface. It identifies when the FBW Map value has changed and holds the overlay on for three seconds.

FBW Display Drive Math:

a6(choose([CALPOT_C]==@a1,0,1));

If Calpot C value has changed, set value of A6 to 1

a1([CALPOT_C]);

This defines Calpot C value at the previous cycle

a2(choose(@a6==1,30,@a2));

If A6 is 1 then set A2 to 30

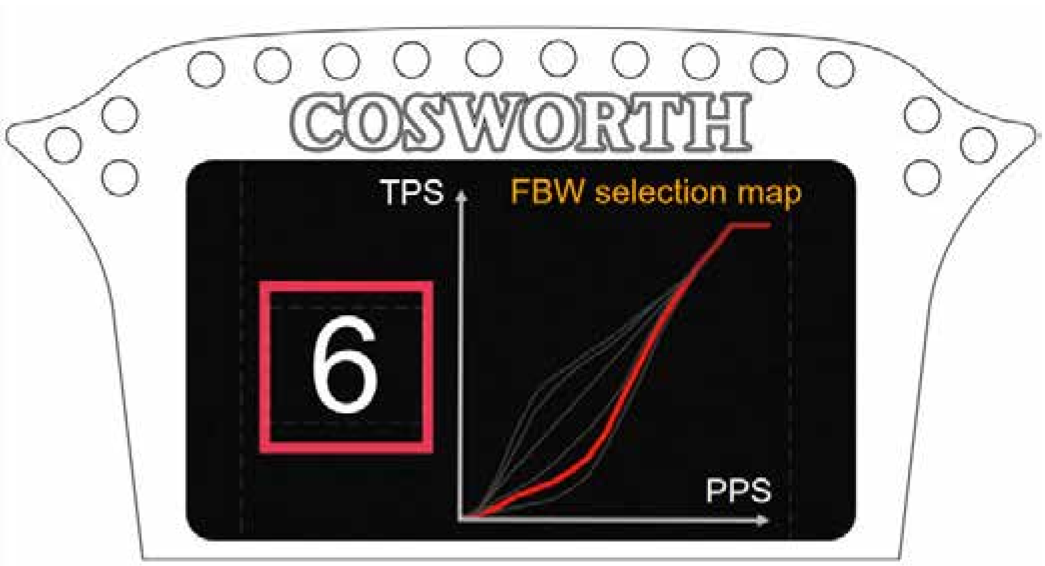
a2(choose(@a2>0,@a2-1,@a2));

If A2 is greater than zero reduce its value by 1

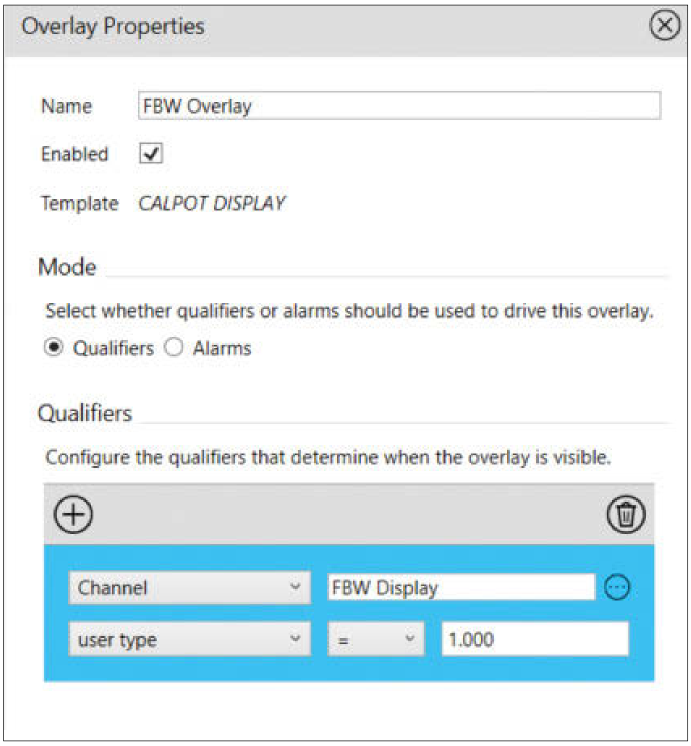
choose(@a2>0,1,0)

Output 1 of the value of A2 is greater than zero

As this calculation is run at 10Hz, the 30 cycles where the output will be '1' equals three seconds.



This overlay is driven by one user-configurable maths channel which is written within the Pi Toolset interface



The maths at the top of this page is added as a qualifier to the FBW overlay, switching the overlay on for three seconds any time the FBW map is changed

Colours and triggers

This piece of maths is then added as a qualifier to the FBW overlay, switching the overlay on for three seconds any time the FBW map is changed. Similarly, the shift light and LED interface incorporated in Pi Toolset allows for full customisation for colours and triggers including alarms and events like wheelspin and wheel lock-ups.

Bright side

LED and display brightness are also fully adjustable and can be programmed to any of the rotary positions or buttons on the CCW. This allows the driver to select the optimum settings whether driving in bright sunlight or dull weather.

Cosworth has been a market leader in custom and off-the-shelf steering wheels for over a decade now and the CCW MK2 is the culmination of the company's commitment to optimising the feedback the driver receives from the racecar's onboard systems.

Nose to tail aero on a BTCC racer

Analysing drafting scenarios with Team Hard's VW CC

We have had the pleasure of putting the low drag Team Hard VW CC BTCC contender through its wind tunnel paces in recent issues, and have seen the effects of changing wing angle, removing the rear wing altogether (not permitted in the rules and certainly not desirable), altering the front cooling inlet size, and adjusting rake and roll angles. Given that BTCC technical regulations strictly control downforce to very modest levels, drag is said to be the most important aerodynamic parameter when it comes to lap time, and reductions in the car's already very competitive drag level were found.

Team Hard's technical leader, highly experienced designer and race engineer Geoff Kingston, suggested it would be interesting to try some drafting scenarios, so team boss Tony Gilham's road-going VW CC with 2017 BTCC body kit (but no rear wing) was borrowed for the day. This was our first wind tunnel-based drafting study since we examined a project MIRA had run on two ASCAR racecars back in 2006; that produced a matrix of four longitudinal separations line astern and at two different lateral offsets. But we just had time at the end of our session for two longitudinal separations in 'leading' and 'following' positions.

Pushing boundaries

Ahead of that, because the wind tunnel's boundary layer fence had to be removed in order to put the second car in front of the test car, we first performed a run on the test car without the boundary layer fence in order to establish a new baseline for the drafting comparisons. This also gave the opportunity to look at the effect of removing the boundary layer fence on this particular car, and the results are shown in **Table 1**.

Thus, the boundary layer fence had the effect of increasing both drag and front downforce, and both could be explained by increased mass flow under the car. As the purpose of the fence is to 'trip' the airflow into a rolling vortex that creates downwash and brings high energy flow back down to floor level, so thinning the floor's boundary layer just ahead of the car, our results would seem to fit with expectations. Different configuration cars would respond with different results, depending especially on ground clearance.

Table 1: The effects of removing the boundary layer fence

	CD	-CL	-CLfront	-CLrear	%front**	-L/D
WithBL fence	0.343	0.189	0.151	0.039	79.8%	0.550
WithoutBL fence	0.323	0.171	0.128	0.042	75.1%	0.529
Change, counts*	-20	-18	-23	+3	-4.7	-21
Change, %	-5.8%	-9.5%	-15.2%	+7.7%	-	-3.8%

**1 count is a coefficient change of 0.001. **Changes in %front are absolute, not relative*

Table 2: Data on the following car compared to the baseline data without the boundary layer fence

	CD	-CL	-CLfront	-CLrear	%front**	-L/D
Baseline without boundary layer fence	0.323	0.171	0.128	0.042	75.1%	0.529
½ car length behind	0.273	0.169	0.186	+0.018***	110.1%	0.620
Change, counts*	-50	-2	+58	-60	+35.0	+91
300mm behind	0.145	0.126	0.137	+0.010***	108.3%	0.869
Change, counts	-178	-45	+9	-52	+33.2	+340

**1 count is a coefficient change of 0.001. **Changes in %front are absolute, not relative.*
****Positive value indicates positive lift, not downforce*

First draft

With only enough time for four different drafting scenarios we elected to run half a car's length (about 2400mm) and 300mm longitudinal separations, line astern, with the test car on the wind tunnel balance and the second car in front and then behind. **Table 2** shows first the data on the following car – that is, with the second car in front.

The drag reductions appear to fit the expected trend, with the following car's drag reducing by more the smaller the separation was. Total downforce had changed little with half a car's gap, but there was a change in the aerodynamic balance with a significant gain at the front and a very similar loss (in terms of counts) at the rear. However, when the gap had closed to 300mm front downforce

This is the first time we've studied close-quarter drafting in the wind tunnel since 2006

Boundary layer trip fence (the red strip above) had to be removed to fit a second car in

Pic 1: A closely following car modified the aerodynamics of the leading car, and vice versa

Pic 2: The lack of a rear wing on the leading car produced a very different flow field

Pic 3: When the car was alone in the tunnel the rear wing turned the smoke plume a little

Pic 4: A closely following car reduced the effective angle of incidence of the rear wing

Table 3: Data on leading car compared to baseline data without BL fence

	CD	-CL	-CLfront	-CLrear	%front**	-L/D
Without BL fence	0.323	0.171	0.128	0.042	75.1%	0.529
½ car length in front	0.286	0.134	0.132	0.002	98.5%	0.468
Change, counts*	-37	-37	+4	-40	+23.4	-61
300mm in front	0.261	0.112	0.136	+0.025	122.0%	0.427
Change, counts	-62	-59	+8	-67	+46.9	-102

** 1 count is a coefficient change of 0.001. **Changes in %front are absolute, not relative*

returned to close to baseline, but the loss of rear downforce was still evident.

The cause of the reductions in drag is self-evident, but the cause of the increases in front downforce is less obvious. Clearly the flow to the front end of the following car is very different when close behind another car, and the loss of air feed to the splitter would be expected to cause a loss of downforce. However, perhaps of more significance was a reduction of the front lift that always occurs on the bonnet, and maybe also a reduction in the lift that occurs over the top of the front screen to the forward roof area. **Pic 1** shows that the lead car at 300mm separation was certainly modifying the smoke plume's path aft.

The front downforce gain was much more pronounced at half a car's separation

Yet the front downforce gain was much more pronounced at half a car's separation. We must keep in mind that when acquiring the data on the following car, the lead car had no rear wing, and this will certainly have produced a different flow field on the following car than if a wing had been fitted. Compare **Pic 2** with **Pic 1** to see how the smoke plume path on the cars' centreline differed with and without a rear wing at the 300mm separation.

Draft dodging

Table 3 shows the reversed situation, with the data shown on the leading car – that is, with the road-going car now following.

The leading car also benefited from a significant reduction in drag at the two separations evaluated, and once again the effect was more pronounced at the closer separation. The effect wasn't as potent as it was on the following car, but clearly the leading car feels a significant benefit.

As in the following car case, the leading car also felt overall downforce reductions, but again this was not a balanced picture, with small increases being felt on the front end, which probably arose from the mechanical effect of the somewhat greater downforce losses at the rear. And the losses at the rear can probably be largely explained by the effect of the following car modifying the effective angle of incidence to the airflow to the leading car's rear wing, as is seen by comparing **Pic 3** with **Pic 4**.

One can't help surmise that teams with more than one car could almost certainly gain from the drag reductions if they ran nose to tail on some parts of a track. However, it's also clear that the aero balance changes on both cars when they're running close together, to the extent of significant forward shifts in an already forward biased aero balance, which might make life interesting when running closely nose to tail through high speed corners.

CONTACT

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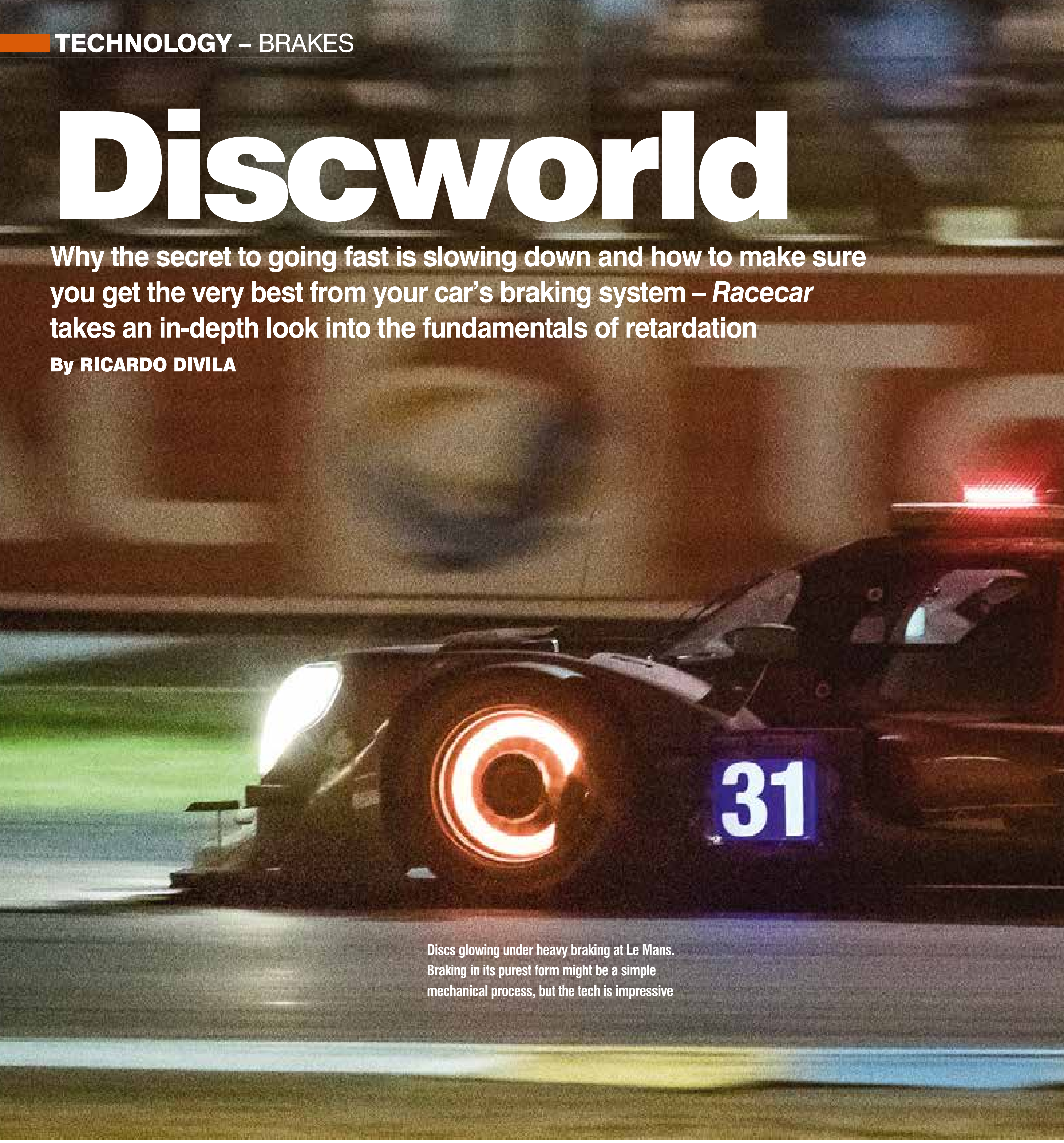
In these pages he uses data from MIRA to discuss common aerodynamic issues faced by racecar engineers

Discworld

Why the secret to going fast is slowing down and how to make sure you get the very best from your car's braking system – *Racecar* takes an in-depth look into the fundamentals of retardation

By RICARDO DIVILA



Discs glowing under heavy braking at Le Mans. Braking in its purest form might be a simple mechanical process, but the tech is impressive

Juan Manuel Fangio once said: 'Knowing how to drive is a lot more than steering; it's knowing how to brake. Braking is an art.' He had a point, but it is also a science, and this is what we will be looking at in this piece.

To begin with, let us take the hypothesis that you have a near 1000bhp racecar, such as an F1 or LMP1 car. Looking at the energy available for the different phases you will see that you can brake at higher deceleration forces than you can accelerate, not because of tyre capacity, but because of the power available.

We can see this clearly in a GG diagram **(Figure 1)**. Here top is braking, bottom is accelerating, sides are lateral *g*, circles are 1.5 and 3*g*. In this example where we achieve over 3*g* in braking and cornering but are limited to 1*g* in pure acceleration, we can see that a fair amount of acceleration is powering out of LH (left hand) corners, as the GG plot is loaded on that side and the straight line acceleration is less as it is showing the effect of drag as it progresses down the straight.

So how does all this work, what are the problems you can encounter and how do you optimise braking? We will have a restricted look into the systems, mainly focusing on brake discs (sometimes called rotors) and pads, without discussing brake fluids, caliper design (this merits an article on its own) or a complete overview of the physics and mechanics of it all.

Braking works by friction, by having pads rub against discs attached to the wheels, being clamped by hydraulic actuation, dissipating energy as heat. We are purely dealing with the simple case of mechanical brakes and therefore avoiding the aero losses caused by body drag, tyre rolling resistance and the much more

Formula 1 has around 350 braking sections during the race at Spa whereas an LMP1 car at Le Mans would have over 4000

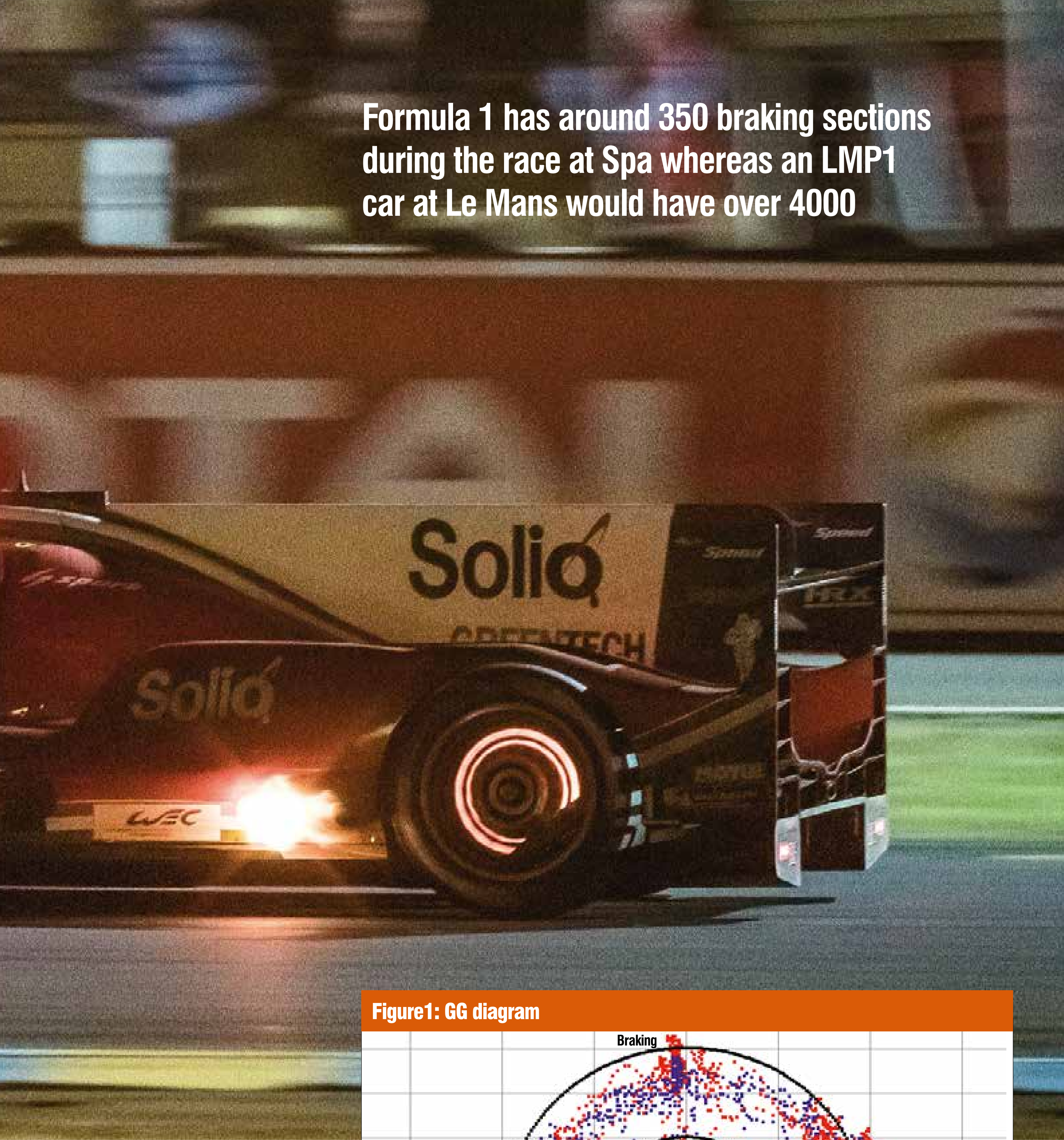


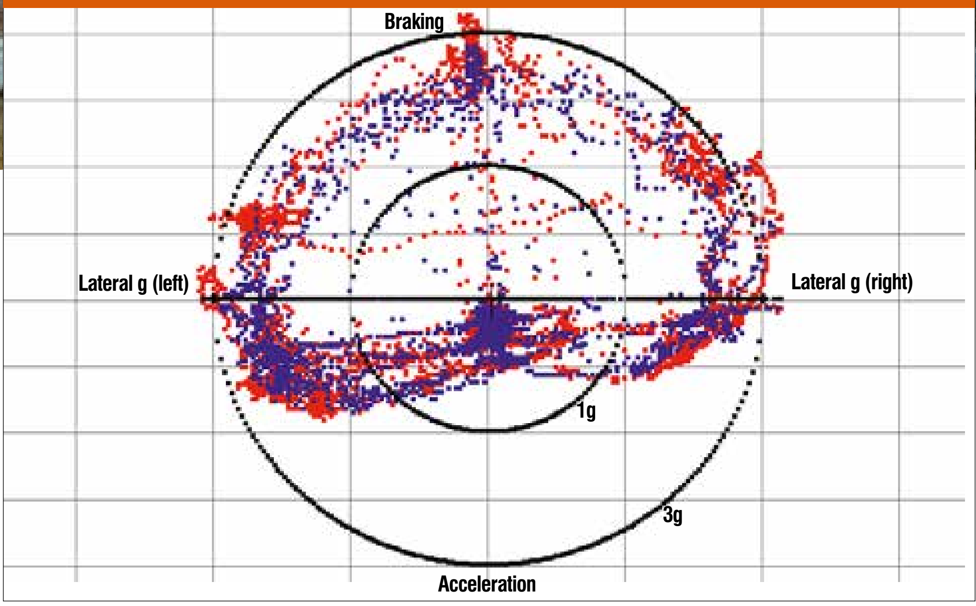
PHOTO CREDIT: Darren Wheeler (www.thatcameraman.com)

complex case of recuperating kinetic energy into various ERS systems through generating electricity and storing it into batteries, capacitors or flywheels, to be harvested later during acceleration. Neither will we consider the particular case of ABS, current in road cars, but usually prohibited in top level racing.

Gains on track

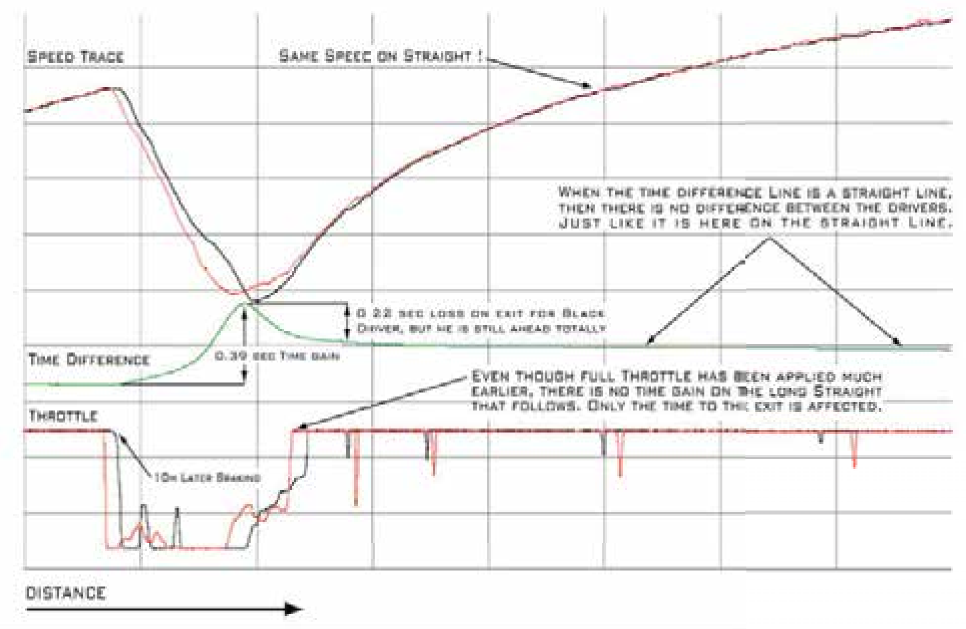
Figure 2 shows the effects of braking 10 metres later, and accelerating 10 metres earlier. As the graph gives speed on the *Y* axis and distance on the *X* axis, the time differential is given by the

Figure1: GG diagram



Each track has its own percentage of time spent braking, but it is not necessarily correlated to top speed or length of straight, nor the percentage of time at full throttle

Figure 2: Effects of braking 10m later, and accelerating 10m earlier



Make a brake for it

Early brakes, used in carriages and carts, consisted of a wooden block that could rub against the wheel rim. As the beast that pulled the carriage could be depended to provide most of the acceleration and deceleration through its feet, these rudimentary brakes were useful to help the animal when going downhill and to immobilise it when stopped. When the horsepower started coming via a motor, something else was required. Early cars tended to use a bigger version of the wooden block, usually actuated by cable and mostly on the rear wheels.

As performance improved, brakes had to follow, evolving from blocks on rim to drum brakes with leather, then asbestos shoes still actuated by wires or rods, then eventually mutating to a hydraulic actuating system on front and rear wheels and in the fullness of time we ended up with disc brakes, now the industry standard in racing. For lower performance and cost production cars we can still see hybrid disc/drum installations, while some trucks, buses and tractors will still use drum brakes all-round.

Disc brakes

Disk brakes were first tried out in the 1890s and as early as 1910 the 20bhp Lanchester had them on the rear axle. Frederick Lanchester had patented the system in 1903, and while these were actuated by cable the principles were much the same as today. They turned up much later in racing and were a derivation of what was then used in aircraft, with the first recorded use of disc brakes in racing on a BRM Type 15 F1 car in 1951, which sported a Girling-produced set. They later, more famously perhaps, appeared in 1953 on the Jaguar C-Type sports racing car and were used on that year's Le Mans winning Jag, the system developed in the UK by Dunlop.

Carbon discs and pads also came from aircraft braking systems, such as those used on Concorde, and were introduced into Formula 1 by Brabham together with Dunlop in 1976.

Carbon–carbon braking systems reduce unsprung weight, have better frictional performance and better structural properties at high temperatures, compared to cast iron. I was involved in the early development of carbon discs, and it was an interesting period. The single disc layout common nowadays was only one of the configurations tried, we tested the multiple stack of nested discs, common in aircraft (they have small diameter wheels for their size compared to racecars, easier to retract when in flight) and before material spec and manufacturing methods were refined there were several cases of discs exploding under mechanical and temperature stresses, usually taking the rim with it, resulting in an instant deflating of the tyre. Interesting times for the crews, and even more so for the drivers.

area enclosed between the two curves in the different phases. Even though here the black car's trace shows that apex speed is lower than the red car, and the red car starts accelerating earlier by a similar amount, elapsed time gain is still with the black racecar.

We can throw some numbers to give an example of what we are talking about. A Formula 1 car's braking deceleration can surpass 5*g*, for example at Monza up to 5.8*g*. LMP1s at Le Mans do not go over 3.5*g*. There are several reasons for this, one of which is that the deceleration given by drag is much bigger in Formula 1 cars than in prototypes (yes I know we said we would ignore drag, but in this case, for comparison, we cannot let it go unmentioned). At top speed lifting off the throttle can give nearly one *g* just with the drag on a Formula 1 car. To calculate the forces we use the following formula:

$F = 0.5CdDV^2A$
where,
F is Aerodynamic drag
Cd is Coefficient of drag
D is Air density
A is Frontal area
V is Velocity

F1 cars have Cd values of about 0.85 with corresponding CdA (m2) values close to 1.2, around three times that of a road car, somewhere in the region of a brick or a bus. There is also the difference in tyre grip (endurance cars can do up to four stints on a set, so about four hours running, twice a grand prix distance, and a 24 hour race is 12 times the length of an F1 race). Pad and disc wear is less, due to different compounds in the material.

In the past discs and pads used to be changed mid race, but carbon now goes the whole distance. You also have sprint and endurance material, but less wear equates to less stopping power. Compare the Spa GP with Le Mans, for example. F1 has around 350 braking sections during the race whereas an LMP at Le Mans would have over 4000. One other difference is the disc diameter, conditioned by the rim diameter. It is ironic to consider that the current F1 13in diameter is defined by the rules and was brought in the interest of curbing braking capacity. Well, since then brakes have improved tremendously but the rules have pushed aero, suspension and car design into a particular direction.

It's worth looking at horsepower equivalence of braking here (**Figure 3**). To calculate we have:

Horsepower = 0.00268WcDmS
where: Wc = weight of car in pounds
Dm = max deceleration in *g*
S = Speed in mph

Braking and wear

Each track has its own percentage of time spent braking, but it is not necessarily correlated to top speed or length of straight, nor percentage

Figure 3: Horsepower equivalence of braking

Formula= Horsepower=0.00268$W_c d_M S$ where W_c= weight of car in pounds
d_M=max decel in G's
S=Speed in mph

Car Weight(lbs.)=	2000	0	W_c	4000
or Kg=	0			0
Max decel in G=	2.5	0	d_M	0.8
or m/sec2=	0			0
Speed(Mph)=	200	0	S	60
or kph=	0			0
Hpower braking=	2680.0			514.56

Examples

Type of car	W_c(lbs.)	S(Mph)	d_M(G's)	Power(hp)
Large sedan street tyres	4000	60	0.8	515
Small sedan street tyres	2000	60	0.8	257
Racing stock car,racing tyres	4000	200	1.2	2573
Fast race car, high downforce	2000	200	2.5	2680
Small race car , low downforce	1000	120	1.2	386

Note aero drag not taken in consideration
One horsepower is equivalent to 550 ft-lbs of energy delivered each second
Formula gives total power dissipated during stop

time at full throttle. It is rather dependent on downforce, the amount of time between corners to cool down, ambient temperature and grip level. **Table 1** shows some Formula 1 values from pre-KERS times, to show just the mechanical braking effort.

The hardest braking section at Monaco is after the tunnel, going from 290km/h to 95 in less than 50m, braking for 1.8s, giving a 5*g* deceleration and load of 144kg on the brake pedal. At Mirabeau the speed drops from 232km/h to 83km/h, with a longer 1.83s time and a 39m distance with a load of 136kg on the pedal and a 4.5*g* deceleration. Top speed is 287km/h, reached on the start finish line, and St Devote is taken at 123km/h, braking for just 1.52s. For an F1 analysis see **Figure 4**.

Table1: Braking effort in Formula 1 – from pre-KERS era

Track	% lap full throttle	Longest full throttle (m)	Top speed (km/h)	Brake wear
Singapore	44	650	297	Very high
Melbourne	65	735	303	High
Hungarian	58	750	291	High
Bahrain	63	1050	309	High
Nurburgring	62	800	300	High
Monaco	42	510	286	High
Monza	70	1320	351	High
Suzuka	67	1230	313	High
Shanghai	55	1370	310	Medium
Valencia	59	930	306	Medium
Silverstone	64	890	294	Low
Spa	70	1865	310	Low
Interlagos	65	1220	314	Low
Barcelona	57	1140	308	Low
Sepang	65	830	297	Low
Istanbul	63	1200	315	Low

Brake balance

When braking, all forces must be reacted through the contact patch, at ground level. The mass being decelerated, acting through the centre of gravity will transfer weight from the rear to the front axle (**Figure 5**; *Fz* in red on illustration, *Fx* in blue) thus most of the braking force comes from the front, as *Fz* directly influences the force a tyre can accept at the contact patch – this is also the reason why cars went to all-round brakes early on, this being the most efficient way to slow them.

On high downforce cars there is an additional problem as *Fz* distribution is directly related to the deceleration, but as you slow down you also lose downforce (the *V* in the formula decreases), plus as downforce is reduced the car ride height will rise, reducing downforce even more, and pitch change can alter your downforce distribution. Trimming the car to have ideal brake balance, if you don't have a pre-set brake setting that can be changed, means you would have to have the brake balance set to your maximum deceleration, so at all other corners you can't have the maximum braking available, usually on the rear.

The illustration in **Figure 5** is of a GT, incidentally, the Nissan GT-R, which despite theoretically being disadvantaged by its weight distribution (over 59 per cent front) actually can out-brake other GTs with a rearwards bias. On an absolutely flat surfaced track it would unload the rear quite a lot and load the front, so overall braking capacity would be less than a rear bias car, but in reality the forward mass has an auto stabilising effect over bumps in the braking zone, much as a featherless arrow will go straight if the arrowhead is heavy enough. Very rear biased racecars will tend to pull over a bump, and the rear bias will try to turn the racecar, this is very much like the effect that wearing a backpack has when you are running and you try to change direction.

Using a static weight distribution of 46 per cent front and 54 per cent rear, as we brake, for example, at 3*g*, and using a mass of 750kg (at the percentages above this means 345kg.ft axle and 405kg rear), height of CG height of 0.25m and wheelbase of 3.3m will give us 750 x 3 x 0.25/3.3 = 170kg.

So, after transfer we will have a new FZ distribution, and also assuming that the braking force is a linear fit to braking capacity we then have:

Front: (345kg + 170kg = 515kg) 515/750 = 68.7 per cent
Rear: (405kg - 170kg = 235kg) 235/750 = 31.3 per cent
Thus your brake balance would be set at 69 per cent front.

Just as a short side note here, racing in the rain will make you transfer bias to the back as your grip level is lower, thus lower maximum deceleration *g*, so less transfer. If you keep your dry bias you will lock the fronts.

The **Figure 6** graph shows the front and rear forces needed at different *gs* (*I* curve). Looking at a typical brake pressure trace, it looks something like **Figure 7** (note the relation between speed, brake pressure, disk temp and deceleration). Data logged is the inline pressures on front and rear calipers (magenta and red on first panel), but the ratio of pressure is not the distribution. The final braking force at each axle will also be dependent on disc diameter, caliper piston sizes, wheel diameter (if different front and rear it will give different RPM at a given speed, thus different tangential speeds on the mean pad centre, thus torque developed at disc), other values can be read off graph **Figure 8**.

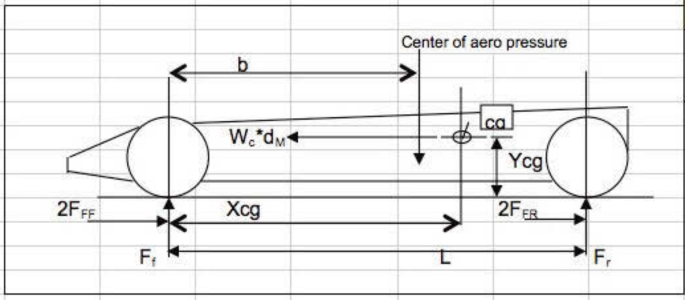
The operating range of F1 brakes is between 350 and 1000degC, LMPs 350 and 800degC

Figure 4: Formula 1 braking

Formulae=

$F_f=W_c[1-X_{cg}/L+\mu Y_{cg}/L]+F_A[1-b/L+\mu Y_{cg}/L]$	1300
$F_r=W_c+F_A-F_f$	700
$d_M=\mu+F_A\mu/W_c$	1
$F_F=\mu F_f/2$	650
$F_R=\mu F_r/2$	350

2000	W_c=	weight of car in pounds
1	μ=	Grip coeff tyres
2000	L=	wheelbase
0	FA=	Aero downforce
300	b=	Dist ft axle to Cpress
1000	Xcg=	Dist ft axle to cg
300	Ycg=	Heigth cg to ground
1300	F_f=	Vertical force on both ft tyres
700	F_r=	Vertical force on both rr tyres
1	dM=	Max decel (g's)



Assume all heat from braking flows into disc rotor
Assume drag from all sources are zero (engine braking, aero drag & rolling resistance) valid for braking under 150 kph
Ignores kinetic energy stored in rotating parts (This assumption and the assumption of zero drag causes errors in opposite directions)
Ignores cooling of brakes during stop.Heat flow into brakes is rapid compared to cooling)

Kinetic energy (ft-lbs)=	$W_cS^2/29.9$	
K_B Initial Kinetic energy (ft-lbs)=	$W_cS_I^2/29.9$	2675585
K_A Final Kinetic energy (ft-lbs)=	$W_cS_F^2/29.9$	167224
K_C change in Kinetic energy (ft-lbs)=	K_B-K_A	2508361
Temperature rise (deg F)=	$Kc/77.8W_B$	806.029

2000	**W_c=Weight lbs**
200	**S= Speed MPH**
200	**S_I= Initial Speed MPH**
50	**S_F= Final Speed MPH**
2508361	**K_c= Change in kinetic energy**
40	**W_b= weight of disc rotors (lbs)**

On the graph in **Figure 8** we can look closer at the interactions. The datum line is set at the point of maximum pressure. The front and rear pressures are different due in part to different master cylinder diameters and also because of the position of the balance bar. We can see that the disc temperature is still increasing and as the *mu* (friction coefficient) increases with the temp the driver reduces the pedal pressure during the rest of the braking phase. Note also that at the start of braking the disc temperature is around 400degC, in the right window for the disc use.

Setting your brake distribution at the race track is done by turning your brake adjuster, and it works by shifting the fulcrum of the cross-bar, mounted on a spherical joint in a cross tube, and kept in position by the extremities, where the master cylinder is threaded on a barrel nut.

Handling effects

Braking is not only applied in a straight line. Trail braking describes braking force being applied even as the car is turning into the corner and is commonly used in most turns; the driver coming off the brake gradually. Braking can also be used on a nominally full throttle corner to balance the racecar, as it will change chassis reaction either by anti-lift or anti-dive through its reaction of braking torque through the wishbones or suspension links.

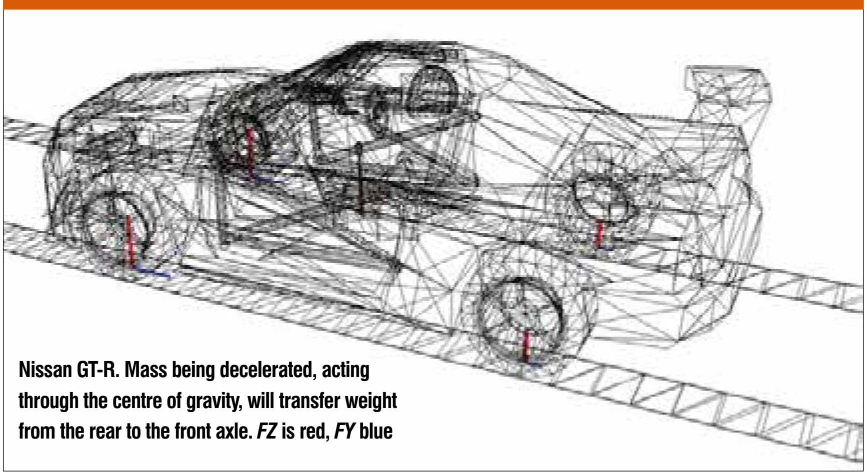
Braking effort distribution can also be used for car balance on GTs and smaller formula racecars. Taking bias slightly to the rear will degrade lateral capacity on that axle and help to rotate the car, taking it to more oversteer on turn in. Like all tweaks, this is a second effect change, being limited by brake lock. Conversely, carrying more bias to the front will slow the turn in, all courtesy of your tyre capacity under longitudinal and lateral *g* under transfer.

Heat and brakes

Considering the operation of the brakes depends on friction, we know that the biggest by-product of retardation will be heat. The art of getting the best thermal efficiency and thermal conductivity is thus keeping discs and pads in the correct working range; also the linearity of retardation in relation to the pedal force applied is crucial for the driver to modulate the amount of force he is using.

Pads and disc materials used currently can be either nodular cast iron or carbon, with

Figure 5: Weight transfer



Nissan GT-R. Mass being decelerated, acting through the centre of gravity, will transfer weight from the rear to the front axle. *FZ* is red, *FY* blue

Figure 6: Front and rear forces needed at different *g* levels

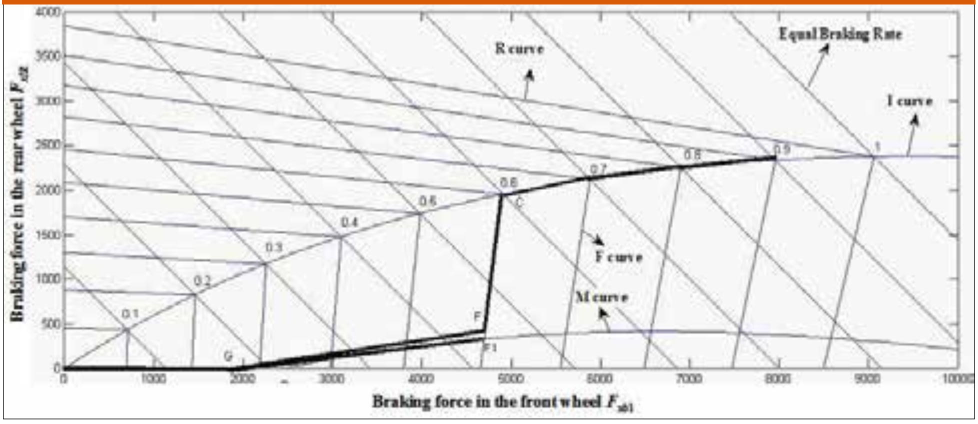
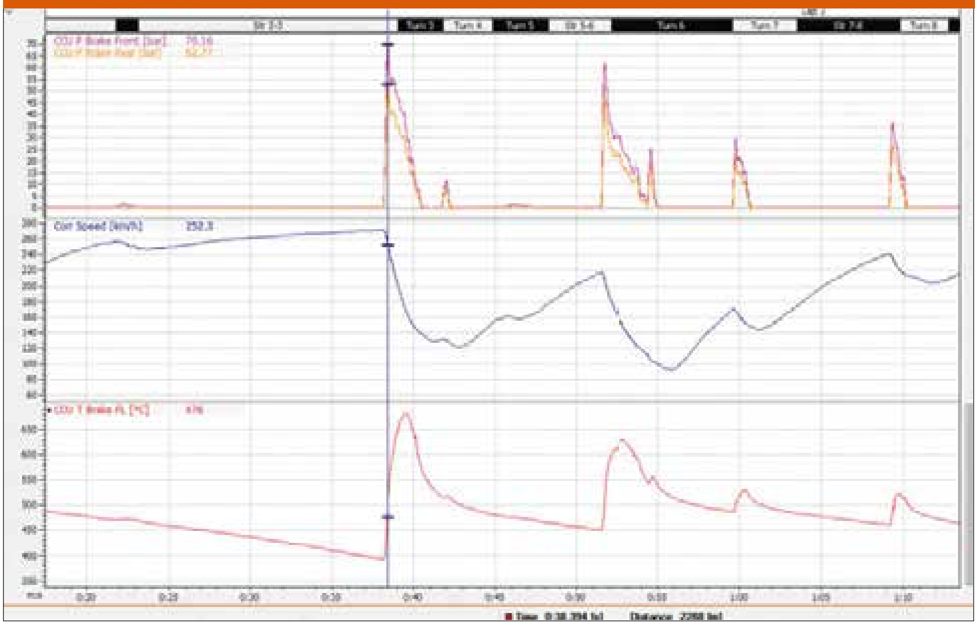


Figure 7: Brake pressure traces

Figure 8: Brake pressure graph



ceramics also coming into use on high range cars. Cast iron does not have a minimum operational temperature, they just have to be monitored to be sure they do not overheat, which can then boil the fluid in the calipers and 'lose' your pedal, but carbon has an ideal temperature for use. Carbon discs, for example, should be used above 350degC. If not they might glaze, which reduces the braking capacity, or worse, increases the wear.

Working range

Discs and pads, much like tyres, have an optimum working range. Low temperatures are not an issue on Formula 1 cars, rather the opposite, as witnessed by the over 1200 radial holes drilled in the discs put there to help with cooling, compared with around 400 on an LMP disc. The operating range of Formula 1 racecars is between 350 and 1000degC, LMP cars between 350 and 800degC.

GT racecars and LMP cars can be confronted by varying ambient temperatures during endurance races, as this can obviously vary between night and day. Maintaining the correct operational temperature at Le Mans, for example, can be quite a difficult task, often requiring different masking of the cooling intakes as you go into the Saturday night, and then opening them up again as the day warms up on on the Sunday morning.

Teams will be monitoring the telemetry continuously for disc temperatures with thermocouples fitted to the upright to verify where they are. Le Mans is less of a problem now that they have the chicanes on the Mulsanne Straight, but when they had the full 6km straight the long blast down it could get your discs too cold for the approach to the Mulsanne corner, where maximum braking was used to bring speeds down from over 380km/h to around 80km/h.

Getting the correct bite meant that you had to carefully calibrate cooling at Le Mans, walking the tightrope between having enough to cool the brakes after the braking zone, but not having it too cold for the next corner.

The amount of energy dissipated brought one of the most impressive sights I have seen at a race track, when standing at Mulsanne, watching a Porsche 962 wheel through the corner, all four discs white hot, illuminating the ground as if it had four arc-light searchlights in the wheel wells during the night.

Paint by numbers

If you don't have thermocouples the most reliable method for monitoring the temperature of the disc is the application of paints. Green (430degC) and red (610degC) paints are normally used. Once you start just turning red you are on a good temperature range, and if you don't then work the green brake harder or, if locking brakes by doing so, then close some of the scoops. As Fangio said, it's an art.

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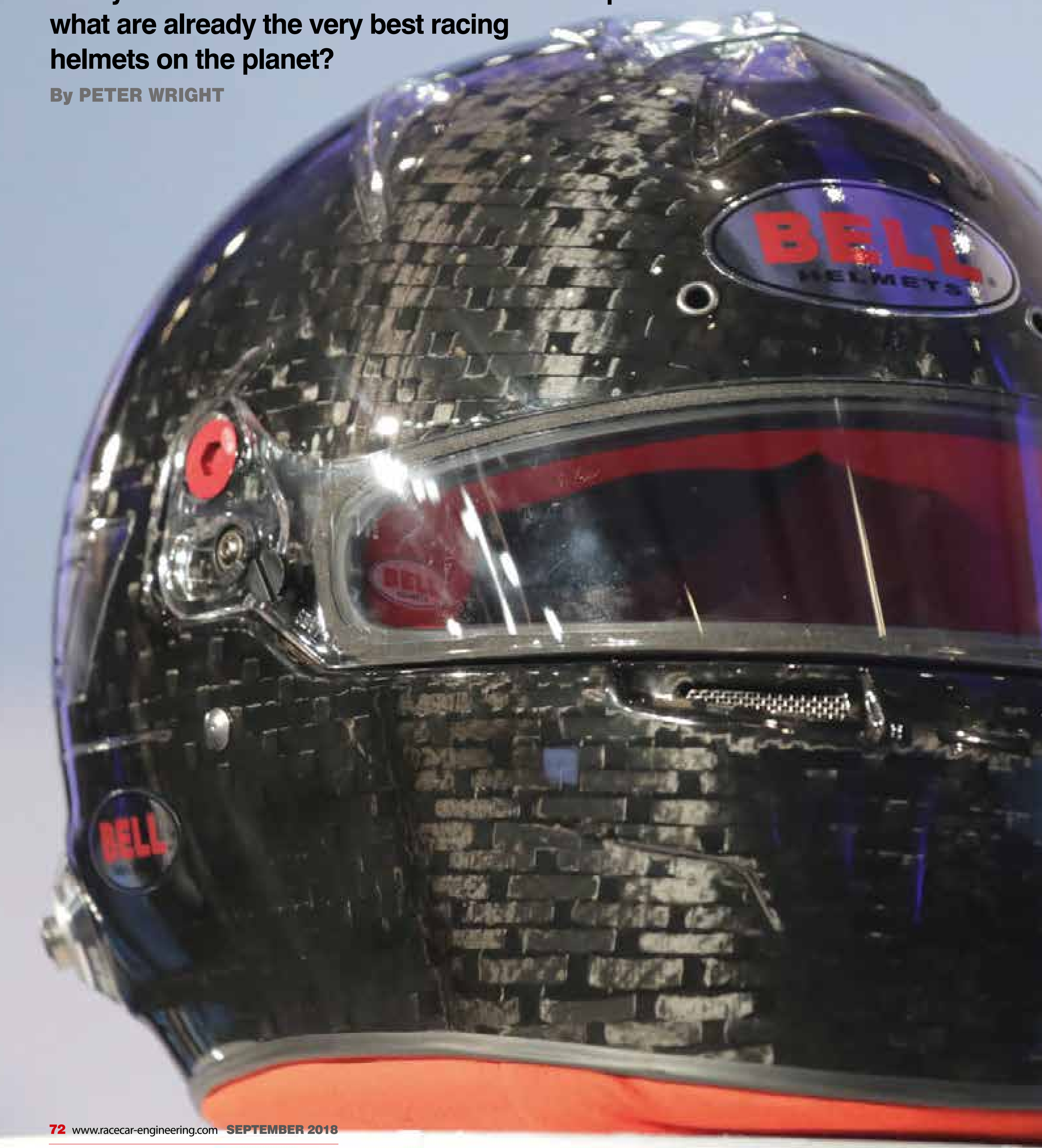
Head first

The FIA's updated helmet standard, which will be mandatory in Formula 1 from 2019, promises to take driver safety to 'the next level' – but how will this improve what are already the very best racing helmets on the planet?

By PETER WRIGHT



The 8860-2018 helmet standard extends the test areas at the sides of the helmet to match the car components

The FIA worked closely with Stilo, Bell Racing Helmets, Schuberth, and Arai while formulating its new 8860-2018 helmet standard

FIA

In motor racing's early days drivers made do with leather helmets and goggles to protect them from stones, dust, wind and rain – but not head impacts. Then, in 1954, Bell Sports developed the first mass produced motorsport helmet, and five years later the Snell Foundation developed the first motorsport helmet standard.

Nearly 60 years on the FIA has now updated its racing helmet standard, 8860-2018, launching it at the FIA Sports Conference Week in Manila in June. This standard provides the most sophisticated and protective performance in a motorsport helmet. The helmet industry – represented by Stilo, Bell Racing Helmets, Schuberth, and Arai – has worked with the FIA throughout and developed their prototypes for this standard. The first homologated products will be available for Formula 1 in 2019, quickly followed by other top FIA championships (see box out on page 86 for the full spec).

Head start

A modern motorsport helmet may look simple, while also being stylish, but it provides protection to the driver's most valuable asset, their head, under extreme and emergency conditions when involved in a crash. It sets out to restrain the head, via the built-in FHR (frontal head restraint) anchors; to prevent skull fracture and limit deceleration to below 300*g* whatever the head hits in his racecar, at the highest likely head velocity relative to the car. It must also protect against a loose object at an impact velocity of over 250km/h without inhibiting vision. All this with a structure that is just 50mm thick and at a weight of under 2kg.

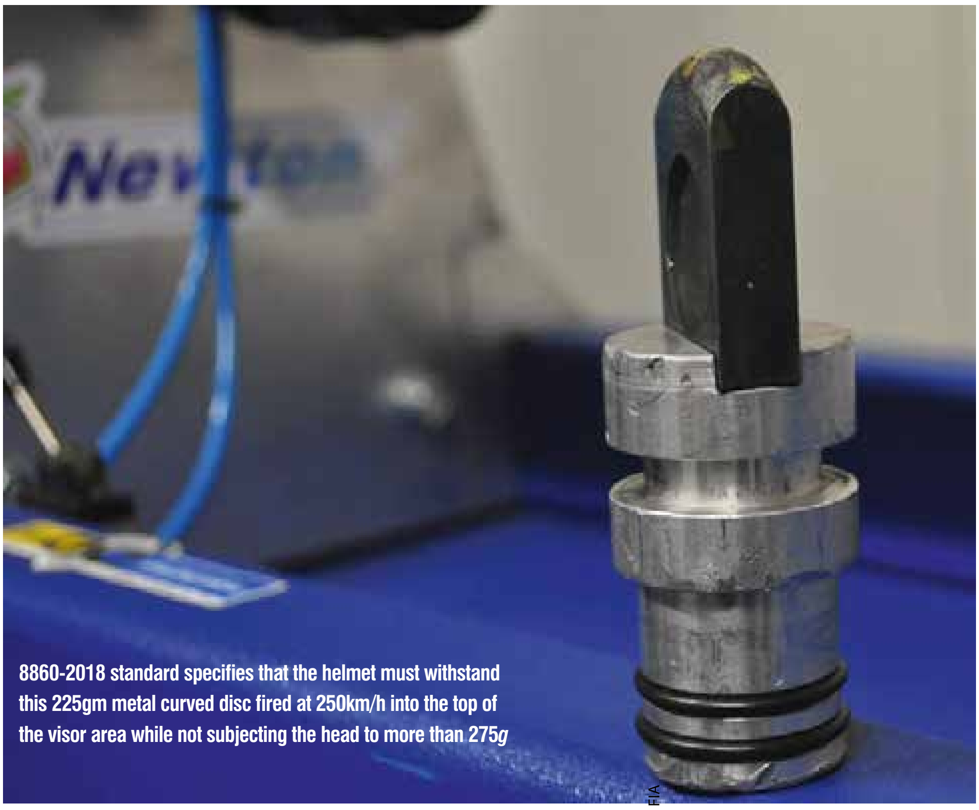
Andrew Mellor is the person who has, over the last 20 years, steadily progressed the FIA's helmet standard, working with the industry and test laboratories to develop test standards, protocols and helmet construction methods to achieve the latest performance standard. Mellor worked at TRL (Transport Research Laboratory), performing the R&D and writing the specifications for the UK DOT's Advanced Motorcycle Helmet. Since working with the FIA Institute (now the Global Institute) he has authored a series of helmet standards: 8858-2002, Auto Racing Helmet; 8860-2004, Advanced Racing Helmet; Visor reinforcement for 8860 in 2011; 8860-2010, update; 8859-2015, Premium Helmet and now 8860-2018 update.

With so much experience in the R&D of helmets, there is no one better than Mellor to discuss the physics and engineering behind the latest motorsport helmet standard.

Bone dome

Since composite and polystyrene foam replaced leather and cork in the 1950s, the concept of a strong, semi-rigid outer shell and an energy absorbing liner has dominated helmet construction. Carbon fibre has replaced glass fibre for the shell, whose task it is to prevent penetration or fracture that would leave the skull vulnerable to injury, and to spread the impact load into the foam liner and limit the deceleration of the brain and its connections experienced during an impact.

Unlike motorcycle accidents on the public roads, what the helmet actually strikes can be tightly controlled in most motorsports these days. In the past, the driver's head could hit the road, barriers, trees, and other cars, but today the helmet and the car are regulated as a single protective system. The development of FHR,



8860-2018 standard specifies that the helmet must withstand this 225gm metal curved disc fired at 250km/h into the top of the visor area while not subjecting the head to more than 275*g*

FIA

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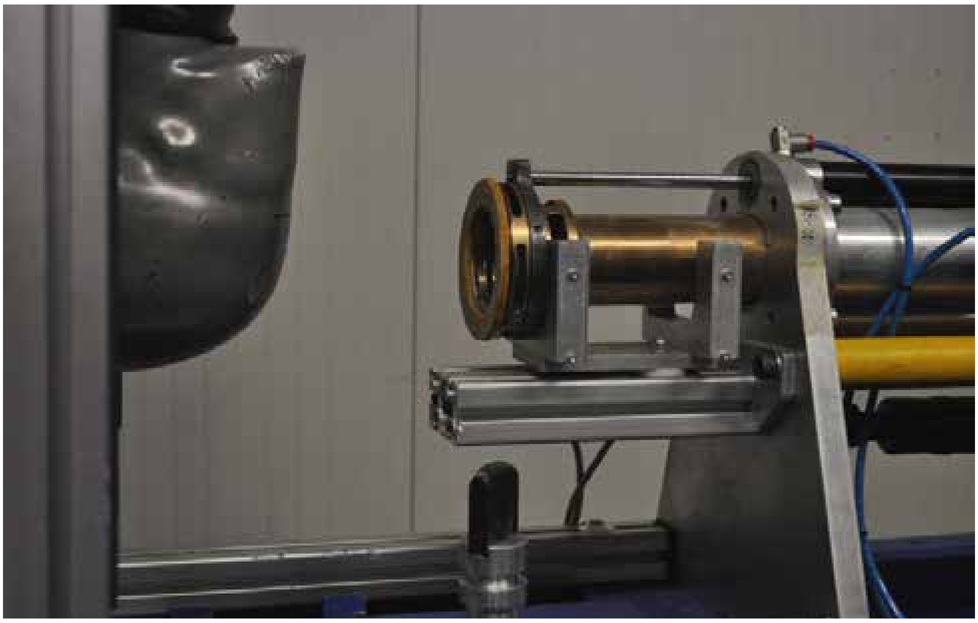
The projectile is loaded into the barrel of a pneumatic gun powered by a pre-charged reservoir of compressed air (this test rig was developed by the FIA and Newton Laboratories)



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The velocity of the projectile is measured at the muzzle of the gun. The target is instrumented with a tri-axial accelerometer

The concept of a strong, semi-rigid outer shell and an energy absorbing liner has dominated helmet construction since the 1950s

headrests, steering columns, racing nets, roll cages, and seats are all specified to interact with the helmet. The 8860-2018 helmet standard takes this compatibility to the next level by extending the test areas at the sides of the helmet to match the car components.

To limit head acceleration to less than 300*g* – a level at which there should not be long-term medical consequences – the new drop test is conducted at 9.5m/sec, the equivalent of a head impact at a head velocity of 35km/h! To pass the test requires careful design and use of materials characteristics for the shell and helmet liner that spread the load into the head below the skull fracture load, and ride down the head at a deceleration that does not exceed the 300*g* limit. The average *g* over the 30mm of effective liner crush will be at least 150*g*.

One issue that has evolved with the very high average *g* necessary is that the energy absorbing materials, whether in the helmet or headrest/seat foam, have to be very stiff. This stiffness tends to lead to quite high peak *g* at lower head impact velocities, potentially leading to concussion. Balancing the trade-off between concussion and severe head trauma has led to the use of Confor foam in headrests and seats. This is relatively soft at low velocities and stiffens up at high velocities due to its inherent viscous damping properties.

Visor panels

Then, in 2009, Felipe Massa was struck on the head by a rear suspension third spring at the Hungarian GP. The spring penetrated his visor and helmet and caused skull fracture. After extensive simulations of the accident at Aermacchi's ballistic impact test facility in Italy, Mellor developed a visor reinforcement panel for the 8860 helmet. This consists of a 50mm wide strip of Zylon composite, bonded to the top of the visor and covering 25mm of the helmet just above the eye port. The 25mm of visor covered by this strip is generally used for a sponsor banner, so does not reduce vision. Tests showed that this would have prevented helmet penetration in Massa's accident.

Since being used in Formula 1 and in IndyCar, this anti-penetration strip has prevented serious or fatal injuries on at least three occasions. However, fitment and maintenance of the protective strip requires significant servicing, so it could only be mandated in open-cockpit championships where helmet manufacturers were able to provide this service.

The 8860-2018 standard, as applied to helmets used in open-cockpit championships, incorporates this protection directly into the helmet, with the eye port upper edge lowered

ANDREW MELLOR

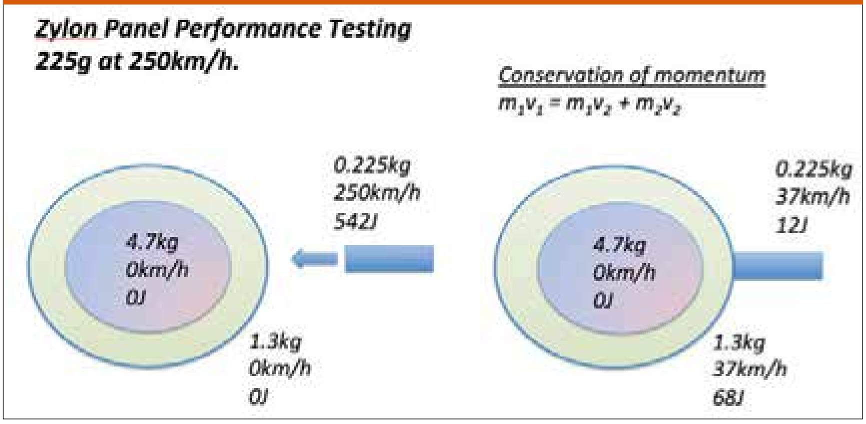
Being suspended, the helmet and headform are free to move longitudinally and laterally to achieve the right body dynamics

ANDREW MELLOR

This shows the actual hit of the projectile against the helmet and visor. The test helped prove that using momentum transfer worked

This protection, built into the 8860-2018 helmets, will deal with small loose objects such as the spring that struck Felipe Massa in Hungary in 2009

Figure 1: Development of FIA standard 8860-2018



ANDREW MELLOR

Table 1

	Projectile	Helmet shell	Head
Mass:	0.225kg	1.3kg	4.7kg
Velocity:	250km/h	0km/h	0km/h
Energy:	542J	0J	0J

Table 2

	Projectile + helmet shell	Head
Mass:	1.525kg	4.7kg
Velocity:	37km/h	0km/h
Energy:	80J	0J

10mm, and does so using a simple but clever physical principle: momentum transfer.

The standard specifies that the helmet must withstand a 225gm metal curved disc fired at 250km/h into the top of the visor area, and not subject the head to more than 275*g*. Such a projectile has energy of 542 Joules, exceeding the muzzle energy of most pistols … except for Dirty Harry's .44 Magnum.

The physical conditions just before the projectile hits the helmet are shown in **Table 1** while **Figure 1** shows just after impact, during which momentum is conserved.

The loss of energy is accounted for by the plastic deformation of the Zylon panel, which dissipates the energy by the crushing of the composite in the same way as the composite crash structures on racing cars absorb impact energy. Now the helmet shell is travelling at only 37km/h relative to the head. These conditions are such that there should not be significant injury to the head (**Table 2**).

Head shot

The test rig and procedure was developed with Newton Laboratories, in Milan. The projectile consists of an aluminium piston and the curved steel impactor, weighing 225gm in total. This is loaded into the barrel of a pneumatic gun, powered by a pre-charged reservoir of compressed air. On firing, the velocity of the projectile is measured at the muzzle. The target is an inverted, suspended headform, instrumented with a tri-axial accelerometer, on to which the test helmet is fitted. Being suspended, the helmet and headform are free to move longitudinally and laterally to achieve the representative body dynamics.

Development of the specifications for Mellor's approach to using momentum transfer theory showed that it worked in practice. If the panel fails to prevent penetration of the shell, the projectile easily passes through the liner and strikes the headform, resulting in head *g*s of over 330*g*. When the panel prevents penetration, *g*-levels are kept below 50*g* – probably a headache, but not the appalling injuries that Massa suffered.

This protection, built into the 8860-2018 helmets, will deal with small loose objects such as the spring that struck Massa in Hungary in 2009, then. But it will not deal with large, heavy objects such as a wheel and tyre (Henry Surtees, 2009) or a nosecone (Justin Wilson, 2015). It is for protection against these objects in particular that the Halo was developed.

Barrier brief

Momentum transfer is not just used in ballistic protection for helmets. It is also employed in the design of high-speed barriers. To bring a car to a halt from 200+km/h without hurting the driver requires deceleration at around 60-70*g* over around 3m. The FIA high-speed barrier achieves this partially by momentum transfer. Segmented barriers of a prescribed mass (110kg) are set up in layers, with spaces between the rows. Built into the sections are anti penetration layers, just like the helmet's Zylon panel, but in this case they are steel to resist the pointed nose of the car. The car connects with the barrier at the point of impact and draws connected sections of the barrier inwards and forwards, progressively adding mass to the car. The initial deceleration as the car hits the first barrier is attenuated, and energy is dissipated by the crushable nose cone and the friction between the barrier segments and the ground. Once the car has coupled with sufficient barrier mass, raising the total by a factor of around three times its running mass and totalling around 2.5 tonnes, it will have slowed to 60km/h, which

Carlos Sainz's accident at Sochi in 2015 was a good example of how momentum transfer works in the Tecpro crash barriers

Momentum transfer, or the conservation of momentum, is a principle that forms a valuable tool in the motorsport safety toolbox

These days crash helmets reflect a driver's personality and allegiances and also carry advertising. But this should not detract from their main purpose; saving lives

Helmet spec 8860-2018

- Standard impact. Helmet impact at 9.5m/s. Peak deceleration on driver's head shall not exceed 275*g*.
- Low velocity impact. Helmet impact at 6m/s. Peak deceleration shall not exceed 200*g* with a maximum average of 180*g*.
- Low lateral impact. Helmet impact at 8.5m/s. Peak deceleration shall not exceed 275*g*.
- Advanced ballistic protection. A 225gm metal projectile fired at 250km/h. The peak deceleration shall not exceed 275*g*.
- Crush. A 10kg weight falling 5.1 metres on to helmet. Lateral and longitudinal tests. The transmitted force should not exceed 10kN.
- Shell penetration. A 4kg impactor dropped on to helmet at 7.7m/s.
- Visor penetration. An air rifle fires a 1.2gm pellet at the visor. The pellet must not penetrate the interior of the crash helmet.
- Visor coating. Transmitter test to ensure colour and vision is not significantly changed or distorted.
- Retention system. Roll-off test and dynamic test to ensure strength of chin strap and its attachments.
- Chin guard linear impact. Impact test with full headform at 5.5m/s. The peak deceleration shall not exceed 275*g*.
- Chin guard crush. A hammer hits the chin guard and measures its ability to keep impact away from the head.
- FHR mechanical strength. A test to ensure high strength of attachment points for the frontal head restraints.
- Projection and surface friction. Test to ensure helmet surface uniformity and that friction is minimised. Shell surface also subjected to BARCOL hardness test for resistance to penetration.
- Flammability: Helmet exposed to 790degC flame; it must self-extinguish once flame is removed.

is dealt with by crushing the barrier sections against the Armco or concrete final barrier.

Carlos Sainz's impact at Sochi in 2015 at over 150km/h, when he hit three rows of Tecpro barriers spaced to give an overall depth of 3m, illustrates this effect very well. The barriers slowed him to under 60km/h at an average of 20*g*, and the final phase, as the car crushed the Tecpro blocks against Armco, had a peak of only 40*g*. This progressive slowing enabled both the car and the driver to race the next day.

Sudden stops

Momentum transfer, or the conservation of momentum, is a principle that forms a valuable tool in the motorsport safety toolbox. Whoever it was who said: 'It's not speed that kills, it is the sudden loss of it,' was right. Excessive deceleration or dissipation of energy into a human is injurious. Firing the 225gm helmet test projectile at 250km/h into a stationary 2-tonne car would stop the projectile and accelerate the car to under 3km/h. Collision with a 3km/h car would not injure a human if it hit them. Matching up the masses of a helmet and projectile and managing the energy of the system is a neat trick of physics.

Other changes to the helmet standard have set out to generally increase the helmet's performance characteristics. Tests to check the overall crush resistance, and resistance to penetration of the shell are uprated. To meet these tests the shell structural properties are tuned along with the impact requirements. Because helmets are produced in a range of sizes to suit the full spectrum of adult head dimensions, the variation in head mass that goes hand-in-hand with size means that each size of helmet/head mass needs tuning to the homologation standards to provide the same level of protection.

Visor performance, chinstrap strength, and flammability have also all been improved.

Evolving knowledge

The head is the most vulnerable part of a racecar driver, particularly in an open-cockpit car. Injuries to the head are among the most serious, being either life-threatening or leading to long-term impairment. Although for many years drivers relied on a leather helmet or reversed cloth cap, science has provided a very high level of protection in the event that the head is either struck by an object or strikes some part of the car's structure. Research continues in line with evolving medical knowledge about brain trauma and the physical forces and accelerations that cause it.

Not only does the racing helmet protect the driver but it also provides a surface upon which he or she can express aspects of his or her personality and allegiances to the world. In that respect it is so much more than a safety device these days – but as a safety device it is still a seriously effective piece of kit.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Saved by the Bell

Bell Racing boss Kyle Kietzmann offers his perspective on the new 8860-2018 crash helmet standard

By RACECAR STAFF

Kimi Raikkonen uses Bell helmets. The new standard has been developed with the helmet's interaction with parts of the cockpit, like headrests, in mind

Bell Helmets has long worked with the FIA to establish new standards in head protection, and so it was appropriate that its product was presented in Manila by the FIA when the 8860-2018 standard was announced (see page 72). Other manufacturers will have to produce this same standard of protection for next season. From a manufacturing point of view, this was an evolution of previous helmets, rather than anything that was revolutionary, but the standard was still a tough one to meet.

'The initial intent of the new standard was to integrate the protection that was available with the visor panel into the shell itself, so that the performance of the helmet could be optimised with the visor panel creating several challenges from a manufacturing standpoint,' says Kyle Kietzmann, Bell Racing USA president. 'The other significant change to the standard is the transition to variable mass head forms, to account for the relationship between head size and weight; larger heads weigh more than smaller ones.'

New manufacturing techniques were deployed in the construction of the helmet, such as the use of more compression moulding that allowed Bell to build a lighter, stronger outer shell. That, combined with some of the advanced carbon materials that are now available, allows it to develop products that previously would not have been possible.

'Bell uses pre-preg aerospace grade carbon fibre materials with a specialised resin system embedded into the carbon material and have developed proprietary compression moulding machines to construct the shell,' says Kietzmann. 'The mould is two-piece aluminium milled tool. The materials are laid up on a male mandrel that fits inside the tool and with a combination of heat, pressure and time we are able to bind the pre-preg carbon layers together to create a strong outer shell.'

Soft centre

The decision to use pre-preg means that the company can reduce weight, increase strength while minimising weight variation. The inner liner of the helmet has also been developed so that the driver's head gets the softest landing possible in case of an accident. 'The other advance that has enabled helmets to be certified to this new FIA specification is the custom EPS bead materials we are now using that are specially formulated based on Bell's design criteria,' Kietzmann says. 'We use a multi-piece liner, so we are able to incorporate different densities in specific areas of the liner which enhance the overall energy management capability of the inner liner system. That, combined with the advances that have been made in material and helmet shell construction by Bell, has allowed us to be at the forefront of this new standard.'

Interaction with car components that are close to a driver's head, such as the headrests, has also been taken into consideration. 'The FIA wanted to make sure that the impact area in the lower region of the helmet that is in alignment with the headrest was optimised to work with the headrest,' Kietzmann says. 'It was a concern, and other aspects such as the incorporation of the head and neck restraint devices have been a consideration in helmet design for many years, not only the placement of the M6 terminals in the shell, but also some of the reinforcement that is done in select regions of the shell to accommodate the head and neck restraint devices.'

This was an evolution, but the standard was still a tough one to meet

Back in time attack

Disillusioned by the technophobia he sees in modern motorsport, and the rise of spec formulae, our numbers man felt the need to return to the scene of one of his past triumphs to prove a very important point

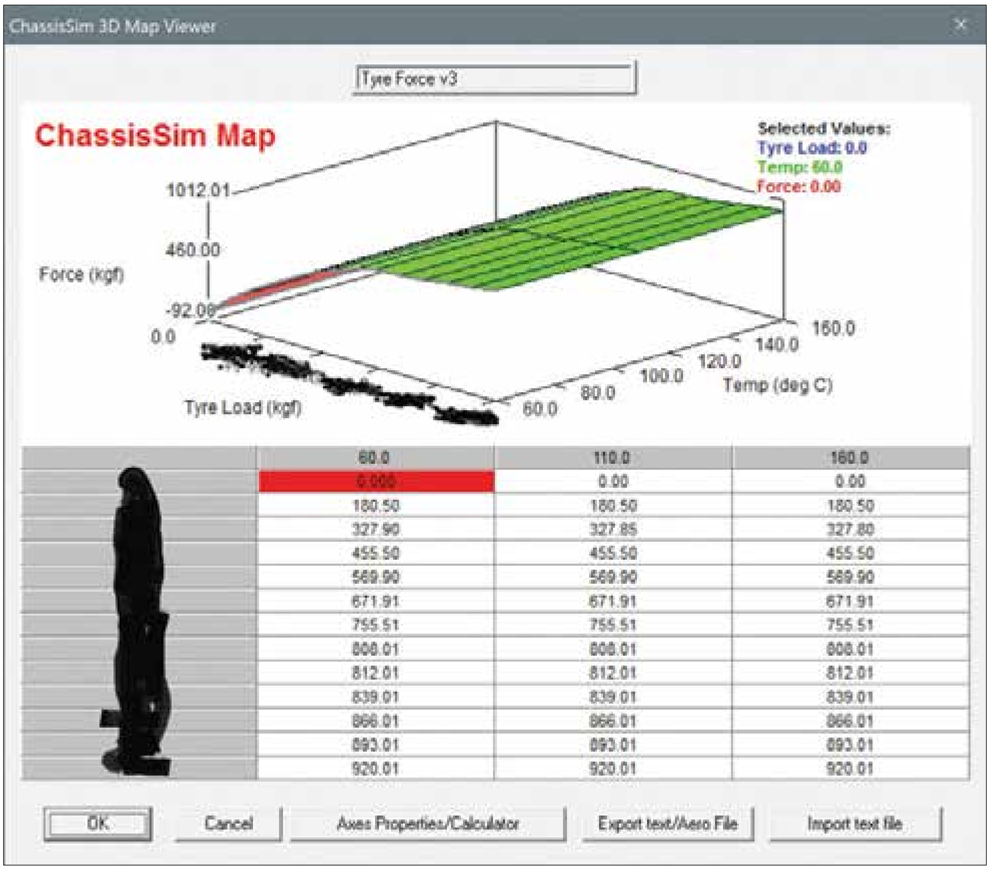
By DANNY NOWLAN

I will only very rarely repeat an article I've used before, but given my recent trip to Le Mans and what I saw there the content of this piece is not just necessary but it is even more important than when I first wrote it a couple of years ago. This needs to be emphasised.

The following article is about how I race engineered an Open Class car in World Time Attack Challenge to a podium finish back in 2016. It is an in-depth discussion into how technical tools such as aerodynamic aids and simulation aren't the work of the devil. Rather, when used properly, they can hugely boost performance. Also, shock horror, this does not spoil the show.

The reason this article needs to be repeated is a reminder of two great afflictions affecting motor racing right now. The first is the scourge of the spec formula. The second is the resident technophobia that grips motorsport, in particular the pervasive belief that simulation, CFD and in-depth engineering analysis have somehow destroyed the show. I believe the events of World Time Attack Challenge 2016 illustrate the ultimate intellectual bankruptcy of both of these afflictions.

The two biggest misunderstandings about simulation are that you need terabytes of data to do it and that it can be shuffled off as low priority



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 1: WTAC tyre model; without this the NA AutoEng team would have been completely lost when it came to simulation

It's not that often I get to comment on what goes on in my own backyard, let alone when I'm an active participant. However, on October 13-15, 2016, the stars aligned and I engineered a customer's car at the 2016 World Time Attack Challenge in Sydney. If you ever wanted a flashing neon sign to show what simulation can do in the right hands, then this weekend was the perfect example. I engineered the NA AutoEng Mitsubishi Evo 6 entry in the open class. Previously it placed 17th. With an aero package from AMB Aero and chassis tuning courtesy of ChassisSim, this year NA AutoEng placed third. This is the story of how we did it.

The reason I'll be going into depth about this is to disprove two of the biggest misunderstandings about simulation; that you need terabytes of data to do it, or it can get shuffled off as a low priority. Bottom line, these are excuses. I can tell you right now had NA AutoEng not had access to a tool like ChassisSim they would have struggled to crack the top 10. Also, when I was engineering the car, the vehicle dynamics knowledge I had built up over the years came into play. If you're serious about results, ignorance is not an option. If you want to take your results to the next level, read on.

Evo solution

The Sydney weekend also illustrated the great cancer that has infected our sport. This cancer is the view that in order to level the playing field we need to tightly regulate the cars. For all its faults World Time Attack Challenge shows the utter foolishness and intellectual bankruptcy of this. Without this technical freedom the car I was engineering wouldn't have got onto the podium.

Like all Time Attack cars, the Evo started its life as a standard car, then had a new motor put in and aero stuck to it. If there is a racecar equivalent of the Millennium Falcon then this car is it. To quote Han Solo, it doesn't look like much, but it's got it where it counts and that is speed. Anything else is rubbish. It sports a front splitter and a rather ample rear wing courtesy of AMB Aero. Extracting the very most out of this package was ChassisSim's job.

The foundation of what we were able to achieve this weekend was in the tyre model

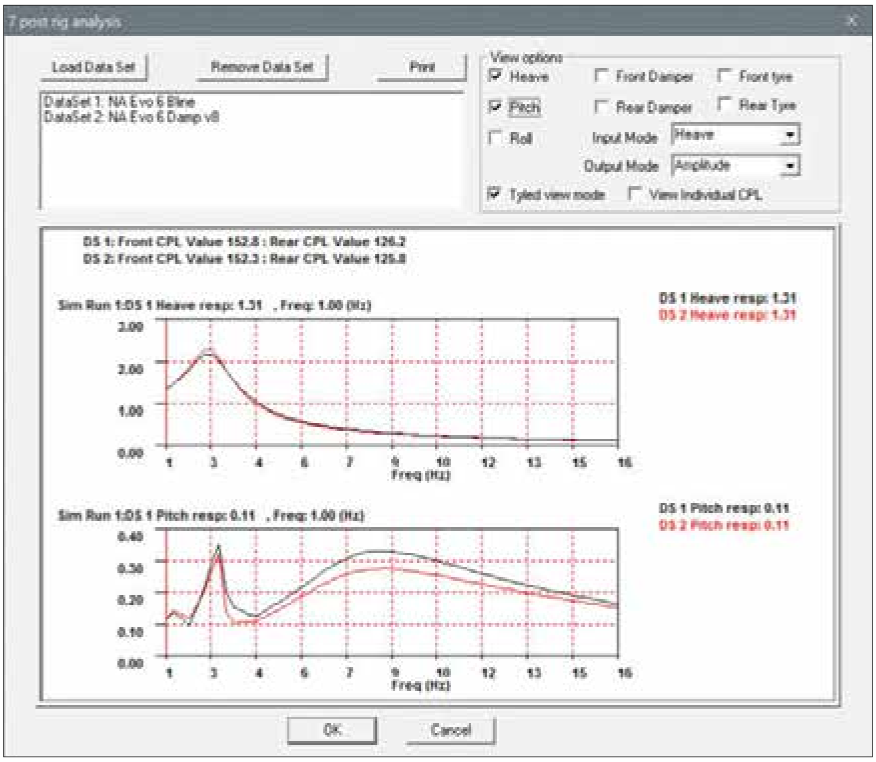


Figure 2: Example of using the ChassisSim shaker rig toolbox – one of the key building blocks for the weekend

Table 1: Aero numbers for NA AutoEng Evo	
Aero paramater	**Value**
CLA	3 +
CDA	1
Aero balance	45%

Table 2: Rough outline of damping ratios	
Damping ratio range	**What this applies to**
0.3 – 0.4	Ideal for filtering out bumps
0.5 – 1.0	This deals with body control.
1.0 +	This deals with extreme body control/ driving temperature into the tyres.

Table 3: Rough values for damping ratios	
Damper section	**Damping ratio value**
Low speed bump	0.7
High speed bump	0.4
Low speed rebound	0.4
High speed rebound	0.4

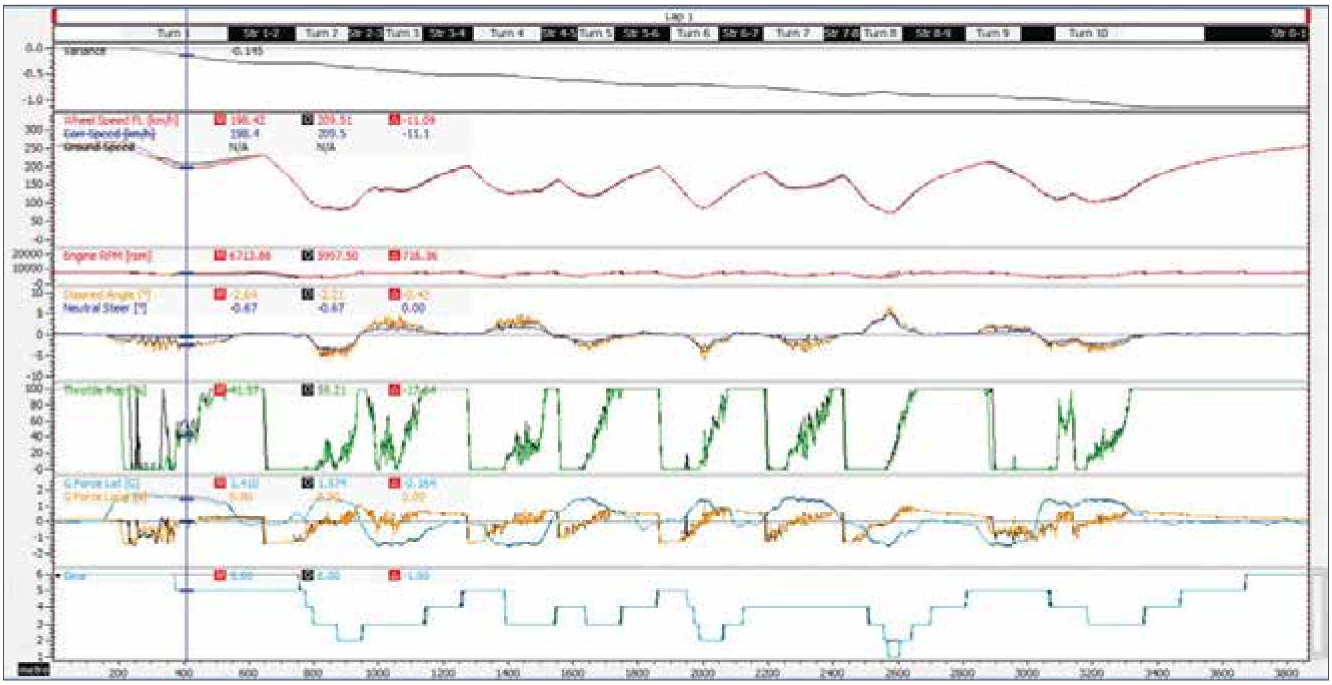


Figure 3: Front dive plane change. Coloured trace is set-up baseline and black trace is the dive plane change with the spring change the team was also planning to make

that I discussed in a previous feature on World Time Attack challenge (*RE* V26N11). Using the ChassisSim tyre force modelling toolbox the World Time Attack tyre was constructed from race data. This is shown in **Figure 1**.

In the previous article on World Time Attack I discussed this in some depth, but one thing I will add here is that some of that data was coming from cars that were falling apart. So this shows you don't need perfect data to get the job done. I can also add that without this we would have been completely lost.

Where this job started was with hand calculating the aero of the car from last year's data and also confirming this from the first day of running. It gob-smacks me why 95 per cent of race and performance engineers don't do this. Without this we would have been flying blind. The approximate aerodynamic numbers for this car are shown in **Table 1**.

This racecar had a weight distribution of 60 per cent. The full significance of this number would become apparent later.

The next job was specifying the dampers. When we talk about setting up dampers we are all convinced this is rocket science that requires an IQ of at least 300. The reality is somewhat different. The first port of call was using the damping ratio guide that I have discussed on a number of occasions here. But to refresh everyone's memory there are some rough rules of thumb shown in **Table 2**.

Damper ratios

So, all that had to be done was determining the transition between the low and high speed section of the damper and specifying the damper ratios. To that end the damping velocities from a smooth circuit simulation filled in these blanks very nicely.

Once that was determined then all that had to be determined next was the damper

The simulated baseline was a 1:31.0s lap. The simulated change was a 1:29.5s lap. My first thought was this was too good to be true

ratios. The approximate values are shown in **Table 3.** Anyone familiar with this will realise this is textbook stuff, from my first ever *Racecar* article on how to select damping ratios.

Solid platform

The next step was to refine this damping ratio selection using the ChassisSim shaker rig toolbox. The priority here was using the shaker rig toolbox to minimise contact patch load variation, and given how aero sensitive these cars are we also concentrated on minimising the cross pitch mode in heave. **Figure 2** is an example of the analysis that was done.

As you can see, there is no rocket science here and I do not have to solve a 15th order differential equation. I'm just following a simple process and sticking to it. All of this was critical because the car now had a solid platform that was well controlled. This was one of the key building blocks for the weekend.

The next step was race engineering the car. The ability to listen and having the vehicle dynamics knowledge was critical. The first question I asked the driver/owner Nick Ashwin was: what is your biggest problem? The answer to this was mid-corner to turn-exit understeer.

At this point, because I knew this was where the peak loads were, I knew the areas to focus on were springs and bars and the rear ride height. The springs and bars controlled the distribution of the load transfer. The rear ride height controlled the aero platform, in particular the aero distribution. The reason I could make these decisive calls was because of the decades of vehicle dynamics study I have had, that now boiled down to one day. Also, we didn't do anything silly. It was one change at a time, confirmed by looking at the data.

Dive planes

While we had made progress the inherent understeer in the car still hadn't been dialled out, and it was here ChassisSim came to the rescue. When we concluded the first day's running Ashwin said to me: 'We have dive planes that we can use at the front if you need them'. I was almost going to wait until midday Saturday to try them, but then it hit me in the eyeballs. Hang on, this isn't a spec formula. I can do what I want. So I ran the numbers in ChassisSim and the end result can be seen in **Figure 3**.

The coloured trace was the set-up baseline from the end of Friday's running. The black was the dive plane change with the spring change we were going to do. The simulated baseline was a 1:31.0s. The simulated change was a 1:29.5s lap. My first thought was this was too good to be true. But then I noticed how consistent the compare-time plot was and how consistent the speed differences were. So, first thing on Saturday morning I called the change.

While by modern spec formula standards this was a Hail Mary pass it worked exactly as expected. NA AutoEng's best time until this point was a 1:32.00s lap. When this was put on the car it was a 1:30.26s lap. The next lap would have been a sub 1:30s, but the car was held up in traffic. The comparison between actual and simulated data is shown in **Figure 4**. As always actual is coloured and simulated is black. I'm the first person to admit this is far from perfect and needs dialling in. However, the trends are undeniable and it shows you how far you can get with a model that is not actually perfect.

The other revealing thing about the weekend is what I discovered about what happens when you have significant technical freedoms to play with. When I started engineering the racecar during the test day and the first day of running, I approached it with the mindset of a spec car. That is, being very careful with the car and being very deliberate with the changes. That in itself is not a bad thing, because it ensures you don't get lost. However, the sim work on the Friday night showed what you can do when you do have those technical freedoms to play with. Unfortunately, it's a skill set that we are on the verge of losing.

Free formula

The other huge takeaway of this weekend was recognising the complete and utter intellectually bankruptcy of motorsport regulatory bodies' restrictions on technical freedom. To be quite honest this is technophobia run amok, that borders on complete hysteria. The critical tweaks for this weekend was the use of ChassisSim, the aero package from AMB Aero, and the front dive plane that provided the finishing touches. So to get this matter resolved once and for all let's break down the costs, shown in **Table 4** and quoted in Australian dollars

All up price is $7000. This enabled an amateur driver like Ashwin to keep a pro driver (who would eventually win the event) awfully honest. So, I have a simple question to any motorsport regulator or any motorsport red neck reading this. How exactly does technical freedom spoil the show or not allow low budget small teams to compete with their more resourced counterparts?

In closing, the NA AutoEng Evo 6 is the perfect case study of what happens when you have technical freedom and a tool like ChassisSim at your disposal. Using tools such as the ChassisSim tyre force modelling toolbox, the damper guide, and the shaker rig toolbox laid the foundation. All that was left was to use the ChassisSim lap time simulation to harness the aero package from AMB Aero. Without all these tools this podium would have been impossible and this shows that you ignore tools like ChassisSim at your peril.

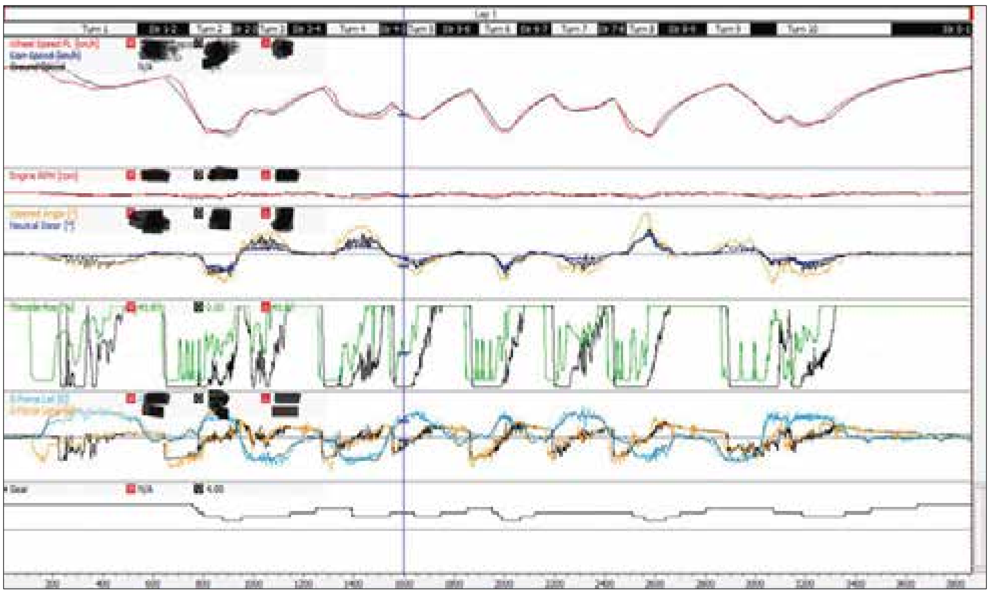


Figure 4: Comparison between actual (coloured) and simulated (black) data for the NA AutoEng Evo 6 World Time Attack car

Table 4: Costings of NA AutoEng tweaks for the Evo 6

Item	Cost
AMB aero package	$5000
ChassisSim set-up service	$1500
Front dive plane	$500

Ahead in the cloud

How advanced simulation in the cloud plays a crucial role in initial design and ongoing racecar development at crack NASCAR outfit Richard Childress Racing

By JOHN KIRKLEY

PICTURES FROM GETTY IMAGES

Cloud-based simulation is playing a massive part in the development of the Chevrolet Camaros that are fielded by NASCAR Cup operation Richard Childress Racing

The RCR Camaro ZL1 that won this year's Daytona 500, NASCAR's largest and most prestigious race, at first glance bears a resemblance to the road going Camaro. But what sets it apart from its street car cousin is that it's been built from the ground up by Richard Childress Racing (RCR) engineers and other automotive experts, using high-performance computing (HPC) and applications such as computational fluid dynamics (CFD) and finite element analysis (FEA). All of which also play a continuing and key role in the car's development.

'It takes about two years to develop a racecar with the power and the complexity of the Camaro ZL1,' says Eric Warren, chief technology officer at RCR. 'That includes working with a manufacturing stylist to make sure the car retains the basic shape of the production vehicle, while incorporating innovative components and design features that conform to tolerances supplied by NASCAR. All manufacturers have to take their submissions to a wind tunnel test to make sure the vehicle fits within a set of very strict performance specifications.' Prior to this test, engineers will use CFD software to simulate that testing to work out the kinks before submitting a vehicle to expensive wind tunnel testing.

Tunnel vision

Actual physical testing can be very expensive – testing in a full-scale moving ground plane wind tunnel can cost over $3500 an hour for just the wind tunnel rental alone. Tests are not only run at full scale but at speeds up to 200mph. Typically, because of cost considerations, the test measures only the total force and moment values, which are typically downforce, sideforce and drag along with their distribution between the front and rear of the vehicle; what you don't get is all the information about the flow field around the car. Adding to the cost of physical testing is the fabrication of test parts. Also, a substantial number of trained personnel are needed to conduct the physical tests.

Cost effective

Simulation is far more cost effective. RCR uses Ansys Fluent to model and analyse the flow field and determine how the air is behaving as it moves over the car. 'Fluent allows us to understand the shape from an aerodynamic point of view and design the vehicle so that it meets those specifications while providing optimal performance,' Warren says.

Ansys Fluent software is used to study the sensitivity of the car's unique shapes and how slight variations in the shape in different areas of the car affect the total forces on it. Using adjoint solver methods available in Ansys Fluent, advanced simulation methods can actually direct how the car should be reshaped

During a season RCR redesigns its cars based on changing NASCAR requirements, competition exigencies and race results *every week*

to improve performance. Historically, it's been up to the designer or engineer to change a shape and test the effect of that change in the wind tunnel or CFD. Adjoint methods can greatly speed up the process by guiding the engineer or stylist to the areas that make the most difference. 'This is a very complex and compute-intensive undertaking,' Warren says. 'We are modelling the 3D flow field around the car, which requires the numerical solution to a complex set of differential equations. The results are effectively a map that allows us to improve the drag coefficient – or any other parameter such as downforce – and create the top performing vehicle on the race track.'

Warren says that one of the challenges encountered by his team in preparing the Camaro for the track was how to move the downforce balance rearward. Cars from previous years were balanced more to the front and one of the main objectives with the design of the 2018 Camaro ZL1 was to move that balance to the rear, producing more downward thrust on the rear tyres and less on the front tyres.

Downforce balance

The downward thrust produces more tyre grip, but it also produces more drag, thereby slowing the racecar. Finding the optimum trade-off between total downforce and downforce balance is one of the many compute-intensive tasks solved by the simulation software.

Not only do the engineers use Ansys Fluent to model the full body, but also components such as the electrical system, powertrain, and the engine. Modelling the entire vehicle allows RCR to create a digital twin of the car that can be used to study its performance on the track. Sensors and actuators on the physical car allows RCR to capture data that is used to validate the digital twin of the car as well as using the data for real time analytics monitoring and predictive maintenance. The twin is running on a high-fidelity simulation of the actual race track, which was scanned down to an accuracy of 2cm.

'This simulation enables virtual testing so we can develop shapes and parts that will have an improved likelihood of being successful as parts on the final, full-scale physical car,' Warren says.

Cloud and clear

None of this would be possible without access to the capabilities of today's high-performance computers. Rather than build its own in-house supercomputers or clusters, companies like RCR are turning to cloud service companies such as Rescale to provide the computational power and expertise needed to meet NASCAR requirements and create a top racecar.

Rescale collaborates with Intel and R Systems to run its cloud services on a platform that provides the performance gains of Intel Xeon Phi processors with the high-speed Intel Omni-Path Architecture fabric for data intensive, cloud-based workflows.

RCR is making full use of these capabilities. Warren notes that by working in the cloud, the RCR engineers can scale up to add more processors when needed without having to pay for additional, on-premise, HPC systems. 'We routinely run two or three CFD cases with 180 million grid points in a day,' he says. 'With full transients to capture and compute flow that adds up to a lot of computation. Last year we could only run one 180 million grid point case per day and 10 years ago that same job would have been just about impossible to run. Best case it would have taken at least a week.'

Today RCR uses Ansys Fluent for aerodynamic optimisation and Ansys Mechanical for FEA and structural optimisation. With the significant boost in capabilities provided by HPC in the cloud, the RCR team can optimise its preparedness by performing the simulations in real time with the driver in the loop, much like aviation flight simulators.

Also feeding in to the simulation is data gathered during actual races from sensors on the car transmitting information in real time about the steering, brakes, throttle, GPS and

Track conditions can be replicated in simulations far better than they ever could be in the costly environment of a wind tunnel

Sensors on the racecar, transmitting information in real time, feed data gathered during the Cup races in to the simulation

RCR makes use of Ansys Fluent for the racecar's aerodynamics and Ansys Mechanical for FEA and structural optimisation

other key data. This telemetry data from the car allows RCR to correlate its digital twin much faster, which enables its engineers to simulate their car during practice sessions and races and provide insights not possible before.

Armed with this detailed performance data, during the race RCR can compare its performance with that of its competitors. For example, the team can determine the impact on the car's performance of changing two or four tyres during a pit stop and/or make other chassis or suspension adjustments accordingly.

Core values

Analysis of the data allows RCR to quickly modify the design between races by knowing how all the car's systems best work together to improve the total performance of the vehicle. 'This was extremely difficult or impossible to do in the past,' says Warren. 'Now advances in cloud and HPC capabilities have provided us with resources we didn't have before. It can take about 30,000 processor cores to turn this large simulation around in a matter of hours.

'We couldn't do those kind of calculations before, because we just didn't have that powerful an HPC facility on site,' Warren adds. 'Today I can go to our cloud provider who can scale up significantly to meet our most urgent demands. This allows us to analyse the tremendous amount of data we gather at the race track and change the design of the racecar in a much shorter time-frame.'

Finding the optimum trade-off between total downforce and downforce balance is one of the many compute-intensive tasks solved by the simulation software

The racecar's configuration is also impacted by track conditions that are nearly impossible to test using a wind tunnel. At the super speedway tracks such as Daytona International Speedway and Talladega Superspeedway, racing conditions place a premium on external aerodynamics. The detailed simulation of both the track and the car allows the engineers to determine how fast the car can cut through the air and what drag forces they can eliminate. Because of the processing power available in the cloud, they can determine what tactics the driver should adopt in a variety of situations – for example, when the car is lined up with others in a drafting situation or when it finds itself caught in traffic on the track.

Quick work

Fast turnaround is key. Chevrolet design cycles for its consumer vehicles are in the one-year to 18 months time-frame. During a racing season RCR redesigns its racecars based on changing NASCAR requirements, competition exigencies and race results *every week*. Simulation and dedicated staff members make this possible.

For example, on a Friday the RCR engineers may decide to run a million simulations and then come back the next morning to determine what component and shape changes should take place that following week to bring the car into optimal racing condition.

For Warren, turning around a redesign in a week was a challenge to get used to compared with his previous work at NASA, where such an effort might take years or decades.

'Ansys simulation allows us to design the racecar more quickly than any other method,' Warren says. 'Powering the Ansys Fluent and FEA software with the right HPC capabilities really shortens the design cycle. And in our world being able to improve the car faster than the competition is everything.'

Tyres
Flying with Falkens

Japanese tyre manufacturer Falken now offers its competition specification tyres to motorsport teams across Europe.

The Azenis race tyres, available now in slick, intermediate and wet variants and multiple compounds, can be acquired in sizes ranging from 240/660R18 to 330/710R18 with more size derivatives to be added later on in the year.

Developed at the Nurburgring using the company's BMW M6 and Porsche 991 GT3 cars as well as Subaru's WRX 4WD racecar, Falken's Azenis range is derived from the tyre that scored its first overall win in the VLN series last season.

Alongside its own fleet of racecars, mentioned above, Falken has already also tested its tyres on a 991 Cup car, a BMW M235i and a TCR SEAT racer.

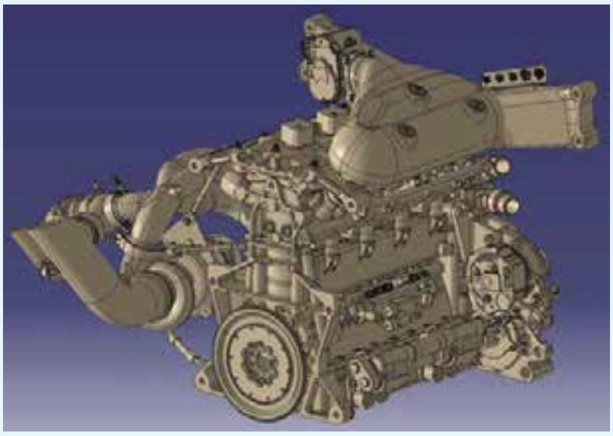
To support N24 and VLN competitors, Falken has appointed Meuspath, Germany-based Tyre Trade Center to sell its tyres and provide technical track-side support in the paddock at all VLN events at the Nurburgring, as well as the N24.
www.falkentyre.com

PRODUCT FOCUS: AER P63

In partnership with Mazda, the P63 variant of the MZR-R engine was successfully designed, developed and tested by AER in 2014 as exclusive engine for the Indy Lights series, ahead of rolling out for the 2015 season.

The engine is a fully stressed 2-litre, turbocharged, 4-cylinder unit generating 450bhp with a 50bhp push to pass function.

The engine retains port injection fuelling and with a rebuild interval of 5000 miles, it's capable of performing a full season of racing and testing without change. The all-aluminium design and full carbon fibre inlet plenum derived from AER's extensive experience in endurance racing gives a dry crated weight of less than 105kg. Controlled by Life Racing electronics, the engine benefits from advanced control and protection strategies such as adaptive knock control and wastegate position based boost control. For further Indy Lights information, see our interview with Dan Andersen on P94.
www.aerltd.com



Simulation
En-Durance driving

A new state-of-the-art simulator facility has been launched by Dura, a company best-known for its modular workshop furniture.

Located in Brackley, UK, Dura Race Performance Simulator offers race professionals and keen amateurs authentic track time experiences to hone their driving skills. The RPS suite is surrounded by a 180-degree 4m curved screen.

It also features a choice of 130 circuits worldwide, allowing for different vehicle set-ups and weather conditions.
www.duraperformance.com

Data logging
The Lotus position

Platinum Experience at the Lotus Driving Academy has been set up to help drivers use data loggers to slash lap times.

The Academy has created this driving course, that combines advanced driving skills coupled with data logging experience, to cater for experienced track day participants and race drivers.

The course covers skills such as left foot braking, trail braking as well as understanding how to use data logging to improve using objective measurement. Using both a Lotus Exige Sport 350 as well as the Exige Cup with its track suspension set-up, the day provides a chance to gain experience relevant to circuit racing with Racelogic's Vbox system. It's held at Lotus' test track at Hethel and costs £1199.
www.lotusdrivingacademy.com

Interview – Dan Andersen

Switching on the Lights

The promoter of the Road to Indy championships explains how he aims to bolster the thin grids that have plagued Indy Lights this year

By MIKE BRESLIN

'There is a kind of a perfect storm for our Indy Lights operation right now'

The finish to this year's Freedom 100 at Indianapolis on the Friday of the Indy 500 weekend was single seater oval racing at its very best. Six Indy Lights cars battled for victory at just under 200mph for the last few laps, sometimes inches apart, with the win not sealed until the chequered flag. The only thing that spoiled the spectacle was that there were only two other cars running.

And that's been the issue with Indy Lights this season. The category that sits just below IndyCar on the Road to Indy ladder – the US F2 in many ways – has seen thin grids all year, which is puzzling when it's considered that it's not especially expensive to compete in the series – less than $1m we're told, even with a decent amount of testing – and it comes with a very good prize fund plus a $1m IndyCar scholarship for the winning driver.

Indy Lights, and the two other series on the Road to Indy ladder, USF2000 and Pro Mazda, is looked after by Andersen Promotions, headed by Dan Andersen, a businessman in the building industry who has been involved in racing, running teams and series, since 1990. He took control of Indy Lights for the 2014 season and says of the current situation: 'There is a kind of a perfect storm for our Indy Lights operation right now. We were not full last year in our Pro Mazda level, which is step two in our three step ladder. We were in the final year with an old car and we were having a tough time filling those seats. The introduction of the new Pro Mazda car this year has been very successful, and the field is once again populated with young drivers who are career minded and are moving up, and so we should have enough drivers coming up the ladder for next year.'

Team talk

Yet Andersen also says that the series is in some ways a victim of its own success, with teams as well as drivers now moving up to IndyCar; Carlin being a good example. 'They say they're coming back, but they parked their four cars and focused their attention in 2018 on IndyCar solely,' Andersen says. 'But once they have got that sorted then they will resurrect their Indy Lights team. They are important to us, because they are a pipeline into the European driver ladder. Juncos Racing has also jumped into IndyCar, but they've kept their Lights operation, but at a lower level, so those two teams moving up has really had an effect.'

As always in racing there's the financial situation to think about, too, for while Indy Lights is relatively cheap in single seater terms, a million dollars is still a million dollars. 'The exchange rate is certainly not helping us, the dollar is too strong,' says Andersen. 'European money is not buying as much. So we have taken a hard look at controlling budgets and we are likely going to do a little more control on testing for next year, and we'll work with our series partners on reducing the costs of spares and reducing the cost of engine leases. [We have a plan for the] next five years to resurrect Indy Lights to the position that we want it to be at, which is at least 15 cars, but really 20 cars is the target goal, with eight to 10 teams functioning. We have a lot of partners supporting this plan and IndyCar is doing what they can to assist us. Indy Lights is very near and dear to IndyCar and they will help us do what we have to do.'

Without IndyCar, of course, there would be no Road to Indy, so you can bet Andersen has been keeping a close eye on all that happens at the top level. 'I think they have come a long way and I think their car, right now, with the changes they've made in the aero kit, has produced some great racing and the teams are more happy than I've seen them in years,' he says.

Payback

Keeping teams and especially team owners happy in his own series is also important to Andersen. 'I started off as a team owner and I lost a lot of money being a team owner!' he says. 'I have a real heart for team owners. People don't understand. A lot of drivers think the team owner is getting rich because they come to a team with 300,000 to 400,000 dollars to go racing. They think the team owner is just making a lot of money, but I can tell you from personal experience and from knowing my team owners that they are not making much at all, they are basically making a living, that's all.'

New cars for the first two rungs of the ladder have now gone some way to helping the team owners make that living, too. USF2000 saw the introduction of its new car last year; the

The racing is great in Indy Lights but there have been few cars on the grid this season

Tatuus-built USF-17, a full carbon composite and aluminium honeycomb monocoque chassis. Meanwhile, Pro Mazda has received its new car this season, the PM-18, which also uses the USF-17 chassis as a base, to help control the costs for teams who want to move up from USF2000.

With the new chassis the technical regulations will be stable for a while now, which is sure to attract teams and drivers. That said, there could be one change on the horizon. Cockpit protection is now the hot topic for single seater series the world over and IndyCar is looking at a screen-type device, but Andersen says his series will not necessarily follow its lead and a Halo is a possibility. 'We are looking at that,' he says. 'Whether IndyCar goes that way or not, our tech team is encouraging me to come up with a solution that would offer some kind of protection, Halo or something that provides that type of protection. So yes, that is definitely on our radar.'

Holding the ladder

But it's not all about the cars, of course, and developing the drivers is a key aspect of the Road to Indy initiative. 'We have the summit programme,' says Andersen. 'We have clinics on dealing with the media; physical fitness; we have an oval clinic which is very well attended. We also have a team manager or team owner who comes and speaks about what they're looking for; we try and give the drivers a good overview of what their career in open wheel racing will look like and train them outside of the seat. There are a lot of talented drivers, but the reality in today's racing is they have to not only be fast, they have to represent a sponsor and know all the moves to be a professional.'

In the end professionalism is what it's all about, and yet it's not all hard-nosed stuff. You don't race if you don't love it, and the same goes for running a series, or indeed a series of series. 'This is not a deal that I'm involved in for personal profit, I take nothing at all out of the series in terms of salary or any other type of compensation,' Andersen says. 'I have another business that supports me, and this business is just a hobby that I love doing.' And a fair proportion of the drivers now plying their trade on the IndyCar grid should be thankful for that.

RACE MOVES

XPB

Susie Wolff is now team principal at the Venturi Formula E operation. The former Williams test and development driver has also become a shareholder in the Monaco-based team. Wolff hung up her helmet at the end of the 2015 season and since then she has mostly concentrated on the Dare to be Different initiative, aimed at encouraging more women to enter motorsport, which she launched in 2016.

Gerald Tyler, who was recently appointed technical director at IndyCar operation Harding Racing, has now taken on a race engineer role within the team, overseeing the car of **Gabby Chaves**. Veteran engineer Tyler replaces **Matt Curry** in the post, the latter having been moved to a different engineering position within the organisation.

Jeff Pratt has been appointed managing director of the £80m UK Battery Industrialisation Centre (UKBIC), a national facility that will support the UK's industrialisation strategy for battery R&D. Pratt was previously general manager at Nissan's Lithium Ion Battery Plant in Sunderland. The UKBIC will enable the development of next-generation battery systems across the full spectrum of R&D activities. The facility is due to open in 2020.

Motorsport and automotive PR agency Influence Associates has appointed **Christopher Foster** as a director. Foster brings a decade of experience in automotive technology and motorsport to the well-known firm, having run a successful technology communications agency, re-branded a sports car manufacturer, advised on strategy for clean-tech businesses and worked in the marketing departments of both Ferrari and Honda in Formula 1.

Ben Collins, the race driver who is perhaps best known for his time as The Stig on the BBC's *Top Gear*, is behind a new three-day motorsport engineering course for year-12 maths pupils (16 to 17-year olds) that will be held at the University of Hertfordshire in the UK. The course, which is being held in conjunction with the Smallpiece Trust, aims to give students an insight into motorsport technology.

Benedikt Helling (25) from Mutlangen, Germany, is the European winner of the Infiniti Engineering Academy 2018 – the initiative which gives students from seven regions around the world a six-month work placement at Renault F1 in Enstone and a further six months at Infiniti's Technical Centre Europe in Cranfield.

Sylvain Filippi is now the managing director at the DS Virgin Racing Formula E team. The Frenchman, who has been with the team since the very start of FE, has headed the organisation since **Alex Tai** stepped down from the team principal position in June, though he previously worked under the job title of chief operations officer.

Tim Rose, a professional racing driver and racing school instructor, is now the general manager at the **Bob Bondurant** School of High Performance Driving. Rose previously managed the School's IMSA programme, supported its sponsor and vendor relations and helped to procure new business opportunities.

Tim McGrane is now the CEO of the Sports Car Racing Association of the Monterey Peninsula (SCRAMP), the organisation that runs the Laguna Seca circuit. McGrane, who is originally from the UK, has a background working in high-end car auction houses and holding major automotive events, many of which were connected with the famed Californian track.

NASCAR has announced that **Steve Waid** is to be the eighth recipient of the Squier-Hall Award for NASCAR Media Excellence. Waid began covering motorsport in 1972. In 1981 he moved to *Grand National Scene*, a weekly NASCAR publication that became known as *NASCAR Scene* and he would later become its publisher. He also published the monthly magazine *NASCAR Illustrated* and he remained involved with both titles until his retirement in 2010.

Tech boss Costa to take on advisory role at Merc F1

Aldo Costa, the engineering director at Mercedes, has decided to step back into a consultancy role within the team.

Costa's decision has sparked a broader tech management shake-up within the Mercedes team which will see chief designer John Owen step up to head the engineering effort, reporting to technical director James Allison.

Costa has been with Mercedes since 2011 and before that he was at Ferrari and Minardi – he was the Scuderia's technical director from 2007. He has been a key element in Mercedes' recent success but has chosen to move into the role of technical advisor to the team from the beginning of 2019 in order to spend more time with his family.

Other changes at Mercedes include the upcoming loss of performance director Mark Ellis, who has decided to take a sabbatical from the middle of next season. The former Red Bull, BAR and Jaguar man will be replaced by current chief vehicle dynamicist Loic Serra at the end of this season.

XPB

From the start of 2019 Aldo Costa will no longer head up the engineering team at the Mercedes F1 operation

Mercedes team principal Toto Wolff said of the moves: 'This is a significant moment for our team and a great opportunity. We have said many times that you cannot freeze a successful organisation; it is a dynamic structure and I am proud that we are able to hand the baton smoothly to the next generation of leaders inside the team.'

Costa said: 'Over the past year, I have worked with Toto and James to develop a long-term succession plan to help the next generation do the job in the best possible way. I am happy to leave the baton in the capable hands of John and James.'

Boullier steps down from McLaren Formula 1 position

Eric Boullier is no longer racing director at McLaren, having resigned from his position as the team continues to struggle for pace this season, while Gil de Ferran has been given a new role in the wake of his departure.

McLaren has now 'simplified' the organisation of its technical management team, with former Indianapolis 500 winner de Ferran – who joined recently as a consultant – becoming sporting director. While the Brazilian is widely known for his experience in US motorsport he has also held a sporting director role in F1 before, at BAR (then Honda when it changed identities) from early 2005 until mid-2007.

Meanwhile, chief operating officer Simon Roberts has been given responsibility for production, engineering and logistics and new performance director Andrea Stella is now in charge of track-side operations.

Boullier came to McLaren in 2014 and before that he was team principal at Lotus F1, now racing as Renault. He said of his departure from McLaren: 'I am very proud to have worked with such a brilliant team over the past four years, but I recognise now is the right time for me to step down.'

McLaren CEO Zak Brown insists the decision was purely down to Boullier, while of the wider changes within the team he said: 'It's the start of a journey to get back to our winning ways. It's going to take a little bit of time and a lot of hard work. We have got the energy, we've got the support from our shareholders. We promoted Andrea Stella to performance director and ultimately he's responsible for getting the most out of the racecar.'

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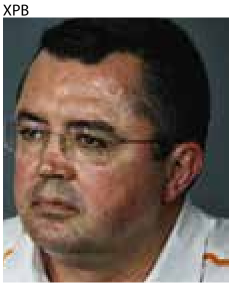
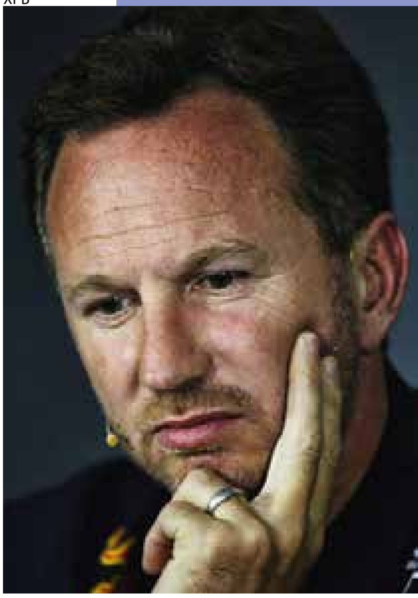


Eric Boullier has resigned from his post as racing director at McLaren as the team continues to struggle

RACE MOVES – continued

XPB



Christian Horner, the team principal at Red Bull, has received an honorary degree from Cranfield University in recognition of his contribution to motorsport. Horner has been the Red Bull boss since 2005, when he became F1's youngest ever team principal at 31. On receiving his degree Horner also launched Cranfield's new Advanced Motorsport Mechatronics masters course.

Leonora Surtees, the daughter of 1964 Formula 1 world champion, multiple motorcycle world champ, and former F1 team owner **John Surtees**, has been appointed managing director of the Buckmore Park kart circuit, a venue bought by her father in 2015. Surtees, who invested heavily in grassroots motorsport towards the end of his life, died last year.

Ferrari was able to successfully argue that it was not in breach of Formula 1 curfew rules at the French Grand Prix, after a team member arrived at the paddock before the 10am cut-off, because he was not an active member of the F1 operation. The FIA accepted the explanation that he worked for the team's driver academy and was therefore in the paddock to look after its drivers in the supporting F2 and GP3 races.

Paul Wolfe, the crew chief on the Team Penske No.2 Ford in the NASCAR Cup Series was fined $10,000 after the car was found to be running with an improperly installed lug nut at the Chicagoland Speedway round of the top level NASCAR series.

Mike Wheeler, the crew chief on the No.11 Joe Gibbs Racing Toyota, was also fined $10,000 for the same infringement at Chicagoland (see above). Both of these infractions were discovered at post race inspection.

In the NASCAR Xfinity Series round at Chicagoland the No.19 Joe Gibbs Racing Toyota was also found to have a lug nut improperly secured. Crew chief **Chris Gabehart** was fined $5000 for the infraction.

Gregor Hembrough has been appointed head of Polestar Automotive USA, the newly-established United States subsidiary. Hembrough has a wealth of automotive expertise built up over more than 25 years and he moves to Polestar from Volvo Cars North America.

Australian Supercars' deputy race director **Michael Masi** and co-chairs of the stewards panel **Matthew Selley** and **Christopher McMahon** have been selected by the FIA for its list of future stewards. They are now on course to work on international events including Formula 1 races and rounds of the WEC and the WRC.

Dee Ann Andretti, the wife of **Mario Andretti** and matriarch of one of the most prominent families in US motorsport, died at the age of 76 in July, a few weeks after suffering a heart attack. She met Italian-born Mario while she was teaching him English in Nazareth, Pennsylvania. They were married a few months later in November 1961.

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Party like it's 1995

Walking the IndyCar paddock at Road America was like stepping back into Formula 3 in 1995, but with more good teams, and drivers who are already world class. Back then British Formula 3 featured the likes of Helio Castroneves, Christiano da Matta, and Gonzalo Rodriguez – and Juan Pablo Montoya a year later. There was even then a knowledge that these guys could go on to greatness, and they all did, in the US racing series. Others found their fame in their own, unique ways; Christian Horner left Alan Docking Racing to run Arden then Red Bull Racing, while David Sears Racing's James Matthews went on to marry Pippa Middleton.

Oliver Gavin and Ralph Firman competed for the title in 1995, Gavin coming out ahead with a win and a third place in the final rounds at Silverstone and Thruxton. Both went on to have long and successful careers; Gavin now called Dino the dinosaur by his Corvette Racing team mates who, secretly, have an immense respect for this elder statesman, while Firman forged a more than successful path in Japan.

Racing then was on the outstanding British circuits which included Pembrey – where series manager Jeremy Lord was once pinned to a wall by some rather drunk ladies in a nightclub that he accidentally finished up in while trying to leave an organised dinner – and Oulton Park. This championship really was of an analogue era.

The driver involvement was high and the relationship with the engineer one of the few links between the car on track and the pit. You have to understand that these were the early days of mobile phones; the internet was still some kind of magic, and no one has experienced frustration until you tried to send stories from south Wales by modem. If you don't know what a modem is, do yourself a favour, and don't try to find out; the fax machine was far easier. I never did figure out how to couple the modem to a regular telephone handset. Also, the memory of the mobile phone black hole of hell that was Silverstone is still a shadow burned into my brain.

At Road America 23 years later, teams were working out of an awning on the side of what are, admittedly, bigger and more polished trucks than in 1995, and technology has moved on significantly. It has moved on to such a degree that IndyCar has now started to ban tools that in Europe have become commonplace, with a view to maintaining the analogue ethos.

'You have to have a debrief between the driver and the engineering staff,' says Rob Buckner, Chevrolet Racing's engineering programme manager in IndyCar. 'You don't want to just release the driver back to the bus after the session, because the car has released so much data and you have people analysing it. The driver still has to get the most out of the car, and if you look at the successful pairings [of driver and engineer], they know each other well, and once that personal aspect has gone you have lost a big part of it.'

IndyCar does not have ABS, or traction control, or fuel flow meters, or anything that requires a huge amount of engineering support. 'There is so much technology now that if you apply it all to racing, you could just have them all radio controlled by a group of engineers, parading around the track, it is endless what you can do now,' says Buckner. 'Put the lines down where we want to compete, what do the fans want and appreciate.' I had only asked about the possibility of going to hybridisation in 2026, when the next set of regulations will be introduced. But IndyCar's position in the world of motorsport is like stepping back in time, to a point where racing was a great deal more fun. The driver is able to translate what he or she is feeling (in 1995 Paula Cook drove in Class B before moving up to Class A in 1996), and there was not a huge number of people surrounding the car with laptops and furrowed brows. That was a time when lap time was measured in tenths, rather than hundredths of a second, and the margin of error was centimetres rather than millimetres.

The IndyCar paddock of today is full of petrolheads rather than computer technicians

The IndyCar paddock of today is full of petrolheads rather than computer technicians. Some teams need a little work on the organisation front, as they too seem to have weekends stuck in 1995, but the quality of the racing is as high as any you will find in the rest of the world. The keyword for everyone is 'sustainability'. While Europe chases hybrid power units and achieving outstanding aero figures, IndyCar introduced the UAK18 aero kit, has elongated the life of the DW12 chassis to what will be 10 years before its scheduled replacement, and mandated a 2.4-litre twin turbo engine for the next rule set. As Formula 1 teams struggle with multi-million euro engine lease deals, IndyCar is capped at $1.3m a season, which takes into account four engines over 10,000 miles of running.

European racing is really driving technical development and this must, of course, be celebrated, but there is a large part of me that deeply loved the IndyCar paddock. It's fun, loud and sustainable, and it certainly has a vital role to play in the next decade of motorsport.

ANDREW COTTON Editor

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