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This year's Williams pictured in illustrious company. We celebrate the team's 40th year in F1 by examining the FW40 (P8) and reappraising the radical six-wheeler (P16)


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Impressive CV

Paying homage to an unlikely icon of automotive design, the Citroen 2CV

When one of the design requirements for a car is that the customer should be able to drive eggs across a freshly ploughed field without breaking them, you know some unusual choices are going to be made. Especially if interpreted by an unusually gifted engineer.

In 1934 Citroen went bankrupt, and so Michelin, its largest creditor, took it over. It then did a market survey to see what a low-end car should be able do. France at that time had a large rural population which could not yet really afford cars.

From the results of the survey Pierre Boulanger, the vice president of Citroen and chief of engineering and design, derived the main items for the 'mechanical umbrella on four wheels', and listed the requirements for what was called the TPV (Toute Petite Voiture – very small car).

It would be a sturdy, low cost, low maintenance car, more basic than that other icon, the Ford Model T, able to transport four passengers and 50kg of goods across muddy rutted regional roads and not use more than three litres of fuel per 100km (95 miles per gallon). It also had to be easy to drive, for first time drivers.

French persistence

The designer of the car was a mechanical genius, Andre Lefebvre. He had already designed the Citroen 7CV 'Traction Avant', a front-wheel-drive sedan that broke new ground in handling, performance and efficacy, turning it into a favourite of bank robbers, because it was the ideal getaway car.

Lefebvre had come to Citroen from Voisin, an aircraft and car manufacturer, where he had designed the Voisin C6 Laboratoire, a grand prix car that was probably the first monocoque racer, bringing his experience as a race and rally driver

The Laboratoire was unusual. It had a small frontal area, a very narrow 50cm rear track to avoid the weight or need of a differential (later widened to 75cm) and a modern looking steering wheel with a flattened top and bottom for visibility. To cater for extra cooling requirements at high speed there was a supplementary propeller-driven water pump.

The Citroen TPV evolved until 1939, when 250 prototypes were ready to be presented at that year's Automobile Salon in October. Due to the start of WWII this did not happen. These prototypes used aluminium and magnesium parts and had water-cooled flat twin engines with front-wheel-drive.

When the press tools of Citroen were requisitioned by the Germans, Boulanger managed to get the Resistance to re-label the rail cars on which the tooling had been loaded with the result that they ended up scattered all over the Europe, making it difficult to recover them even after the war, when Citroen was trying to get them back.

Hard as snails

The car that was finally produced from 1949 was a marvel of frugality and ingenious design. It had a starter motor by then, rather than the pull-cord original starter system, was made of steel instead of aluminium because of material scarcity, but was still rugged and light, the results of Boulanger's specially created department that looked at every item on the car, examining the need for it, and then lightening it as much as was possible.

In the redesign for steel it went for flat panels, another result of the scarcity of presses, which

The first iteration of the 2CV was minimalistic in the extreme; note the single headlamp. Body steel was corrugated for extra stiffness

were still scattered all over, and was corrugated for stiffness. It had only one headlight and tail-light, the minimum required by law, the windshield wiper was driven by the speedometer cable, giving a variable speed, contingent of course on the vehicle speed.

Lefebvre's racing heritage was most evident in the handling of the car as his speciality was chassis design and he was particularly interested in maintaining contact between tyres and the road.

The suspension system, designed by Alphonse Forceau, had front leading arms and rear trailing arms, connected to eight torsion bars beneath the rear seat: a bar for the front axle, one for the rear axle, an intermediate bar for each side, and an overload bar for each side. The front axle was connected to its torsion bars by cable. The overload bar was for when the car had more than two people on-board. This meant an extremely long suspension travel, soft ride and good off-road capabilities.

It was pretty good on track, too. During a circuit drive recce for the Nurburgring Formula 1 race in 1976 I witnessed the possibilities of its handling when the driver of a 2CV on Dutch plates saw our Mercs, driven by F1 drivers Emerson Fittipaldi and Carlos Pace, and was so excited recognising the drivers of the cars that were overtaking him he was spurred into an outstanding attempt to keep up with us. He not only succeeded in doing this on corners, but stayed ahead, as we were laughing so hard at the impossible angles the little car was assuming that we nearly crashed.

It also incorporated inboard brakes at the front and a dashboard mounted gear-lever for direct linkage to the four speed synchromesh gearbox, the fourth being considered an overdrive. It also used mass dampers, which surfaced in F1 many, many decades later, and were subsequently banned.

Cloud nine

The engine was another marvel of ingenuity. A two-cylinder opposed air-cooled 375cc with just nine horsepower, it didn't use any gaskets, due to the fine machining of the matching surfaces and it also had a 'lost spark ignition system', where the plug sparks in the combustion phase and the exhaust phase, thereby halving the number of components in the ignition system.

One other item in the design brief that contributed to its initial impact was Boulanger's main specification: 'Looks are not essential, just efficacy.'

For any engineering student and prospective F1 designer, it's well worthwhile delving deeper into this design for the lessons it can give into real engineering to a purpose. The dean of motoring writers, LJK Setright, described the 2CV as: 'The most intelligent application of minimalism ever to succeed as a car'. Also saying that it was a car of 'remorseless rationality'. High praise indeed.

There were over eight million cars produced from 1948 to 1990, and that is the true measure of the 2CV. It was a huge commercial success: within months of it going on sale there was a three-year waiting list, which soon increased to five years.

At the time a secondhand 2CV was more expensive than a new one because the buyer did not have to wait. And its toughness and lightness was not lost on discerning customers, either. The British Royal Marines adopted it as a helicopter-transportable vehicle be used in jungles in the 1950s. Citroen 2CV, we salute you.

Lefebvre's racing heritage was most evident in the handling of the 2CV

Factory records

Why do car manufacturers often fail to capitalise on their motorsport exploits?

Mainstream automotive manufacturers are all over the place at present, with emissions scandals, EVs, autonomous cars, environmental issues, saturated markets, uncertainties regarding Brexit and currency exchange rates all adding confusingly to their strategies and therefore to the mix of where to place their motorsport marketing dollars. This is not all bad perhaps, but it does dilute finances, prestige and competition within established premier forms of motor racing, from which manufacturers are increasingly withdrawing.

The WEC is in trouble, with potentially no imminent manufacturer representation at all in LMP1. The DTM is in turmoil due to Mercedes' shock pullout. In World Rallycross Peugeot is in deeper (another blow for the WEC as the ACO seemed to be counting on Peugeot to return under revised regulations, but now it won't), but Ford is out. The WTCC has a significant question mark over its continuation. NASCAR is no longer the fan pleaser and money-making machine it was. And Indycar still fails to attract more than the two manufacturer-financed engine suppliers it currently has.

Youth appeal

On the more positive side, F1, though still uncertain and heavily dependent on a less expensive and more exciting future engine specification, is promising but could benefit from at least one additional competing manufacturer. But there are still the thorny issues of a more balanced distribution of revenue to teams, plus greater appeal to the younger generation, whose spending power sponsors and manufacturers are desperate to capture.

Formula E is attracting great manufacturer attention, as it has attached to it the fashionable key buzz-word of 'electric', but this is arguably disproportionate to its spectacle and its actual importance. With budgets set to rocket upwards now that the likes of Audi and Mercedes are involved, the series risks a similar cost/benefit crunch as those that caused these big players to desert the WEC and DTM in the first place.

The fact is that automotive corporations are increasingly becoming transport vehicle manufacturers rather than car companies, and are no longer much influenced at high level – fortunately with some notable exceptions – by 'petrolheads' (probably now a dirty word).

Nor to a large extent can they afford to be. These are vast corporations employing hundreds of thousands of people directly and indirectly, with collective global interests generating and spending billions of dollars annually, often capable of holding governments to ransom. Therefore, as most top executives have little in-depth knowledge of motorsport and of those benefits it brings which don't necessarily show on the bottom line, in the scale of their overall responsibilities and ambitions racing programmes are not their highest priorities.

Fraction control

In absolute terms, the budgets required to compete at the highest levels are actually almost inconsequential for manufacturers. Dieselgate has cost VW Group around $22bn to date and that cost is still rising, with other manufacturers also feeling the heat; investment in new vehicle platforms and powertrains and the production-line facilities needed also approach similar colossal figures. So committing even two or three hundred million dollars annually for an LMP1 or F1 programme is relatively small beer. The key of course is the above-mentioned cost/benefit, or return-on-investment, particularly crucial when totally unexpected crises such as lawsuits reach epic proportions.

However, marketing divisions and their communications departments, who are generally the proponents of any participation in motorsport, are often their own worst enemies in getting the best bang for their company's buck. Where, for instance, have there been the compelling media features and advertisements extolling the amazing efficiency advances of the power units both in Formula 1 and LMP1, with their environmental benefits transferred to assembly-line vehicles?

These factors were the raison d'etre for manufacturers' participation in the first place. Why, with their considerable advertising spending power, do they allow national newspaper and TV to cover only Formula 1, some of these major media outlets not even *mentioning* Le Mans? Surely before a single dollar, yen, pound or euro is spent, the publicity and promotional programme should be laid out and costed. It often seems that the hospitality and other softer options are the ones that take precedence, rather than the message to the masses being driven home. Perhaps this essential part of the deal is too boring and unglamorous for those responsible?

It appears that motorsport as a means of promoting a manufacturer's specific objectives is seldom worked hard enough and consequently is not sufficiently justifying the investment made. Which is a great pity for all concerned.

Peugeot's committed to World Rallycross instead of returning to LMP1. Car makers have struggled to get a good return on their investment in the WEC

Vanishing market

While governing bodies and event promoters bemoan insufficient major manufacturer involvement, with the increasing prevalence of one-make formulae they simultaneously risk putting out of business that other type of manufacturer, the designers and builders of pure racing chassis and engines. The most recent decisions – to make LMP2 restricted chassis with a single engine supplier, followed by the FIA Formula 3 International Championship becoming all mono-make in 2019 – means that the variety of good, professional companies previously participating are having to scratch around for whatever business they can find elsewhere. Apart from the tender-winning F3 engine supplier, all that the other engine builders can expect now is to supply the regional championships, but even these are to become mandatory one-make supply.

Despite cost reduction being the aim of this decision, I have little doubt that the price to win in the International Championship will soon be just as much as it currently is. It's simply the nature of the competitive beast.

In absolute terms, the budgets required to compete at the highest levels of the sport are actually almost inconsequential for car manufacturers

Mid-life **crisis**

Williams is celebrating 40 years in Formula 1 with a type number that reflects the anniversary – but is the FW40 stuck in a conceptual rut, and can Williams become a top-line team again? *Racecar* investigates

By SAM COLLINS

Williams is the last independent team in Formula 1 with the owner's name still above the garage door. It's been around a while, too, and this year Frank Williams' eponymous outfit celebrates its 40th anniversary – only Ferrari and McLaren have a longer continuous record in grand prix racing.

Fittingly, the team has named its car FW40 to celebrate this anniversary (if tradition was followed it would be called the FW39). But the team's anniversary year has not all been about looking back, it's also seen significant upheaval at the team's headquarters in Grove, England.

Williams' former technical boss Pat Symonds retired at the end of the 2016 and in something of a coup for the team he was replaced by Paddy Lowe, who headed up the Mercedes F1 technical team throughout its period of dominance from 2014 to 2016.

Lowe arrived at Williams when the design and development of the FW40 was essentially completed and so did not have much of an influence on it. But it was possible for him to compare the approach of Williams to recent regulation changes to that of the current World Champions. 'When I arrived it was interesting to see how people had reached different technical solutions to the problems faced by all of the teams,' Lowe says. 'There is quite a lot difference between the two cars [Mercedes and Williams]. Some of that we need to change in 2018, but in other areas Williams clearly has a strong

'In this business it is not just about building fast racing cars, it is about making them quick at every circuit'

TECH SPEC

Williams FW40

Chassis: Monocoque construction laminated from carbon epoxy and honeycomb surpassing FIA impact and strength requirements.

Power Unit: Mercedes-AMG F1 M08 EQ Power+; ICE: 1.6-litre, 6-cylinder; bank angle 90-degree; 24 valves. Max rpm ICE 15,000rpm; max fuel flow rate 100kg/hour (above 10,500rpm); high-pressure direct injection (max 500bar, one injector/cylinder); pressure charging single-stage compressor and exhaust turbine on a common shaft; max rpm for exhaust turbine 125,000rpm. Mercedes AMG HPP ERS.

Suspension: Double wishbone, pushrod activated springs and anti-roll bar front; pullrod activated rear; in-house developed dampers.

Transmission: Williams 8-speed seamless sequential semi-automatic shift plus reverse gear; gear selection electro-hydraulically actuated; carbon multi-plate clutch.

Brakes: AP Racing 6-piston front and 4-piston rear calipers with carbon discs and pads.

Steering: Williams power assisted rack and pinion.

Fuel tank: ATL Kevlar-reinforced rubber bladder.

Electronics: FIA SECU standard electronic control unit.

Cooling System: Aluminium oil, water and gearbox radiators.

Driver protection: 6-point driver safety harness with 75mm shoulder straps and HANS system; removable anatomically formed carbon fibre seat.

Wheels: Apptech forged magnesium.

Tyres: Pirelli: fronts: 305/670-13; rears: 405/670-13.

Dimensions: Overall height 950mm; width: 2000mm.

pedigree in design going back many years and they have developed in certain directions which are different, not necessarily better or worse. I think the main point I found was that there was lots of opportunity for next year, there are a few things we definitely need to do differently.

'I think in some areas of the company Williams is better than Mercedes, and the same is true for some bits of the car too,' Lowe adds.

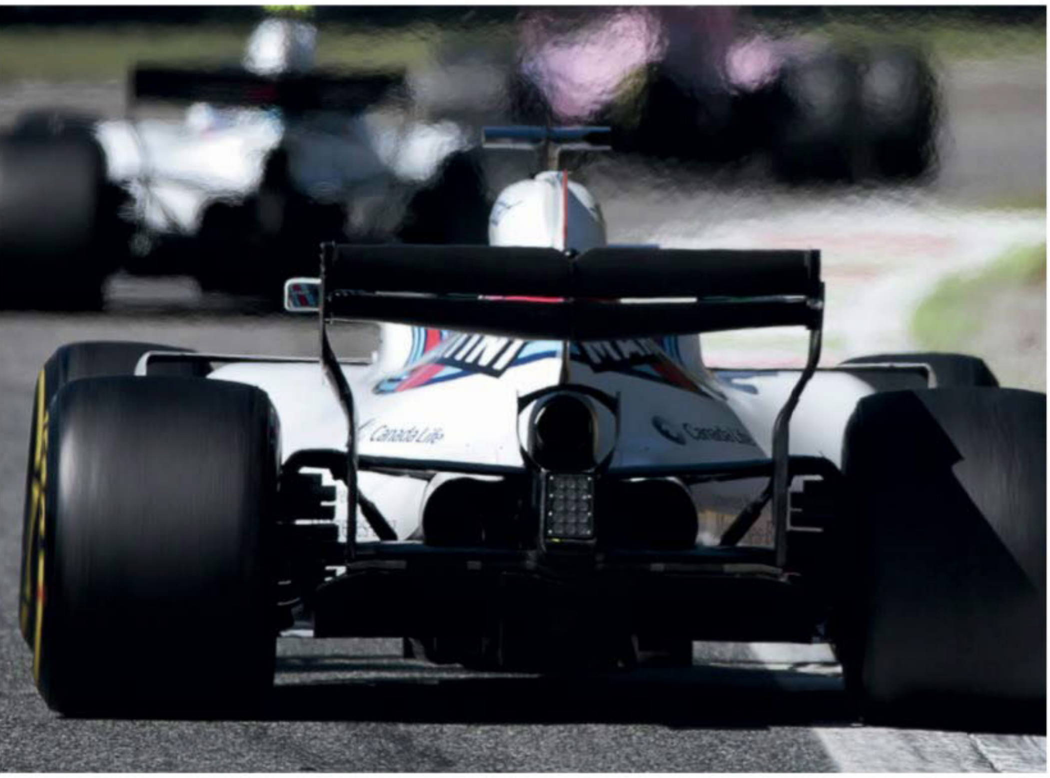
Comparing the Williams FW40 to the 2017 Mercedes W08 is interesting as the two share the same power unit, but the similarity largely ends there. For instance, while Mercedes continues with its twin-skin transmission concept with a composite casing and a aluminium insert, Williams has its unique (in Formula 1) cast aluminium gearbox.

'That is a fairly substantial difference to others on the grid,' Lowe says. 'There are some advantages to doing it this way, but we have been doing some work in that area to establish what the right direction for the future is. It is not quite the no-brainer that some people would think, [when they] make the assumption that everything made in carbon fibre is the best.'

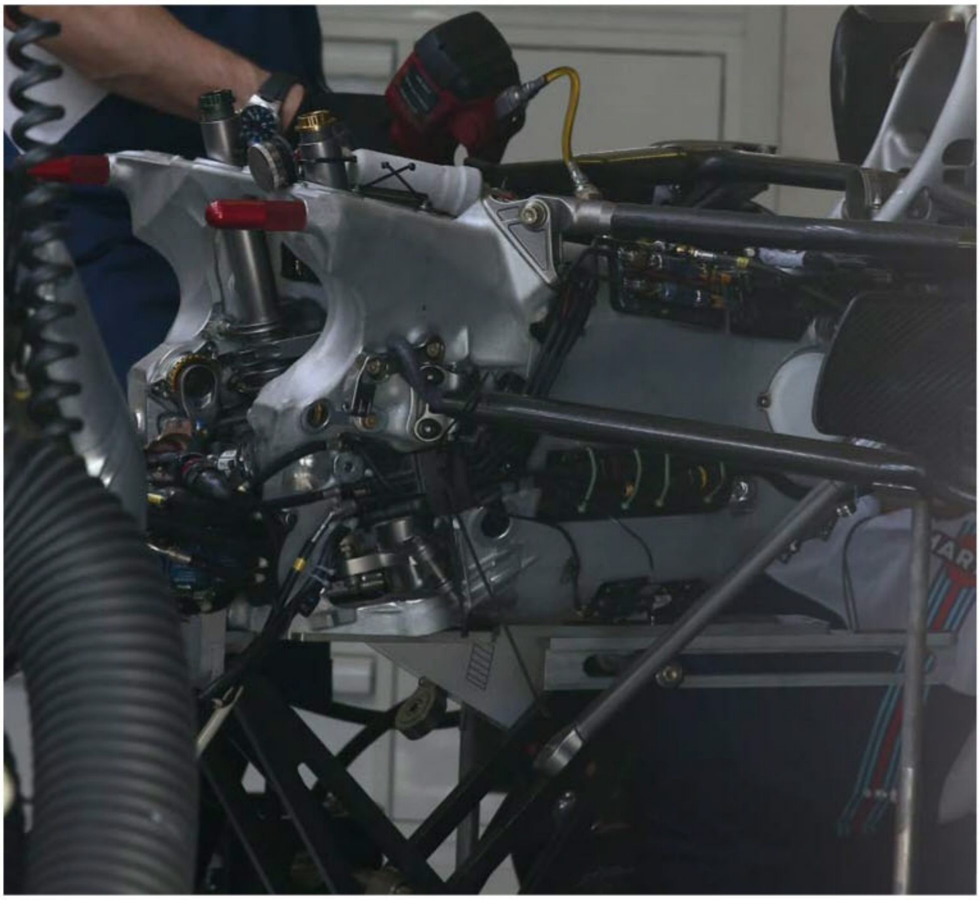
Rear view

The rear end of the FW40 differs to most other F1 cars in other respects, too, including its suspension. The general rear suspension layout is fairly conventional with pullrod actuated torsion bars and dampers mounted in the bellhousing, but it is in the details where these

'In some areas of the company I would say Williams is better than Mercedes, and the same is true for some bits of the car too'



Williams uses the Mercedes power unit. Tech boss Paddy Lowe previously worked for Mercedes but says that while now he's a customer, and perhaps not the main priority for the PU builder, he's still been able to move key PU projects forward



Williams does not use the Mercedes transmission and instead has a cast aluminium gearbox casing of its own design which is unique in Formula 1. The team says there are a number of advantages to this approach, but it is currently re-evaluating it

differences can be seen. 'The construction of the rear suspension is different to pretty much every other car,' Lowe says. 'It is about the selection of materials, and on the FW40 the components are substantially more metallic than on other designs. In general the suspension all through the field is a hybrid of metal and composite, but on this car the ratio of metallic components is probably higher. It is not something done for cost reasons really, like with the gearbox there are advantages and disadvantages to doing it.' Lowe would not give more detail on the exact details and differences between the Williams solution and others, for obvious reasons.

The front suspension of the car is fairly conventional with pushrod actuated torsion bars and dampers, and a third element. These sit slightly behind the front bulkhead and are accessed via hatches on the upper bodywork.

Customer service

In some areas the car simply has to be similar in concept to the other Mercedes-powered cars on the Formula 1 grid. And so Williams, Force India, and Mercedes all share roughly the same roll hoop layout with centreline cooling. This sees an additional cooler for the ERS mounted above the bellhousing, and it can allow teams to reduce the volume of the sidepods.

Lowe, in his previous role at Mercedes, would be used to getting priority at Mercedes HPP, which develops the power units at its facility in Brixworth, but at Williams his relationship is that of customer team. 'It's a slightly different relationship,' Lowe says. 'It's more about issues of priority, I still have a great relationship with Andy Cowell [Mercedes HPP boss], and we work closely with our colleagues at Brixworth. We will do projects together but the real difference is that with the finite effort available the priority will always be the works team. But actually most of those priorities, the key projects, are the same between Williams and the works team.'

Aero compromises

In his Mercedes days Lowe singled out Williams as a team with a curious performance bracket, unsure of why it had a high top speed and often reasonable cornering speeds, too, seemingly defying the trade-off between downforce and drag. However, now he is back in the Williams fold (Lowe worked at the team in the 1990s) he has a clearer understanding.

'It is true that top speed certainly is a strong element with this car; you have to develop your car in a wind tunnel, and generally around a certain set efficiency regime,' Lowe says. 'That is by definition a compromise, because the optimum efficiency for Monza is completely

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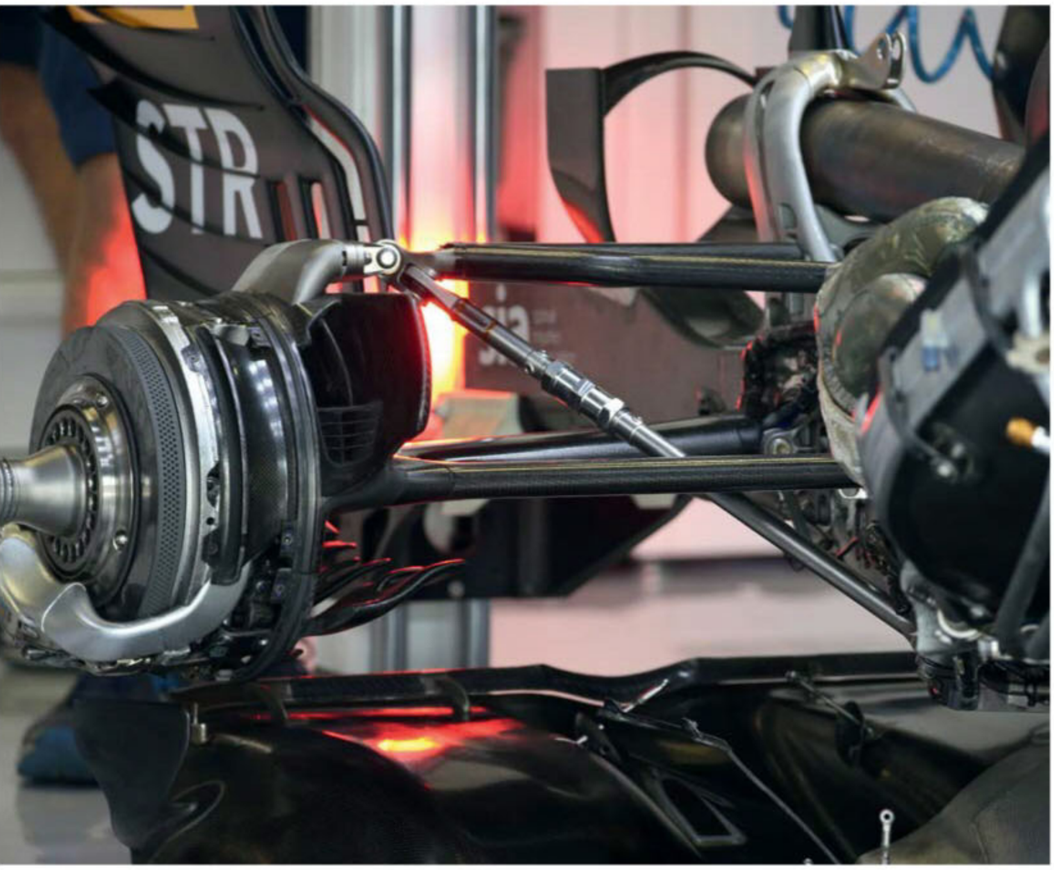
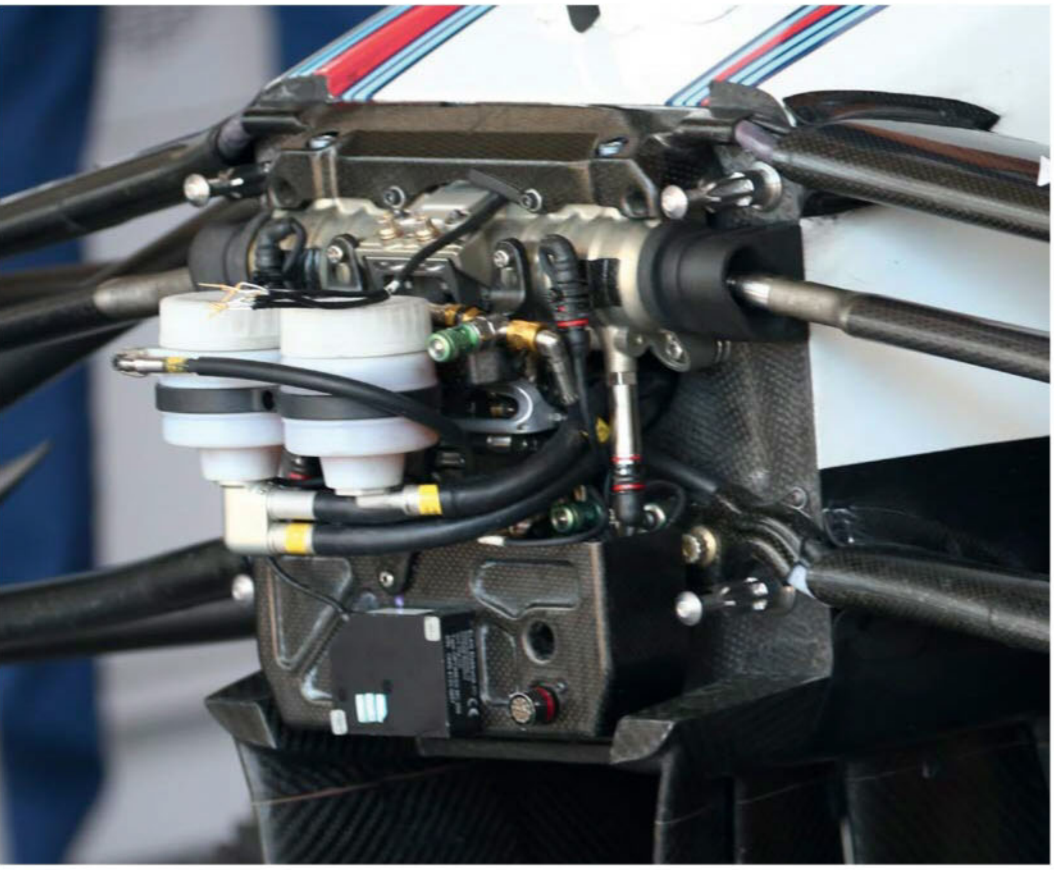
‘Some assume that everything made in carbon fibre is the best’



The rear suspension layout is conventional with pullrod actuated torsion bars and dampers mounted in the bellhousing, but its construction is slightly unusual, with Williams deciding to make more use of metal components here rather than carbon



Pushrod actuated torsion bars and dampers and a third element sit slightly behind the front bulkhead and are accessed via hatches positioned on the upper bodywork. Steering is via a Williams designed and built power assisted rack and pinion

different to Monaco or Singapore. You cannot develop a racecar to meet all of those efficiency targets at once. The extent you can tailor the car to the different circuits is a function of the budget and development capacity you have, but it’s not the whole story.’

Indeed, the FW40 only seems to work at certain circuits and in the right conditions, something that the team has taken note of. ‘The inconsistency is something we are looking at, in this business it is not just about building fast racing cars it is about making them quick at every circuit,’ Lowe says. ‘There is huge variety, going from Monza to Singapore, these two circuits couldn’t be more different. Unfortunately there seems to be a bit of a tradition at Williams of accepting that at certain circuits the car will be really bad. What I’m trying to do is develop the idea that this attitude will change; it is not something the team should just accept. A lot of it is wrapped in the DNA of the designs of the car though, so we need to unravel all of that and not develop cars that have these set characteristics. We have to break the mould, literally. There is this tradition that Williams will always be rubbish at Monaco, and that has got to change. In general I think we know the circuits with this car where we will struggle. That is based mainly on previous experience, so we need to work more on understanding the reasons for it.’

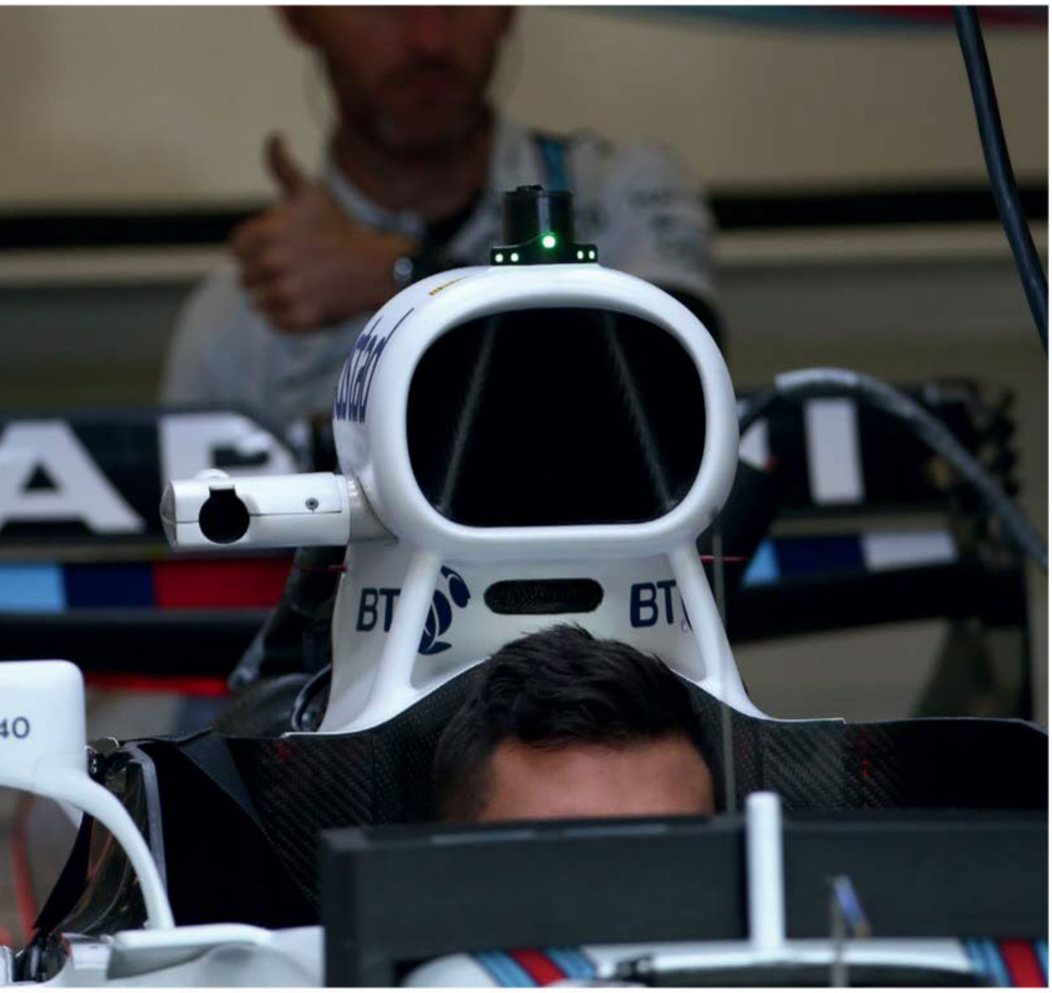
Window addressing

This year Williams is not the only team to suffer with a narrow operational window. Indeed many teams on the grid, including Mercedes, are struggling to get their cars working in all conditions. ‘It’s interesting that even the top two teams are expressing concerns about it,’ Lowe says. ‘It’s quite pronounced this year but to some extent it has always been like that. I remember the fight we had with Ferrari when I was at McLaren in 2007 and 2008. That was tooth and nail every race, where one car would be quicker at one track and the other at the next. That was a matter of a couple of tenths in favour of one or the other, you will always have that level of difference. But this year the level of swing we have is rather too large between the circuits we are strong at and the circuits we are weak at.’

The new-for-2017 wider Pirelli tyres are thought to be at the root of the problem. No really representative testing was available before the official pre-season tests at Barcelona, so teams essentially had to make educated guesses about how the tyres would actually work.

‘The tyre defines, to a great extent, the operating window of the car because it’s fundamentally the temperature window of the tyre, sometimes the pressure window, where the tyre delivers the best performance,’ Lowe says. ‘So depending on how narrow or wide or peaky

‘We are not going to throw away where we have got to, the rules are the same next year so we can build on the platform we have’



FW40 roll hoop concept is same as fellow Mercedes PU users Force India and Mercedes itself, with main duct segmented into three. The outer segments feed a cooler on the centreline of the car, while central segment is the combustion air feed

Brakes are AP Racing 6-piston front (above) and 4-piston rear calipers with carbon discs and pads. Wishbones are beefier this year to cope with the higher loads while cornering, which are a result of new-for-2017 aero regulations and wider tyres

that window is, determines how difficult it is to make the car work at the fastest level.’

Lowe’s real priority for Williams is looking to the 2018 and 2019 seasons in an attempt to move the once dominant team back into a position where it can win races again.

‘One of my main objectives is taking the car forward, right now the car is clearly not at benchmark pace so we need to make a much quicker car.’ Lowe says. ‘There are some things we can do which will allow us to catch up, but there are also some things we are working on which [will] let us jump ahead of the field, the more of those we can find the better. We are not going to throw away where we have got to, the rules are the same, so we can just build on the platform and not start over.

‘But it will be a stronger team with new ideas, and new knowledge,’ Lowe adds. ‘I think the aerodynamics team at Williams is pretty strong, they have been doing some great work, and I’m quite optimistic about what they can bring in the future, for example.’

And if Lowe and the engineers at Williams can find gains with the team’s 2018 racecar then it might be just enough to put a Williams driver on the top step of a rostrum for the first time since 2012, and at the top of the world championship standings for the first time since 1997; half of its lifetime ago.

Dashing design

When Paddy Lowe arrived at Williams and looked over the car he immediately noticed one unique feature of the FW40 that stood out. ‘I think it’s interesting that Williams is the only team that keeps the dashboard on the chassis and not on the steering wheel,’ he says.

‘I don’t actually remember the history of how all the other teams migrated to having the dash on the steering wheel, or indeed why they did it,’ Lowe adds. ‘It was probably driven by the drivers saying they wanted that, it was a trend or a fashion that started somewhere – some of these things are just a fashion rather than for any technical merit.

‘I never really got it, for me the right place for the dashboard is on the car, not the wheel,’ Lowe says. ‘It puts weight on the wheel, why would you want to do that? The driver’s head does not rotate through corners that much, so why does the dash, on the wheel? If you are trying to read something you should keep the letters at the same angle as your head. For me, having it on the car is the right solution, so it was nice to find that here.’

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Six appeal

Faced with the threat of rival teams running high-power turbo engines in the early '80s Williams had to think outside the box. Sadly, its six-wheeled racers never saw F1 action. *Racecar* re-evaluates this radical concept

By WOUTER MELISSEN

It's among the most successful of all F1 teams, yet Williams has never really been known for its obviously ground breaking designs. Instead, the team, founded by Frank Williams and Patrick Head in 1977, usually managed to improve and perfect an existing design or idea, though many times using novel ideas to achieve this behind the scenes.

A great example of this was the FW07 raced by the team in successive evolutions between 1979 and 1981. It adopted the ground effect aerodynamics pioneered by Team Lotus but coupled with a much stronger chassis capable of handling the high aerodynamic loads attained. This resulted in the 1980 drivers' championship for Alan Jones and back-to-back constructors' titles in 1980 and 1981. Ironically, the Williams FW07 was so good that many rival Formula 1 teams copied its design.

Despite the success of the FW07 chief engineer Patrick Head and his aerodynamicist Frank Dernie recognised a serious threat on the horizon; the advent of the hugely powerful and ever more reliable turbo engines. In 1981 these were the preserve of works teams like Renault and Ferrari, so Williams had no option but to carry on with the readily available Ford Cosworth DFV V8. But a superior grasp of aerodynamics and chassis design would not be sufficient to bridge the estimated 200bhp deficit of Williams' naturally aspirated engine. Especially considering ever-stricter regulations aimed at pegging back downforce to reduce cornering speeds. With no turbo engine supply deal in sight, Williams opted to, uncharacteristically, explore a solution that was well outside the box.

Although not a first for the sport (see box out), Williams' solution of six wheels instead of four was still unconventional. Tyrrell had previously and quite successfully raced the P34 with four front wheels, while a March was also tested with two pairs of rear wheels. Head and Dernie opted for the latter approach, using four wheels that were narrower and not quite as tall as the rear wheels used at the time.

Throwing a six

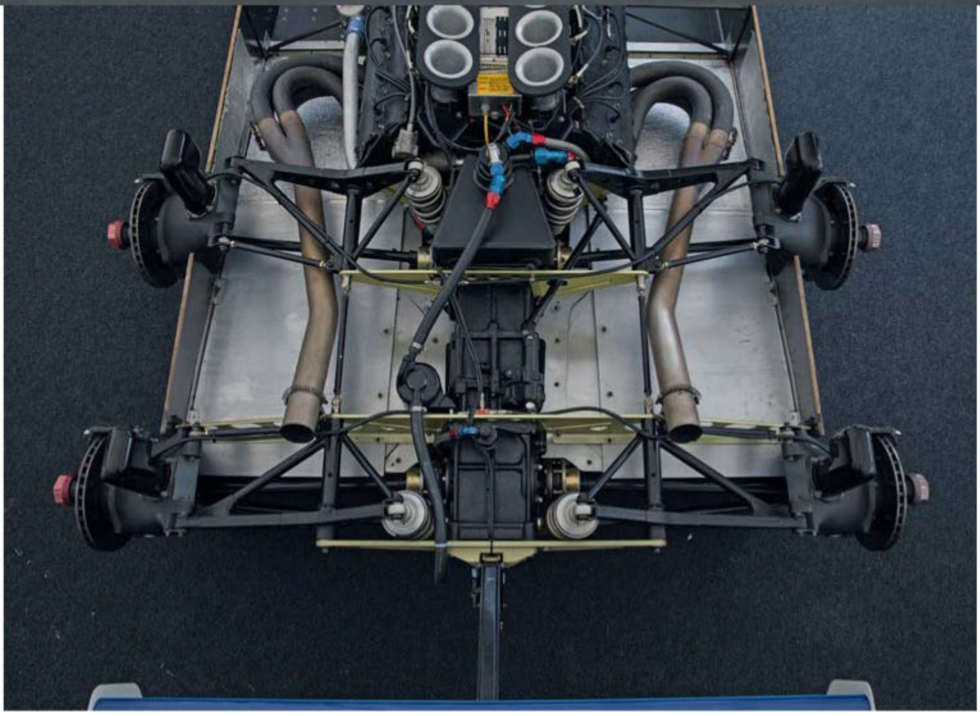
The main objective was to reduce drag sufficiently to match the speed of the turbo cars on the straights. 'The Tyrrell six-wheeler had been purported to have been built to reduce

The main objective was to reduce drag sufficiently to match the speed of the turbo cars on the straights

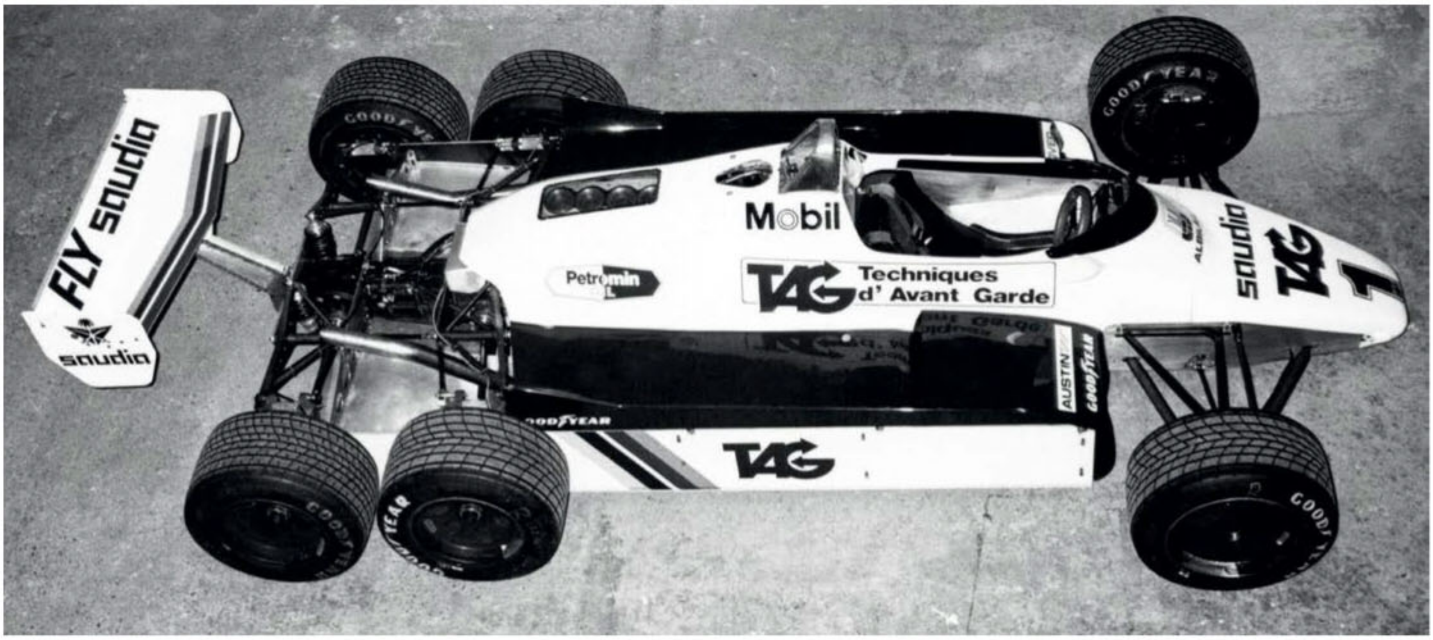
frontal area,' Dernie says. 'But as we know, that is a misunderstanding of the term, which isn't referring to the area of the front of the object but the area of the front *elevation*, which was dominated by the rear tyres in those days'

With the gearbox also boasting the suspension mounting points, it was relatively straightforward to create a four-wheel rear-end. In terms of the rolling chassis, the only changes required were aft of the engine. Very much Head's pet project, a completely new gearbox had to be conceived. Dernie: 'Despite having done my apprenticeship at David Brown I had nothing to do with Williams' gearboxes, except on the six-wheeler, making sure the two bevel gear sets were of opposite hand, crucial for reliability.' This was the very first gearbox ever conceived by Williams. Mounted between the two axles, it featured a single input shaft at the front while the secondary shaft was connected on either end to the two limited slip differentials. The selector mechanism had to be moved to make room for the second crown wheel pinion.

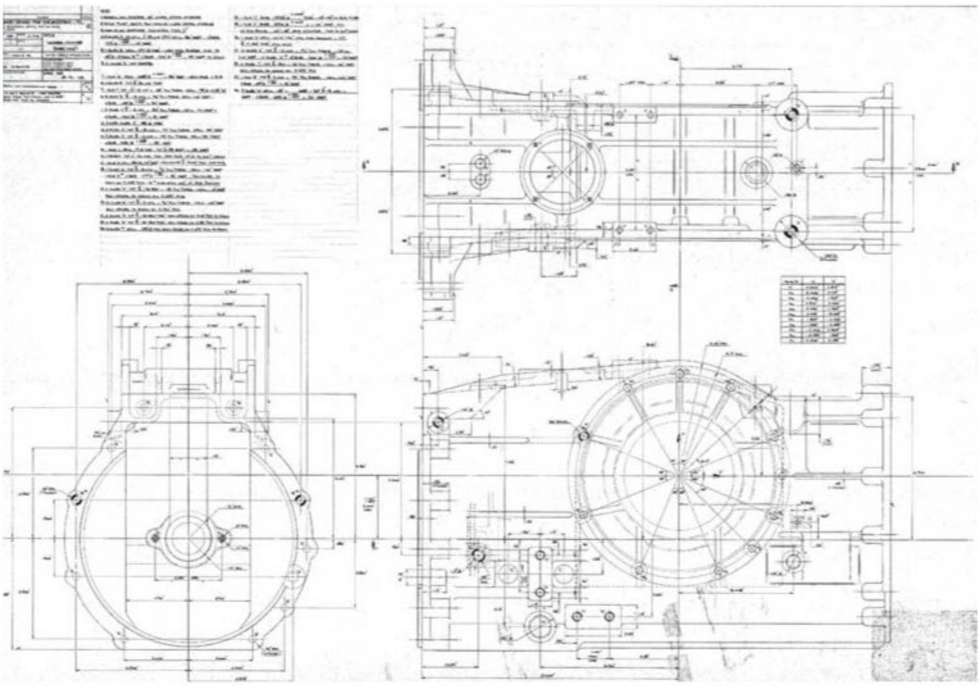
An added advantage of the extra pair of rear wheels was the additional space available



Main picture: The Williams six-wheel experiment began with the FW07D, on to which the four-wheel rear end was grafted. This retained the bodywork of the FW07C. The team then developed a six-wheel version of the FW08, called the FW08B
Above: The gearbox was the key component. It featured a single input shaft at the front while the secondary shaft was connected on either end to the two LSDs. Twin rear axles also meant Williams could mount the rear wing further back



While the concept was all about drag reduction FW08B was able to find good ground effect downforce from this layout and it might have been raced without both front and rear wings



Drawings for the transmission maincase. This was the first Williams-designed gearbox and it was Patrick Head's pet project

for the ground effect tunnels. Not only could they be longer but also wider as both the wheels themselves and the new gearbox were narrower. In fact, there was so much additional area that it raised its own problems, Dernie says: 'There was also the benefit of keeping the tunnels going further back, which was not huge because preventing stall back there was difficult anyway so a bigger area was difficult to exploit. Also the longer chord exacerbated the problem of the poor span to chord ratio of ground effect under-wings.'

The only real issue was the weight gain of 45kg, when the F1 minimum weight was around 585kg

Generating more downforce as such was never the main objective of this project, but improving the L/D (lift to drag) ratio was. That said, the additional downforce generated by the bigger tunnels ultimately did allow for the front wing to be removed altogether.

Aero benefit

A more substantial aerodynamic benefit concerned the rear wing. The maximum overhang of the wing was limited in the regulations in relation to the rear axle. The further back the wing could be mounted, the more efficiently it worked. The rules were not written with twin rear axles in mind, so the overhang was measured from the second of the two axles, while the effective centreline was actually between the pair, gaining 'almost 25cm where 1cm made a difference,' says Dernie.

During the second half of 1981, Williams assembled the first twin axle around Head's new gearbox. To accommodate for the wider track, longer driveshafts and new hubs, wishbones, rockers and uprights had to be built. For both axles the same set of components could be used. The only difference was that the rear-end was turned around 180 degrees, so the right rear suspension components could be substituted for the bits used for the left front. The twin axle was simply bolted to the back of an existing FW07 to create the FW07D. Intended solely for testing, the bodywork and underbody sections consisted only of modified FW07 components.

Gaining traction

The main objective of running the FW07D was to find out how the additional rear wheels affected the handling of the car. Head feared the car would struggle with power understeer, particularly around very tight corners. For this reason the team dispatched Jacques Laffite to try the FW07D at Croix-en-Ternois in France. The car was surprisingly well behaved and Laffite later reported to Head that he had forgotten all about the second pair of rear wheels after a few laps. Dernie oversaw the test: 'Traction was great; I even tried four wets and two slicks on the back axle in the rain reasoning the rearmost tyres were on a drained track,' he said.

The only real issue, but one that was not easily overcome, was the considerable weight gain of 45kg at a time when the minimum weight was set at around 585kg.

Although the test had shown that the idea certainly had merit, the realities of a new Formula 1 season and a title defence took priority. For the 1982 season, Head and Dernie

An added advantage of the extra pair of rear wheels was the additional space available for the ground effect tunnels

created the new FW08, which was stronger still than the successful FW07 it replaced and also featured a cleaner aerodynamic package to help it keep up with the turbo cars on the straights.

On the backburner

But while developing the FW08, the twin axle idea was always at the back of the mind of the two engineers. Dernie: 'There was always a possibility that the FW08 would be a six-wheeler so the chassis was kept as short as possible.'

As expected, the FW08 could not match the turbocharged cars over a single lap and driver Keke Rosberg scored only one victory. Yet, thanks to the very reliable and consistent package, and the misfortune of others, this one win proved enough for Rosberg to be crowned champion at the end of the season.

The 1982 season had proven the writing really was on the wall for the naturally aspirated engines but with no turbo engine deal in sight yet, the Williams team turned to the twin rear axle once more in preparation for 1983. The rear-end was now bolted onto the 1982 car to form the FW08B. Again, no bespoke bodywork was fitted for testing, which was now entrusted to Jonathan Palmer. Back at the factory models of the various configurations were tested in the wind tunnel. Sufficient downforce was generated by the longer and wider tunnels that the FW08B could be run without a rear wing altogether. These tests showed that the FW08B offered a 60 per cent L/D ratio improvement over the conventional FW08, which in itself had shown a 17 per cent improvement over the FW07C it had replaced. Dernie's crude simulations showed that the FW08B could match, even outrun, turbo cars on the straights.

Hit for six

The additional weight, however, remained an issue. Before this could be properly addressed or even a purpose-built body could be built, the sport's governing body first stipulated F1 cars had only four wheels and then banned ground effect altogether by mandating a flat floor.

But before that stroke of a pen had rendered the six-wheeler Williams obsolete, it had caught the attention of rival Team Lotus, which was also still forced to run the naturally aspirated V8. That said, its engineers had pursued a different approach to optimising the aerodynamic efficiency. Peter Wright, former aerodynamicist at Lotus, says: 'We were well down the route of the Type 80, Type 88 and Type 92 active car. With the Type 80, we generated more downforce than we knew how to control, and so the Type 88 and then active suspension was all about controlling the attitude of the car. I think the six-wheeler Williams would show very good overall L/D efficiency, but at a weight penalty. It was banned before we could really consider it – like just about everything we were doing!'

Williams did eventually secure a supply of turbo engines, from Honda, and it was hugely successful in 1987 with the team's own active suspension set-up that had been developed by Dernie. What also contributed considerably to the success, but was even more hidden from sight, was the fact that Williams, during this period, became the first Formula 1 team to run an in-house wind tunnel or use CAD computer design for components. Patrick Head again had the opportunity to create a pet project in the form of the CVT gearbox of the early 1990s, but this was also banned before it was ever raced.

Straight six

Williams only built one 'four-wheel-drive' gearbox and associated suspension components, which remains bolted to an FW08 chassis. At a rare public appearance in 1994, former Williams racer and period test driver of the FW08B, Jonathan Palmer, used the unique machine to set the then record time during the Goodwood Festival of Speed. The car has also recently been demonstrated as part of the team's 40th anniversary celebrations.

Six pack

The Williams project was by no means the first six-wheeler, and some of its predecessors even got to race.

For example, back in the 1930s Auto Union helped solve a traction problem with its 600bhp grand prix cars in hillclimb events – the European Mountain Championship was hugely prestigious in those days – by running four wheels across the rear axle.

On the other side of the Atlantic a six-wheeler was also seen at Indianapolis. The Pat Clancy Special was entered in the 1948 and 1949 editions of the Indy 500, but was less than successful. The curious-looking car, which had four wheels at the rear in a similar format to the Williams concept, had good traction but suffered from terrible understeer in the long turns and finished 12th (albeit 10 laps down) at its first attempt and failed to make the flag at the second time of asking.

But the most famous of all six-wheelers has to be the Tyrrell P34, which not only raced for two seasons in Formula 1 (1976 and 1977) but even chalked up a clutch of podium finishes and a grand prix win, the Swedish GP in '76. The P34 was also a huge PR coup for Tyrrell and its sponsors.

Part of the thinking behind the P34 was to both free up the air to the rear wing and tuck the smaller four front wheels behind the front wing, to help reduce drag and also improve front wing efficiency.

March also produced a six-wheeler similar in concept to the Williams in 1976, the 2-4-0 using four driven wheels at the back, while Ferrari experimented with a set-up that harked back to the Auto Union approach, in this case using four front wheels/tyres on the back axle. This project, the 312T6, was tested in 1977, but proved to be too difficult to drive.

In 1983 the FIA banned racecars with four driven wheels and the Formula 1 regulations were later changed to stipulate a maximum of four wheels.

The Type C Auto Union used four rear wheels to help with traction in hillclimbs

The grand prix-winning P34 is the only six-wheel car to have raced in Formula 1

Tank battle

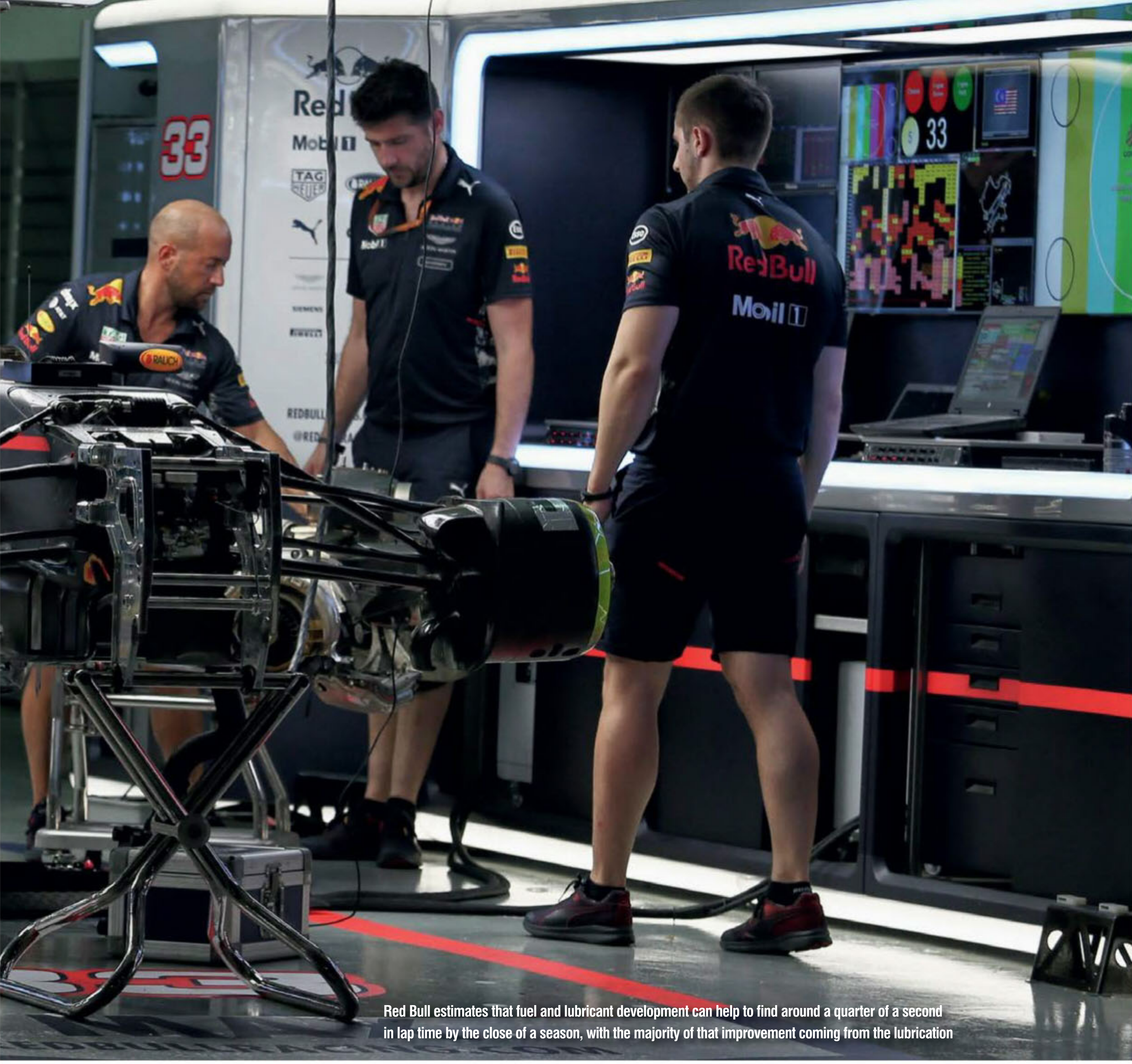
A largely unreported, yet hugely significant, fuel and lubricant development war has been waged in Formula 1 this season – *Racecar* spoke to those on the front line to find out more

By SAM COLLINS

It was all change for F1 fuel suppliers at the start of the 2017 season. ExxonMobil, a former partner to McLaren, switched to supplying the Renault-powered Red Bull Racing and Toro Rosso teams with its Esso and Mobil 1 products. Meanwhile, BP-Castrol opted to supply McLaren and the Renault works team, while Total quit F1 in favour of the WEC.

This supplier reshuffle came at very short notice for the teams, the oil companies and the power unit manufacturers, especially considering that the Renault power unit, which had been designed around products from Total, would suddenly now be running both Mobil 1 and BP-Castrol, while Honda, which had developed its V6 with ExxonMobil, would now also be using BP products.

This switch came so late in the day, in fact, that there were rumours that both Renault and McLaren were unable to use their official



Red Bull estimates that fuel and lubricant development can help to find around a quarter of a second in lap time by the close of a season, with the majority of that improvement coming from the lubrication

partners' products at the first test in Barcelona and had to rely on those from ExxonMobil.

David Tsurusaki, Global Motorsports Technology manager at ExxonMobil, says: 'It was a ridiculously short amount of time, that was the biggest challenge. Even though we had an F1 product the timeline was way too short, because we really need the previous year to work on the next year. From the fuel standpoint, we started out with a baseline and we quickly adjusted it after the first couple of tests and then, by the time of Barcelona testing, we had it well dialled in by the second week.'

Pump action

According to Tsurusaki, that initial baseline was not just 2016's Honda fuel, but was something new, due to the differing demands of the two V6 engines. 'It's not the same product at all,' he says. 'We started with a baseline from what we understood about a current F1 engine already, and once we understood how the Renault engines ran we made our adjustments from there. The chemistry is different, and while I can't really go into details, I can say that of the things we look at with fuel one is obviously getting the power and reducing the knock. We want to try and minimise the knock as much as we can with adjustments in the chemistry.

'But it has to change as the year goes on and as the compression ratio changes,' Tsurusaki adds. 'As Renault do different things to the engine, we have to modify our product. The unique thing with Formula 1 fuels is that it is so experimental, you're using in some cases chemicals and concentrations of chemicals that are not typical in an everyday fuel.'

Indeed, while Formula 1's fuel specification is broadly based on EU fuel regulations the actual difference between the product used by F1 teams and that available at the pump is substantial. But they are still fuels, and the track is a useful development arena for the road.

'Our R&D department's workload is split equally between road fuels and race fuels, so techniques and solutions learnt in racing can be transferred to the road fuels,' says Mike Frost, ExxonMobil technical adviser. 'That is the biggest reason for a company like this to sponsor a racing team. It allows the team to improve performance on track while we can improve our commercial product.

'If you looked at a road fuel, it is far more complex,' Frost adds. 'There are a lot more components and it is a lot more uncontrolled. It comes off a refinery stream, the key four or five components will get you the RON or MON number and that will be good enough for a road car. Every time you fill up, if you tested the fuel, then the trace you would see on the gas

ExxonMobil had limited time to get to grips with 2017 Renault PU (above) pre-season; 2016 unit was developed with Total

Mike Frost (left) and David Tsurusaki from ExxonMobil. Its Mobil 1 and Esso brands are now aligned with the Red Bull and Toro Rosso teams

chromatograph would probably be completely different, that is the biggest thing. But the race fuel is always the same; it is far more precise, and it has fewer components.'

The reason for this precision is that the fuel used is tested for compliance not only with the technical regulations but also for the specific specification used, as teams are limited on the number of different fuels they can use each season. 'The fuel is designed in conjunction with Renault,' Frost says. 'Once they are happy with the performance it is sent to the FIA, they then check it conforms to the regulations and if it does then we are clear to use it at the track. The FIA also has a gas chromatograph and will check our fuels against the trace.'

While fuel specifications are limited, some teams have gone as far as saying that it is one of the biggest areas of performance development through the year, though others disagree and point to the lubricants instead. 'At an engine sensitive circuit the improvement was about a tenth of a second from the fuel; the oil brings more,' says Paul Monaghan, chief engineer at Red Bull Racing. 'I think, all things considered, the Mobil 1 [and Esso] products will have improved our pace by a quarter of a second at season's end, and that is a big improvement.'

'We want to minimise the knock as much as we can with adjustments in the chemistry'

Science friction

Much of that performance development with lubricants comes from simple track running. The more running the power units get in the cars the more the suppliers learn about them. 'You can get some performance gains if you minimise wear. So if you can minimise friction where you can get a rateable measured horsepower improvement, if you're doing the combination of that and wear protection, you can reduce wear metals which is something we're monitoring closely right now,' Tsurusaki says. 'We're looking at small amounts of wear metals; we're testing for parts per million of various materials. If we can reduce those wear metal amounts, that means we're protecting the engine better, it means it's going to last longer, it means there's less friction, so more horsepower. We track it by engine; by every start, every practice session, every qualifying and race; we're doing analysis at all the tyre tests too. You can get small incremental steps, and that's what we're trying to do. It all adds up.'

But the gains in performance do not just come from the engine oil, Tsurusaki says. Many other fluids and greases play a role all over the car. 'One of the first changes we made with this partnership was the lubricant on the wheel bearings. We actually use a commercial product there, and going to the synthetic grease over what the team had used previously resulted in the temperature of the bearings going down. That means that there was a friction reduction which, in turn, should mean improved performance. It's hard to measure the effect of small things like that, but they do all add up.'

For all PU suppliers in F1 the lubricants used in the V6 engines also play a key role in preventative maintenance, through that same process of studying the oil itself, with samples being analysed in the garages after every run.

'We have a spectrographic analyser in the Red Bull garage,' Frost says. 'It has two electrodes, rather like an arcing welder. The oil sample is passed through the electrodes and in about 30 seconds you get a result. It excites all the molecules in the oil and that produces light, each component in the oil has its own signature in light, and that includes the metals. From that we can see what metals are found in the oil.'

Monitoring wear

The oil samples post-run can give a clear indication of what is going on inside a Formula 1 power unit, which is otherwise sealed by regulation. 'From working with Renault you know what components are made of what materials, and that can give you a very clear indication of the wear of components in the engine,' Frost says. 'Sodium is something we look at a lot. That is a marker of an additive in the coolant, so if there is a water leak in the race, the water will boil off, then you start to see elevated levels of sodium in the oil. So if you have sodium showing in this result then you can make the assumption that there is water in the oil.

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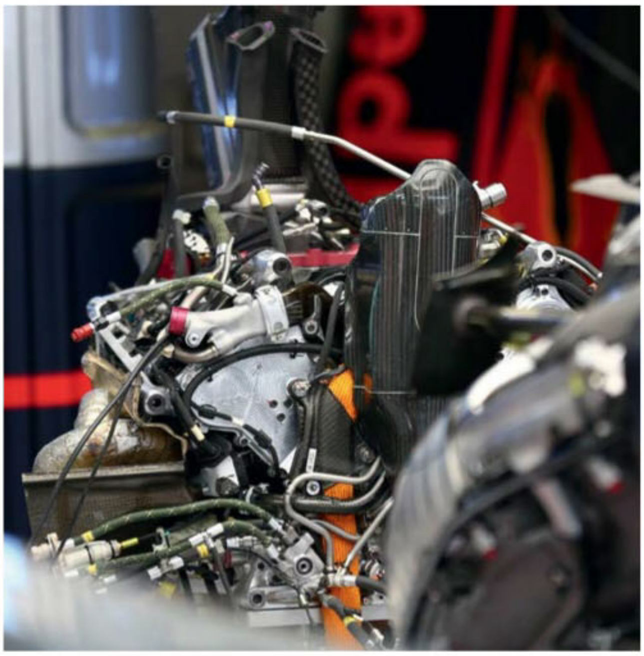
Red Bull garage lab has spectrographic analyser that picks up light signals from oil components and from metals in the oil

Analysing the fuel and lubricants can give a vital insight into what is actually happening inside the sealed F1 power units

‘If we can reduce those wear metal amounts it means there’s less friction, so more horsepower’



The oil tank is located at the front of the V6 block on Renault PU. The lubrication system plays a largely unsung role in the cooling of a modern Formula 1 racecar

‘Lead and Indium we look for as they are the bearing materials, aluminium is the pistons, iron is the bores, gears, crankshaft so all of those act as a tell-tale of what is going on inside the engine,’ Frost adds. ‘You know what the engine’s appetite for oil is and you keep an eye out for potential problems. You tend to see the issues in the practice sessions when the older engines are used, and over the years, before the car has even left the garage, I have identified issues which I knew would cause the car to stop on track, and as a result I have condemned engines. It can be the only way to see inside the engine.’

Oil cooler

Unlike most production car engines the lubricant in some F1 V6s also has to act as a coolant for some components within the power unit. ‘Copper is the material for the squash plates for the bearings, and some of the cages for things like the bearings in the MGU-K,’ Frost says. ‘The problems people have had with the MGU are well known, that is an electric motor cooled by oil, and so you can start seeing high levels of copper in the oil when there are issues.’

But perhaps Frost will not be looking out for copper as much as he used to in the lubricants used in the current Renault V6, due to a change in the design of the power unit. ‘At one point this season we had the MGU-K being cooled by the engine oil, so our oil had to be able to not only lubricate the engine but also act as a coolant,’ Tsurusaki says. ‘So, we started out with one product and we ended up with a different product because of that. [But] now it’s separate.’

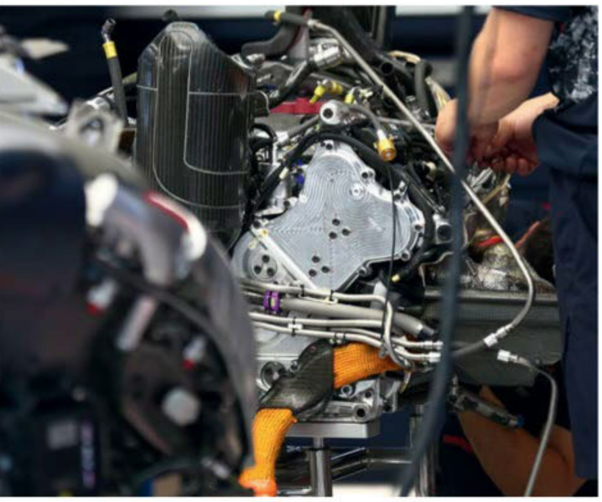
Hot oil

The properties of the lubricants used by teams can also play a significant role in the overall car design, especially in terms of the cooling system, so teams work very closely with partners to get the products exactly right. ‘You have to consider ambient temperatures,’ Monaghan says. ‘We race in Singapore and Malaysia where it is very hot; we also race in China and Silverstone where it is not, so we need the oil to be able to deal with that variation. We want an oil that weighs nothing, has zero pumping losses, needs no radiator and pushes us up 50bhp!’ he jokes.

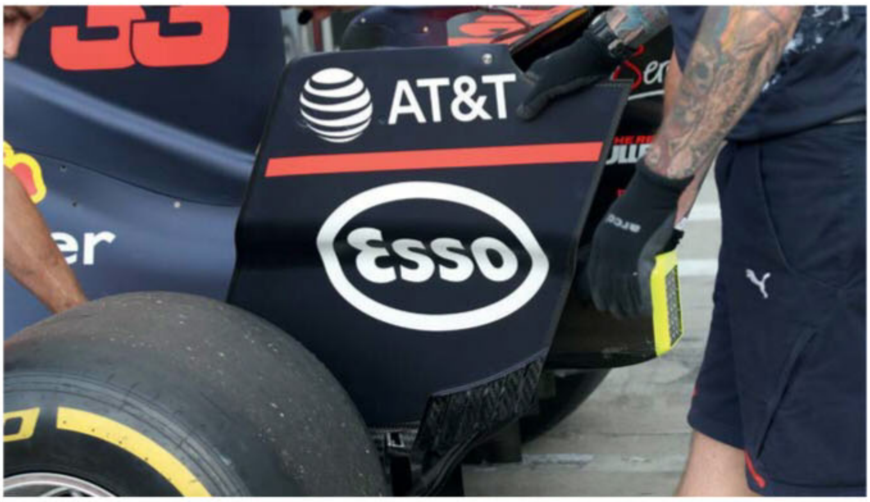
‘The heat rejection of the engine is to some extent influenced by the efficiency of the lubrication system,’ Monaghan adds. ‘So the more friction there is the more heat you have to take out. The question is then how do you take it out; by the water system, the oil system or just general radiant heat to the surroundings? Once you have established a heat rejection into the oil system the temperature delta becomes about the specific heat capacity of the oil. In other words, how much energy does it take to warm up 1kg of oil by 1degC; from that you know how much oil you should need, its flow rate, and the area required for the cooler.’

But the individual properties of the oil, such as its cooling requirements, cannot be

'The cam follower is actually running on an incredibly thin layer of oil'



An in-season change to the MGU-K on the Renault PU meant that supplier ExxonMobil had to develop a new engine oil for Red Bull



Oil companies are more than just F1 sponsors and ExxonMobil, which promotes its Esso and Mobil 1 brands on the Red Bull RB13, says its involvement in Formula 1 will lead to better fuels for the road in the future

considered in isolation, its performance has to be considered in the context of its use in a complete oil system. 'It is one of those things that might seem simple; you drive some oil around the engine, cool it and stick it back in the tank,' Monaghan says. 'But it is amazingly complicated. You need to work out the pressure drop for the oil system, so it doesn't come back with zero flow. The way you get an oil to adhere to a metallic surface is quite impressive. It sticks to a surface on a molecular level so in a rubbing contact such as a camshaft and a follower the oil has adhered to the camshaft so the follower isn't actually running on the cam; it is actually running on an incredibly thin layer of oil. But at the bottom end of the engine the demands are different, with oil fed bearings, and that changes the demands on the oil too.

'Then you look at the cylinder pressures we are running and the forces in the crankshaft, they are enormous; you look how quickly you want to open and close the valves and the stresses the camshaft sees as the valves approach their maximum and minimum acceleration, it is immense,' Monaghan says.

Even with components such as silicon in the lubricant, preventing the oil from foaming too much is a major challenge. 'You take all of those forces and demands then you blow oil around all the other little bits we want to lubricate such as the gears at the front of the engine and various bearings dotted around with rolling elements or static pushes,' Monaghan says. 'You have to gather all of that into one pipe to get it through a cooler, get it back into the tank and then provide multiple pressure supplies into a power unit with no bubbles in it, and you have to keep it at the right temperature.

'So you have to consider that you have to de-aeriate it as well as cool it somewhere too,' Monaghan adds. 'You are churning it round inside an engine and on the way it picks up air bubbles and you have to get those out, which is something that can be done pre- or post-cooler.'

Development threat

The freedom of development of both lubricants and fuels is something which has attracted major oil companies to Formula 1. But as F1 looks to the future and a new power unit rulebook in 2021, there are suggestions that a single specification fuel could be adopted, as it already has been in the WEC. This is something that Tsurusaki is very much against,

'We feel very strongly that fuel still needs to be part of the open regulations, so that we can have the ability to modify and tweak it to optimise the engine.' Tsurusaki says. 'That's an important part of our relationship, because we're doing fuel and lubricants with the race teams to build on technology so that this technology gets to road cars. Testing and looking at next generation technologies for fuel and lubricants is attractive to us as a company. If you don't have fuel development as part of F1 you take away half of why we are involved with the sport. It is the only racing area left where you can do this. We have had some technology breakthroughs over the past year or so based on F1 that we think could be used in the next generation of mass production fuel.'

For now, though, the quiet development war will continue to rumble on, while also, according to some in the industry, improving the performance of your road car.

Burning issue

Just before the start of the season Paul Monaghan of Red Bull Racing asked the FIA to clarify if it was permissible to use lubricants as fuel. The resulting technical directive was extremely clear: it was strictly forbidden to do so, echoing a similar technical directive issued in 2013. Yet throughout the 2017 season there have been rumours and thinly veiled allegations directed at two teams in particular claiming that they are indeed using engine oil as a supplement to the fuel.

'The potential benefits of doing it are clear to us, but I can't be exact on how big those benefits are because we have not pursued it,' Monaghan says. 'If you are not in breach of the regulations then the technical directives should make no difference. In the current formula you have a limit of 100kg/h of fuel into the engine, but a compressor which will squeeze in as much air as you want. Once you have an air fuel mixture target that your engine can run at then your main performance limitation is that fuel limit, so if you can supplement your fuel supply then you remove or reduce that limitation.'

Oil rigged

In response to the allegations the FIA issued a new technical directive halfway through the season limiting the maximum level of oil consumption allowed to 0.9 litres per 100km (roughly 2.7 litres over a race distance), but this was not welcomed by all. One engineer in the paddock suggests it is like telling Tour de France cyclists that drugs are banned, but then telling them the maximum amount of EPO they can take.

Others echo that sentiment. 'I told the FIA that they should not just set an arbitrary limit.' David Tsurusaki says. 'Because it suggests that you can go up to that limit without penalty, if it is clear that lubes can't be used as fuel then there really isn't a discussion.'

The situation has arisen because the current 1.6-litre V6 engines vent excess lubricant directly into the combustion chamber. The adoption of catch tanks, as used in many other series, would seem an obvious way of removing the possibility of using oil as fuel. However, sources within at least two PU development teams indicate that this alone would not fully resolve the issue.

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In full flow

Leading fuel flow meter producer Sentronics talks us through the intensive product development programme that has helped it scoop the Formula 1 supply contract for 2018/19

By GEMMA HATTON

Motorsport engineers are notorious for going to any length to gain performance. For example, the latest fuel flow meter (FFM) variants can achieve accuracies of better than one per cent and yet teams have still invested time and money to find a small advantage here. In some cases they've purchased several fuel flow sensors for testing and established which one under-reads the most. By fitting this they can squeeze an extra few tenths of a per cent of fuel into the engine, while still complying with the regulations. It's quite clear, then, why these devices need to be as accurate as possible.

Mechanical flow meters traditionally use an impeller located between the inlet and outlet of a pipe. The flow of the fluid spins the impeller and the number of revolutions are counted; measuring the flow rate. However, in a racing engine a mechanical system cannot keep up with the highly dynamic changes in flow rate caused by moving from zero to maximum throttle within a fraction of a second.

'An impeller has mass by its very nature,' says Neville Meech, director of Sentronics. 'As a result of this, when the impeller attempts to rotate at a rate matching fuel consumption the inertial effects will cause the device to overshoot and then undershoot, resulting in immediate measurement errors.'

Solid state

'The other problem with most mechanical devices is they do not respond well with rapid reverse flows,' Meech adds. 'When the brakes are applied and the engine revs drop, typically a water hammer effect is momentarily created within the fuel system due to the fuel column coming to an abrupt stop. An impeller flow meter cannot stop quickly enough, and then reverse its direction, so once again you introduce significant errors. These fundamental problems were identified many years ago during potential technology assessments and this is why the core technology at the heart of our fuel flow meter is solid-state.'

Solid state essentially means no moving parts and, in principle, the most suitable non-invasive alternative to measure fuel flow is ultrasonic technology. The challenge, however, was to take the concept of ultrasonic flow measurement that had traditionally been used in large oil and gas pipelines, and develop an accurate meter which could then be packaged for use on a racecar.

'At the time, highly accurate ultrasonic devices were limited to six-inch pipe diameters and greater, and the technology was not suited or robust enough for motorsport,' says Meech. 'Some said that it would never work, especially as we needed to achieve measurements within +/- 0.25 per cent error, which was at least four times better than any similar sized ultrasonic equipment could achieve back then. As engineers we questioned the scientific reason behind this – was it because no one had ever tried to develop it before? Because if so, we wanted to pioneer the technology to make it happen.' The latest Sentronics Fuel Flow Elite Sensor, which will be used in Formula 1 next year, is specified to achieve accuracies of +/- 0.25 per cent of reading across operating conditions, which conforms to the technical specification set out by the FIA since 2014. Mission accomplished, then. But how?

Quickened pulse

Located at either end of a thin tube are two piezoelectric transducers. These are effectively ceramic discs, suspended in a fuel resistant housing, which convert electrical energy into ultrasound pulses. In principle, a pulse is sent from one transducer to the other, in the direction of flow. This is then followed by another pulse sent back to the original transducer in the opposite direction. With the distance between transducers known, the time of flight of both pulses is measured and then subtracted to determine the velocity. As the tube diameter is also known, the flow rate of the fuel can be easily calculated.

'One problem with ultrasonic flow measurement is its fundamental principle is volumetric, this means to calculate mass flow accurately a density measurement is required. Very accurate density measurement is typically

The challenge was to take the concept of ultrasonic flow measurement and develop an accurate meter that could be used on a racecar

Sentronics is an industry leader in the development and manufacture of solid state ultrasonic fuel flow meters

Low flow technology could be particularly useful in a sportscar series that requires refuelling

performed using a Coriolis or tuning fork densitometer, which just don't work when subjected to vehicle NVH (Noise, Vibration and Harshness). Hopefully this will change as densitometer technology advances but the best option at present is to calculate density using a very accurate temperature measurement, and calculate density based on fuel samples which have had the density properties very accurately measured under laboratory conditions,' explains Meech. 'If you were 3degC out on temperature you could end up with a 0.5 per cent error within the sensor.'

Once the temperature of the fuel has been identified, the necessary look-up is performed and mass flow rate is calculated, which is the final figure all the engineers are after.

But what is the optimum strategy for sending the ultrasound pulses to achieve the highest accuracy? How often and how quickly should the signals be sent? And is it better to send the signals together or one at a time?

'The biggest complexity comes when you have to measure the flow rate faster than 200 times a second, which is generally the industry standard for ultrasonic flow meters,' Meech says. 'Acoustic energy takes time to decay away, less time between measurements means you need techniques and algorithms to deal with any unwanted ultrasonic signals that have not had time to fully decay. Our patented technology allows us to achieve highly accurate time of flight measurements even with all these interfering signals being present.

'It was established early on in development that the industry standard measurement rates were just not going to give accurate readings for on-vehicle applications, we needed to

‘We needed to increase the measurement rate, to sample the flow rate in excess of 2200 times a second’

increase the measurement rate to sample the flow rate in excess of 2200 times a second to ensure that any vehicle or engine borne vibration exerted into the fluid column is measured correctly and not aliased.’

A further consideration is the type of materials used. As ever, it’s crucial to minimise weight, but, for once, composite components may not be the answer. By using a range of materials, the different rates of expansion with temperature can become geometrically complex and result in introducing a further source of error and potential leak paths. Therefore, to ensure consistent device-to-device repeatability it is more effective to construct the sensor out of one type of material, rather than using the algorithms or calibration to compensate for different material expansion rates. In the case of Sentronics, the fuel flow sensor is made purely from a single metallic material, avoiding the need for any plastic parts.

All materials used also have to be compatible with all the different variants of fuel including ethanols, methanols and additives. This is particularly important for any rubber seals because when rubber is impregnated with fuel it can increase in stiffness, which can effect the ability to transmit the ultrasound pulses.

Another challenge is repeatability. ‘It’s difficult enough to make one *perfect* sensor which achieves the required high levels of precision, but the bigger challenge is making that repeatable, when you have to make 100, 500, or more,’ Meech says.

‘Ultimately, our aim has been to create a technology where the sensors native response to a flow rate stimulus is consistent from meter to meter. This has been our biggest achievement over our four year development and we look forward to the devices becoming commonplace in motorsport.’

Toyota practices changing the FFM, located behind driver’s door on LMP1 cars. Flow meters measure average flow in WEC

Calibration methods

Any sensor supplier may state impressive accuracy, but how do they know the measurement readings are actually true? This is where calibration comes in. Calibration is defined as a series of interrelated measurements and operations which compare the reading of a device to a traceable standard. In this way, a relationship is established between the quantity measured by the device and the measurement of the same quantity by the reference.

For regulatory use, each sensor is measured against a known stimulus and, once adjusted, the combined measurement uncertainty cannot exceed +/-0.25 per cent of flow rate across a range of flow conditions that will

All the GT and prototype cars in IMSA will carry a fuel flow meter next season because, according to the series, the teams’ fuel consumption reporting has been ‘questionable at best’

P63 Indy Lights Mazda

P60 AER V6 WEC

P91 Mazda DPi

To ensure consistent device-to-device repeatability it's more effective to construct the sensor out of one type of material

Top left: Sentronics has won the tender to supply the Formula 1 grid with its fuel flow meter for 2018

Above: The front half of the fuel flow meter contains the tube where the ultrasound pulses are transmitted and the rear half houses the electronics

Left: The modular design of Sentronics' FFM has allowed it to adapt the technology to both low flow and high flow applications

A brief history of FFM

While Sentronics was not the original supplier of the fuel flow meter (FFM) back in 2014, it is worth noting here that the introduction of the technology into Formula 1 and the World Endurance Championship was controversial.

The original plan was to use the restriction of fuel to balance cars, rather than an air restrictor which had been common for many years.

While the FIA required an accuracy of +/-0.25 per cent of reading, and this was largely achieved, some teams identified a problem with aliasing, where information was being lost due to under-sampling of the flow rate. At the Australian Grand Prix in 2014, Red Bull Racing attempted to prove that its measurements were more accurate than that of the FFM, but it lost its case as the FFM was judged to be the tool by which the FIA measured the rate of flow.

The aliasing issue remained a problem for some teams, despite numerous upgrades from the original supplier, but now will finally be eradicated with the introduction of the Sentronics 2018 FFM.

In the WEC, meanwhile, an accuracy problem was identified and unfortunately amplified in the diesel engine, where flow and return sensors were required. With its high diesel return temperatures the Audi R18s suffered with accuracy. The FIA subsequently homologated a high-temperature sensor to particularly help the diesel engines, which was developed and supplied by Sentronics. Unfortunately, these sensors never saw action, as Audi quit the WEC before they were used.

When it was in the WEC Audi's R18 suffered with fuel flow meter accuracy problems caused by the high diesel return temperatures

Cash flow

Today, the sensors are infinitely more accurate than in 2014, but having improved the accuracy, the challenge now is to reduce the costs to make the technology more accessible (and useful) to other race series throughout the world. With this in mind Sentronics says it has been able to reduce the price of the sensor itself, due to an increase in demand, and is now actively offering the benefits of the technology to lower formula series.

be experienced on the vehicle. This is a very thorough process and tests conformity across a range of temperatures and flow-rates.

Low flow

The concept behind Sentronics' fuel flow technology has proven so successful that both low flow and high flow variants have been developed. 'Low flow is a very difficult parameter to measure accurately due to your zero flow error becoming the overriding source of inaccuracies,' explains Meech. 'For example, if you have one per cent error in your measurement and you are measuring flow rates of five litres/min then there is plenty of difference in ultrasonic pulse timings to allow for small errors. However, if the flow rate is four ml/min, which is less than a teaspoon of fuel per minute, one per cent error is +/-0.04ml/min, which equates to timing differences of sub pico second levels. This is an incredibly difficult task.'

For reference, since 2014 the new F1 power units are using approximately 2.2 litres/min maximum fuel flow (100kg/hr), compared to the 2013 V8s which were 3.3l/min (150kg/hr).

Low flow measuring devices have become essential for both OEMs and automotive testing companies because WLTP (Worldwide Harmonised Light Vehicle Test Procedure) and RDE (Real Driving Emissions) tests are now mandatory in the EU for new vehicles. This focus on emissions testing requires companies to publish figures such as fuel consumption, so being able to very accurately monitor the amount of fuel going into the engine has now become even more of a necessity.

Strategic measures

In motorsport terms, low flow technology could be particularly useful in series such as IMSA, and other sportscars series that require refuelling. With the ability to measure low flow conditions with +/- 0.25 per cent accuracy, when off throttle or mid-corner, the engineers can get a much better understanding of the overall fuel consumption figures which can in turn help them to strategise their pit stops more effectively. 'I think we're going to see a mind-set change with this technology,' Meech says. 'The feedback from those who have tested with this sensor is extremely positive because they can change their thinking of the fuel load they need to carry, when they carry it, and when is the best time to refuel.'

One of the secrets behind the development of the low flow variant is the modular design of the original Sentronics fuel flow meter. The sensor itself is built in two halves; the front half houses the tube and the piezoelectric transducers, with the other electronic components situated in the back half. Therefore, the tube for the low flow version could be redesigned and then bolted on, without Sentroncis having to modify or interfere with the electronics housing.

Going with the flow

Josef Newgarden won the IndyCar title for Penske driving with a fuel flow meter, which helped the team with its strategy

Corvette has used FFMs this season. They help the team to monitor the fuel consumption during the full course cautions

Restricting fuel flow is just one application for the fuel flow meter – as used by the FIA which regulates either maximum flow (in Formula 1) or average flow (WEC) – but there are other uses, as Corvette and Penske have discovered in US racing.

Fuel consumption is relatively well-known under normal conditions, but behind the safety car it's more of a challenge, and teams are left to calculate consumption at reduced speed. Over the past 20 years, more than a quarter of the laps at the Indy 500 have been run under caution, leaving teams relatively blind to their actual consumption figures.

But with the fuel flow meter transmitting live information back to the pits, teams are completely aware of when they need to stop for fuel, rather than relying on ECU injector data alone, and that has led to some interesting decisions from teams that are using these meters.

Economy drive

Corvette has been using the fuel flow meter in the second half of the season, and has been able to stretch its fuel to the limit to make up for what the team says is a disparity in on track performance with the other GT cars. The team says that it has not got a performance advantage on track through the Balance of Performance, or in the pits where its refilling time is longer than its competitors, but by being able to stretch the fuel to its limit it can deliver the results.

IMSA has confirmed that fuel flow meters will be mandated in 2018 for its prototype and its GT cars as it targets race capability rather than one-lap speed. 'Stint lengths [in 2017] continued to be a challenge for IMSA as the team fuel consumption reporting was questionable at best,' says Geoff Carter, senior director technical regulations and compliance, IMSA. 'For 2018, IMSA will require a spec fuel flow meter in the IMSA-mandated data-logger. The erroneous reporting led to incorrect refuelling restrictors/refuelling times and incorrect capacities.'

Customer service

When it left LMP1 it didn't mean the end of sportscar racing for Audi and its customer racing programme has thrived. The arrival of the R8 LMS GT4 should mean even more sales success

Audi's GT4 offering should be delivered in time for the Dubai 24 hours in January. It retains the production bodywork, suspension and gearbox, but it is 2wd rather than the 4wd of the road car

There is an old saying among manufacturers involved in motor racing; a factory programme spends money, customer racing makes it. With the end of the R18 Le Mans programme, Audi was left with DTM and now Formula E, and its customer racing programme, which has expanded rapidly in the past two years.

The rise of the TCR series around the world, for low-cost touring cars, has made the racing department more aligned with a production car environment, and it now delivers five cars a week to customers. GT3 is less intense, but no less profitable. And now Audi has entered the GT4 market, and can expect to see a further jump in the number of racecars it delivers with the Audi R8 LMS GT4 going on sale in October.

GT4, like TCR, is heavily focussed on customer racing and takes on the original philosophy of GT3 back in 2005. The premise for the original GT3 was to take cup class cars, from Maserati Trofeo and Porsche Carrera Cup, and introduce them into multi-class racing, all balanced by the SRO's then newly-introduced balance of performance system. It was the first series that was built primarily on the BoP, and the manufacturers flocked to it with more than 50 cars on the grid for the first race in 2006.

Cost effective

Since then, GT3 has become more professional, the cars more expensive to buy and now, such is the competition, they have also become more expensive to run. With the latest evolution of cars, the aero has become a dominant factor that has put the racecar more into the realm of the professional driver than the customer, opening up an opportunity for GT4.

GT4 has actually been in existence for almost 10 years. The low-cost formula has proven to be popular among series that are looking for cars to run, teams that want cost effective racing, and for the gentleman drivers who want to compete for a title, and enjoy their racing.

Audi's entry into the category, alongside cars such as the Porsche Cayman GT4 and the Ginetta G55, is feared by competitors who believe that the company will over-engineer the car and take the category to a higher level.

Audi, however, disputes this. 'If you look at our GT3 model we are one of the few that runs the true business model, we have one of the most reasonably priced cars and customer support,' says Christopher Reinke, head of Audi's customer racing division. 'To over engineer the car in GT3 is not what we do. Why should we change this successful philosophy in GT4? We know what the customer needs, focus on gentleman customer base, so we make it bulletproof so you can run it off the trailer, in all conditions … and just be able to have the thing to be able to run. The GT4 is clearly focussed on gentleman drivers.'

The Audi R8 LMS GT4 (2017) is based on the Audi R8 production car, using production bodywork, suspension and gearbox. For that

'Our R8 LMS GT4 is clearly focused on the gentleman drivers'

The LMS R8 GT4 keeps the standard electronics, which includes stability control, ABS and traction control. This should help make it a driver friendly racecar

TECH SPEC

Audi R8 LMS GT4

Chassis: Two-seat sportscar according to GT4 regulations (SRO). Carbon fibre composite materials and aluminium body. Audi spaceframe (ASF) featuring an aluminium-CFRP-composite design with weld-in and bolted steel safety cell.

Engine: 90-degree V10 petrol engine with combined multi-point and gasoline direct injection; four valves per cylinder; four double overhead camshafts. Engine longitudinally mounted in front of the rear axle.Two Bosch MED 17 (master-slave concept); 5200cc; torque: over 550Nm; power: up to 364kW (495bhp)

Transmission: Rear-wheel-drive; 7-speed double-clutch S tronic transmission with paddleshifters; constant-velocity joint shafts

Steering: Electro-hydraulic rack-and pinion steering, height and length adjustable steering wheel.

Brakes: Hydraulic dual-circuit braking system, steel brake discs front (380 x 34mm) and rear (365 x 32mm).

Clutch: Two electro-hydraulically operated wet-type multi-plate clutches.

Differential: Mechanical limited-slip differential.

Suspension: Double wishbones front and rear; two-way gas pressure dampers, ride height, toe, camber and stabilisers adjustable.

Wheels: 5-hole cast aluminium wheels front: 11in x 18in ET 63; rear: 12in x 18in ET 56.

Wheelbase: 2650mm.

Fuel cell: FT3 safety fuel cell; 118-litre capacity.

Seat system: Audi Sport customer racing Protection Seat PS3, aligning with FIA Standard 8862-2009.

Electrical system: Production level, modified for motorsport purposes.

Weight: 1460kg.

reason – and the fact that the ride heights are mandated – the car has not been in the wind tunnel. The rear wing is a 'well known profile' according to Reinke, and that helped to speed up the development of the GT4 car, and to keep the costs under control.

Driver friendly

Part of the cost control in GT4 is to provide standard electronics, which means that the cars will race with full stability control, ABS and traction control, which will help the gentleman driver. The engine is standard across the range, from road car to GT3 and GT4, with a 5.2-litre V10 longitudinally mounted in front of the rear axle that produces 495bhp depending on the balance of performance restrictions. The engine is durable, with maintenance after 10,000km and a rebuild after 20,000km in the GT3 model, and this is likely to be longer in GT4 guise. The car is two-wheel-drive, unlike the four-wheel-drive production car, due to the regulations, which helps to save weight. The standard 7-speed gearbox is fed by two electro-hydraulically operated clutches and gear change is by paddleshift behind the steering wheel.

The suspension is also the same as on the production car, with double wishbones front and rear, while the race-specific brakes with modified calipers are steel front and rear. The car will feature adjustable racing-specific dampers and springs as well as adjustable stabilisers. For the steering, Audi has adopted the hydraulic rack and pinion unit from the GT3 model, albeit with an electronically operated pump.

The basic level of the GT4 R8 means that the cost will be relatively low, in keeping with GT4 philosophy, with a price tag of €198,000, less than half the cost of a GT3 R8 LMS.

In terms of passive safety, in addition to the standard equipment such as a fire extinguishing system, safety nets for the driver and crash foam for the doors, the customer racing PS3 safety seat represents the most recent evolution of this seat. The safety belt system is GT3 standard, while the car also features in its roof a hatch to reach drivers in the event of an accident to help to stabilise a potential neck injury before removal from the car, as well as allowing for removal of the helmet before a driver is extricated from the car. Inside the car, the steel safety cage is mounted at six points to the Audi spaceframe, featuring an aluminium-CFRP mixed-material construction, with two connections to the engine bay.

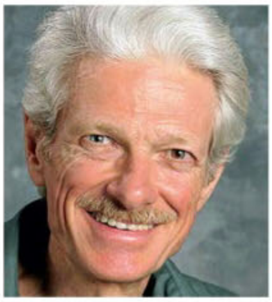
Car sales

The R8 GT4 raced at the Nurburgring in the 24 hours in May in almost finished guise; only driver ventilation, rear brake ventilation and a small amount of aero work regarding holes in the bodywork had to be finalised, and the team hopes that it will be homologated by the end of the year, with the first cars delivered in time for the Dubai 24 hours in January.

Audi Sport's confident the GT4 will sell well, too. 'It is hard to predict final numbers because there is enthusiasm about this class, and there are race categories and promoters who want to pick up on this class, but it is not happening yet,' says Reinke. 'To give you a range, we for sure expect in 2018 to sell around 50 cars.'

The GT4 category is rapidly growing, another success story outside the auspices of the FIA, clearly designed with customers in mind. And it is an interesting development that GT3, GT4 and TCR are all becoming global phenomenons. They are expanding rapidly, with intelligent control of the regulations, and customer-focussed racing programmes with these cars are now flourishing in national and international championships.

'It's hard to predict final numbers, but we expect to sell around 50 cars in 2018'



Anti-squat and jacking on a Dirt Modified car

Getting to grips with power-induced lift at the rear of an oval racer

QUESTION

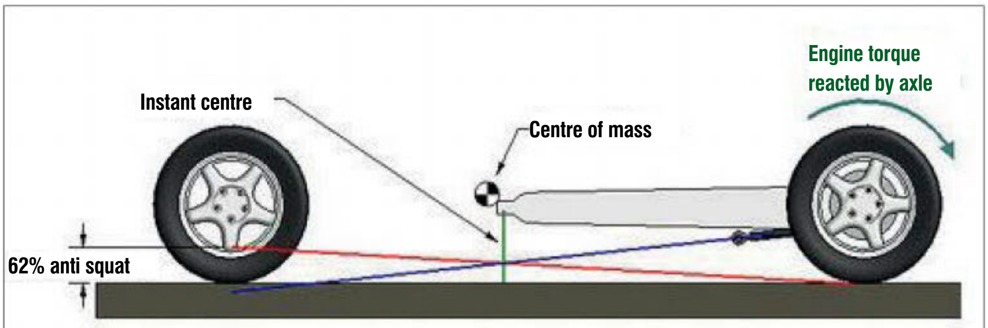
I have been helping a friend with a Northeast 358 Dirt Modified. He has always built his own cars. In the autumn of 2015 he wanted to build one more car. We finished it near the end of the 2016 season and ran the car four times. The last race we thought we had a set-up that he was happy with, but had an idea of how we could improve it just a little over the winter.

The car is built with a 30in long torque arm with two radius rods. The two rods are 31 inches long and mounted 7.5 inches below the centre of the axle tubes, they can be installed at 2.5, 5, 7.5 and 10 degrees on the frame. While running the car in 2016 we had both rods mounted at 7.5 degrees. He felt that he had to chase the car up the track a little too much and wanted to try a longer right rear radius rod. We installed a 45-inch long radius rod on the right but mounted it at the same height off the floor as the 7.5-degree mount for the 31in long rod. We started the 2017 season with the same set-up as we ended 2016, except for the longer radius rod. He felt the car drove straighter but it jacked the left rear up too far on acceleration. No matter what we did, we just were not able to calm that jacking down.

My thought was that we messed up the anti-squat balance and we were about to go back when health problems got in the way and we had to quit. I thought I understood how to figure anti-squat with this type of suspension, but when I drew it out I ran into questions, and this is why I'm writing.

I have an article, written by Herb Adams, I think back in the 1980s, when guys, including myself, were building Reese bar torque arms. This agrees with a diagram I've been working to, which I recently found on the internet, and which shows how to determine anti-squat with a torque arm. The vertical line drawn through the mounting point of the torque arm falls at the same point as the front mounting point of the 31in radius rod.

According to the article, you draw a line from the centre of the rear tyre through the point where the radius rod and the vertical line intersect to a vertical line drawn through the centre of the front tyre. If that point is below the centre of gravity that is your percentage of anti-squat, but if that point is above the centre of gravity I assume that it becomes lift?



Stock torque arm acceleration instant centre

Here is my problem: on my drawing, if I leave the front mount of the radius rod the same but move the rear mount up closer to the axle tube to the point where the rod is level, according to that information, the anti-squat would be the same?

There must be a way to figure out how the angle of the radius rod affects the anti-squat? It seems to me after installing the long rod that the anti-squat is as important to these racecars as rear steer. People always seem to talk about the rear steer, but I never hear anyone talk about anti-squat.

Could you please explain how to determine anti-squat with this type of rear suspension?

I think it is important to understand what happens when these radius rods are moved and maybe there should be more adjustments; think of all the adjustments available with the four-link rear suspensions in dirt late models. I don't think they are just adjusting rear steer. I know that for every action there is an equal but opposite reaction, so when there is lift on acceleration there would be squat on deceleration, but at the same time of backing-off there is turning left. While turning left, weight is trying to roll to the right. With the right radius angled up towards the front, wouldn't there be some resistance to roll created by the angled radius rod – the more the angle the more the resistance?

THE CONSULTANT

You provided two diagrams with this question. The first diagram you describe is correct. The solid force line is what would give 100 per cent anti-squat. The dashed force line is what we get with the geometry shown, which provides about 145 per cent anti-squat. Point A is the effective side view instant centre.

The second diagram is similar but it does contain two errors. The effective side view instant centre is where the green and blue lines cross. The arrow doesn't quite point there. The red force line is drawn correctly but the per cent anti-squat is mislabelled, or else the drawing is out of scale. Scaling the graphic, I get about 43 per cent, not 62 per cent.

When the system has 100 per cent anti-squat, that means the jacking coefficient is such that the induced jacking effect exactly counters the increased loading due to rearward load transfer under power, and the suspension does not compress or extend, regardless of spring rate. When there is zero anti-squat, the increased loading is resisted entirely by the springs. When there is 40 per cent anti-squat, that means 40 per cent of the load increase is resisted by the jacking force and the suspension compresses 60 per cent as much as it would with zero anti-squat.

The jacking coefficient is such that the induced jacking effect counters the increased loading due to rearward load transfer under power

It's clear that the link jacking effects are inextricably related to roll steer

This month's question concerns determining the ant-squat, and eliminating the jacking, on a US Modified dirt track car

When there is 140 per cent anti-squat, the suspension extends 40 per cent as much as it would compress with zero anti-squat. When there is 200 per cent anti-squat, the suspension extends the same amount that it would compress with zero anti-squat. Note that when there is more than 100 per cent anti-squat, the rear of the car will actually sit higher under power with soft springs than with stiff ones.

Squatters rights

We can have negative anti-squat, or pro-squat. If we have -40 per cent anti-squat, that means the suspension compresses 40 per cent more under power than it would with zero anti-squat. The related effect under braking is called anti-lift.

With a beam axle, the two-dimensional, side view geometry methods shown in the illustrations are only valid when the system is symmetrical. When the system is slightly asymmetrical, as in a road car with a bit of roll displacement, the 2D method is still a fairly close approximation. When we have a beam axle with pronounced asymmetry, for good accuracy we need a more complex approach.

With a torque arm and two trailing links, we have jacking forces acting on the frame at three points. We have compression loads on the two trailing links, which are transmitting the thrust from the axle assembly to the frame. If these are not horizontal, each one induces a vertical force equal to the thrust force at that link times the slope of the link. The links are inboard of the wheels, so each link reacts some of the thrust from each tyre, but each link reacts more of the thrust from the near tyre than from the far one. With a locked axle, the thrust from the two tyres can be very unequal, and can often be negative at one tyre. Roll moments resulting from the link jacking forces will then vary dramatically depending on the distribution of thrust from the two tyres. However, we can assume for simplicity that the thrust forces are approximately equal when we are experiencing wheelspin on dirt, although when we are cornering at the same time there will probably be more thrust from the outside tyre than from the inside one due to the outside tyre having more load on it.

It will be apparent that the link jacking effects are inextricably related to roll steer. When we add roll oversteer by putting slope in either of the links, we also add anti-squat, mainly on the side we change.

Lifting force

The torque arm exerts only a lifting force, because it has a slider or a drop link at its front end and can't react thrust. The torque creating the lifting force is not necessarily equal to the axle torque when the trailing links are below the axle (or above it). The torque is equal to the combined moments of the two contact patch thrust forces acting about an axis of rotation. That axis of rotation is defined by the rear pivots of the trailing links when those are directly under the axle, or the two points where the link centrelines intersect the vertical axle plane (*YZ* plane containing the axle centreline). This torque divided by the torque arm length is the lifting force at the torque arm. The total lifting force, divided by the load increase due to sprung mass rearward load transfer, times 100 per cent, is the overall per cent anti-squat.

When the car has four trailing links and two birdcages, each combination of a birdcage and two links acts like a single link with one pivot at axle centre and the other at the side view instant centre defined by the links.

In the questioner's example, where the links and the torque arm have nearly equal length, raising the rear of the links reduces the jacking force from the links but increases the jacking force from the torque arm. Lowering the front of the links reduces the link jacking force without affecting the force from the torque arm. Lengthening a link while leaving the front at the same height, as on the right side of the questioner's car, reduces anti-squat and anti-lift on that side of the racecar.

To reduce rear steer without increasing torque roll, and without reducing overall anti-squat, we could raise the rear of both links. Or, we could level out both links by moving the front down or forward, but that would reduce overall anti-squat.

With any car, there is a simple way to measure the jacking coefficient for propulsion, braking, or cornering for any wheel. If we can measure how much the contact patch moves longitudinally (*x* axis, propulsion or braking) or laterally (*y* axis, cornering) per inch of suspension travel, we know the jacking coefficient for that mode. For propulsion, the wheel must be locked at the engine (car in gear, engine off). For braking, the wheel must be locked with the brakes. With a beam axle, we need to move both wheels at once. In many cases, the jacking coefficient will be different for braking and propulsion. In the suspension we're discussing here, they will be the same.

For example, if the bottom of the tyre moves rearward as the suspension compresses at a rate of a 10th of an inch per inch of suspension travel, we have a 1:10 jacking coefficient. The force line has a slope of one in 10 and the system generates one pound of jacking force for each 10lb of thrust at the tyre.

For propulsion with rwd, the per cent anti-squat is the jacking coefficient times the wheelbase divided by sprung mass centre of gravity height, times 100 per cent. For braking, the per cent anti-lift is the jacking coefficient, times the wheelbase divided by the sprung mass c.g. height, times the percentage of braking done by the rear wheels.

CONTACT

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

Working the wheel in the 21st Century

Cosworth's impressive CCW Mk2 proves that these days a steering wheel is used for so much more than merely turning the racecar

Cosworth's Carbon Wheel (CCW Mk2) is a lightweight, FIA certified, 280mm carbon steering wheel designed specifically for professional motorsport applications. Incorporating a high resolution, fully customisable display this steering wheel has found its way into a number of series; it is part of the FIA LMP2 electronics package used in WEC and IMSA, for example.

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.

Dialed in

Meanwhile, 10 fully programmable switches and six rotary dials allow for adjustments to be made by the driver at any time, accounting for both car and track conditions. CAN communications are the primary method for sending the button and rotary messages across to any control device, but there is also two programmable opto-isolated outputs which allow any two buttons to be sent across as a directly wired signal. Similarly, the top two forward facing rotary switches can be sent as hard-wired signals. This set-up allows a certain level of redundancy in the driver controls, should any issues arise with the car's electronics.

Using Cosworth's configuration software Pi Toolset the CCW is associated with any Cosworth datalogger 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. The display has also got an overlay feature which allows the user to show only relevant data at an appropriate time. This can be in the form of alarms or simply confirming any driver input. For example, if the engine map position switch is moved the ECU can issue a feedback to confirm that the correct map has been chosen. The CCW Mk2 screen configuration can then have an overlay that pops up for a short amount of time to show which map has been selected.

Shift work

Shift lights and warning LEDs are also configured in Pi Toolset, they can be linked with alarms, strategies or in fact any other event that requires attention from the driver. The colour of the LEDs is configurable and they can be made to flash or change colour. All depending on how the driver prefers to be alerted.

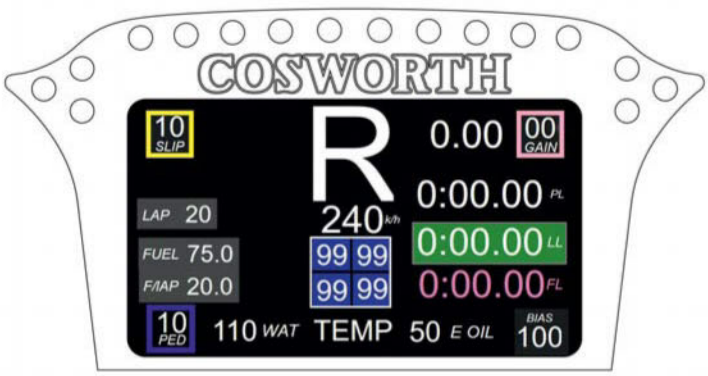
The shift light colour and pattern are also configurable in the same way.

Extra paddles

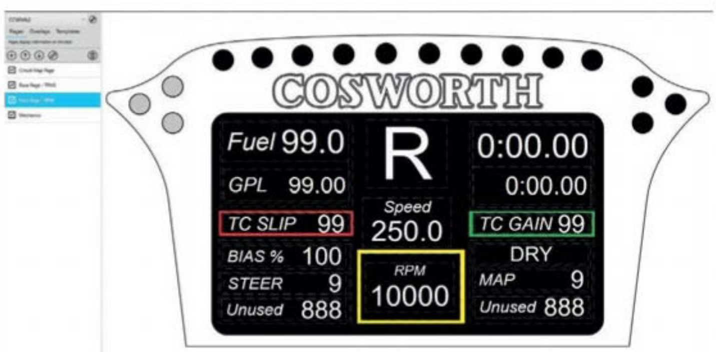
On the back of the steering wheel there is space for two sets of paddles, standard is to have just two shift paddles, for up and downshifts, but there is also an option to fit analogue paddles, which could be used for clutch control or hybrid recovery/deployment control. Or, in fact, anything else clever race engineers can dream up.

The shift and clutch signals are doubled up so it is possible to take either the direct electrical signal or a CAN based signal, or a redundancy

CCW Mk2 display has a row of 10 shift lights plus six alarm LEDs



The CCW overlay feature allows user to show just the relevant data



Display pages can be created to show a multitude of parameters

This set-up allows a certain level of redundancy in the driver controls, should any issues arise with the car's electronics

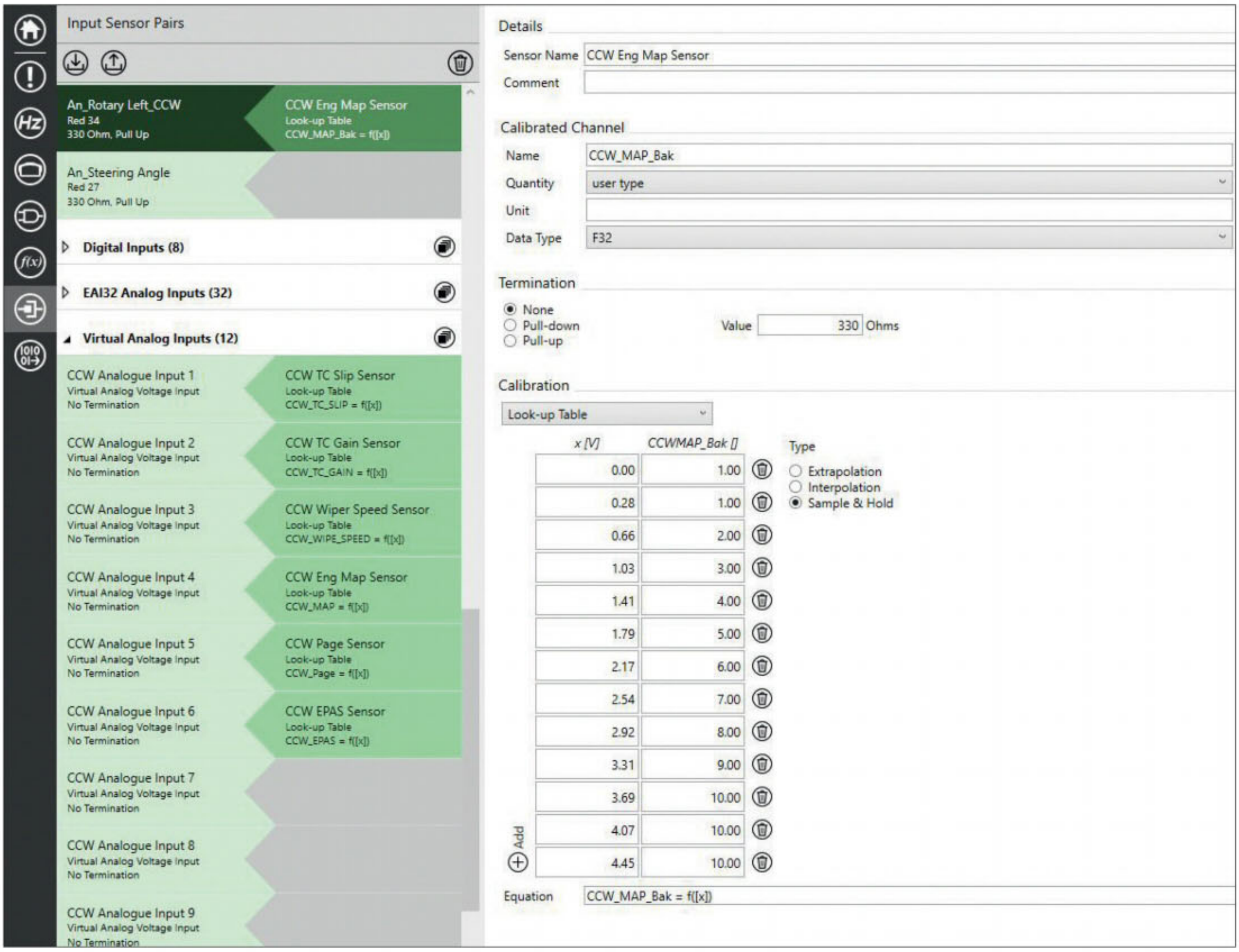
Shift lights and warning LEDs can be configured in Pi Toolset. They can be linked with alarms or anything else that will grab the attention of the driver

strategy can be implemented to allow a switch between the two.

There are three main methods for the CCW MK2 to interact with the car systems. So far two have been discussed, direct hard-wired signals in the form of analogue and digital outputs which allow direct connections to control devices, for engine, clutch, gearbox and hybrid systems. And there is also a CAN port which can be used to transmit all the signals coming from the steering wheel. The third communications route is Ethernet.

This is where all the configuration and channel information is sent across to the steering wheel from a Cosworth system. The Ethernet protocol allows for extremely fast transmission of vast amounts of data as well as allowing very complex two-way communication to take place.

Those who know about Ethernet communications will acknowledge that getting the wiring right is critical for flawless communications. In a racecar the biggest mistake people make is to use standard wires for Ethernet communications. This can sometimes work, but in the majority of cases it causes problems. Certified Ethernet wires with adequate shielding should always be used for any Ethernet wiring, be that on a racecar or otherwise.



This is an example of how a direct output from the CCW is calibrated in a Cosworth system. Note also the CAN based signal used as a virtual analogue input, which can be calibrated in the exact same way. This would allow a redundant system to be created should an issue arise with either CAN or with direct wiring

There is also an option to fit analogue paddles, which could be used for clutch control, or for hybrid recovery and deployment

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Sharpening a Sabre for Bikesports battle

Our Aries Sabre aero study begins with a rear wing assessment

The 750 Motor Club's RGB and Bikesports categories, like their analogous bike-engined categories in the USA, Australia and elsewhere, are popular and competitive club level entry paths into sports prototype racing. In the UK, the Bikesports category is currently numerically dominated by Radical, with other manufacturers such as Spire involved, examples of which we studied in our June to August 2016 issues. The latest to enter the fray is Aries, with its two-seater Sabre.

The Sabre was becoming increasingly competitive in the RGB series, which features 1000cc bike engines, no wings and generally restricted aerodynamics, but Aries boss Phil Edwards wanted to move into Bikesports and the BRSCC's Open Sports Series (OSS). An elegant new body was designed for the car in conjunction with no less a luminary than ex-F1 and LMP design engineer Enrique Scalabroni.

After sourcing a suitable wing supply, the car was ready to be upgraded to Bikesports specification, running in class C, for engines up to 1100cc. This was, then, a very suitable time for all parties involved for *Racecar* to put the car in the MIRA full-scale wind tunnel.

A busy pre-session preparation spell saw the car arrive in the wind tunnel with many of the test parts already fitted, working on the principle that it is often quicker to remove components than to fit them. So the initial baseline test was in a completely untested specification. The data are given in **Table 1**, showing comparisons at 60mph and 80mph, with the differences in counts, one count being a coefficient change of 0.001.

Light Sabre

Looking first at the different parameters, this data set shows that in baseline trim the car had quite low drag and fairly modest downforce with an aerodynamic balance (per cent front) that was slightly too far forwards. The static weight distribution was said to be approaching 50 per cent front with driver aboard, so a target figure for the aerodynamic per cent front value would probably be between 45 per cent and 50 per cent, depending on driver preference.

It was also evident that downforce slightly increased at both the front and the rear as speed was increased from 60mph to 80mph, suggesting that the flows on downforce inducing devices had not quite fully attached at the lower speed. Usefully, however, the aerodynamic balance did not shift materially across this speed range.

How did the car compare with other sports racers we have previously tested? The most recent and relevant cars we have had in the tunnel are the Spire RGB and Bikesports cars, and the basic data in roughly comparable states of balance are shown in **Table 2**.

Coefficients multiplied by frontal area are used here, since the cars had different dimensions and the Spire RGB car didn't have a wing (or the associated frontal area). Thus, comparing the CD.A and –CL.A values enables direct comparison of drag and downforce.

Table 1: Baseline aerodynamic coefficients at 60mph and 80mph

	CD	-CL	-CLfront	-CLrear	%front*	-L/D
60mph	0.461	0.598	0.303	0.295	50.7%	1.297
80mph	0.460	0.613	0.307	0.306	50.0%	1.333
Difference, counts	-1	+15	+4	+11	-0.7%*	+36

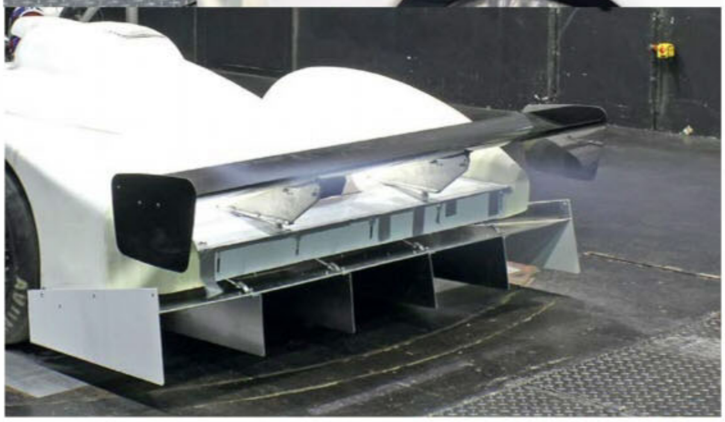
**Absolute rather than relative difference in percentage front.*

Keeping the drag under control was high on the team's priority list

The Aries Sabre G2 sports racer has recently been upgraded from RGB to the Bikesports category, which means a big step-up in aero

Table 2: Comparisons with similar sports prototypes

	CD.A	-CL.A	%front	-L/D
Spire RGB	0.665	1.037	44.2%	1.560
Aries Sabre	0.640	1.060	42.9%	1.656
Spire GT3 BS	0.751	1.861	43.9%	2.476



Top and above: The Sabre's new single element rear wing was mounted low and well back and it overlaps the trailing edge of the racecar's extended bodywork and the rear diffuser

Spire GT3 Bikesports we tested in 2016 had more downforce and drag than the Sabre

Figure 1: Aero balance *vs* wing angle

Wing angle versus per cent front shows how the wing altered the aerodynamic balance

Table 3: Δ (delta) values from wing angle adjustments

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
+3deg	+16	+69	-12	+80	-6.7%	+100
+6deg	+32	+126	-21	+147	-11.3	+170

**Absolute rather than relative difference in percentage front.*

The Sabre obviously performed very differently to the two Spire cars. The Sabre's drag was lower than either of the Spires, and considerably lower than the single seater Spire GT3 Bikesports. The Sabre's downforce was slightly higher than the Spire RGB car, and well down on the Spire Bikesports. However, the latter car featured a dual element rear wing and a front end that balanced that wing, so it was to be expected that it would create more drag and significantly more downforce.

This raises the obvious question about whether the aerodynamic package of the Aries Sabre was a good choice for the class in which it runs. It featured a new, full width single element, well-cambered wing mounted well back and low down, hopefully interacting with the car's underbody (of which more in a subsequent issue). And at the front the splitter incorporated (also for the first time for this test) wide prototype diffusers.

Recall, though, that the Sabre is destined for Bikesports class C running up to 1100cc engines (1000cc in this case) and OSS Class E (up to 1000cc), which produce up to 40 per cent less power than the Bikesports Class A and B engines, for example; so keeping drag under strict control was understandably high on the team's priority list. This inevitably puts a rein on total downforce, too (the planned 340bhp 1.6-litre Ford EcoBoost-powered variant will have different needs). However, in a recent Bikesports race the Sabre set a new Class C lap record and ran in fourth overall before drive chain problems forced an early retirement, and that was with a much less effective aerodynamic package than that which was fitted for our wind tunnel session. So it would appear that the team is on the right track.

Flying low

The rear wing, as mentioned, was mounted quite low and with a modest overlap on the trailing edge of the extended body and rear diffuser. The smoke plume showed a less than fully energetic flow reaching most of the wing's span, although the feed between the chassis and the wheel pods was reasonably good.

So how would the car respond to wing angle changes? The rear wing was at zero degrees relative to the horizontal in the baseline trim, and two angle adjustments were made to allow response to be gauged. The 'delta' values or changes arising from the adjustments are shown in **Table 3**.

Despite the wing not being in fully energetic air, adjusting it produced a strong response, and each parameter saw almost linear changes, with slight tailing off at the steeper angle. **Figure 1** shows the per cent front plotted against wing angle and indicates that in this configuration a wing angle of between one and two degrees would have produced a reasonable balance. In this part of the adjustment range, one degree of wing adjustment made a 2.5 per cent difference to the per cent front value.

Next month we will examine the difference between a flat splitter and one with front diffusers, and also map front diffuser angle.
Racecar's thanks to all at Aries Motorsport.

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

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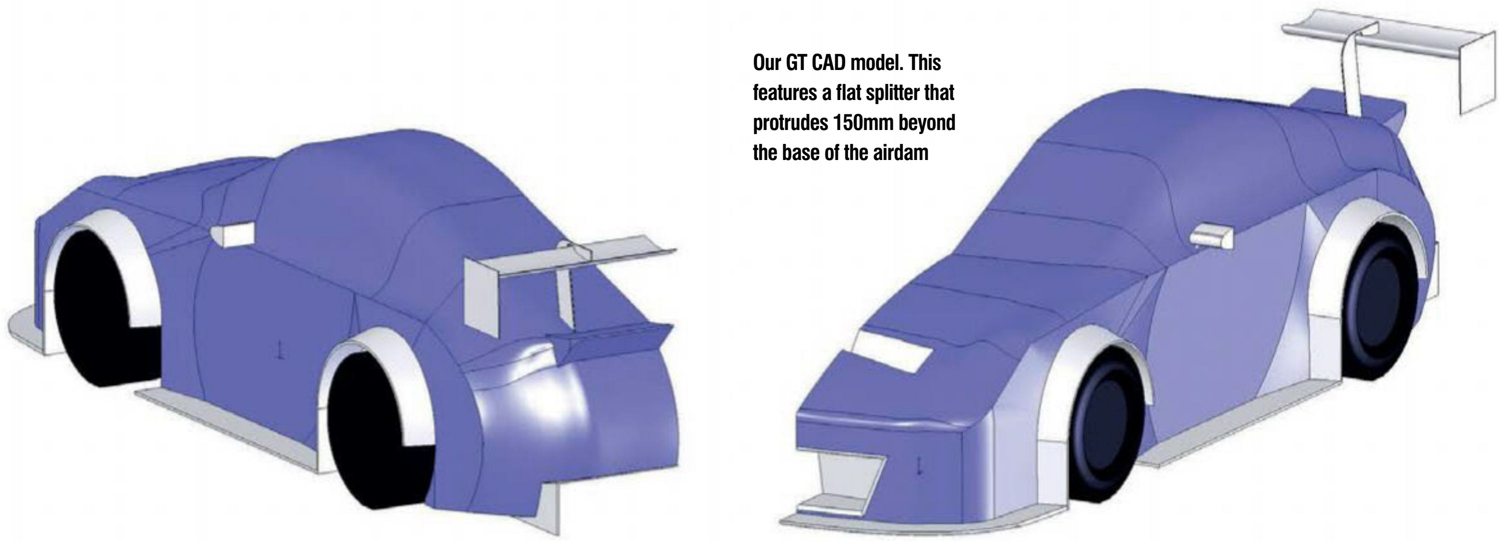
Split the difference

In the second part of our series on the basics of GT aero we fire up the CFD to examine one of the most potent devices of all – the splitter

By SIMON McBEATH



Our GT CAD model. This features a flat splitter that protrudes 150mm beyond the base of the airdam

Splitters feature on many different types of racecars, usually on closed wheelers although variations on the splitter and devices that function in a similar way can also be found on open wheel racecars. Typically, though, we see them on saloons/sedans, sports racers and GT cars, protruding forwards from the bottom of the front airdam/bumper.

We have studied simple splitters on numerous occasions in *Racecar's* monthly wind tunnel-based *Aerobytes* column. And we have covered some of the basics affecting splitter performance here, such as the length of the forward protrusion – longer splitters create more front downforce and usually do so with little or no drag penalty.

So, splitters are incredibly useful and efficient aerodynamic devices that inevitably attract the attention of rule-makers, with restrictions on dimensions and other parameters. But how exactly do splitters function? And how can we enhance their performance? To address these questions we've used ANSYS CFD to work through the fundamentals on our generic GT CAD model.

First things first, though: how does a protruding flat panel create aerodynamic benefit? We used the reduced detail GT CAD model introduced in our June 2017 issue (V27N6) to illustrate. This model featured a simple, flat splitter that protruded 150mm beyond the base of the airdam and which followed the plan view peripheral shape of the front of the car, connecting outboard to the wheel arch extensions. The splitter extended below the front end to create a complete flat underside that ultimately fed the rear diffuser. In this baseline configuration the car had front and rear ride heights of 60mm and 75mm (at the axle lines) respectively, and at this rake angle the leading edge of the splitter was 47mm above the ground.

Figure 1 shows the raised pressure (orange) region on the front panel of our model, which in turn has raised the pressure on the upper surface of the splitter, making a contribution to downforce. More importantly, the streamlines illustrate how the airflow turns down and accelerates under the leading edge of the splitter, as shown in **Figure 2**, which is a view from the underneath. This rapid turn by the airflow demonstrates why a generously radiused leading edge is preferred over a thin, sharp edge, which causes flow separation under the leading edge.

Figure 3 shows the same view as **Figure 2** but with the streamlines removed and the floor and body delineated in black so that the extent of the designated splitter is evident, along with the large area which is at reduced pressure (blue). This is what creates the majority of a splitter's downforce; the raised pressure on the upper surface contributes too, but it does not impinge on such a large area as does the reduced pressure beneath. **Figure 4** is a side view of the pressures on the longitudinal symmetry plane that further illustrates how the pressure differential on the upper and lower surfaces creates the splitter's downforce.

The plots from our June 2017 article on GT aerodynamic basics, shown in **Figures 5** and **6** here, illustrate what proportions of drag and downforce were created by the major components of the baseline model, and while the splitter's drag contribution was negligible, its downforce contribution was actually slightly greater than that of the rear wing; indeed it has to be of that order if a front to rear aerodynamic balance is to be achieved, depending on how much downforce is created by the floor and rear diffuser and where the centre of pressure of that section is located. It's easy to see then that the splitter has an important role to play.

We also saw in our June 2017 feature how changes to the car's set-up such as reduced ground clearance, increased rake angle and more nose-down pitch angle all increased front end downforce by causing greater suction under the splitter. How then can we alter the splitter itself to increase its downforce contribution (other than by increasing its length)?

Positive inclination

The simplest of modifications would be to apply an angle to the splitter panel, and in the case of

How does a protruding flat panel create an aerodynamic benefit?

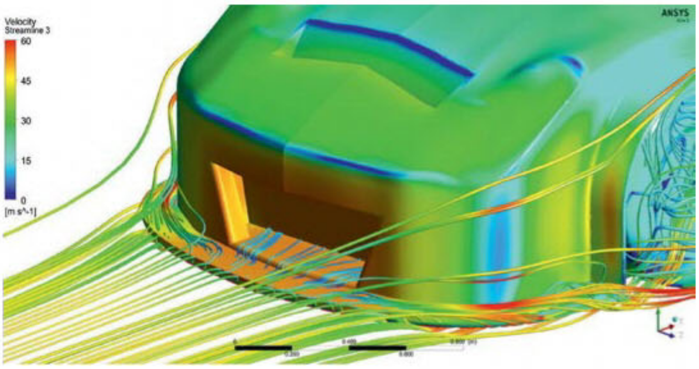


Figure 1: High pressure on top of the splitter is just part of the story

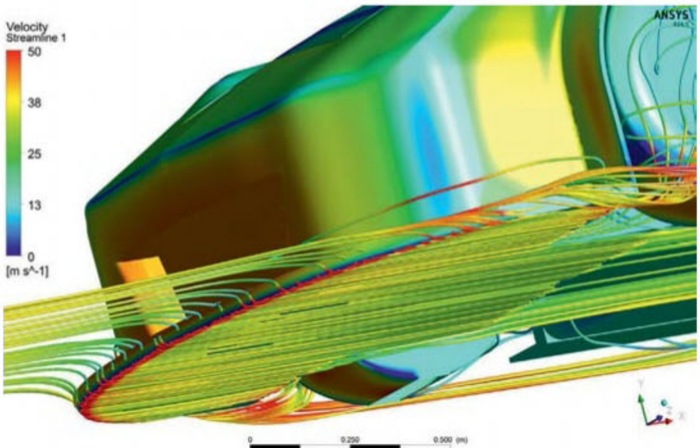


Figure 2: Air accelerating under the splitter generates most of the downforce

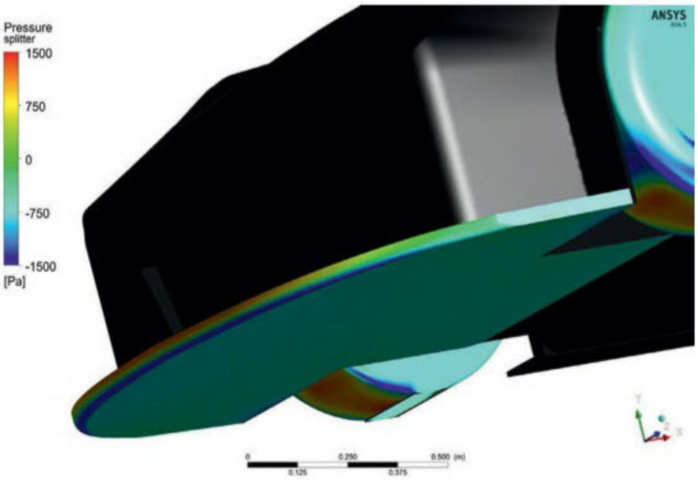


Figure 3: Underside without streamlines. The splitter panel on our model extends under the front to level with the axle line; all this area was at reduced pressure

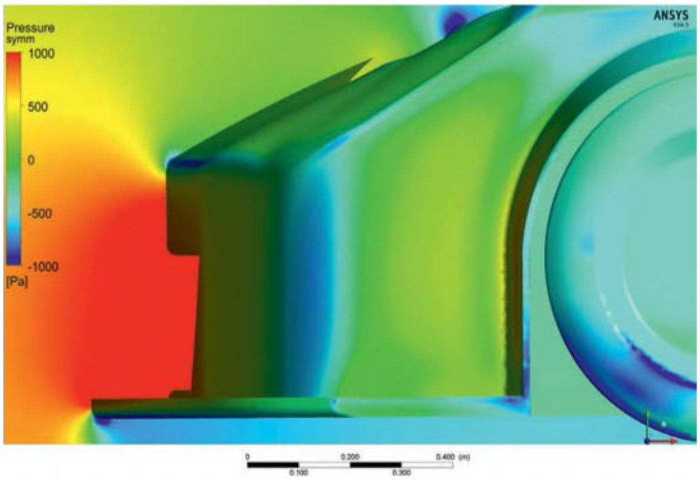


Figure 4: Pressures on the symmetry plane show the differential between top and bottom surfaces of the splitter, further illustrating how a splitter creates downforce

some technical regulations this is a permitted modification where otherwise the splitter must remain as a flat panel. So, the widest section of the splitter back to the leading edge of the front wheel arches had its trailing edge raised by 25mm, equating to an inclination angle of just over two degrees (in addition to the overall rake angle of about 0.36 degrees). The floor between the front wheels was thus 25mm higher than previously, and this was then blended back down to the main floor level with a radiused fillet in line with the back edge of the front wheel arches.

The results are in **Table 1**; data given as 'delta' (Δ) values, or changes to the previous configuration, in 'counts', one count equalling a coefficient change of 0.001.

In short, tilting the splitter produced a 17 per cent gain in overall downforce for no change in drag, with a modest forwards balance shift. It's particularly interesting that an increase in rear downforce was also created, implying there was an overall increase in mass flow, and hence velocity, under the car, leading to greater pressure reductions under the car as a whole. The comparison of surface pressures on the undersides of the baseline and tilted splitter configuration shown in **Figure 7** bears this out. The forward section of the splitter saw increased suction, the area between the front wheels saw higher pressure than the baseline model, but then the transition to the main floor and to the rear diffuser both saw increased suction again. Tilting a splitter may well therefore be a parameter to be explored further.

Front diffusers

Commonly seen under the front splitter panels of many racecars these days, the front diffuser's purpose is, logically, to increase mass flow under the splitter and hence increase its downforce. A common query though is 'why would a diffuser located ahead of the front tyre be of any use? Surely the tyre would block the flow? Wouldn't it be better to just use a diffuser located ahead of the gap between the tyre and the chassis, where there is a relatively unobstructed exit for the air to find its way downstream?'

To put this to the test a set of three different front diffusers was modelled, all 400mm long with a conservative six-degree roof angle, with widths ranging from 200mm

Sources of drag

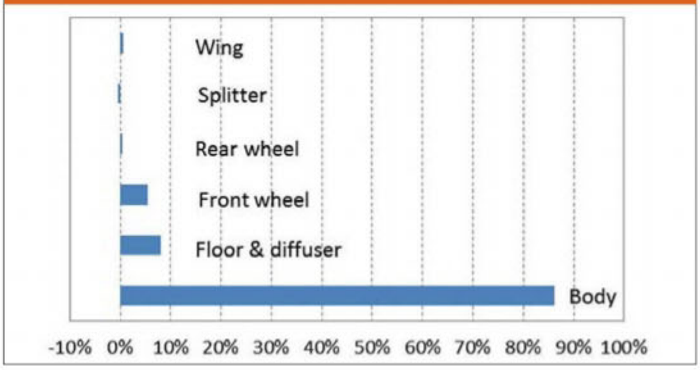


Figure 5: The splitter's contribution to the drag on our GT aero model was minimal

Table 1: The effects of tilting the splitter

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
With tilted splitter	-	+146	+82	+63	+2.16%	+306
Δ %	-	+17.0%	+22.9%	+12.5%	-	+16.9%

**Absolute rather than relative difference in percentage front.*

The simplest of modifications would be to simply apply an angle to the splitter panel

Sources of downforce and lift

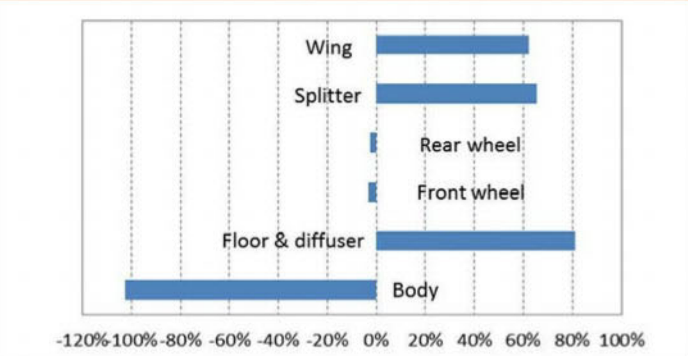


Figure 6: The splitter contributed downforce that was comparable to that of the wing

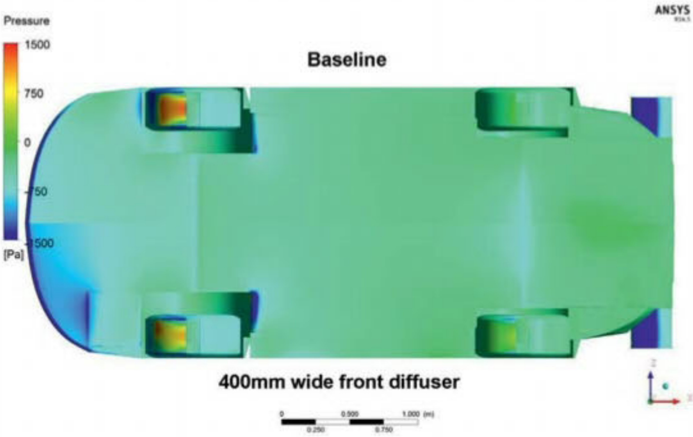


Figure 8: This clearly shows that front diffusers added significant splitter downforce

Table 2: The effects of changing front diffuser width, relative to the flat splitter

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
200mm	-11	+10	-	+9	-0.49%	+63
300mm	-3	+58	+72	-16	+5.3%	+132
400mm	-6	+200	+231	-32	+14.0%	+448

**Absolute rather than relative difference in percentage front.*

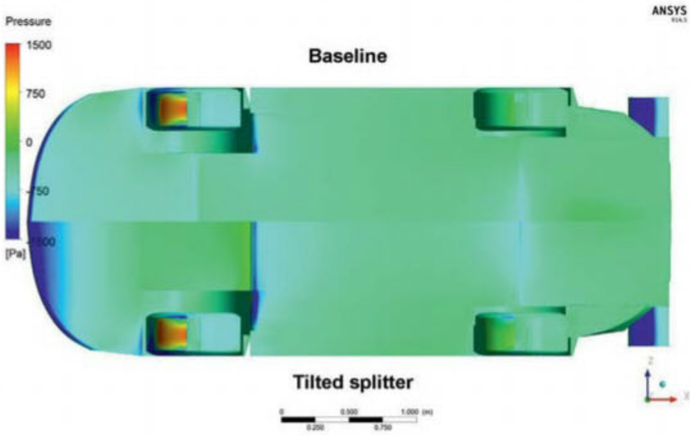


Figure 7: Tilting splitter generated more front downforce and helped rear underbody too

Table 3: The effects of changing front diffuser length

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
350mm	-	+20	+8	+11	-0.21%	+44
450mm	+9	-136	-79	-57	-0.23%	-326

**Absolute rather than relative difference in percentage front.*

(which saw the outer wall of the diffuser in line with the inner wall of the front tyre) to 400mm (which put the outer diffuser wall just inboard of the outer wall of the front tyre). The intermediate 300mm wide diffuser's outer wall was roughly in line with the middle of the front tyre.

The results are in **Table 2** as delta values compared to the baseline model in counts again. Note that although the CFD solver was run in each case until the forces on the major components were deemed to be steady, there was a margin of error of up to +/- 2.5 per cent in the forces in some cases, and without time averaged data sampling, as done in the wind tunnel, confidence was not high in the third decimal place in the calculated coefficients; as such small changes in the delta values should be regarded with caution. But confidence should be good in the stronger trends.

The clearest trend in this data is the increase in front downforce and the associated forward shift in the aerodynamic balance (per cent front) with increasing front diffuser width. The response was not linear, but the gains from the widest front diffuser certainly indicate that the tyre blockage hypothesis was incorrect.

The surface pressure plot shown in **Figure 8** comparing the baseline (no front diffuser) with the widest diffuser clearly shows how the suction under the splitter was much enhanced by the wide front diffuser. Interestingly, the force breakdown showed that only splitter downforce increased this time, unlike in the case of the titled splitter where the floor and rear diffuser also gained downforce.

Full width

The logical sequel to widening the front diffusers outboard was to widen them inboard, and so the next trial was done on a full width front diffuser, making the underside of the front end more akin to the underside of a simplistic ground effect wing. This also necessitated blending the now raised floor area between the front wheels with the main floor, and this time a V-divider was installed, reaching from a central apex level with the trailing edge of the front diffuser out to the chassis sides in line with the centre of the front wheel. Intriguingly, this produced very similar aerodynamic coefficients and an identical per cent front value to the 400mm wide front diffusers, even though the pressure distributions on the underside of the front of the car were quite different, as **Figure 9** illustrates.

Although the flat 'throat' section of the splitter was obviously at lower pressure with the full width diffuser, the area ahead of the V-divider was at higher pressure, and overall the splitter with the full width diffuser produced about 10 per cent less downforce than that with the 400mm diffuser. However, its centre of pressure was 140mm further forward, helping to attain the same per cent front value. The downforce lost by the splitter was made up by the floor and rear diffuser generating roughly 10 per cent more downforce.

On reflection, the V-divider could have been better conceived, and perhaps a simple filleted transition to the main floor, as used with the tilted splitter earlier, would have performed better. However, the splitter throat performed better with the full width front diffuser, and perhaps with further mods to the wheel arch behind the front wheels to permit improved air egress from this region more gains would have been made. We'll return to that parameter shortly.

Within the space available from the leading edge to the trailing edge of the splitter, how long should the diffuser be? Using the 400mm wide front diffuser, 350mm and 450mm length options were compared to the 400mm long baseline, utilising the same diffuser exit height in each case, which meant that the diffuser roof angle changed with length. The results are in **Table 3** in counts relative to the baseline 400mm long diffuser.

In this case the shorter diffuser produced slightly more total downforce than the 400mm baseline, but the 450mm diffuser produced significantly less downforce than the baseline. In both cases downforce changes were felt at the front and the rear, with the floor and rear diffuser losing downforce as did the splitter at the longest front diffuser length, and vice versa, hence the per cent front value changed little in either case.

As a quick look-see, just one alternative diffuser angle was evaluated; using the 350mm diffuser length the exit height was increased

These gains indicate that the tyre blockage hypothesis was incorrect

Table 4: The effect of increasing front diffuser roof angle

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
12.9deg	+6	-24	+57	-80	+6.6%	-80

**Absolute rather than relative difference in percentage front.*

Table 5: The effect of re-shaping the front wheel arches

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
Modified wheel arches	+21	-56	+34	-89	+6.02%	-216

**Absolute rather than relative difference in percentage front.*

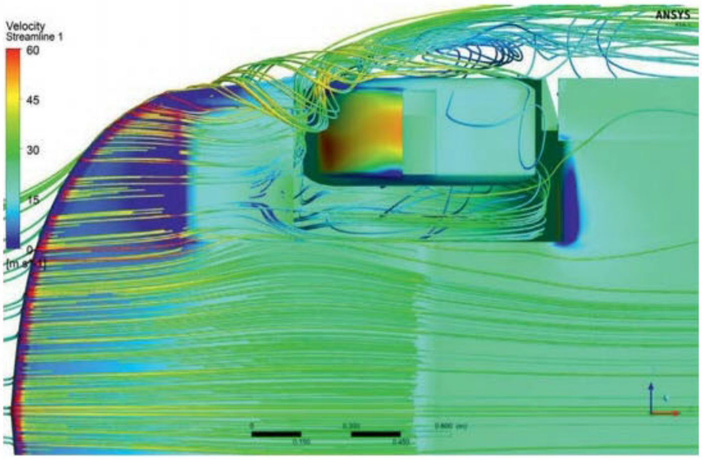


Figure 10: Steepest diffuser showed signs of stall ahead of, and just inboard of, the tyre

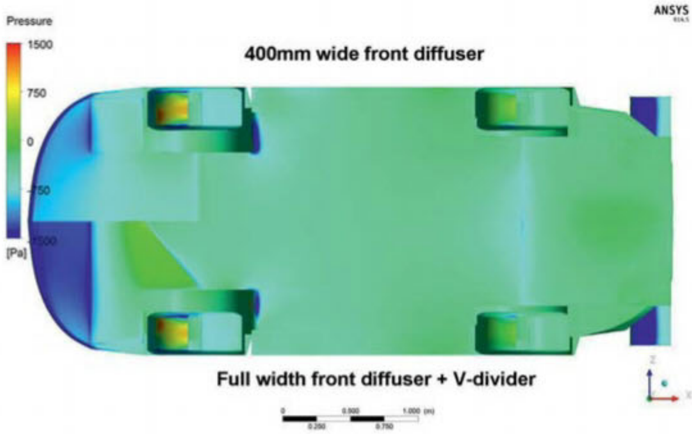


Figure 9: Full width front diffuser created yet more splitter downforce, but trade-offs meant there was no overall improvement over the 400mm wide diffuser

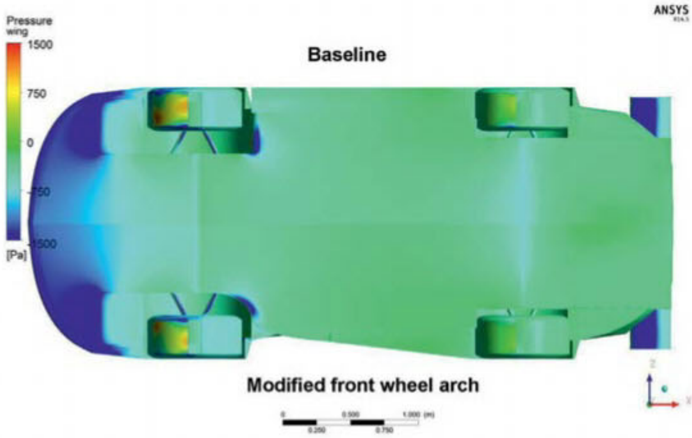


Figure 11: Modifying the rear of the front wheel arches improved splitter performance

to 80mm, roughly doubling the roof angle from 6.5 degrees to 12.9 degrees. The changes relative to the 42mm high, 350mm long diffuser are shown in **Table 4**.

Doubling the front diffuser roof angle may have been a step too far, with a significant forward balance shift but a loss of total downforce. In fact the splitter gained just under eight per cent downforce but the floor and diffuser lost just over eight per cent downforce, with the rear diffuser transition generating noticeably less suction. **Figure 10** shows that the front diffuser exhibited partial stall just inboard and ahead of the inside of the front tyre. So although overall the splitter produced more downforce, perhaps this partial stall compromised mass flow to the downstream underbody sufficient to cause the loss of downforce there.

Clearly diffuser length and angle need further detailed study, but shorter and steeper up to a point seemed to be the tenet here.

Arch enemy

We have seen that front diffusers increased front end downforce very significantly. Yet, so far, no downstream modifications to assist with the egress of the extra mass flow under the splitter have been made. Would suitable shaping of the wheel arches behind the front wheels provide a more effective escape route for the air passing through the front diffusers? Would this boost splitter performance still further? And what would the downstream effects be?

To evaluate these questions a straightforward modification to the area behind the front wheels was made, incorporating what amounted to a concave-convex scalloping of the rear part of the front wheel arch to, hopefully, provide a less restrictive escape route for the air exiting the splitter/front diffusers.

This re-shaping of the rear of the front arches also involved tapering the side running boards, a move that was expected to make little difference since the static pressures on the upper and lower surfaces of the forward running boards were much the same. Incidentally, the model now incorporated simple suspension and uprights which, when baselined against the model without the suspension, produced very similar data and no change in aero balance.

The slightly surprising data from the modified front wheel arch model are shown in **Table 5** as delta values compared with the 'new' baseline model incorporating the suspension. The front diffuser in this instance was the shortest, steepest one tested previously; 350mm long, 400mm wide and 80mm high at the exit.

Notably, drag increased and total downforce decreased with this modification, both of which were surprising. There was an increase in front downforce and a significant forward shift in aerodynamic balance, but the balance shift was more to do with rear downforce reducing. The forces on the key components provide more clues as to what was happening here; splitter downforce did actually increase, as hoped, by around six per cent. However, the downforce contribution of the floor and rear diffuser reduced by about 15 per cent, and this represented the lowest downforce contribution from the floor and rear diffuser so far.

The underside surface pressure distribution comparison in **Figure 11** shows the relatively subtle increase in the area of reduced pressure under the splitter with the modified front wheel arch, but also the reduced suction in the rear diffuser and (more subtle still) over wider areas of the floor and rear diffuser. **Figure 12** shows streamlines superimposed on the same image, and it is possible to see here that with the modified front wheel arch there was outward flow visible in the underbody aft of the front wheels, and furthermore that the width of the region of the fast streamlines entering the rear diffuser was narrower.

All these bits of circumstantial evidence point to the fact that the modified front wheel arches have reduced the mass flow passing under the floor and into the rear diffuser, which would have been responsible for the reduction in downforce from that area. Thus, while the front arch modification does appear to have strengthened the splitter's contribution, it has in this instance also reduced downforce from the rest of the underbody. Once again, further development would be needed to claw back floor performance, but the principle of helping the splitter and front diffusers seems to have worked.

The modification has reduced downforce from the rest of the underbody


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Table 6: The effects of splitter end fences

	ΔCD	Δ-CL	Δ-CLfront	Δ-CLrear	Δ%front*	Δ-L/D
Fence 1	-	-14	-1	-15	+0.86%	-29
Fence 2	-2	+56	+19	+36	-1.57%	+121
Fence 3	+33	-51	-69	+18	-3.20%	-236
Fence 4	+36	+44	+68	-24	+3.24%	-69

*Absolute rather than relative difference in percentage front.

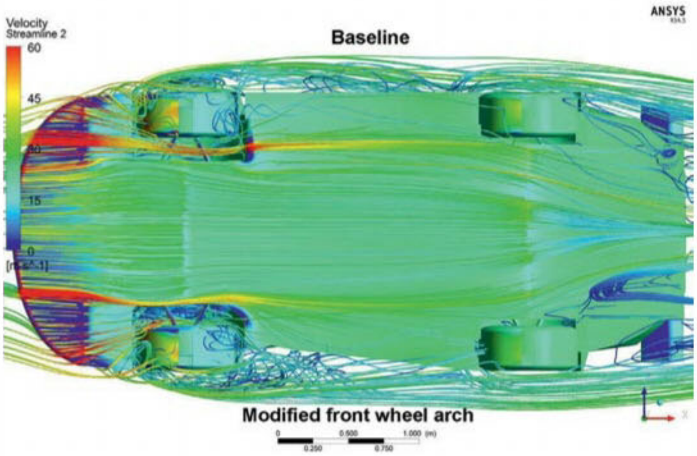

Figure 12: With modified front wheel arch outward flow was visible in underbody aft of front wheels and the width of fast streamlines entering the rear diffuser was narrower

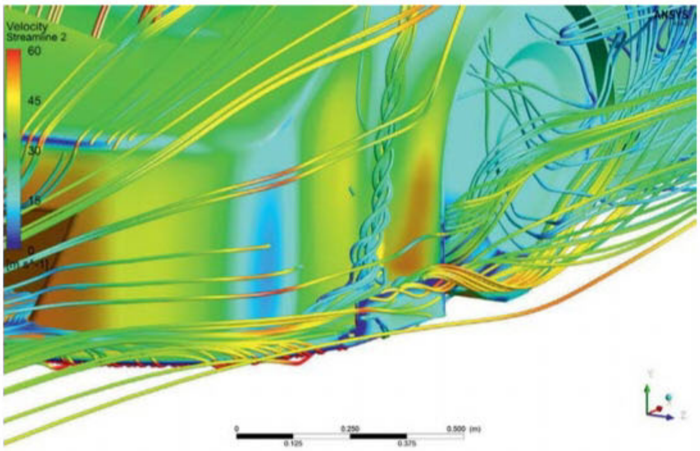

Figure 14: Fence 2 modified the forming of the horizontal vortex at the end of the splitter

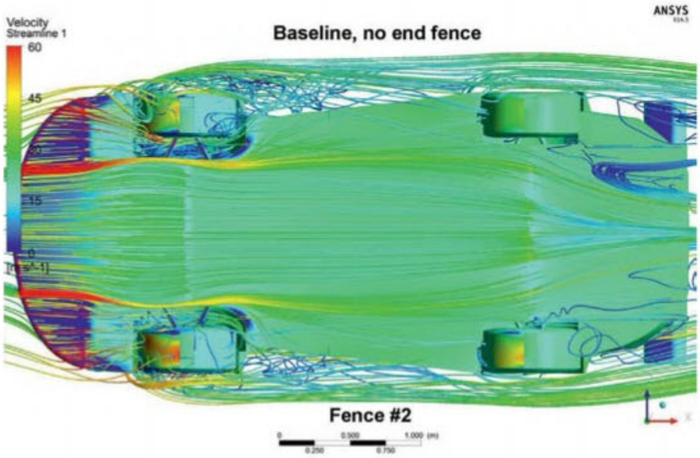

Figure 13: Splitter end fence number 2 modified the airflows in the front diffuser

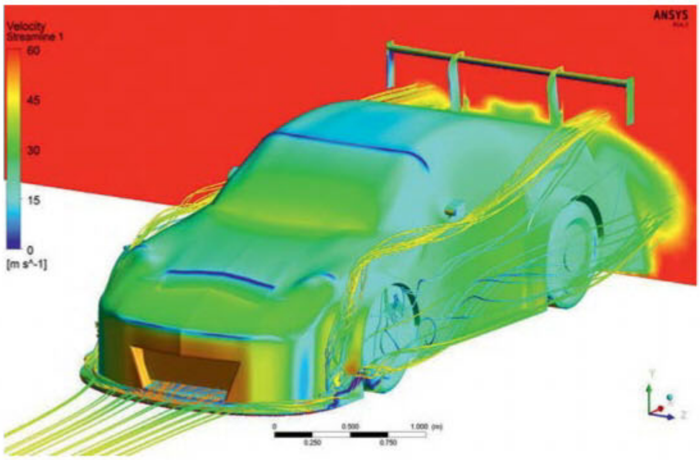

Figure 15: The upper vortex from Fence number 4 eventually encountered the rear wing's flow field, suppressing total pressure (energy) slightly under the rear wing

We have studied splitter end fences from time to time in our wind tunnel-based *Aerobytes* projects, and in general we have seen that small fences can be quite efficient at generating more front downforce while larger ones are less efficient and can cause drag increases and rear downforce reductions. How would our digital model compare, and could we learn more about the mechanisms at work with visualisations? Four fence configurations were tried:

Fence number 1: 260mm long, 58mm tall at the front, with a 50mm gap at the rear.
Fence number 2: 310mm long, 58mm tall at the front, sealed to the front wheel arch.
Fence number 3: 310mm long, 158mm tall at the front, sealed to the wheel arch.
Fence number 4: 310mm long, 58mm tall for 150mm, rising to 158mm at the rear.

The results relative to the 'no fence' baseline model are given as delta values in **Table 6**.

Fence 1 was of no value then, but Fence 2 was, it added downforce at both ends of the car, and more at the rear. Drag was essentially unchanged, making these small fences very efficient additions. The underside surface pressure distribution comparison shows that suction was enhanced under the very outer portions of the splitter, but also at the rear diffuser transition, which is where the increase in rear downforce accrued. The comparison of the underside streamlines shown in **Figure 13** requires close study but does show that with Fence 2 more of the streamlines in, and from, the front diffuser were pulled further outboard, and this appeared to be associated with the change in the vortex structure at the end of the splitter caused by the fence, seen from above in **Figure 14**. This may have been responsible for the change in flows and pressure distribution through the floor and rear diffuser in this case.

Fence 3 had generally negative effects, adding to our wind tunnel findings that tall fences are not necessarily a good idea. Fence 4, however, caused quite a significant increase in front downforce although this time with a drag penalty and also a loss of rear downforce. Once again the outer portions of the splitter saw enhanced suction compared to the baseline, although not as much as Fence 2 produced, but this was made up for with more suction in the centre of the splitter. The rear diffuser transition area again saw higher pressures than the baseline. In addition, along with a trend from the baseline to Fence 2 and Fence 4 that saw splitter downforce increase (total +5.6 per cent), body lift decreased (by 3.9 per cent) and wing downforce decreased (by 4.3 per cent), **Figure 15** shows that the streamlines of the vortex triggered at the base of the bluff wheel arch extensions eventually encounter the rear wing's flow field, where the total pressure (energy) slice shows there is a small reduction in the energy of the airflow coincident with these streamlines. This may partly explain the reduction in rear wing downforce, but the decrease in body lift and in wing downforce may simply indicate reduced mass flow over the roof of the car. So these small fences have far reaching effects, making it imperative to evaluate different configurations on individual applications rather than generalising too much.

Small fences can be quite efficient at generating more front downforce


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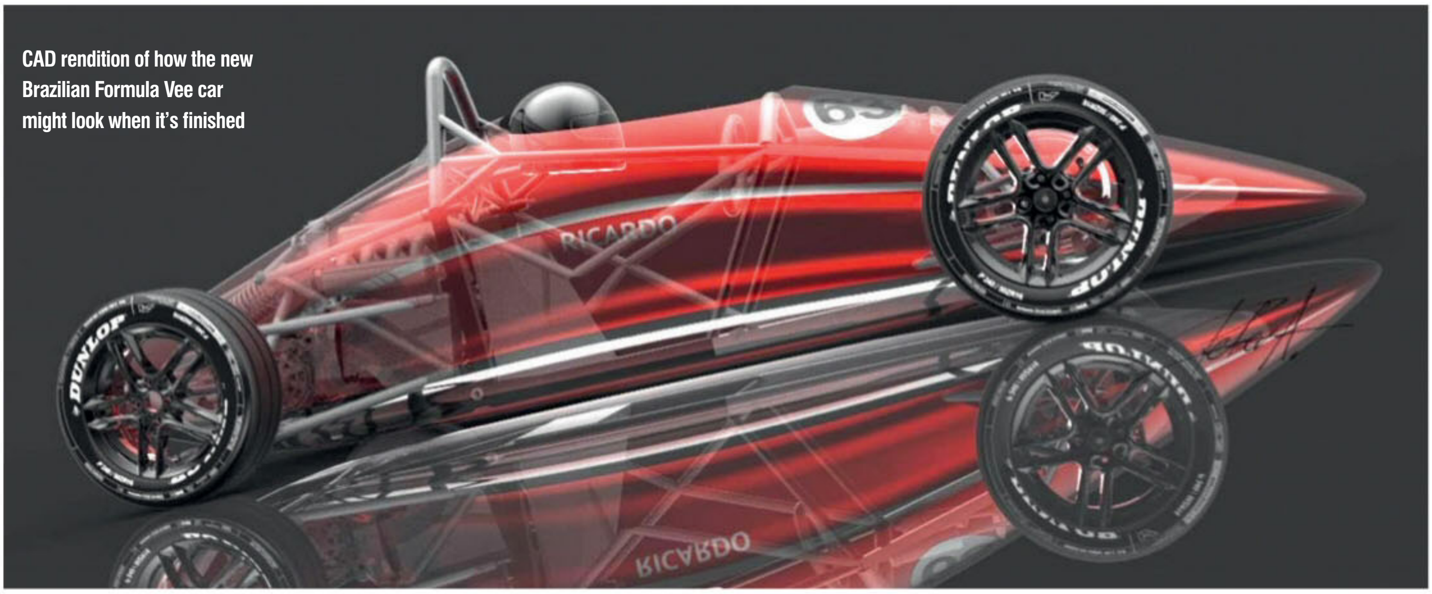
Grand designs

We revisit the ongoing Ricardo Divila-inspired Brazilian Formula Vee project for a master class on designing a cost-effective single seater racecar from scratch

By RICARDO DIVILA



CAD rendition of how the new Brazilian Formula Vee car might look when it's finished

With its antiquated VW suspension the current Brazilian FVee is looking long in the tooth and parts are now hard to source

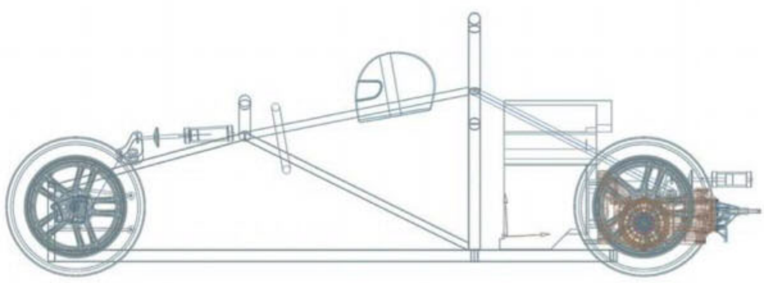
We first looked at the new Brazilian Formula Vee project in the April edition (V27N4). It's a fresh slant on the proven FVee concept, which it is hoped will reinvigorate the grassroots racing scene in Brazil, as well as providing a tough, cheap racecar that should be as at home on track days and at racing schools as it is at the races. In this feature we will be looking at the design process for this – and indeed any – new racecar project.

The first step in any racecar design is to create a design brief, highlighting the concepts to be used, fabrication methods and – as the project in question was for a production run of at least 50 cars over six months – the availability of materials and equipment, and delivery times by the suppliers, had to be taken into account.

Performance target

There are two distinct design processes; design layout and design analysis. Design analysis is where the performance required is specified. In this case, given that an existing championship, albeit local and small scale, had cars already running, these gave the initial benchmark of performance, with their lap times.

Keeping the common running components such as engine, gearbox and wheels and tyres of the old car, plus all the ancillaries, would ease



The initial layout drawing with all the major items placed. The new Formula Vee has been designed with robustness and ease of use in mind as it's also to be employed as a school car

Throughout the process it's always necessary to reiterate, going back through the calculations and layouts until satisfied

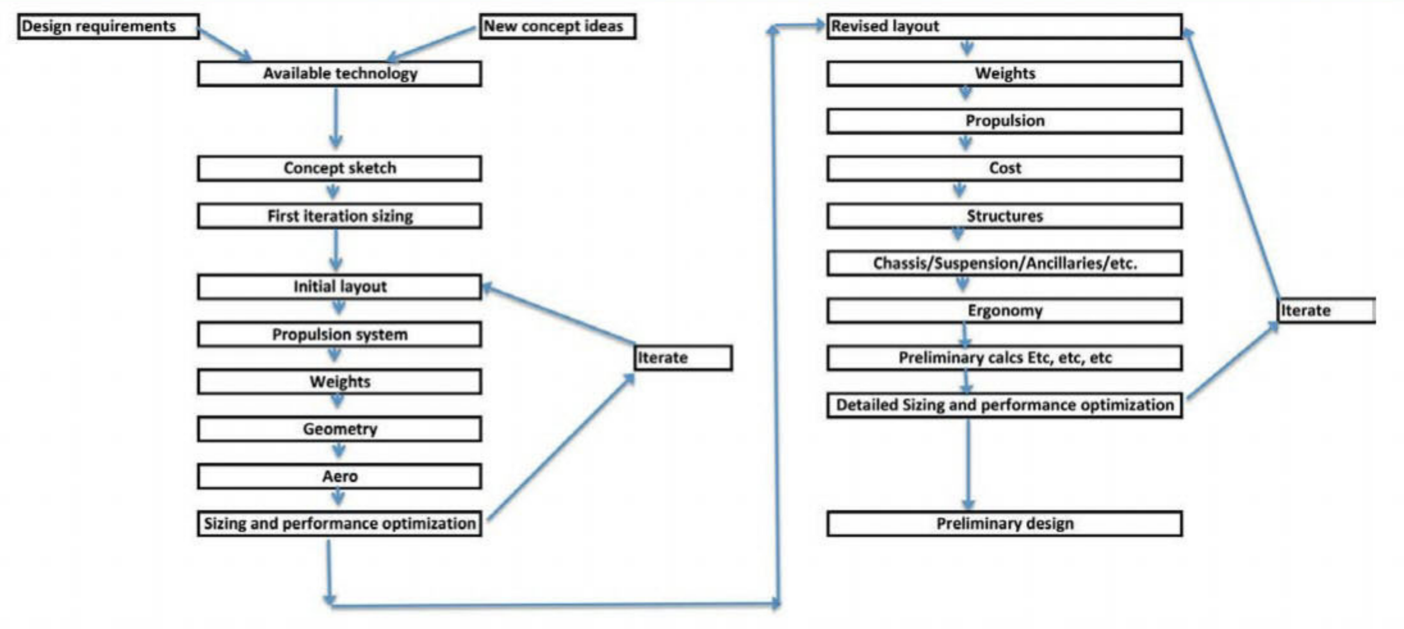
Figure 1: Design requirements

Conceptual design
What requirements drive this design?
What should it weigh and cost?
What trade-offs should be considered?
What does it look like? (The business model might require that it's an attractive car).
Will it work? (Here is where being very, very objective comes into play).

Preliminary design
Freezing the configuration.
Developing the shape.
Developing tests and analytical base.
Designing major items.
Creating weight table and CG position.
Creating actual cost estimate.

Detail design
Designing individual parts to be built, the layout, and the dimensioning and material specification.
Designing tooling and manufacture process.
Testing major items.
Finalising weight and performance estimates.

Figure 2: Design flowchart



the transition. The pool of 20 of the old style cars was reviewed to see which items were to be kept in both the new and old cars, and some modifications were made to existing cars in the interest of also reducing costs.

The existing powertrain was adequate as far as the engine went, it being a 1.5-litre water-cooled production engine, absolutely stock. The wet sump could cope with the cornering *g* generated with the road car belted tyres, the main problem being the fragility of the synchromesh system for gear selection – it's easy to forcibly change gears and beat the syncros, causing shock loads that lead to degradation and eventually to broken gears and input shafts, or just difficulty in engaging gears.

Another design priority was to update the suspension type to a classic double wishbone, moving on from the front trailing-link and rear swing-axle, a simple and cheap system at the time of the FVee's original design in 1967, but becoming increasingly difficult to source for a new car production run, there being a shortage of new parts, as they have been out of production for some decades now.

There were parts available sourced from junk-yards, but this meant a lack of control on their condition, and a lack of knowledge on what loads they had been subjected to in their previous use. Used parts can be used, but are more adequate for a one-off prototype, as logistically they are difficult for a production run.

The initial idea of using the same front uprights from the VW Beetle was explored, but there were geometrical constraints with using the forged components, which could not achieve a decent geometry to cater for very different modern tyres (the axle had trail built-in, and the dimensions constrained the inner points severely). But the decisive factor was the cost and the fact that the ability to use the same upright on all four corners could bring unitary cost to very close to the forged ones, by virtue of having a medium-volume production of 200 uprights on the envisaged 50-car production.

The next step was to decide on which method to use to achieve this. Fabricated uprights have an ease of production, but the

The actual design process can be divided into three major phases

downside is the cost, as each is individually hand-crafted, meaning specialised labour, and it would be difficult to produce the envisaged volume in the projected timeframe. The alternative machined cast aluminium or magnesium upright could reduce this but, once again, finding a sub contractor to cast and machine at a reasonable cost proved difficult.

The ample supply of CNC equipment and machining centres in Brazil proved the best solution, giving the opportunity of having bespoke uprights without any design limitation, except for the condition of having a single plane machining order, where there would be a majority of operations with the raw material held in the vice, with just the bore for the bearings on a second pass. Likewise, dimensioning the upright was dictated by available sizes of ally raw stock, to cut down on the amount of machining needed.

Practically all the design constraints were on the premise of cutting costs to the bone, instead of making the lightest part possible.

The design analysis, which focused on stress and load factors, enabled all parts to be made stronger than necessary, ensuring that maintenance would be less demanding; after all, maintaining a 50-car fleet which would be used every weekend and on track days could not follow the usual full strip-down, check and rebuild of most racecars – also taking into account that the school cars would be subjected to a high wear and tear cycle.

Design process

The actual design process itself can be divided into three major phases, the first of which is conceptual design, where the basic questions of configuration arrangement, size, weight and performance are examined.

The basic question that drives it all is simple: can an affordable car be built that satisfies the requirements? If not, there are two options, either to reformulate the business model, or to reduce the specifications to one that does.

Conceptual design is a very fluid process, subject to the emergence of new problems and ideas. Keeping flexible and not being locked in to pet ideas is important during this phase. It will take a lot of will power to discard something you have spent a lot of time designing and then start afresh. If you don't it will hit hard on the next phase of the process; preliminary design.

Preliminary design is where you can say the major changes are done. You have determined the main car dimensions of wheelbase, track and positioning of major components, you have chosen your suspension layouts and configurations, the ergonomics of the driver environment have been sorted out, the powertrain and ancillaries have been selected and are now investigated in more detail, bearing in mind function, weight, manufacture, assembly and maintenance.

The previous flexibility in thought process has to be reversed now, and the majority of decisions will have to be frozen to allow the car layout to proceed and also prepare for the third phase, detail design. The preliminary design phase has most of the components placed and specified, although minor revisions can still be made, but towards the end of it even minor changes will be avoided. This is also where the parameters for the powertrain, load cases for chassis and suspension structures, are examined in more detail, and the requirements for cooling, fuel lines, tank capacity instrumentation, gear linkage and steering systems, electrical budget, loom layout and design are defined and chosen.


The classic spaceframe, with separate subframe for engine, was chosen over an expensive and impractical carbon chassis


With weight to play with thanks to the ditching of old suspension, safety was enhanced with steel plates around the cockpit

Detail design

The objective of preliminary design is to get ready for the detail design stage, and the locking in place of the supply chain and personnel needed to achieve the goals. Once we have made the production decision, the detail design begins. For example, during conceptual and preliminary design the part – a suspension corner, for example – will be designed and analysed as a whole, running through the geometry, pickup point on the chassis, tyre and wheel dimensions, and load cases. In the detail phase the suspension will be broken down to individual elements, say the upright, hubs, wishbones, pushrods and rockers, plus springs and dampers. Each of these will be analysed, stressed and drawn, taking in all the parameters it will have to obey.

For instance, a top front wishbone, which in this particular design is a symmetrical part – to be used on the left and right hand sides – will then be detailed, which implies the selection of the balljoint that will be used, the size and thread will determine the dimensions of the bushes and inserts, and the angular capacity will be checked to enable the suspension to swing through the full bump, droop and lock determined in the design.

Detail design is also where the fine art of compromise will rear its head, as it is a well-known rule of engineering that there are no free lunches. Likewise, clearances to the wheel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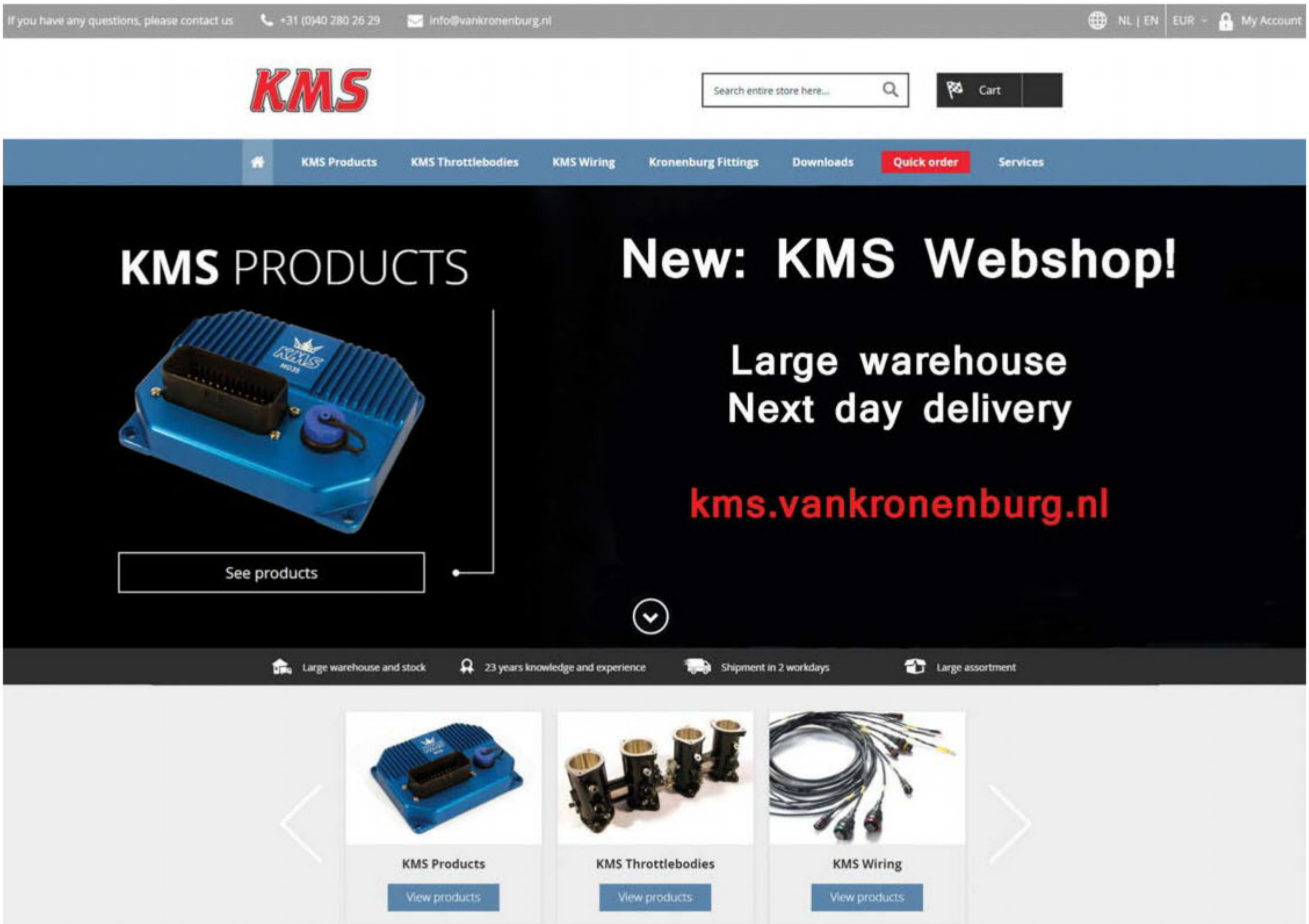
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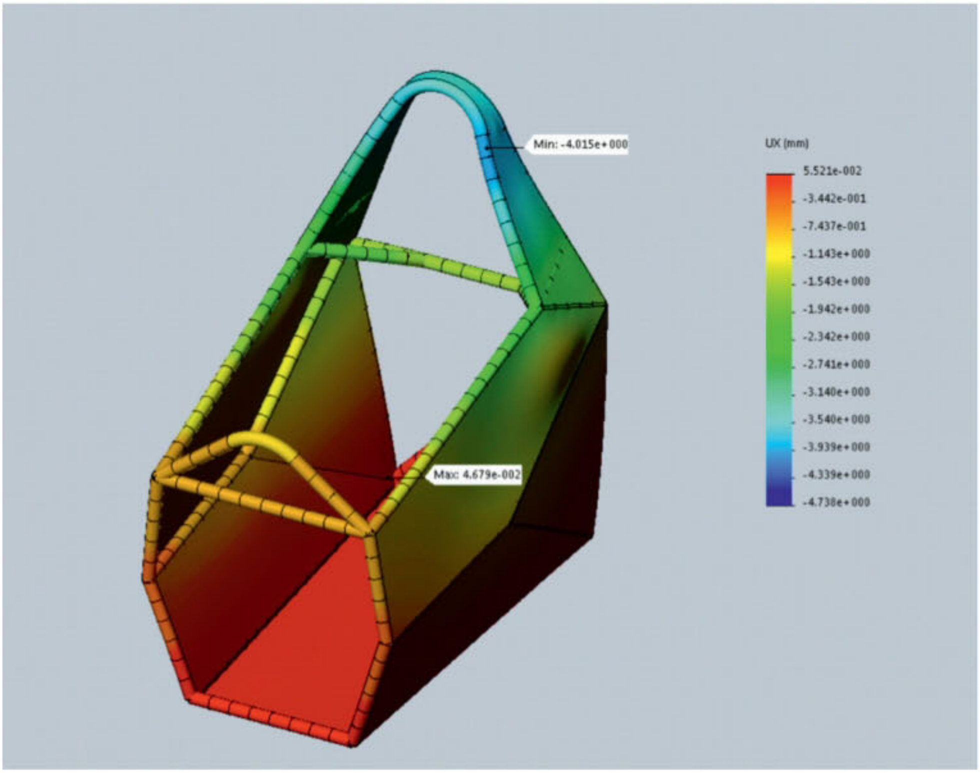
Can an affordable racecar be built that satisfies all the requirements?

and bodywork will drive some of your choices. Common sense would also suggest you check that the wishbone size produced would allow mechanics to pick up the car mid-wishbone to place it on stands or the trailer, a common load case not usually covered in design manuals but prevalent in the business.

Time being what it is, you will probably start manufacturing some major items while the detail design is still being worked on, like the chassis or uprights, because of lead times – there being a very small number of projects where build will wait for all the components to be fully designed. It will at least freeze some configurations as the time and money already invested will preclude changes, unless we have the 'small issue', as it is often described in the industry, which will demand correction. Budget enough time and resources to cater for at least one of these 'small issues' per project, they will happen (see Murphy's Law.) With all these factors examined in the design analysis and added to the design brief, we then proceed to design layout. We have gone through the basic flowchart **Figure 1** and **Figure 2**.

Going back to the Formula Vee design, let's look at the the preliminary phase. One of the items to be implemented was that of having to cater for the expected wide range of driver shapes, bringing problems in the placing of the steering wheel and pedals, plus seatbelt attachment points. The ease of driver fitting is essential for a quick adjustment for use on track days. It's not an easy fix, though solved by having a dedicated pedal box that could be moved back and forwards, plus spacers for the steering wheel and column supports.



The chassis went through 16 iterations with FEA analysis being done to improve stiffness and cockpit safety at every step

Main bulkheads were of rectangular section and perpendicular to chassis base, making for easier manufacture and jigging

Initial layout

At this point we have enough information to have an initial layout drawing, with all the major items placed, and to start a detailed weight budget, where the individual weight and position will give a running check on CG height and position fore and aft, plus polar moments on the three axes. As we go along we can adjust to the required design spec and keep a running tally of how much is available for the rest of the design, more detailed than the gross calcs done right at the beginning of the process.

The new Vee design was actually driven by the analysis of the legacy car. Having dumped the front trailing link beam and the rear swing axle, this gave a 38kg bonus to be used elsewhere. This was the determining factor on the chassis design concept. The 38kg bonus ended up being used in a plated spaceframe that gave the best cost/stiffness/safety/ease of maintenance compromise.

Why a spaceframe? The projected $10,000 cost for a full running car ready-to-go with a full carbon honeycomb monocoque meant this was ruled out. Cost research also showed that the alternatives – aluminium honeycomb and aluminium sheet monocoques – would have a high labour cost to produce, and increased maintenance and crash repair cost, too.

But spaceframes are a well-known technology, so the drive was to improve on the driver cell safety and anti-intrusion capabilities, the weak spots on this type of design. The bonus weight from the ditched front and rear axles on the legacy car was thus used to plate the spaceframe around the driver, creating a survival cell. At this point the choice was between bonded and riveted aluminium panels or a steel sheet, welded onto the frame. Again, knowing the weight available, a steel double skin would ease manufacture and maintenance, with no degradation of the bonds and rivets as you could have on the ally sheeted version.

Tube choice

The design was to have square tubing, of a uniform size throughout, to reduce the number of different tubes and gauges that had to be ordered, as most direct suppliers will have a minimum quantity order. Square tubing is also easier to fit on the intersection nodes.

By this stage of the project, detail design was advanced enough that the bill of materials could specify individual tubes to be produced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The simplified jigs also reduce the overall cost of the project

and supplied by outside non-specialist suppliers, the drawing specifying lengths and angles for ease of assembly and minimal adjustment on final assembly. Any metalworking company can make these. Murphy always being present with his law, before bulk supplies were ordered a prototype chassis was built to avoid the 'small issue' problem when, say, you are receiving 100 of any particular part, and they don't fit.

The ease of construction and maintenance brief had already defined the material to be used, it being SAE 1020 steel for both the tubes and sheeting. As it is easily welded, it avoids any heat induced brittleness or annealing issues.

Due to the shape of the outer envelope, some tubes were changed to round section tubing for ease of fitting of the plated sheets, apart from the roll hoop, already defined by universal regulations as a given section and thickness. The main bulkheads were of rectangular section, and perpendicular to the chassis base, making for easier manufacture and jigging. Unless you are pressed by dimensional constraints and other competitors' products – not the case here – the simplified jigs also reduce the overall cost of the project.

The chassis went through 16 iterations to reduce complexity, weight, and to ease manufacture. FEA analysis was used to improve stiffness and cockpit safety at every step.

Meanwhile, some ancillaries, like the steering box and gear linkages, were run on the legacy cars at the race track to try and validate the design before mass production.

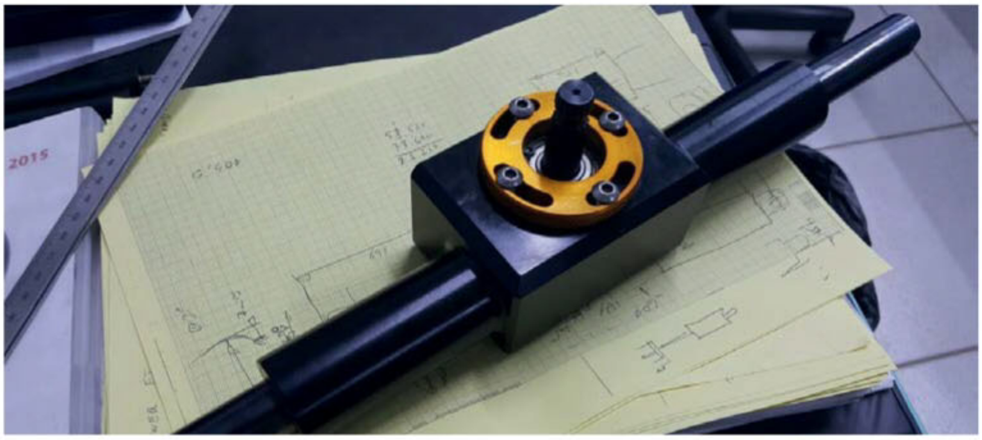
The cost analysis also brought up another consideration. Where the legacy car had bespoke intake and exhaust manifolds, by fitting the original production car's manifolds a cost reduction of 20 per cent of the custom units was found, with the unexpected bonus of improving the power band at the cost of slightly more difficult packaging. So, re-examine all the items, the sum of all percentage increments obtained can bring performance at a reduced cost.

Look at small items, too, like reducing the alternator pulley diameter which will make it turn at lower RPM and sap less power at full throttle – the production pulley ratio being designed to cater for idling, and ancillaries like windscreen wipers, lights, electric windows and air conditioning which are not used on a single seater, while the engine works mostly at the top end of the RPM range anyway.

Rear subframe

Even though the powerplant characteristics were known from the original car, the design also had to cater for the possibility of using other units, while the current mounting and access was also quite labour intensive. This automatically brought in the concept of having a chassis with a separate rear subframe, mounted on the roll hoop bulkhead.

This being the major section of the chassis it was quite easy to maintain axle-to-axle



The new steering rack was tested on the older FVee cars at the race circuit to validate the design, as was the gear linkage

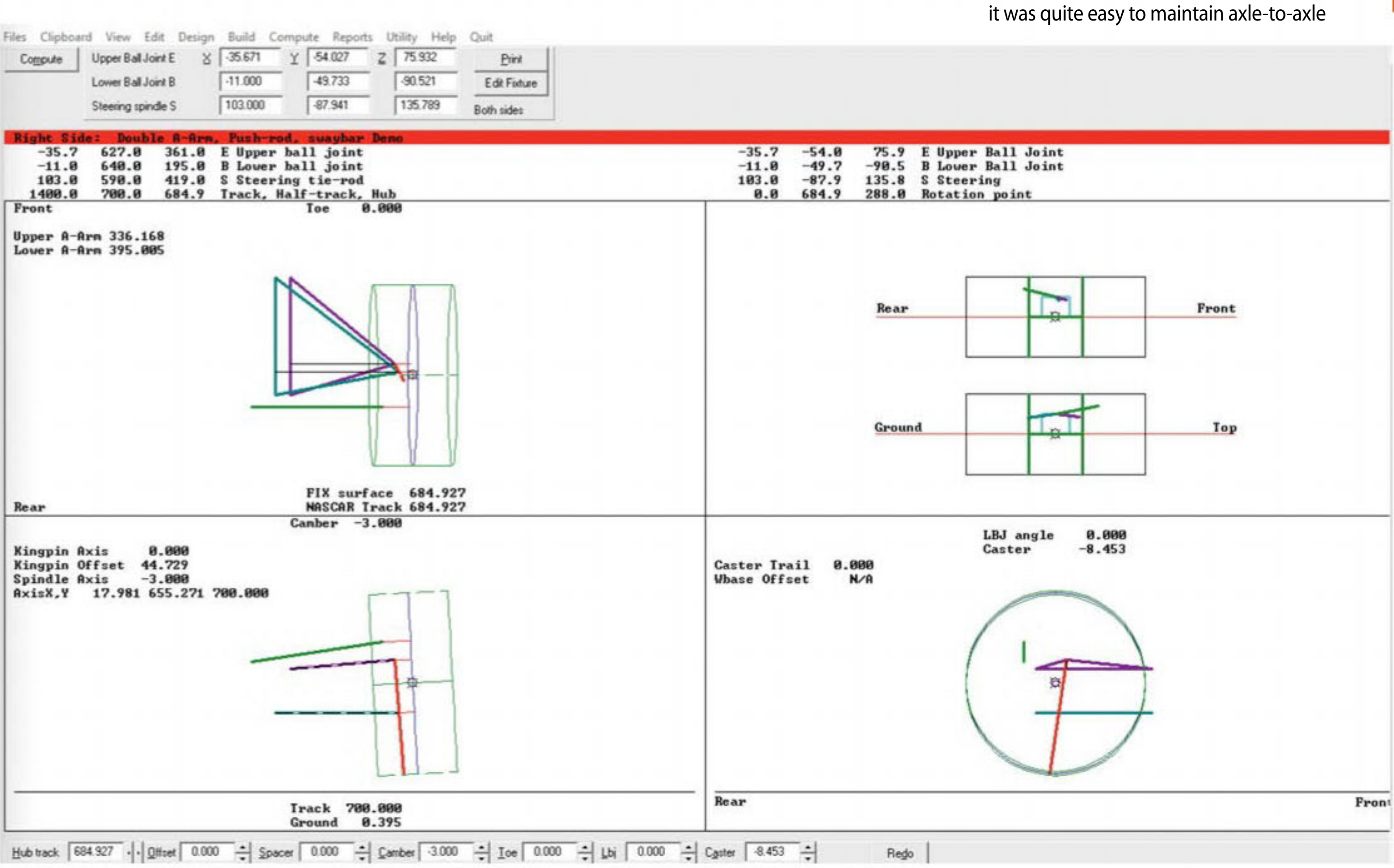


Figure 3: The analysis confirmed that the best suspension option was to use double unequal length wishbones at both the front and the rear, the ubiquitous layout for modern racecars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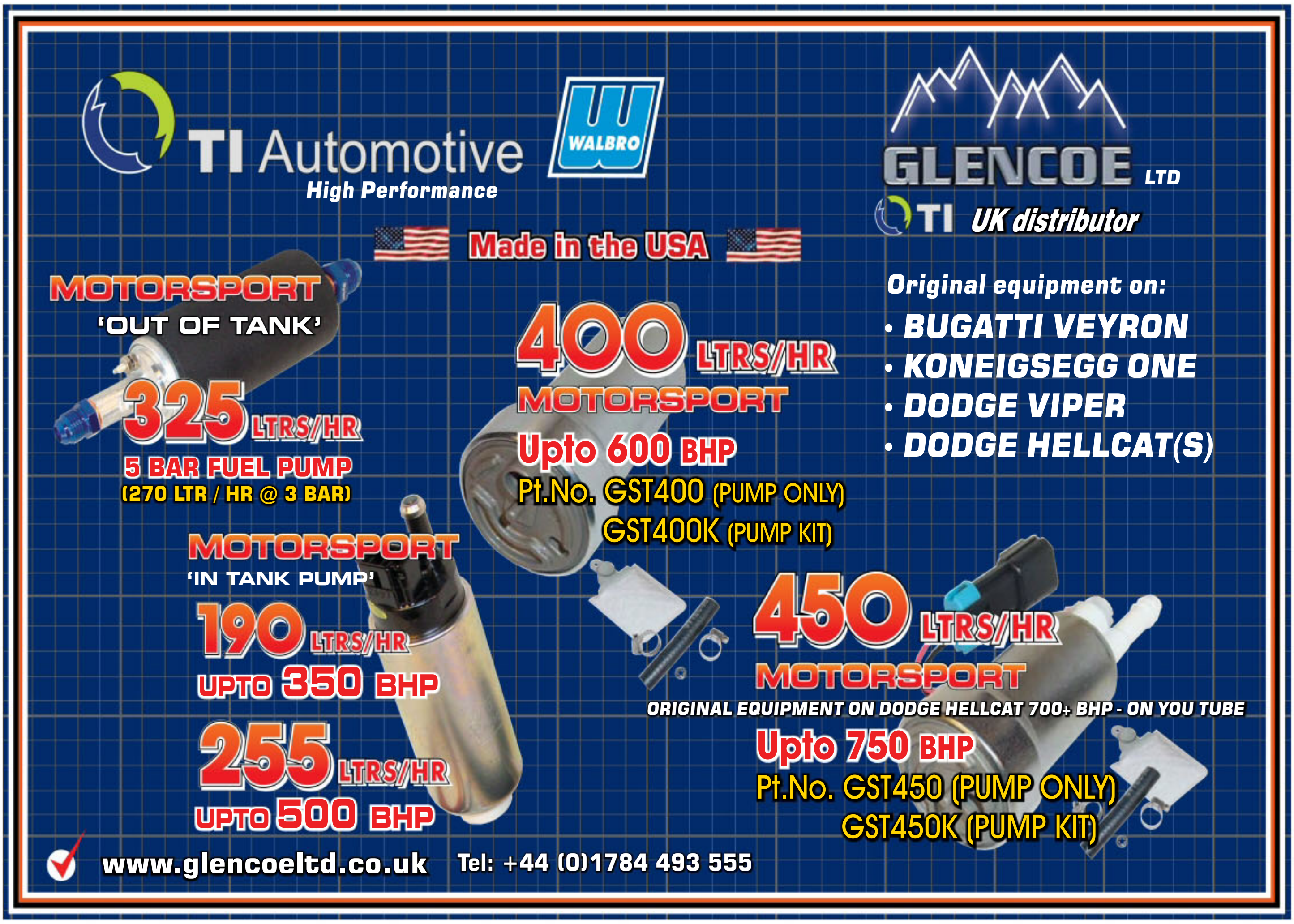
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calculated stiffness, despite expected losses in any bolted items. In the design analysis stage, once we have the rough chassis dimensions and layout, we can then start examining the front and rear suspension geometries.

Suspension design

The FVee, with very little aero except the relevant ducting for the engine intakes, radiators and a modicum of brake cooling, reverts to the classic suspension stiffness of 90Hz for non aero cars running on relatively soft tyre stiffness, and the subsequent high angles of roll, pitch and heave bring the need for a better and more forgiving geometry. There are an infinite amount of geometry programs available commercially for this work, and most design engineers of a certain age will have developed their own programs, the advent of Excel making it even easier to run through all the variables.

The obvious choice for suspension was to use double unequal length wishbones at the front and rear, the now ubiquitous suspension in all racecars, which gives the best compromise in all conditions. For this project, given we were working with a group of young engineering students, mostly Formula SAE competitors at their university, we settled on an old classic they were all familiar with, the late William Mitchell's 'Racing by the numbers' (**Figure 3**).

As with all phases of design, this will involve iteration for your best compromise, and when you have achieved this, you then need to go back to the chassis layout and change your structure to better take the loads.

As this was a completely new design – apart from the dimensions of production parts in the suspension, such as hubs, driveshafts and CVs that is – placing the dampers, rockers and anti-roll bars explored several layouts, particularly on the rear suspension, until the best compromise in characteristics, stiffness and strength of pickups was achieved.

A good example of the iterations feeding back into the chassis design was the need to tilt the engine five degrees (side view) to enable a lower centre of gravity and to lift the output flange of the gearbox, reducing the driveshaft angularity and plunge on the CVs.

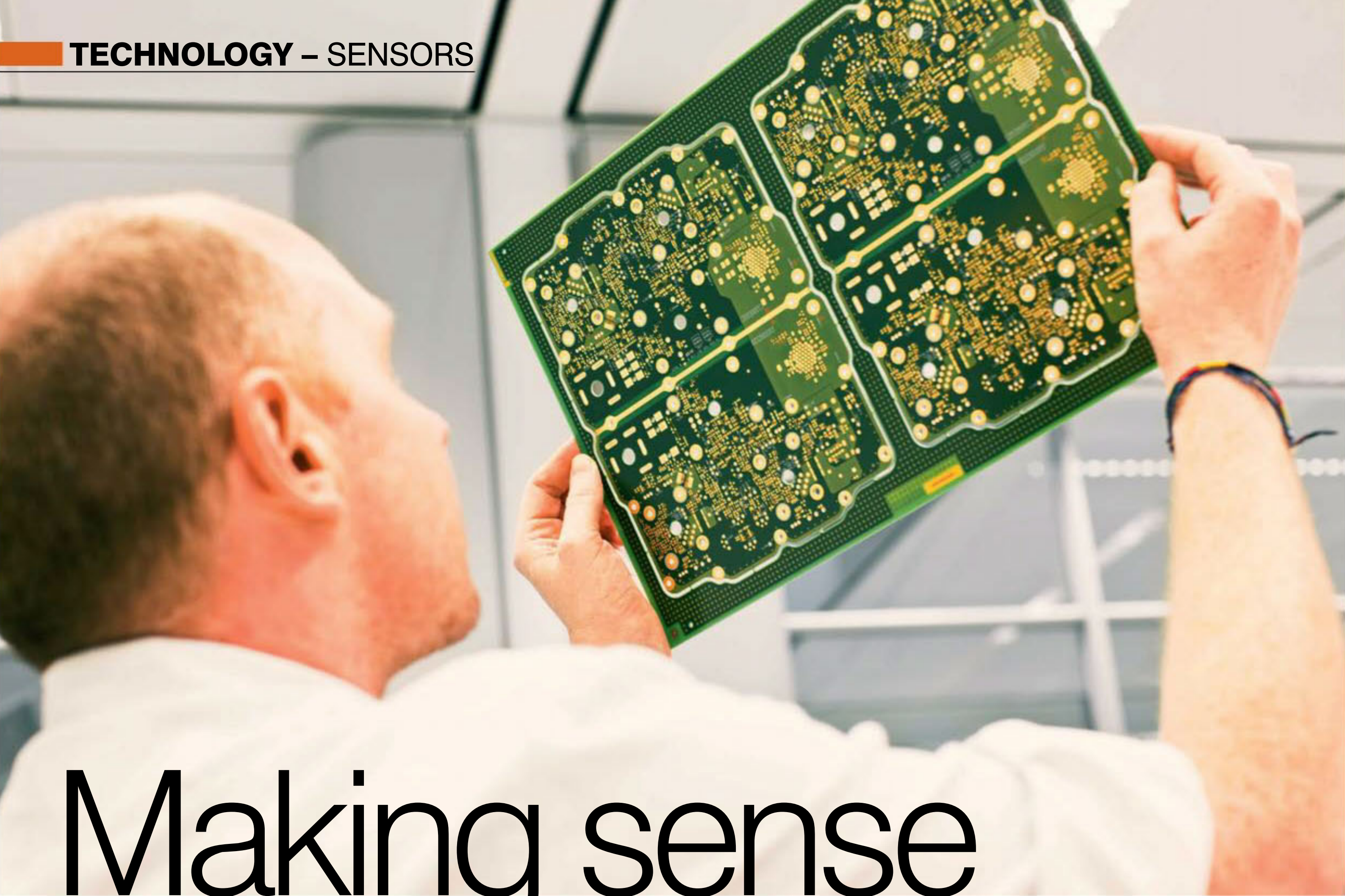
Knowing that the maximum lateral and longitudinal grip available on the belted road tyres would be around 0.9*g*, the Excel tables will give us the transfer and relevant vertical, lateral and longitudinal loads on each corner.

Having the baseline forces and transfers allows you to see what spring rates and rollbar sizes are required, the rocker ratios you need, and from that the dimension of your dampers, providing fully open and closed measurements. If you have a fixed damper you want to use, as is the case in this project, iterating rocker ratios brings you into the range required, allowing extra travel so you will not be going metal to metal either in the dampers or springs.

As you have already calculated the springs required at this point, playing with the range of springs you could use and repeating the calculations, you can now check if you have enough adjustment on the platforms and pushrods for a stiffer or a softer spring.

Throughout the process it's always necessary to reiterate, going back through the calculations and layouts until satisfied. Then do it again doing check-sums on everything. Are you inside your weight budget? Is your C of G where you want it? Are all your balljoints clear to move through the range? Can the components be accessed for assembly and maintenance? Have safety critical components been stress checked?

Now you are ready to start freezing your main components and you can begin detailing individual parts and, as you have your major dimensions and hard points, start defining the body shape to prepare your body buck for the moulds. The initial sketches and renderings of your idealised racecar are then blended in with the mechanical components, maybe requiring some subtle mechanical changes to arrive at the final product.



Making sense of sensors

With over 250 sensors on an F1 car these devices are clearly both diverse in design and vital – but how has this technology developed and what is its future?

By GEMMA HATTON

The racecars of today are without doubt data hungry. Each F1 car has over 250 sensors, logging approximately 1000 channels, which equates to a total of 30GB of data during a race weekend. Whenever the ignition is on, live telemetry is sent from the racecar to the pits at 5MB/sec, which is then distributed to the team's engineers both at the track and at mission control, with the necessary channels also transmitted to suppliers. In the course of a one-and-a-half hour grand prix, a total of 10TB (1024GB) of data flows through this system, making a Formula 1 race the biggest science project on the planet during that time.

The biggest challenge for any sensor or connector on a racecar is being able to endure the harsh temperatures, vibrations and *g*-force levels whilst achieving accurate measurements. 'When we introduced our Autosport range of connectors, we ensured that they met the requirements of the military specification as well as the brutal 38999 test,' explains Paul Webb, who is the Global Products manager at Deutsch Autosport Connectors.

'The ultimate challenge of 38999 is the gunfire test,' Webb adds. 'This is where the connector is subjected to the same vibration and heat levels that it would experience on a jet engine as a gun fires. Yet, a few years later, the connectors that survived this test would get completely destroyed on the powertrain of a Formula 1 car. We did a test years ago to try and establish the magnitude of these energy levels and within a lap the connectors would fail because they were experiencing over 1000*g*.'

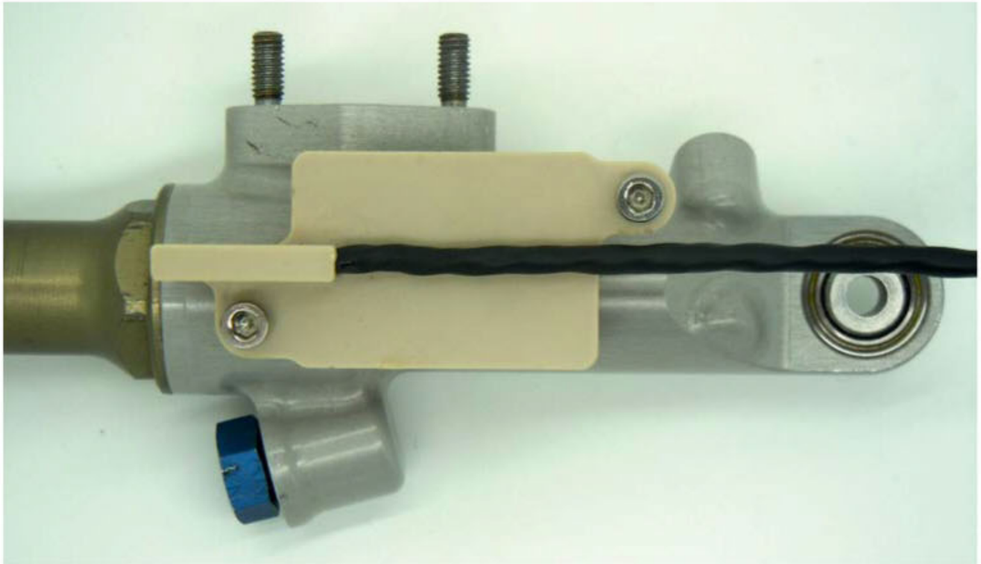
When subjected to vibration, a component can reach its own internal harmonic, and at particular frequencies the amplitude can triple and end up destroying itself. Often the solution is to adjust the location of the connector or sensor to a more benign area where those extremely high energy levels don't exist. Of course, with the design of the car continually evolving throughout the season, these areas of high energy also continue to change, requiring a trial and error approach.

'Unfortunately, there is no big book of vibration where you can look up the location on a racecar and see if your connector will survive those energy levels,' Webb says. 'Even the most experienced teams have to use trial and error because there is no other way around it.'

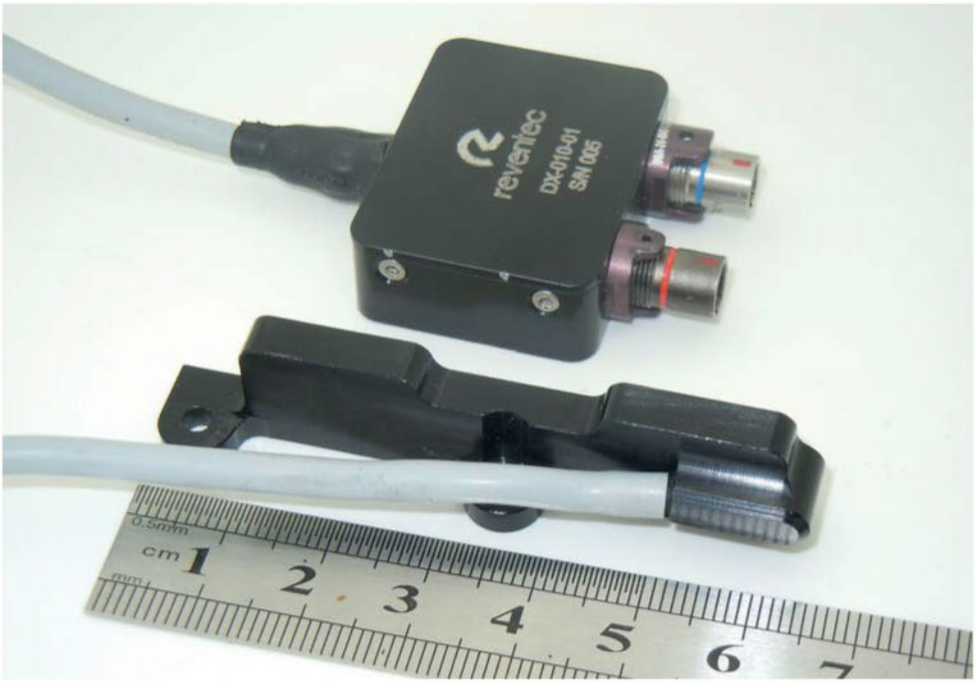
Tyre sensors

Managing tyre temperatures can be the driver's biggest weapon to gain performance; whether it's during a qualifying lap or in the race, but it's critical that the tyres are monitored not only continuously, but accurately as well. To this end

The TPMS sensor is located on the rim where the tyre bead seats. These not only measure tyre pressure but now also include IR elements to measure the temperature of the tyre carcass



An example of a TMR position sensor fitted to a master cylinder in a braking system. This measures the stroke of the piston



Another example of a TMR sensor. This particular device uses remote electronics and is employed on hydraulic actuators

The key is developing the technology to be rugged enough to survive motorsport, but yet small and lightweight

each wheel has a battery powered TPMS (Tyre Pressure Monitoring System) sensor mounted on the rim where the tyre bead sits. The pressure is measured via a transducer and each sensor uses ultra high frequency (UHF) to transmit this data to the transceiver fitted to that specific corner of the car. This transceiver then decodes the data and outputs it to the car's ECU via CAN communication.

'Originally, tyre pressures were the only parameter TPMS measured, but over the years we have also introduced infra-red (IR) elements into these pressure sensors as well,' says Bob McDonald, head of High Performance Products at McLaren Applied Technologies. 'Situated inside the rim, looking outwards on the inside of the tyre, the five-point IR array measures the temperature of the tyre carcass.'

But the only way to gain an accurate understanding of the tyre's behaviour is to determine the temperature within the bulk of the tyre. The problem is, this is an impossible parameter to measure without physically inserting a sensor into the structure of the tyre, which of course has all manner of safety and connectivity issues. Therefore, the strategy is to measure the temperature of the carcass using TPMS, whilst measuring the temperature of the surface using IR sensors, and then develop complex models to try and determine the bulk temperature.

Sensor sensibility

IR sensors measure the temperature of an object by sensing the emitted thermal radiation from a distance. By using arrays rather than single point IR sensors, up to 64 pixels can be measured with a 16 x 4 array, giving a much more accurate representation of temperature distribution. 'An array allows you to see across the whole of the tyre but that is still a coarse measurement, which is why most teams now use thermal cameras because it offers better resolution,' McDonald says. 'These devices break down an image into a series of pixels, and assigns a value of temperature in degC relating to the colour of that pixel on the IR spectrum. This results in a script of tyre data which can then be transmitted back to the pits in real time because trying to send the entire tyre image over telemetry is virtually impossible.

'However, the tyre image is also logged and can be viewed later when the data is offloaded,' McDonald adds. 'There is also complex image manipulation software which allows the mapping of this script even when the tyre is turned. It is very rare that engineers are looking at a nice colour image of the tyre, they're simply using the technology of a thermal camera to measure the temperature.'

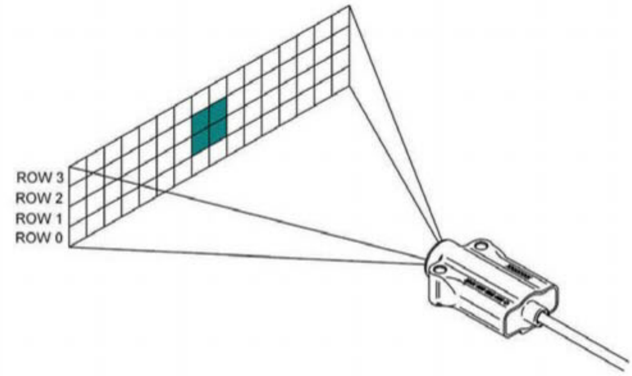


Diagram shows how an IR sensor with a 16 x 4 array has 64 measurement points giving a much more accurate representation of temperature distribution. IR sensors pictured above

Pitot tubes are more visible than most sensors. They are usually mounted on the nose of the racecar and they measure the airflow

If motorsport really is at the forefront of technology, why are we not seeing much data transferred wirelessly?

Brake and clutch sensors

Infra red (IR) sensors are not just used for monitoring tyre temperatures. This technology can also be used to measure the temperature of brakes and clutches, as Texys has proved with its new sensor.

These temperatures are much higher than those found on tyre surfaces, which is why Texys has continued to develop its PCB technology. This, together with specialised high temperature components allows this sensor to cope with temperatures up to 200degC. 'As temperatures within an F1 car increase year by year, we needed to find a solution to minimise failures due to heat soak,' explains Jason Mowle, UK business manager at Texys. 'By developing a sensor to deal with these high temperatures it also reduces the need to use complex air ducting to cool the sensors, which in turn reduces cost for our customers.'

The inner workings of a McLaren Applied Technologies ECU

To improve the resolution of the carcass temperature measurement, however, is a lot more difficult because there is no way a thermal camera would be able to survive the harsh temperatures, vibrations and *g* force levels experienced at the rim. This is why teams have been investing in their tyre modelling departments and simulation tools, because an accurate model is currently the only way to conclude the bulk temperature, at least for now.

Brake by wire

Another area where sensors are vital is in the brake by wire. As explored in the last issue (V27 N11) Formula 1 brake by wire systems utilise two master cylinders; one conventional master cylinder to operate the front brakes and one that operates the rear brakes and is electronically controlled to aid the energy recovery for the MGU-K system. But how do you measure the stroke of a piston within a housing?

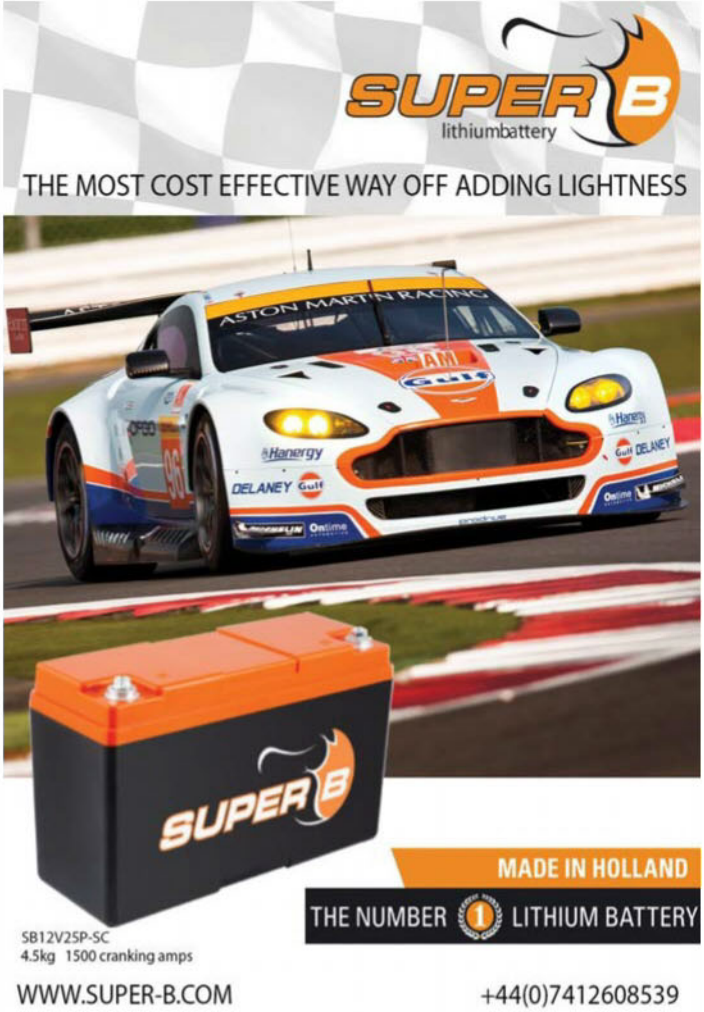
Traditionally, it would have been measured with a series of linear potentiometers attached to the outside of the actuator via brackets. However, by using solid state technology, Reventec can offer a much more reliable and durable solution that can better withstand the harsh environments of a racecar. 'We've further developed our magneto resistive measurement technology, where a small magnet is integrated into the piston itself and the receiver measures the change in flux field as the piston reciprocates,' says Neville Meech, director of Reventec. 'This is done by measuring the change in the flux field angles using sines and cosines and translating them to a linear change in physical position. This technology differs to a Hall effect measurement which is focused on the flux field *strength* of the magnet, whereas we measure the flux field angular *change*.'

One of the main benefits of this technology is that only a small magnet is required for accurate measurement, often providing greater flexibility for the designer. Also, because Reventec is measuring the flux field change, measurements can be achieved with distances of up to 40mm between the magnet and the receiver in some applications which would be near impossible with a Hall effect device. To measure longer strokes of up to one metre, Reventec has developed a multi-headed version of the technology, which essentially uses a 'string' of receivers, and this will be launched at this year's PMW show in Cologne.

Pressure sensors

Every engine will include a wide variety of pressure transducers to continuously monitor the air intake, coolant, oil, fuel and injection pressures. Essentially, these devices work by pressure deforming an elastic material, and this deformation is detected, measured and converted into an electronic signal. In motorsport, there are predominantly two ways to generate this electrical signal. Firstly, there is the resistive type, which uses strain gauges attached to the elastic material. Any deformation will change the resistance of each strain gauge which can then be measured by a Wheatstone bridge. There is also the capacitive type, which uses two capacitive plates, where one is attached to the elastic material, and the other to the unpressurised surface. Any differences in pressure changes the capacitance between these two plates.

'For our pressure transducers, that cover the whole spectrum of motorsport, we have taken the fundamental technology and tuned it for motorsport and can now offer three different variants,' says Peter Trevor, technical director at KA Sensors. 'The lowest cost is our ceramic technology, which covers approximately 75 per cent of our applications. Here, we use a ceramic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Pressure transducers essentially use an elastic material to deform under an applied pressure. This deformation is measured and converted into an electric signal

diaphragm, where the ceramic surface is in contact with the pressure media and on the back is a capacitive or resistive sensing element. We then have thin-film technology which uses a stainless steel diaphragm with a strain gauge embedded inside. Finally, our most accurate solution uses a silicon sensing element together with a stainless steel diaphragm.'

As with most sensors, the key is developing the technology to be rugged enough to survive but yet small and lightweight, particularly as pressure transducers have to accurately measure pressures anywhere between a vacuum (1bar below ambient) and 600bar.

Future trends

The continued push for road relevance in motorsport is resulting in smaller, more efficient and often turbocharged engines, which is increasing the temperatures and pressures that racecar components have to withstand. 'There is definitely a tendency to move towards higher temperature electronics,' explains Simon Peaty, product manager at Gill Sensors and Controls. 'One of the limiting factors of any microprocessor-driven sensor is the microprocessor itself. Traditionally that was because the materials used were only suitable up to 125degC. Now we are starting to see companies release microprocessors that can withstand temperatures of 150degC, which will in turn allow us to develop sensors that can also survive these temperatures. There are other elements that are restricted to 125degC, but I think in the future we will see 150degC become the standard temperature for sensors.'

3D printing

Meanwhile, the potential capabilities of 3D printed parts will unquestionably revolutionise manufacturing, not just for motorsport, but in the wider world as well. Being able to print complex shapes with internal features that you otherwise couldn't achieve with traditional machining techniques, completely changes the way products are designed – manufacturing will no longer restrict designers.

'Metal printing and the increasing availability of new materials is rapidly changing the opportunities for companies such as ours that are often requested to offer bespoke solutions in limited time,' Meech says. 'Our liquid level sensors have been traditionally produced from aluminium and titanium materials using many conventional methods, but with the current advances in printed technology, we now produce several specialist designs utilising key printed components offering significant weight and assembly time savings. Having successfully developed a unique contoured liquid level sensor several years ago, we are now combining this technology with the latest print capabilities to further enhance performance and reliability as well as benefit from weight saving.'

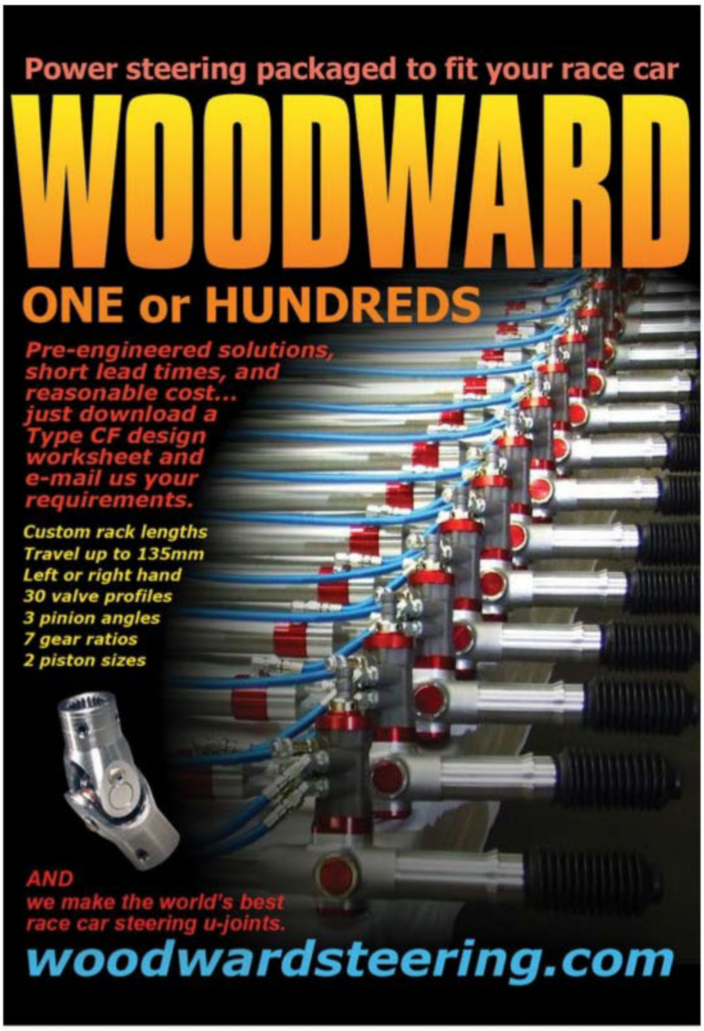
The potential of 3D printing is not just limited to sensors, but connectors as well. 'Nobody seems to buy products straight out of the catalogue anymore,' Webb says. 'Because they always want to customise the part to their specific requirements. 3D printing will give us the capability to manufacture the complex shapes that teams can use in those benign areas to minimise the impact of vibration, although the accuracy isn't quite as good as moulding, so current printed parts require a secondary operation to reach the desired tolerances.

'One alternative would be to machine the inserts and print the rubber seals that go on the front and back of the connector as these don't require such high tolerances,' Webb adds. 'Either way, I don't think it's going to be long before we have the capability to print these customised designs alongside our standard range.'

Going wireless

An impressive 71 per cent of all worldwide mobile communications flow over wireless internet, making Wi-Fi the biggest transmitter of communication around the world. So if motorsport is at the forefront of technology, why are we not seeing much data transferred wirelessly? The main issue is the high level of signals and interference in and around the racecars, garages and circuits. There is also redundancy to consider; Formula 1 teams already invest in several sensors to measure the same thing to guarantee they capture the necessary data. Therefore, before wireless sensors become an alternative, the technology will have to prove it is bulletproof. Otherwise the back up sensors will need to be wired in as normal, contradicting the weight and packaging

Pressure transducers have to accurately measure pressures anywhere between a vacuum, which is 1bar below ambient, and 600bar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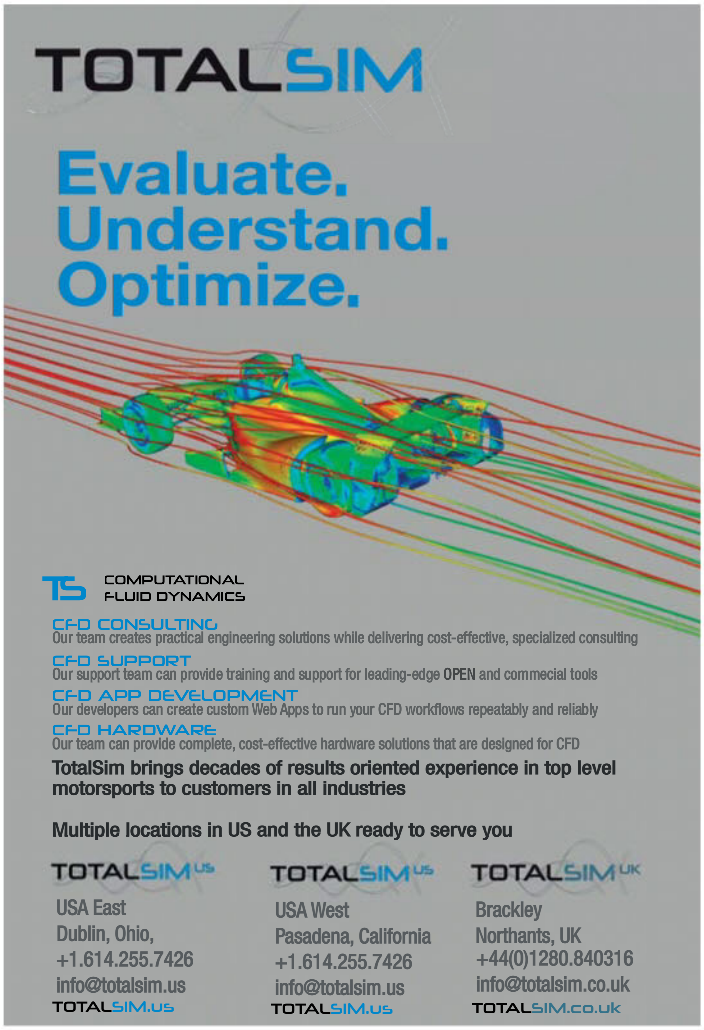
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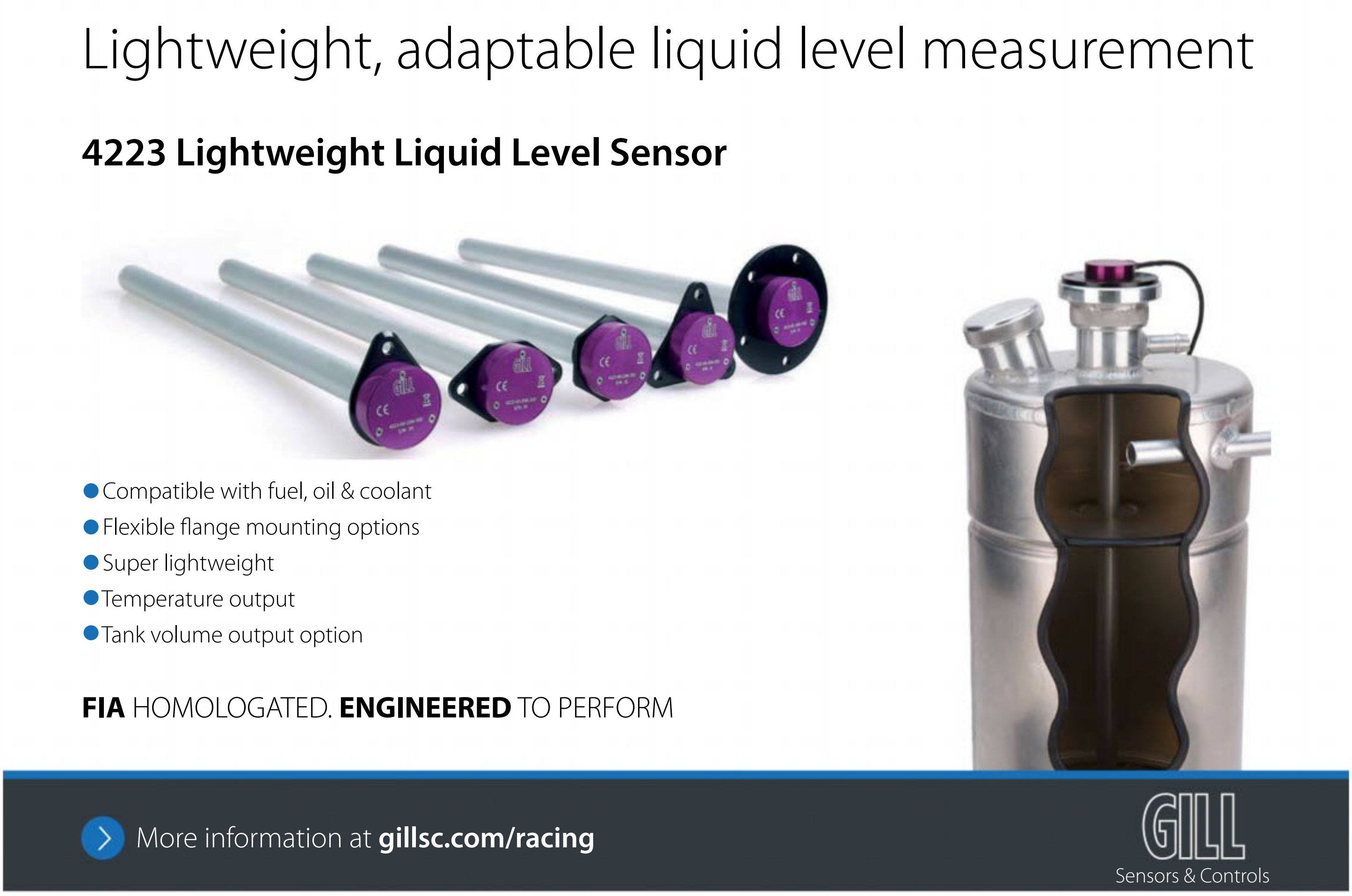
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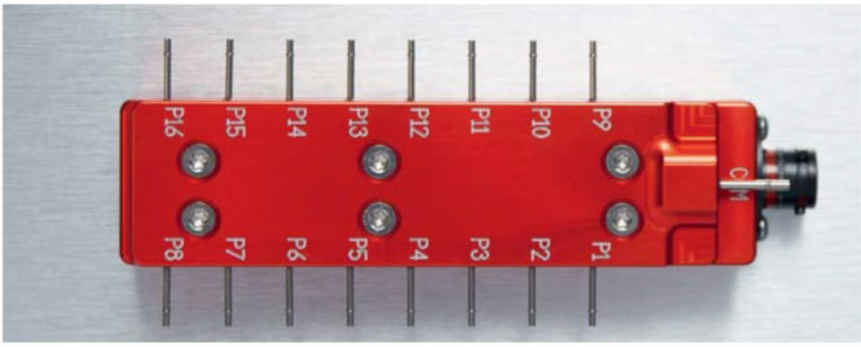
‘One of the limiting factors of any microprocessor driven sensor is the microprocessor itself’

advantages the wireless technology was trying to achieve in the first place. There have been examples of teams using Bluetooth and there are now RFID tags for tracking tyres, but as yet there has been no success with wireless sensing.

‘One of the biggest challenges with wireless sensors will be developing a reliable protocol to allow the communication signals through radio,’ McDonald says. ‘Usually the chips available for similar protocols have been designed for your phone, which obviously won’t work in the high temperatures and vibrations of a Formula 1 car. The engineers may also have to be economical with the data transfer as there will be a limited bandwidth, but that’s similar to what they do now. Although a sensor is measuring two parameters it usually has the capability to measure others, it’s just those are not as important. Wireless technology is something we are looking into because we feel that this will definitely be a future requirement on some level.’

An example of an eight-channel aerodynamic wireless 8xPDIFF-WS sensor (back) together with the high temp INF-V4 sensor (front) from Texys. Wireless tech looks set to be the next big thing in the world of sensors



Wireless sensor with 16 channels. These work in synergy with custom designed tri-band auto-tuning systems

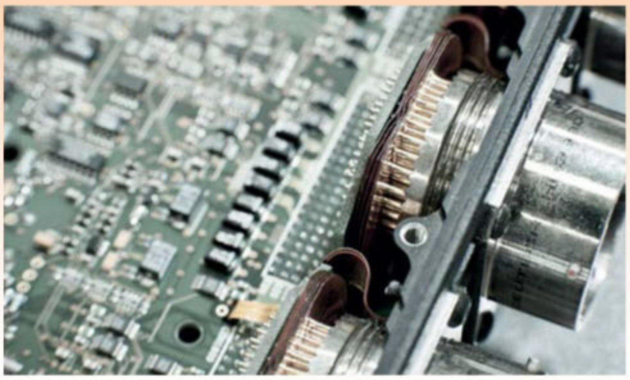
Sensors unplugged

But as it turns out, that wireless future may not be as far away as we think. Texys has already integrated wireless capabilities into a range of its sensors including IR array sensors for tyre temperature as well as multi-channel differential pressure sensors and thermocouple conditioners. ‘A typical wireless installation could see two eight-channel tyre temperature sensors and two eight-channel PDIFF sensors, all paired to the same receiver,’ says Jason Mowle, its UK business manager. ‘To ensure compatibility, all these sensors work in synergy with a custom designed tri-band auto-tuning wireless system. Also, all our wireless CAN sensors are configurable with an Android app, making them easier for engineers to use.’

Another innovation that could revolutionise the sensor industry is using energy harvesting to power sensors. ‘We are currently seeing many examples of how energy can be recuperated, converted and reused on a Formula 1 car,’ McDonald says. ‘Heat and vibration are sources of energy and are in abundance on a racecar, but the trick is to determine how to reliably harvest that energy in a small enough size and a robust enough design of sensor.’

Splice of life

Paul Webb, of Deutsch Autosport Connectors, says: ‘As racecars continue to increase in complexity, data really is everything. The amount of data captured every time a car fires up is increasing exponentially, which means teams need more sensors and connectors with more capability.’ This is why connectors have had to increase the density of the contacts, within the same small available space.



A bird’s-eye view of an arrangement of connectors. Note the high density of contacts within such a compact space; these days most house 118 contacts

Currently, the maximum used in motorsport is the size 18 shell, which houses 118 contacts. Although it is possible to increase this number of contacts to over 200 with a size 24 shell, the resulting bundle of wires which then have to be twisted around the corners within a racecar makes this simply impractical. It is much easier to manage several smaller bunches of wires instead.

Another consideration is that of being able to physically wire a sensor with over 200 contacts in, because the limited space would not only make it an intricately frustrating task, but there would be no space for the markings which could then lead to incorrect wiring and a whole host of other issues.

Advances in material science could result in shifting connector materials away from traditional aviation grade aluminiums to more plastic and composite technologies. ‘There are some clever chemistries and techniques now where during the formation of plastics, the molecules can be arranged in a particular way to improve durability. Material scientists can even incorporate air bubbles into the structure to save weight,’ says Webb. ‘These modern plastics are currently used in Aerospace and UAV applications, but these don’t suffer from the same harsh environments as a racecar so they are not as good as aluminium yet.’

Super models

Racecar's resident number cruncher explains how tyre models work and why, despite their limitations, they can be trusted

By DANNY NOWLAN

Recently I was at the SCCA run-offs in Indianapolis and I was chatting to a colleague of mine who has not yet embrace simulation. His reluctance can be summed up with one key question: can he trust a tyre model? As he put it: 'I know what the dampers and springs are, and within reason I know what the aero does. However, I only know about one per cent of what effects 99 per cent of the racecar, which is the tyres.'

This is a legitimate question, and it's fair to concede that we in the racecar vehicle dynamics community have done a bad job of explaining what you get out of a tyre model and that you can actually trust what it is telling you. This is what we'll be discussing at length in this article.

Figure 1: Tyre model visualisation

A 2D representation of traction circle radius *vs* load

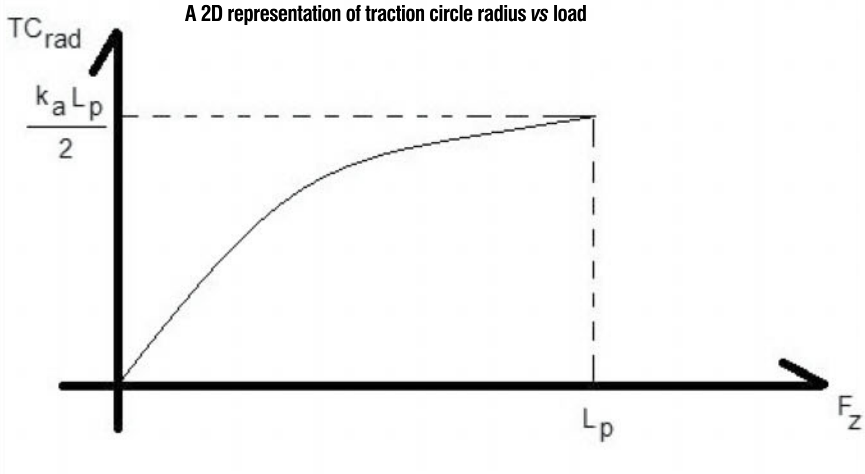


Figure 2: Normalised Lateral force *vs* slip angle

S angle	0.00	0.70	1.40	2.10	2.80	3.50	4.20	4.90	5.60	6.30	7.00	7.70	8.40	9.10	9.80
FFact	0.00	0.15	0.30	0.44	0.57	0.69	0.79	0.88	0.94	0.99	1.00	0.98	0.94	0.85	0.73

The second component is the lateral/longitudinal force *vs* slip angle/slip ratio, which is used with the traction circle radius

Let me make a couple of things about tyre models, and what you need to keep in mind, clear from the outset. Firstly, there is an attitude just simmering below the surface in this business that any sort of vehicle modelling, and tyre modelling in particular, is useless. This is aided and abetted by the technophobia that resides in motorsport. I can tell you right now this attitude is complete nonsense and if it had any sort of validity ChassisSim, my own company, would have ceased to exist years ago. That said, it's true that there is no such thing as the perfect tyre model. Anyone who claims they have the perfect model needs to be jailed for the good of the sport! When reviewing a tyre model you need to be mindful of where it comes from, and the assumptions behind it. This way you can use the model to maximum effect.

First things first, let's develop a simple 2D tyre model that quantifies traction circle radius *vs* load and lateral/longitudinal forces *vs* slip angle/ratio which will get you a significant way down the road. The basic building block of a 2D tyre model is the second order traction circle radius *vs* load equation. Mathematically this can be expressed as shown in **Equation 1**. With this, a tyre can be approximated with **Figure 1**.

Also, if you get this right, you can be forgiven for a multitude of sins later on. However get this wrong, then to paraphrase Mr Miyagi from *The Karate Kid*: Traction circle radius good, racecar model good. Traction circle radius bad, you'd better pack up and go home.

The first thing that stands out with this model is where the peak tyre load is that generates the maximum lateral grip. The peak load, *Lp*, can be expressed by **Equation 2**.

Fully loaded

What all of the above means in plain English is that the maximum force of any tyre can be expressed as a peak load with a peak force of half the initial co-efficient of friction multiplied by the peak load. This, in and of itself, is a most interesting metric. Let's say you have a peak load on the racecar of 800kgf. If the peak tyre load is 1100kgf this has just told you you need to run the racecar soft. Conversely, if the peak tyre load is in the order of 2000kgf it's just told you you need to run stiff spring rates.

Equations

EQUATION 1

$$TC_{RAD} = k_a(1 - k_b \cdot F_z) \cdot F_z$$

Here we have,

TC_{RAD} = Traction circle radius of the tyre (N)

k_a = Initial coefficient of friction

k_b = Normalised friction coefficient with load (1/N)

F_z = Normal load

EQUATION 2

$$L_P = \frac{1}{2 \cdot k_b}$$

EQUATION 3

$$C_f = \frac{\partial C_f}{\partial \alpha_f}\bigg|_{\alpha=\alpha_f} \cdot (F_{m1} + F_{m2})$$

$$C_r = \frac{\partial C_r}{\partial \alpha_r}\bigg|_{\alpha=\alpha_r} \cdot (F_{m3} + F_{m4})$$

$$C_T = C_f + C_r$$

$$stbi \approx \frac{a \cdot C_f - b \cdot C_r}{C_T \cdot wb}$$

Here we have,

$dCF/da(\alpha_f)$ = Slope of Normalised slip angle function for the front tyre

$dCR/da(\alpha_r)$ = Slope of Normalised slip angle function for the rear tyre

$Fm(L_1)$ = Traction circle radius for the left front (N)

$Fm(L_2)$ = Traction circle radius for the right front (N)

$Fm(L_3)$ = Traction circle radius for the left rear (N)

$Fm(L_4)$ = Traction circle radius for the right rear (N)

a = Distance of front axle to the centre of gravity (m)

b = Distance of rear axle to the c of g

wb = wheelbase (m)

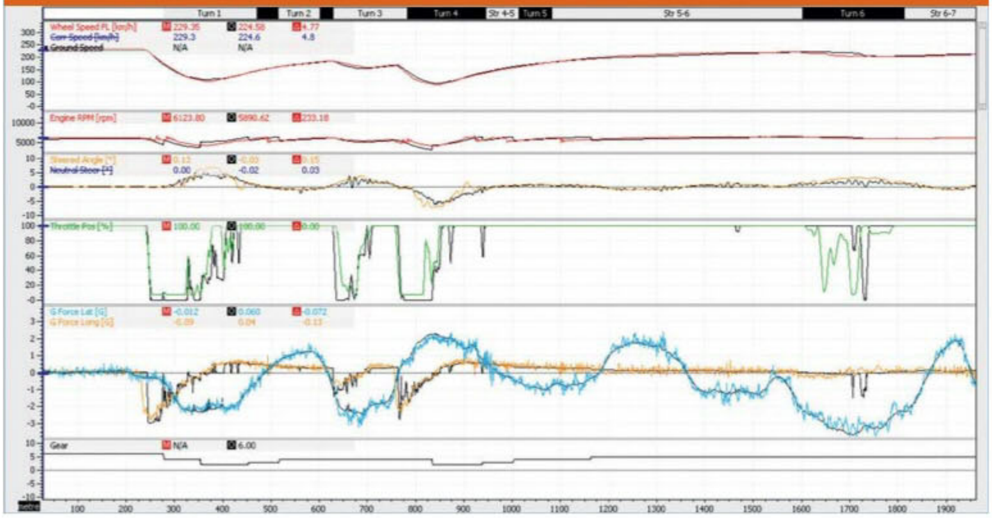
C_f = Slope of front axle force (N/rad)

C_r = Slope of rear axle force (N/rad)

C_T = Slope of total side force (N/rad)

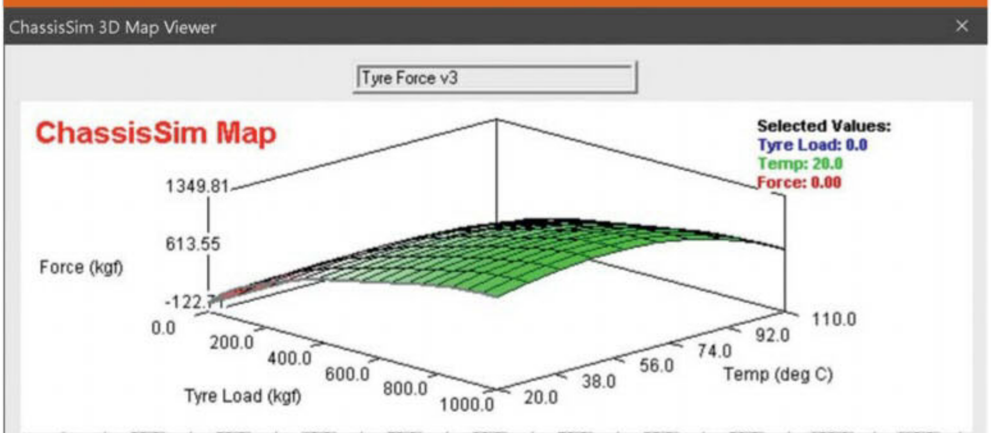
stbi = stability index

Figure 3: ChassisSim correlation using a 2D tyre model



When you use the 2D tyre model this way you can employ your actual data to fill in the blanks of what the tyres are doing

Figure 4: 3D temperature model



	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0
0.0	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52.6	149.03	160.01	167.86	172.56	174.13	171.00	161.58	145.89	123.93	95.69
105.3	271.85	291.88	306.19	314.77	317.64	311.91	294.74	266.12	226.06	174.54
157.9	373.28	400.79	420.44	432.23	436.16	428.30	404.72	365.42	310.40	239.67
210.5	457.65	491.38	515.47	529.92	534.74	525.11	496.20	448.02	380.57	293.84
263.2	528.78	567.75	595.58	612.28	617.85	606.72	573.31	517.65	439.71	339.51
315.8	589.96	633.43	664.49	683.12	689.33	676.91	639.64	577.54	490.58	378.79
368.4	643.97	691.43	725.32	745.66	752.44	738.88	698.21	630.41	535.50	413.47
421.1	693.10	744.17	780.66	802.55	809.84	795.25	751.47	678.50	576.35	445.01
473.7	739.10	793.57	832.47	855.81	863.60	848.03	801.35	723.54	614.61	474.55
526.3	783.23	840.95	882.18	906.91	915.16	898.67	849.20	766.74	651.30	502.88
578.9	826.23	887.12	930.61	956.70	965.40	948.01	895.82	808.83	687.06	530.49
631.6	868.33	932.31	978.02	1005.45	1014.59	996.30	941.46	850.04	722.06	557.52
684.2	909.23	976.24	1024.10	1052.81	1062.38	1043.24	985.81	890.09	756.08	583.78
736.8	948.16	1018.03	1067.94	1097.88	1107.86	1087.90	1028.01	928.19	788.45	608.78
789.5	983.79	1056.29	1108.07	1139.14	1149.50	1128.79	1066.65	963.08	818.08	631.66
842.1	1014.31	1089.06	1142.45	1174.49	1185.17	1163.81	1099.74	992.96	843.46	651.25
894.7	1037.40	1113.85	1168.45	1201.22	1212.14	1190.30	1124.77	1015.56	862.66	666.08
947.4	1050.20	1127.59	1182.87	1216.04	1227.10	1204.99	1138.65	1028.09	873.31	674.30
1000.0	1049.37	1126.70	1181.93	1215.08	1226.12	1204.03	1137.75	1027.27	872.61	673.76

OK | Cancel | Axes Properties/Calculator | Export text/Aero File | Import text file

Once the loading condition of the tyre changes this will effect the temperature. This highlights a limitation of the 2D tyre model

The second component of a 2D tyre model is the lateral/longitudinal force *vs* slip angle/slip ratio. This is illustrated in **Figure 2**.

Once you have this, if you combine it with the traction circle radius from **Equation 1** you can start to determine the baseline stability of the vehicle. To refresh everyone's memory this is presented in **Equation 3**

The great news here is that $Fm(L_1)$ through to $Fm(L_4)$ is given by **Equation 1**.

This doesn't give you the full story, but if gives you more than enough to form the basis of good correlation. This is illustrated in **Figure 3**.

The great thing is that simulation packages like ChassisSim can help you fill in these details. When you use the simulation this way you are using your actual data to fill in the blanks of what the tyres are really doing.

What this tyre model does well is it give you a rough idea of what a set-up will do within a +/- 10 per cent margin of the base set-up. You can use it to see where you are with stability and it will give you a good idea of where the grip is. Also, if you are running aero or running over bumps, because the performance is equivalent it will provide appropriate direction for springs, dampers, bump rubbers and ride heights.

However ,this tyre model will struggle in two key areas, both to do with the fact we haven't taken into account tyre temperature.

It is certainly true that there is no such thing as a perfect tyre model

The first is when you have to make fine set-up changes. Here a 2D tyre model is blind. The second area is where you make huge changes in set-up, like setting the rear springs from 70N/mm to 10N/mm. This leads to big changes in the core temperature of the tyre, which in turn impacts on the traction circle radius. To deal with the issues of set-up sensitivity we need to incorporate surface temperature in the traction circle *vs* load characteristic.

The above is illustrated in **Figure 4**. As can be seen, once the loading condition of the tyre changes, this will effect the temperature and as also can be seen the tyre force and grip will be effected. However, if you think this small change will generate a 0.5s lap time differential, then you are doomed to disappointment.

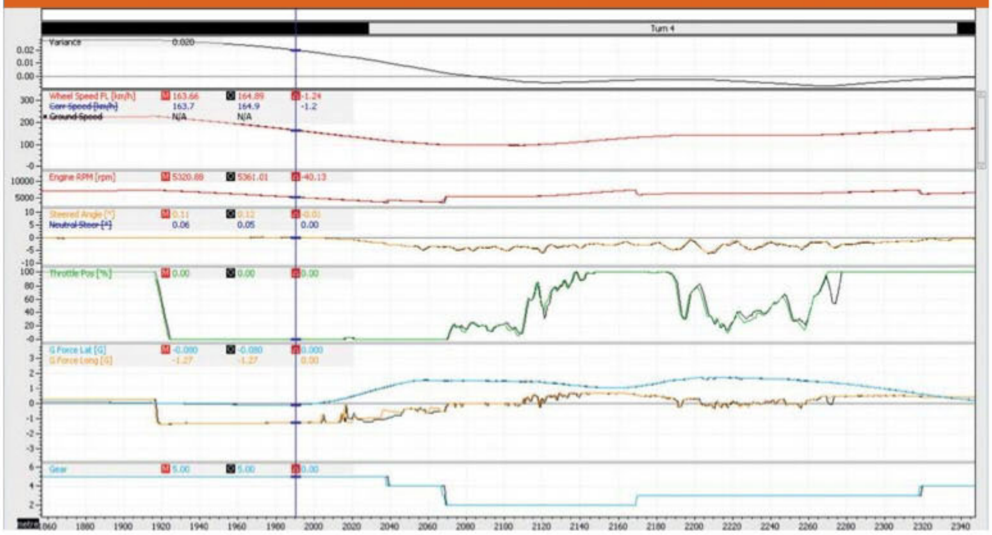
Table 1: Tyre model sensitivity; 2D *vs* 3D tyre model

	2D tyre model		3D tyre model	
Set-up	Std	RRC + 10mm	Std	RRC + 10mm
Turn 1 min spd	153.49km/h	153.34km/h	155.37km/h	155.22km/h
Turn 2 min spd	149.53km/h	149.07km/h	149.1km/h	148.6km/h
Turn 3 min spd	83.85km/h	83.56km/h	84.4km/h	84.1km/h
Turn 4 min spd	97.18km/h	97.4km/h	97.9km/h	97.5km/h
Turn 5 min spd	92.14km/h	91.79km/h	92.05km/h	91.87km/h
Final lap time	67.61s	67.67s	67.69s	67.69s

Figure 5: Compare time plot for the 2D model case

Coloured trace is the baseline and the black shows the roll centre change. Note how consistent the compare time plot is here

Figure 6: Compare time plot for a 3D tyre model



The extra detail is clear to see here. Note the near 1km/h differential on turn in and the 0.03s variation in the compare time

A tyre surface temperature model on its own won't cover huge changes in set-up. We need to take into account core tyre temperatures

2D or not 2D?

To illustrate the above point let's run a 2D and 3D tyre model back to back. Here we will be focussing on a V8 Supercar run at Queensland Raceway in Australia. This is based on an old live axle car and we are raising the rear roll centre by 10mm. The results are shown in **Table 1**.

This is a most interesting spread of results. The 2D tyre model showed, in general, a reduction of corner speed and a loss in lap time. The 3D tyre model consistently dropped corner speed but the lap time was the same. On the surface looking at the numbers you would say the sensitivity is the same. I should also add to the Australian readers reading this that I set the grip factors high to accentuate the effects. Hence the optimistic lap time.

But where the sensitivity shows is in the compare time plots. The compare time plot for the 2D case is illustrated in **Figure 5**.

Coloured is the baseline and the black is the rear roll centre change. Note the compare time plot and how consistent it is. Also note the lack of change of speed. The compare time plot for the 3D showed much more local variation. To illustrate this point we will zoom in on a particular section. This is shown in **Figure 6.**

Again, here coloured is the baseline and the black is the 10mm rear roll centre change. Note the near 1km/h differential on turn in. Also, note the 0.03s variation in compare time. For such a small change there is simply no way a 2D tyre model can replicate this.

Sensitive side

The other thing that this shows is while a 3D surface model will help in terms of local sensitivity there is simply no way a small change will get you a 1s lap time differential. In this particular case this car's rear roll sensitivity was actually in the pocket of the baseline to the plus 10mm rear roll centre location we simulated. Also, the load variation is simply not enough to generate the required temperature differentials. Keep this in mind with your modelling.

However, a tyre surface temperature model on its own won't cover huge changes in set-up. What we need to do here is to take into account the core tyre temperatures.

An excellent case in point is the Michelin TaMe tyre model. A quick introduction to the tyre model is shown in **Figure 7**. The Michelin TaMe tyre model was born out of the French tyre firm's involvement in both LMP1 and F1 in the early to mid 2000s. The correlation speaks for itself and is shown in **Figure 8**. When it comes to tyre models the TaMe is the gold standard.

One of the spin-offs of a core temperature tyre model is that you can use track replay to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predict tyre temperature and pressures. The tyre model in ChassisSim is equipped with this capability and an example of this very useful output is shown in **Figure 9**.

It goes without saying a feature like this has significant pay-offs and this was employed by my Australian Dealer Pat Cahill when he engineered the Maranello Motorsport F458 entry to victory in the Bathurst 12 hours in 2014.

Warm-up algorithm

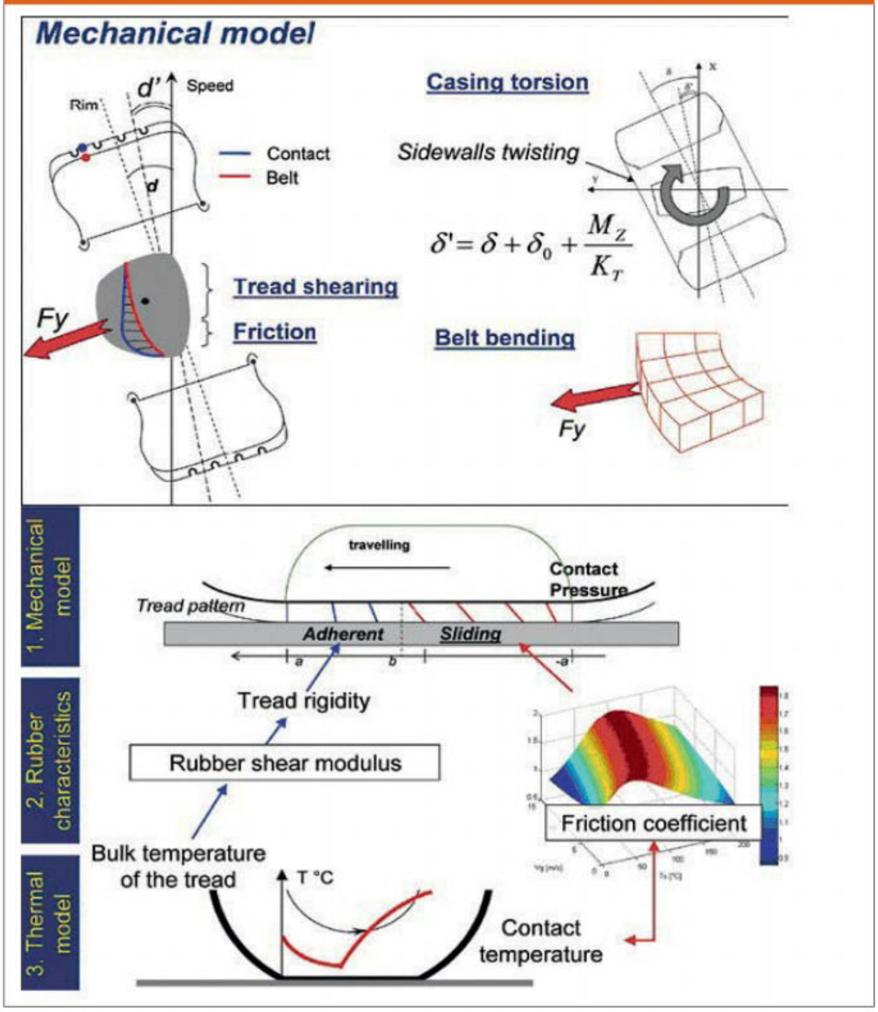
However, a word of warning when using a core tyre temperature model in a lap time simulation package. You will live or die by the warm-up algorithm. If you get this right then you will have the ability to do all sorts of crazy sensitivity studies such as seeing what a 10N/mm spring will do on a 1500kg car. However, if you get it wrong the simulator can well and truly lead you up the garden path. In this situation if you can't trust the warm-up algorithm it's a much safer bet to stick with either a 2D tyre model or a surface 3D tyre model, since the cornering algorithms are much simpler.

Tooled up

In closing, it can be confidentially stated that tyre models are not only valid tools, but they also offer the engineer a great insight in to what the car is doing. However, the key is understanding the animal you are dealing with, and its limitations. A simple 2D model will provide a good representation of the performance of the car. Provided you stay within a certain margin of the base set-up you can use it to investigate other set-ups and car stability characteristics. The thermal tyre models will help you nail down car sensitivities and gross changes in set-up. In short, once you understand what a tyre model is, and what it tells you, it will be a tool that you cannot do without.

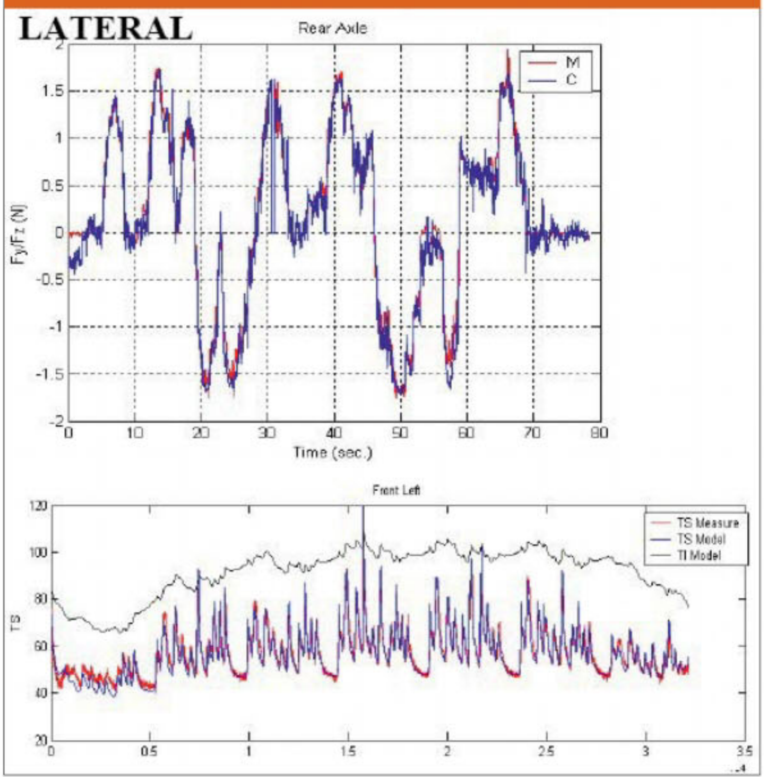
If you do get the warm-up algorithm wrong the simulator can lead you up the garden path

Figure 7: Michelin TaMe tyre model



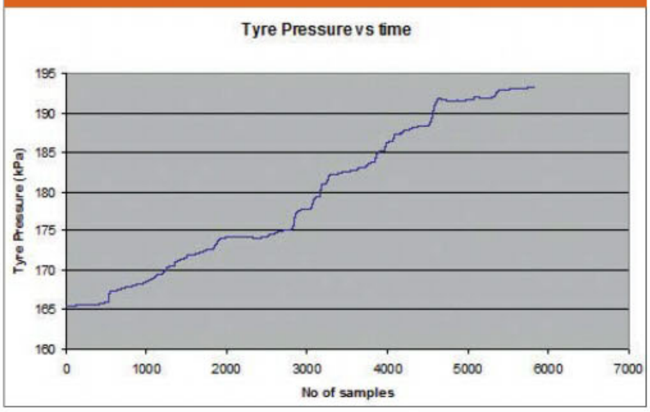
TaMe tyre model is designed to reflect the actual driving conditions by taking speed and tyre temp into account

Figure 8: TaMe correlation

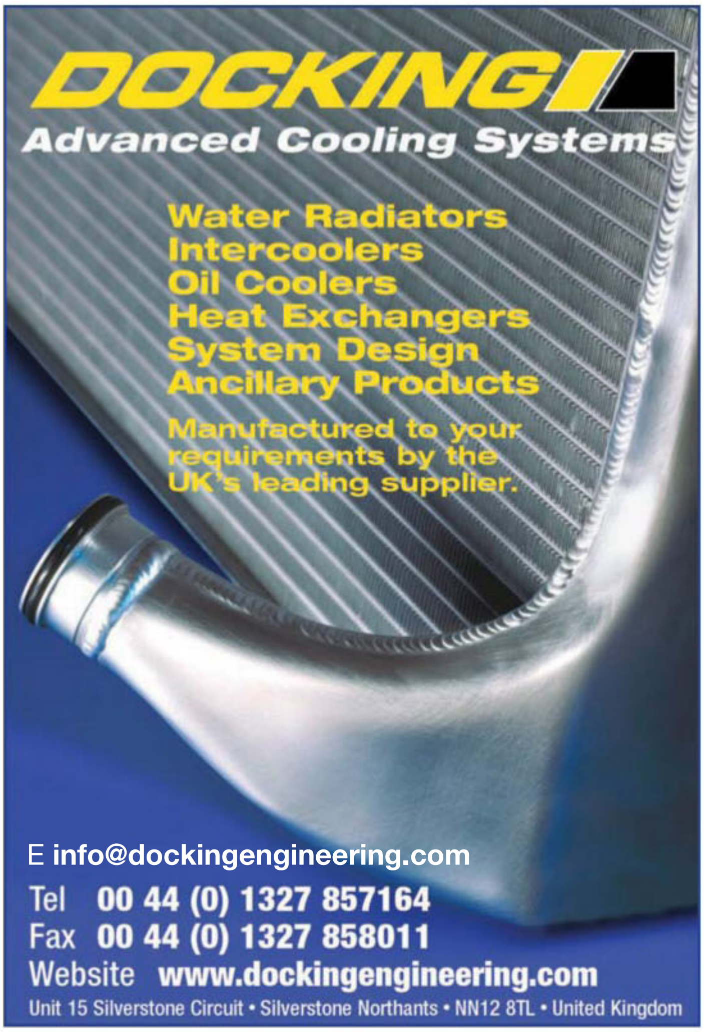


Correlation of Michelin's TaMe model is hugely impressive. Our man says it's the 'gold standard'

Figure 9: Pressure *vs* distance



The ChassiSim tyre model can use track replay to predict tyre temp and pressures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Tactical advance

To win in top-level endurance racing you need the strategic acumen of Napoleon Bonaparte – or failing that some state of the art timing and strategy software …

By PAUL TRUSWELL

If you want to know what's really happening in a WEC race then you need to keep your eyes on the screens

Keeping track of what is going on during a long-distance race has been a problem that has exercised the intellects of racing teams since the dawn of motorsport. In the '50s, the task consisted primarily of instructing the drivers to go either as fast as possible or to a pre-defined pace that the team manager had calculated would be enough to go further than the competition, without putting unnecessary strain on the mechanical parts.

Very often, in those days, no-one on the team would know the positions of the competitors' cars, except by intuition, and even the race officials would sometimes take several hours after the chequered flag to unravel the lap chart and produce a definitive result.

In these days of flat-out endurance racing, things are rather different, both in terms of what is demanded by live TV coverage, and the facilities available. It all changed when competing cars began to be fitted with electronic transponders in the 1980s, which would identify them to the timekeepers automatically, and remove the need for manual calculation of lap times and hand-written lap charts of the race positions.

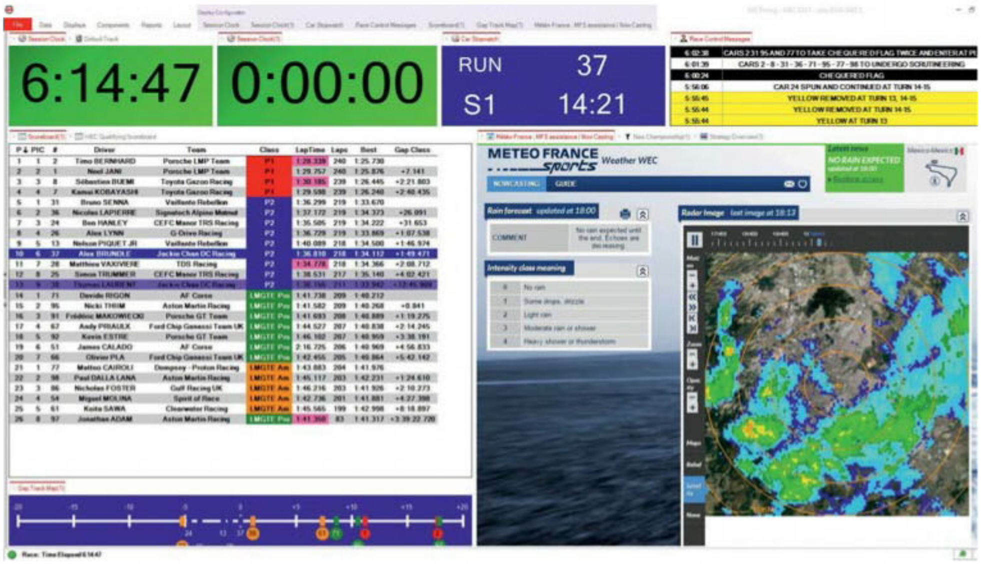
Timekeepers were now able to publish real-time positions on display screens; in race control, in pit garages and commentary boxes. Suddenly, it would take only seconds after a car crossed the finish line before the lap time was displayed and any change of position relayed to the world. This was soon extended and additional sectors were defined around the circuit, providing additional information.

The limitation, in those days, was that teams could only see the information that the timing screens displayed. Obviously, race positions were important, but the choice of which columns to show – laps completed, last lap time, gap to leader, interval to car in front, best lap time, class position, total time elapsed – was left to the individual timekeeping organisations, and was largely arbitrary.

Still today, official timing screens operate to no universal standard, and although all show the race positions, they provide varied information depending on the series organisation. Because of this many teams developed their own systems of spreadsheets and run sheets, which had to be manually populated with data showing the lap time for each lap, the evolving gap between cars, countdown to next pit stop, and so on.

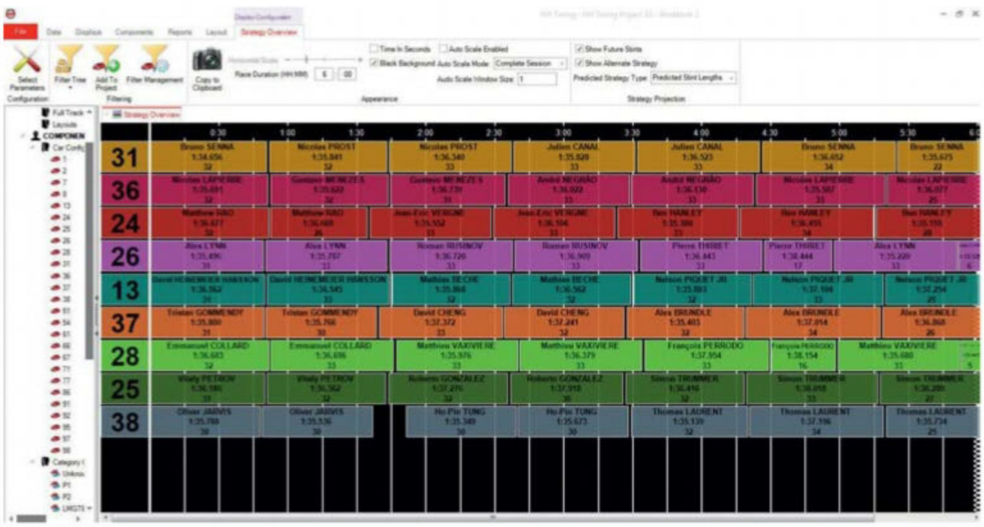
But the availability of a data stream from timekeeping systems in the last few years has

It all changed when racecars began to be fitted with transponders



The amount of data available to race strategists is mind-blowing; the race running order and lap times are just the start of it

Monitoring the gaps to rivals is crucial. All the data is fed from the official WEC timing system so is presented in real-time



Strategy overview shows each stint driven as a block diagram with the number of laps, driver's name and average lap time

Another useful feature is the visualisation of the gaps between all the cars in the class

led to the development of bespoke software which can provide teams with a much more configurable system. One such system is HH Timing, created by Canadian Andrew Hall, of HH Development. 'The initial impetus came in around 2011,' says Hall. 'I wanted to follow the races in more detail, to have some tools for analysis, not only after the race, but during it as well. All of a sudden, I realised that we had a system that provided more information to the teams than most of them had already. After that, we had to learn how to be a bit commercial.'

Good timing

HH Timing was incorporated in May 2014, and its system was being used by eight teams in the LMP2 class at Le Mans this year, as well as by most of the GTE class. Also in their list of customers at Le Mans was the ACO itself.

Jota Sport team manager Gary Holland is a big fan of the system: 'HH Timing is a very powerful tool indeed, providing all the information that we need to make strategic decisions during a race – even Le Mans,' he says.

Jonathan Lynn is the performance engineer at Jota: 'We started using HH Timing at the beginning of the 2016 season when I joined,' he says. 'It is an absolutely critical part of our set-up during the race. It is relatively easy to use, and gives us specific information for our own racecar, as well as a good overview of what the competition is doing: when they have their silver driver in the car, what fuel strategy they are running is, and so on.'

Data feed

The system takes its feed from the official Al Kamel timing system. It's hooked directly into its network, ensuring that data gets stored each time a car crosses any of the timing loops: whether that is at the start-finish, the intermediate sectors or pit in/out. 'We also get the race control messages, so we can match that against the position of the car on the circuit and decide whether it is advantageous to stop when, for example, a full course caution is implemented,' Lynn says.

There are a multitude of different displays available to choose from. Jota runs a nine-screen display, two of which are dedicated to HH layouts. The main display is the 'scoreboard', which shows the race positions, but which can be configured (as Jota does) to only show a single class, and also to show whatever columns a team specifies. In addition to standard columns like last lap time, gap to leader, car in front and behind, sector times, this can also include average of best 10 per cent of laps, worst lap in last 10, laps to next stop, etc.

'It's also important to us to be able to look at all the lap times, sector times and pit stop times for our own car,' explains Lynn. 'We have a separate run sheet, which I use to maintain data from the car's telemetry, such as the fuel and tyre information, but if I miss

'With the strategy overview we can see whether the opposition still have to use their Silver driver, and when they're likely to make their next stop'

a lap, then it doesn't really matter too much because it is all recorded in HH.'

Another key window in HH is the 'strategy overview'. This shows each stint driven as a block diagram, with the number of laps, driver's name and average lap time for the stint (excluding any FCY laps). As with all the modules, the screen is configurable to show just cars from a specific class, and best lap can be shown instead of average lap (useful during practice and qualifying, for example).

'The strategy overview is really useful for us to see what the opposition is up to,' Lynn says. 'We can see whether they still have to use their Silver driver, and when they are likely to make their next pit stop.' This screen can also be configured to show predicted stint lengths, which combined with a calculation of predicted pit stop time, enables the number of stints remaining for each car to be shown.

Drive time

Other screens show lap times for each driver, and driving time, showing not only whether minimum drive time for the silver driver has been achieved, but also if the maximum continuous driving time has been exceeded. Another useful feature used by Jota is the visualisation of the gaps between all the cars in the class, plotted as a graph, lap-by-lap, as the race evolves. 'I tend to have that window open all the time, to see not only our position, but whether we're gaining or losing time overall, relative to the rest of the LMP2 class,' says Lynn.

A problem that sometimes occurs for LMP2 cars, is to know how many laps the race will be in total. Since a normal six-hour WEC event (as well as the 24 hours of Le Mans) ends when the leading car crosses the line after the completion of the allotted time, it may be that a car in one of the slower classes has to complete an extra lap. For example, if the LMP2 crosses the line 30s after the allotted time, and the overall leader goes across the line 60s later, then the LMP2 car will only receive the chequered flag when it crosses the line for the second time. 'HH has a live Excel export function,' Lynn says, 'which we use to export the LMP1 times to a special spreadsheet which we use to work out which P1 car will likely win, and when it will cross the line to start the last lap. We don't usually run the fuel that close, but it is useful to know, just in case.'

The HH system was used by eight LMP2 teams at Le Mans and it helped the Jackie Chan DC ORECA finish second overall

Jota runs a nine-screen layout, two of which are dedicated to HH data. Much of this race data is also studied after the event

Post-race analysis

However, the use of the software doesn't end with the finish of the race. 'After the race, we use all the data in the HH system to analyse the race for our post-race review,' Lynn says. 'We will get together and decide what the turning points of the race were and then look at the data in detail to work out where we lost out, or where we gained an advantage.'

The HH system has a whole suite of standard reports that can be generated after the race, showing the data in graphical or tabular form, and enabling teams to look at everything from driver performance in each sector, to pit stop times for fuel only, or full service stops.

Andrew Hall, who is also involved in the development of the software, says: 'With the limitations on the number of tyres available in the WEC now, it is important to teams to know how much of an impact tyre degradation has, and so the reports in HH can be easily configured to look at 20 per cent, 40 per cent or 60 per cent average best lap times. Our thinking has always been to make HH work just how each of our clients might want it to.'

HH Timing has clients not only in the WEC and ELMS, but also in the IMSA WeatherTech sportscar Championship, the Blancpain GT Series, as well as the VLN and Creventic 24h Series races for GT and Touring Cars, for which interfaces to different timing services are required. 'Because of the architecture of the system, HH has the same look and feel to the user whatever series a team is using it in. We see this as a big advantage,' says Hall.

Interview – Dieter Gass

Gass and electric

Audi's head of motorsport explains why Formula E is now the place to be for the German manufacturer

By ANDREW COTTON

XPB

'Formula E shows electric mobility can be fast and can be emotional, and is an interesting thing to do'

The WEC was shaken to its core at the end of 2016 with the news that Audi, so long a stalwart of endurance racing, had decided to withdraw from LMP1. Coming just a year after the dieselgate scandal that rocked the Volkswagen Group, a shift from racing a diesel to what was perceived as a more green option was perhaps inevitable, and so it was no great surprise that at the same time the firm also said it intended to focus on Formula E in the future.

Audi's works FE programme has now been launched; in late September with Audi Sport ABT Schaeffler unveiling the Audi e-tron FE04. The man tasked with making sure the venture is successful is Dieter Gass, who took over from Wolfgang Ullrich as Audi's head of motorsport at the end of 2016. Gass first worked for Audi Sport in 1994, mainly in touring cars, before a spell in F1. He returned to Audi in 2012, as head of racing commitments, before taking over the firm's DTM effort.

Plugging in

For Gass, the reason Audi went to Formula E is clear. 'If you look around, you see that the world on the roads is going electric, everyone is pushing for that for obvious reasons. I see that there is some reluctance to move towards electric mobility from the people and one of the reasons for that is an image question,' he says. 'If you think about what electric mobility means for people, it is probably sterile, no emotion, slow, and Formula E does give us the opportunity to show that all of that is not necessarily true. It can be fast, it can be emotional and it is an interesting thing to do.'

The 'obvious reasons' mentioned above is emissions. Yet while reducing these could well be cited as a good reason to do FE, Audi's former WEC rival Porsche – which has also now dumped WEC for FE – has said that for a real reduction in emissions the biggest change actually needs to be in the internal combustion engine, to make it more efficient.

'Obviously, because you cannot think that from tomorrow all cars will be electric,' Gass concedes. 'So in order to achieve the emission targets you will need to make sure that the traditional engines get reduced emissions.'

And yet both Audi and Porsche have stopped their hybrid programmes? 'In competition, yes, but not on the road,' Gass says. 'If you look at the WEC – I was not head of motorsport at the time but I was involved – and as an engineer the WEC was one of the most exciting things that you can do in terms of the freedom of development. At the same time, this is one of the big downsides of it, because the costs are going very high, and if you go racing you look at return on investment, there the relationship was not healthy.

'The WEC is something different because of the freedom of development,' Gass adds. 'So you could argue that we could have continued the development there, but it's just the problem with the amount of money that you have to put into it. And [to] develop the engine that does not have the same targets … You talk efficiency but not emissions when you go to Le Mans, so it is not the same. And I think the transfer between motorsport and road cars has somewhat changed over the years. In the past, when there were new inventions brought to the race track [they] then managed to get into road cars, but it is not the same anymore.'

But does that mean motorsport is now an irrelevance when it comes to road car development? 'No, but the input is different … You learn things that you can transfer, but you don't have these new inventions that someone in the race team invents and you bring it to the road cars,' Gass says.

Eclectic electric

Audi is not the only manufacturer that's been attracted to Formula E, with Jaguar already there, as is Renault and others following, but Gass does like to think it was at least a trend setter, certainly for German car makers. 'We are happy that they are there, and many manufacturers are involved, but we are not there because those others are involved. We committed early on, and the others followed.'

Of course, when manufacturers get involved in any series it usually causes budget inflation. So is Gass worried that the arrival of companies like Audi and Porsche, plus BMW and Mercedes, will send costs through the roof?

'I trust [Formula E] to control that,' Gass says. 'If you open up everything then costs will run quickly out of control but I don't see battery development being released [freed up]. We will have the spec battery again, from Season 5 to 7 at least.' Yet it might be argued that battery development is,

or perhaps should be, the raison d'etre of Formula E? 'Who develops their own battery?' Gass asks. 'If you are going to do cell development, I don't think that this is the core competence of many car manufacturers. [But] if it comes to battery development in terms of assembly, cooling and packaging, then I could see this being [allowed], and that is not going to drive the costs completely mad.'

But some working at Porsche think that manufacturers in Formula E *should* be building up their own expertise rather than farming out a core part to an external supplier.

'That is their point of view,' Gass says. 'But that does not mean that the regulations will go that way. I am not sure that [own cell development] is the way. I imagine that battery electric vehicles is not the long term future, it is an intermediate step. You will have fuel cell and other things coming up. Once you have that, the importance of the battery itself takes a step backwards, and so if you look at it as an intermediate period, I am not sure that you should put that element of importance on to the battery or battery cells.'

On the Gass

That's all for the future, then. But as far as the current car is concerned, just how much of the e-tron FE04 is actually Audi's work? 'We have a new MGU with a new gearbox with one gear; new gearbox housing, new rear suspension, we have touched everything that we can, but the main thing is the gearbox, that has been optimised for efficiency,' Gass says.

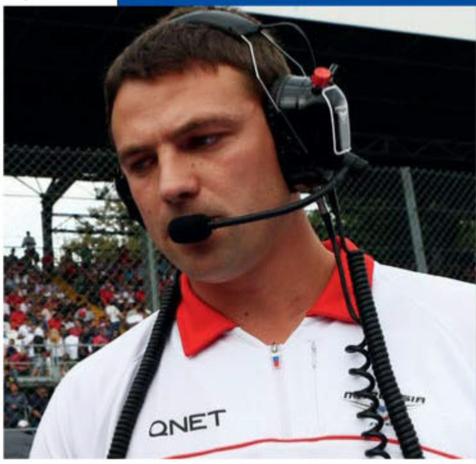
Some, including GT impresario Stephane Ratel in these very pages, have suggested that in the long term Formula E will merge with Formula 1. For a company that's historically been wary of F1, how would that suit Audi? 'I don't think that this is the original target. If you mean replacing, I don't think so because Formula E is something completely different and it doesn't target to replace Formula 1. Traditional motorsport, like Formula 1 is, will at least for a time have more than its right to exist and will be the number one sport. Formula 1 is not so much a manufacturer sport and it exists because there are many teams around whose business it is to go racing and only that. I think it will have a future.'

As for Audi's future in Formula E it will be hoping it will be as successful as it was in WEC, and it's certainly gone very well in testing. But whether victory in FE will ever carry quite the kudos of winning Le Mans remains to be seen.

Audi's works Formula E campaign was launched in late September with the unveiling of the Audi e-tron FE04

RACE MOVES

XPB



Paul Davison has been reunited with **Nelson Piquet Jr** – who he previously race engineered in GP2 – at the Jaguar Formula E team for Season 4 of the electric series, which kicks off at the beginning of December. Davison, who engineered the racecars of **Jules Bianchi** at Marussia and **Valtteri Bottas** at Williams while he worked in Formula 1, will be Piquet's performance engineer.

Well-known race engine builder **John Nicholson** has died at the age of 75. The New Zealander founded Nicholson-McLaren Engines, which was renowned for its work with the Cosworth DFV in many categories, especially F1, where its units powered McLaren to two world championships (1974 and 1976). Nicholson was a race driver, too, with one F1 start to his name, at the British Grand Prix in 1975. He was also a successful powerboat racer.

Carl Faux, the technical director of works Subaru BTCC team BMR, the outfit which guided **Ash Sutton** to this year's championship crown, has left the organisation to take up a position with the newly named Walkinshaw Andretti United team in the Australian Supercars series – Andretti Autosport and United Autosports have bought into the existing Walkinshaw Racing Supercars operation.

Jonathan Lee Recruitment, the engineering and manufacturing specialist consultancy, has signed up **Paul Robson** as its new senior technical consultant. Robson brings 11 years' automotive, motorsport and aerospace experience to the firm and he specialises in electric power. His role will be sourcing product development experts for the transportation and scientific sectors. Robson previously worked at Zytek Automotive.

Justin Taylor, who was a race engineer at the Joest Racing-run Audi LMP1 programme, has rejoined Joest in the same role for its new Mazda IMSA DPi assault. Taylor has spent 2017 working as a race engineer at the Ed Carpenter Racing IndyCar operation. Taylor was present for the first tests of Mazda's RT24-P in Germany in September.

Formula 1 is to open a new office in the US which, according to spokesman **Norman Howell**, will be used for orchestrating US sponsorship deals. Following Liberty Media's takeover of F1 the American concern moved from Bernie Ecclestone's London HQ to a larger building, also in London, and this will continue to be F1's head office.

Bruce Levin, the owner of the Bayside Disposal Racing team during IMSA's halcyon period in the 1980s, has died at the age of 79. His Porsche 962s won six IMSA GTP races in 1987 while as a driver he won the 1981 Sebring 12 Hours in a 935. He also ran an IndyCar team before finally quitting racing in the 1990s.

Adrian Burgess was on hand to help out Australian Supercar outfit Tekno Autosports at the Bathurst 1000 race in October. Burgess split from HSV Racing, where he was the team manager, back in May, and he had previously also helped Tekno at the Sandown 500 round of the series, prior to Bathurst.

Veteran racecar engineer **Allen McDonald** has left IndyCar outfit Schmidt Peterson Motorsports, where he has tended the **James Hinchcliffe** car since 2015. McDonald had been at SPM for the past five seasons and prior to that he had been technical director at the Andretti IndyCar operation.

Phil Charles, **Nelson Piquet Jr**'s race engineer at Renault in F1 in 2008, has joined the Jaguar Formula E operation, where he has taken on the position of racing technical manager. Battery expert **Selin Tur** is to stay on in her role as Jaguar's head of powertrain.

Darian Grubb took on the crew chief duties on the No.5 Hendrick Motorsports Chevrolet of **Kasey Kahne** for the final races of the NASCAR Cup season. NASCAR veteran Grubb returned to Hendrick Motorsports last year after spending four seasons as a crew chief at the Joe Gibbs Racing operation.

Timing of FIA tech head's move to Renault questioned

F1 team bosses have questioned the period of time between Marcin Budkowski leaving his post as the head of the FIA's F1 technical department and his taking up of his new role as an executive director at Renault.

Budkowski is currently on gardening leave until the end of this year, but rival teams have pointed out that in his position with the FIA he has had an insight into current and future designs of other teams and they have called for a longer gap before he joins Renault.

XPB

Marcin Budkowski has left the FIA to take up a position with the Renault F1 team

Paddy Lowe, chief technical officer at Williams, said: 'The concern amongst all the teams has been the very short period of isolation between a role as an officer of the FIA, and working with a team. It's very critical that the teams have a strong degree of trust in their work with the FIA; that really underpins the ability of the FIA to police the sport from a technical point of view.'

Christian Horner, team principal at Red Bull, said before the move had been confirmed: 'We take major issue with that … Obviously, in these individuals you place an enormous amount of trust. In the role that Marcin has been responsible for he has been in an extremely privileged position and extremely recently he has been in people's wind tunnels and looking at intimate details of knowledge of next year's cars.'

Renault managing director Cyril Abiteboul has now said that he is willing to delay the arrival of Budkowski until April of 2018 (six months).

But when asked how long the gardening leave should be Horner said: 'I think industry standard for the type of role that Marcin has been performing would be anywhere between 12 and 18 months.'

OBITUARY – Robert Yates

Renowned NASCAR engine builder and team owner Robert Yates has died at the age of 74.

Yates started his engineering career working with bulldozers, but then found employment in NASCAR in 1968, first with Holman-Moody Racing before moving on to Junior Johnson's team for the 1971 season. Yates-built engines won races for Cale Yarborough and Bobby Allison throughout the 1970s and 1980s.

NASCAR engine building legend and former team owner Robert Yates has died

He then set up his own team, Robert Yates Racing, at the end of 1988, which won the Daytona 500 in 1992. The outfit claimed its one and only Cup title in 1999, with Dale Jarrett at the wheel. Another Daytona 500 victory came along the following year, again with Jarrett driving. Robert Yates Racing scored 57 wins in total before it was merged with Richard Petty Motorsports.

In 2004 Yates had also merged his engine business with that of competitor Jack Roush to form Roush Yates Racing, which Robert's son Doug now runs.

Earlier this year Yates was elected to the 2018 NASCAR Hall of Fame, where he was voted for on 94 per cent of the ballots cast – the joint highest vote ever (with David Pearson in 2011).

NASCAR chairman and CEO Brian France said of Yates' passing: 'Robert Yates excelled in multiple NASCAR disciplines, earning the respect of an entire industry and an everlasting place in the hearts and minds of the NASCAR fan base. His excellence spanned decades, from the 1983 championship powered by his engines and the 1999 title captured by the cars he owned, both of which helped earn him a deserved spot in the NASCAR Hall of Fame Class of 2018.'

Robert Yates 1943-2017

RACE MOVES – continued

Three-time Le Mans winner **Alan McNish** has been named as the team principal for Audi's works Formula E effort. In his new post he will be Audi's official figurehead at Formula E events with responsibility for the overall operation at the track, while he will also communicate with the FIA and FE on the team's behalf.

Hyperdrive, a team of four 15 to 17 year olds from Trinity Grammar School in Kew, Victoria, Australia, has scooped the F1 in Schools 2017 title. It was presented with the Formula 1-sponsored World Champions trophy by F1 CEO **Chase Carey** at the Malaysian Grand Prix. Hyperdrive beat 50 teams from 27 countries, with Aurora, an Ireland-Australia collaboration, in second, and Pioneers from Germany third.

Chip Ganassi Racing laid off 40 staff at the end of the IndyCar season in the wake of its decision to scale back its top-tier US single seater involvement by cutting its effort from four to two cars for 2018. As well as mechanics and engineers, the team has also had to let go machinists, painters, graphic designers and sub-assembly workers.

Mark Heywood QC has been appointed as chairman of the Motor Sports Council National Court, the highest judicial authority in UK motorsport.

Chris Gayle, the crew chief on the No.77 Furniture Row Racing entry in the NASCAR Cup was fined $10,000 after the Toyota he tends was found to be running with an unsecured lug nut at the Dover International Speedway round of the series.

Former Williams Formula 1 team manager **Peter Vale** has replaced **Chris Clark** as the team principal at Australian Supercars outfit Brad Jones Racing. Clark and Vale previously worked in F1 together at the McLaren team and the former played a role in lining Vale up to replace him.

The Ferrari Formula 1 operation has brought in a quality control expert from its parent Fiat Chrysler Automobiles (FCA) organisation in the wake of a number of high profile failures that have hit its 2017 championship campaign. It's been reported that **Maria Mendoza**, previously head of powertrain quality control at FCA, has been given the task of reorganising the Scuderia's quality control department.

Tony Fletcher, who was well known on the UK hillclimbing scene and was also as an MSA Lifetime Achievement Award winner, has died at the age of 74. Fletcher became an RAC timekeeper in 1959 and a Speed Clerk of Course in 1973, officiating at events that eventually became the MSA British Hill Climb Championship, which he went on to coordinate until his retirement at the end of the 2011 season.

Former Williams and McLaren technical boss **Sam Michael** made his first visit to the Bathurst 1000 race in October, as part of his part-time race engineer mentoring duties with Supercars outfit Triple Eight Racing. This was actually his first visit to a race in this role, which involves advising the team's engineers.

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

Winter is coming

It's an irony of the industry that the 'off-season' is often the busiest time

Most motorsport businesses can reflect on another good year as this season comes to a close. The majority of championships created exciting racing which should attract more partners and audiences in 2018, and most technical regulations proved to be up to the task, allowing for the usual crop of criticism.

We enter the busy winter period with various new technical challenges to be met, which bring a boost in business as these need to be developed and delivered quickly. Such is the cycle in the motorsport industry, and long may it continue.

The annual future technology conference of the MIA (EEMS) on the Wednesday before the Autosport show in January will be particularly interesting. Experts will share their vision of the two separate streams of technology which will affect motorsport over the next five years. On the one hand, hybrid solutions requiring super-efficient ICE, and on the other, the response from motorsport to the huge investments being made by the automotive sector in electric drive.

Electric drive

I expect the various hybrid solutions to remain in motorsport for longer than many believe, and create plenty of profitable challenges needing solutions. However, while activity in electric powertrains is already involving more motorsport companies, the conference will discuss how best we can rise to the challenge of making electric-powered sport entertaining, and how we can attract a new younger audience.

The volume of data from our motorsport technology could well be vital to future motorsport entertainment. Transmission of this data will delight young people who have an insatiable desire to access all information, whether through TV or digitally. Our outstanding technology companies must now start collaborating with leaders in digital technologies to pioneer ways to entertain this young, demanding audience using the very latest techniques. Make no mistake, whether you like it or not, the electric motorsport revolution will be upon us far sooner than most imagine, due to the urgency of the investments in electric powertrains from automotive OEMs to meet their emission promises.

The next few years are going to be exciting and stimulating. Ross Brawn at Formula 1 says his team have made entertainment from technology their top priority. Small specialist companies must move fast to be ready to take their share of this market, but will need to think outside the box and collaborate with new friends from the digital entertainment world.

Our EEMS conference will cover this in depth and host some outstanding experts from other industries from whom we can learn. Make a date in the diary for Wednesday January 10 and check the MIA website for details – www.the-mia.com.

You will have read of the threat being posed to the future of motorsport by a current European Commission consultation under Vnuk. If you haven't, then check the MIA website for all the information you need. The MIA has encouraged the UK and the European motorsport industry to respond to this consultation and so avert disaster. The response was outstanding, from the F1 Group and all Formula 1 teams, Volkswagen Motorsport, Mercedes, ORECA, Dallara and many others. This is likely to be merely the first round in a complex battle to protect the future of our sport and our industry.

XPB

Racing into winter. As the season comes to a close the industry faces a number of challenges, but these are matched by the opportunities that are also emerging

Recruitment drive

The MIA was founded by the industry 25 years ago to fight battles such as these on behalf of our members. This won't be the last where we need to come together to take on government bureaucracy. This expensive task is at present funded solely by MIA members, so I make no apologies for this appeal. We need you to join the MIA now as we must build a substantial war chest to fight both this immediate threat and those that follow. Please invest in your own future and join our community – you would be most welcome. See the MIA website for more information on how to become involved.

I hope we meet at one of the international trade shows starting with SEMA, then PMW, PRI and finally Autosport International in Birmingham.

Right now, these are good times for UK motorsport companies to demonstrate exceptional value when selling their capabilities and products due to the exchange rates, but this bonus can easily disappear. I keep telling all companies to find some way of exporting. Even Ireland is a good export market. If you don't already export, then this is a good country to learn the ropes. To begin with start with markets in Europe first – don't be too ambitious, the world will come later.

Export drive

Our International Trade Team work closely with the Department of International Trade, and together we deliver funds to help grow UK exports. Many companies exhibiting at the shows mentioned above have secured grants to help them on their way, but personal advice can always be best, so let me know how the MIA can help.

My advice to get the best return from shows is to work hard long before you get there. Get in touch with and invite all your contacts in the country where you are exhibiting – be blunt, tell them you are going to be at the show, ask for a meeting, set a time and date, don't leave it to chance, as someone else will get to them before you if you do. Promoting your presence long before you attend is definitely the best way of improving your return on investment, yet so many overlook this.

The USA continues to have the most potential and remains the fastest growing export market. There is no slowdown in motorsport across the USA, and the reputation of British high-performance engineering is well established.

They speak our language in the US and share our determination to win whatever competition they enter, so they want the best products to do so. Please plan to visit one of the USA shows, where MIA USA offices wait to help you make contacts.

I suggest you make this winter the time when you either start exporting or go hard to increase your USA business. Good hunting!

The next few years are going to be exciting and stimulating for motorsport

AUTOSPORT INTERNATIONAL
THE RACING CAR SHOW

Seasonal changes

One of the hot topics at January's ASI show is sure to be the new-look WEC calender and its impact on the industry

With the World Endurance Championship announcing a 'super season' in 2018/19, it seems that the winter has become even less sacrosanct. A full winter programme will be undertaken in 2019/2020, culminating at the Le Mans 24 hours in June. The argument for this arrangement, from the teams, is that there are more dates available for the series in the 'off-season' than during the traditional racing season, that used to run from March to October, and so scheduling is easier and transport can therefore be done cheaper.

The decision made the suppliers sit up and take notice. When, for example, would tyre development take place, and when could new products be introduced? Part-way through a traditional season? From a purely logistical standpoint, this is a headache at best, and at worst, it will rob them of teams, drivers, circuits and time at the factory to complete a full development process.

Seasonal work

While some may say that homologation is just paperwork, and can be done, it does create practical problems. Teams that would normally hire out their staff over the winter break will now not be able to do so. And, for the racing shows and suppliers, when is a good time now to start launching new products? Should they stick to the traditional schedule and release their products at the international trade shows in November to January, culminating at the Autosport International Show in Birmingham in January, or should the shows be aware of the new racing schedule, and start to adapt accordingly? If a show was to look for an alternative date, when should it be?

Admittedly, a show in Birmingham at any other time of year would be preferable to the start of January, where traditionally it can be cold and wet. Right now, the only gaps in the schedule appear to be February, which would provide no improvement in the weather prospects, or August, when everyone is supposed to take a holiday and Formula 1 is on an enforced shut down.

Changing times

Shows are a key part of the racing industry, a place at which business is done and products are launched to customers. They are events where new concepts, ideas and creations are discussed or revealed, relationships forged, and those who follow a more traditional schedule can use the shows as originally intended. Yet with the Creventec series, IMSA series and now the WEC looking to shift its focus, these shows may find themselves robbed of customers, suppliers and sponsors.

AUTOSPORT INTERNATIONAL
11 to 14 JANUARY 2018

PUBLIC OPENING TIMES:
Saturday: 9:00am to 6:00pm
Sunday: 9:00am to 6:00pm

NEW FOR 2018, child ticket prices for those under 16 have been reduced. Full ticket price information is as follows:

Standard: Adult £35pp, Child (6-15yrs) £17

Ticket includes entry into Autosport International, the Live Action Arena and Performance Car Show (children under five years of age go for free). Ticket price includes the £2 booking fee per ticket.

Paddock Pass: Adult £46pp, Child (6-15yrs) £27.50pp

Ticket includes entry into Autosport International, the Live Action Arena and Performance Car Show (children under five years of age go for free). Access to backstage Paddock area in the Live Action Arena, Paddock Guide and access to driver autograph sessions.

Family Pass: £87 (2x Adult and 2x Child of 6-15yrs).

Ticket includes entry into Autosport International, the Live Action Arena and Performance Car Show. Valid for standard tickets only. The price includes booking fee charges.

VIP Club: £127 (no VIP Child ticket available).

Ticket includes entry into Autosport International, the Live Action Arena and Performance Car Show. In addition VIP Club includes free parking, seat at VIP enclosure in the Live Action Arena, complimentary drinks and canapes, VIP gift bag and much more.

For more, visit **www.autosportinternational.com**

Products at ASI

Greaves 3D
Stand E1140

A world leader in high-quality pit lane and garage equipment solutions, Greaves 3D, has announced the launch of an exciting new fuel measurement technology product at Autosport International. More details about this development, which is set to herald a new era of recordability and networkability accuracy in fuel technology, will be offered on the trade days at Autosport International.

The team at Greaves has also been working closely with customers to design and manufacture the most comprehensive and compact workstation in the pit lane. The workstation has been designed to travel securely with 180-degree folding mounts, ensuring the monitors are stored correctly during transport, and boasts secure laptop storage, slide out desktop, easy connections for power, TV and network inlets, integrated cooling fans, docking station facility and more.

Well-known pit lane product supplier Greaves has produced this multi-functional garage workstation

Greaves 3D Engineering was founded in 2012 and was born out of a desire to design and manufacture pit lane solutions for racing series, including WEC, WRC, WTCC, IMSA, DTM ELMS, Blancpain and Australian GT.

More details on Greaves 3D's bespoke engineer station can be found on the website: **www.greaves3dengineering.com**

Strepavara
Stand E599

Known for its wide range of powertrain components, such as crankshafts, camshafts, rocker arms, conrods, complete valve-train and engine brake solutions, now Strepavara is aiming to be a key player in the manufacturing of connecting rods and high

precision fuel injection components, such as high-pressure GDI pump bodies.

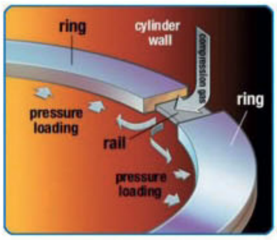
Two plants in Italy produce conrods, camshafts and crankshafts and are developing strategically into racing and motorsport applications with the production of prototypes for the World Rally Championship, MotoGP, Superbikes, and also some other small series applications.

New products are now being launched, such as Titanium conrods and variable compression conrods. Among its customers Strepavara can count Ferrari, Ducati, Lamborghini, Mercedes AMG, Toyota Motorsport, Renault Sport, Magneti Marelli, and MV Augusta.

Total Seal Pistons

Stand E772

Total Seal Pistons is a cutting edge leader in piston development, providing pistons for everything from F1 through to the standard road car. The team has developed a number of separate ring lines from Gapless to Diamond Finish, all intended to improve the sealing of whatever engine the customer has.



Lord of the rings: Total Seal produces a range of high-end piston rings for motorsport use

Total Seal's patented Gapless piston rings are capable of providing increased performance through unmatched sealing of the cylinder and combustion gasses in the combustion chamber.

Increased horsepower and torque are just a couple of the reasons why these piston rings are the best available, the company tells us.

Other benefits include, less friction and a cleaner, more consistent oil, a wider torque curve and, Total Seal claims, a greater probability of a longer powerplant life, plus fewer engine disruptions, allowing for cost saving.

GDS

Stand E1146

Building on its success at the 2017 show, the team from GDS will display an updated version of the Eco-Wall at Autosport International in 2018, which has now been developed further to incorporate some exciting new innovations.

Launched towards the latter end of the 2016 racing season, interest in the Eco-Wall has grown exponentially within Europe and the Far East since its inception. Designed for mainstream motorsport teams, GDS has manufactured a seamless walling system, which requires little work to construct and boasts simple engineering advances applicable to the modern motorsport outfit, such as helmet boxes and alcoves for team equipment, in addition to TV or social media screens and other paraphernalia.

The GDS Eco-Wall system was launched at the end of 2016. An updated version of the product will be shown at ASI

Advanced Fuel Systems

Stand E481

This specialist fuel safety cell manufacturer creates products for the marine, motorsport, air and defence sectors, most notably the monolithic FIA-approved fuel cells seen in the Bloodhound SSC car.

The supersonic car has four of Advanced Fuel Systems' safety cells, each containing 550 litres of jet fuel. The pumps are capable of delivering fuel at a rate of 20 litres per second to the jet engine.

Uniquely, Advanced Fuel Systems simultaneously manufacture both composite materials and finished fuel safety cells, so the shape of the cell can be moulded and optimised to customers' exact requirements. All current products offer improvements in durability, increased flexibility and weight reduction.

To read more about the company's speed record project go to: **www.advancedfuelsystems.com/recordbreaking**

Questmead

Questmead Ltd was founded in 1993 by Alan Brown as a one man business then selling just Mintex Competition products.

With continued growth, Brown now has a team of experienced sales staff providing first class technical support.

The team has clocked up literally tens of thousands of miles attending various events to establish close customer relationships.

Analysing sales history and investing in R&D has enabled Questmead to build up a stock inventory that allows it to supply goods on the next day in many cases.

Centrally located, just north of Manchester, in Rochdale, Questmead Ltd ships out its braking products to trade customers, race teams and preparation companies worldwide. Attending events, such as races, and shows like Autosport International, with a well presented van fleet loaded with carefully selected stock, also has its major advantages; not only for putting faces to names, but also because it is on hand for any professional advice when time is critical.

While it's the UK's biggest distributor for Mintex and AP Racing, Questmead Ltd has also found it important to have supporting products in its widening portfolio. These now include Pagid, PIAA, Fuchs Lubricants and Exedy.


Rochdale-based Questmead has been supplying high-spec braking products to the motorsport world for nearly 25 years

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International diplomacy

Plastered to the wall on the outside of the main straight at Road Atlanta there were the names of the winners of the last 19 Petit Le Mans, an event that launched the American Le Mans Series and started a true relationship between the Americans and the French. The first winner was Ferrari, with the 333SP driven by Wayne Taylor, Emmanuel Collard and Eric van de Poele, and since then the race has become a must-see, must do, event. This year was no exception. Yet while the titles were pretty much wrapped up, in the paddock chaos raged, as those cross-Atlantic relations were becoming strained.

The whole drama centred around the LMP2 regulations, the disparity of performance between the four manufacturers, and what the ACO planned to do about it. As a reminder, the LMP2 cars were supposed to be the global prototype category, running in Europe as customer racing, and in the US with manufacturer support. Four chassis manufacturers were selected, two French, one Italian and one American. The ACO thought this was a marvelous idea, despite the fact that it limited yet another category. If you are a chassis manufacturer now, you can do an LMP1 car, an LMP3, Formula 3...your optios for international racing are limited. Funnily enough, two out of three of these are now in deep trouble.

In the paddock cross-Atlantic relations were becoming strained

With the homologation fixed for four years, the LMP2 chassis manufacturers set about making money. They built the cars to a limited price, and sold them. Three manufacturers looked to concentrate on the US market, with an OEM, and develop their cars for DPi racing in the States. One, ORECA, focussed on the FIA WEC, and amassed a complete grid. In the European Le Mans Series, things were a little more varied. By the penultimate round at Spa, each of the chassis manufacturers had won a race, other than Riley which was not represented.

Despite this, the ACO held meetings and, based on the results in the ELMS, decided that all manufacturers would now be allowed to play their 'joker' (why on earth they call it this I have no idea; it's an update kit). They were allowed to update both their sprint and endurance package. All, that is, except ORECA, which was classed as the 'reference car'. The paddock in Atlanta was up in arms.

As for IMSA, it was not even invited to the meeting which was held during its busiest of weekends, and yet it was expected to adopt the regulations despite having healthy competition throughout its season. It was also expected to conduct the wind tunnel testing for the low-downforce Le Mans kit, despite having only three 12-hour sessions pre-booked with Windshear, a facility that literally has no extra shifts available until the end of 2019.

ORECA was livid, and put out a press release questioning the validity of the ACO's decision, and asking why the results in IMSA were not taken into account. Indeed, why was only the ELMS considered, and what were the criteria considering the diversity of winners? Ligier was upset because it had been told that it could update its Le Mans package, and the sprint was something of a surprise. It then also hinted that the ACO was planning to restrict what could and could not be updated. It's not written down anywhere, what can and cannot be touched. The kits, incidentally, are provided at cost to the manufacturer, not to the customer.

The paddock was bouncing slightly with those who were jumping up and down. One official remarked darkly that the French should consider what the word *collaboration* meant, and clarified that it did not mean decisions were taken, and the partner told to accept everything. Yet, that seems to be what happened.

In the spirit of keeping things alive, IMSA has agreed to test the kits, and will have them track tested and wind tunnel tested ahead of the first test of 2018, at Daytona. The French should consider themselves lucky to have such a willing partner, and the question then follows; what's in it for the Americans?

They could easily have said 'no' to the update kits, and introduced them in 2019 when they also change tyre supplier to Michelin. The paddock in the US is full, and getting bigger with the arrival of Penske, while Joest joins next year with Mazda. Everyone agrees that the Riley chassis was outside the one per cent of performance window compared to the ORECA, and therefore needed to be updated. However, few could fathom the decisions surrounding Dallara and Ligier.

IMSA is working with the manufacturers to create what it calls an 'aggressive development package', which broadly means; stop mucking around, people, you need to help us get this right. I suspect that the manufacturers, which had already approached the ACO to race at Le Mans in 2018 but were told that they had to comply fully with the LMP1 regulations, would still like to go, and IMSA is making that possible for them. IMSA will run fuel flow meters next year, which is a step closer to bringing them in line with LMP1. The DPi cars still weigh 100kg more than an LMP1 car, and still have less power, but with a little bit of flexibility from the French, they could get there. I wonder if that was the deal?

ANDREW COTTON Editor

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