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The magic of Le Mans: it's dusk and the teams are preparing for a long, hard night ahead. Our full analysis of this year's dramatic encounter begins on page 26



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Game of thrones

One man's global quest to find the ultimate in race circuit conveniences

Considering the time spent in paddocks, it is not surprising that a fundamental part of racecraft is to locate and inspect the track's conveniences as soon as you have finished the first job of collecting the garage keys.

Most tracks have now caught up with the 20th century, and in Japan even the 21st, and most F1 level tracks now have toilets in each and every pit. But for a very long time toilets really lived up to the English epithet, *bogs*. So much so that any hard-core racer developed an iron bladder and granite bowels, knowing that when one left the hotel bodily functions would be locked-down until the return, and in the case of the all so common all-nighters that could mean a couple of days' abstinence.

Faecal matters

That's something easier said than done at some tracks, notoriously in Mexico, where Montezuma's revenge regularly afflicts the gringos. One incident noted in the motoring press at Mexico was the alleged hijacking of the toilet paper by Nelson Piquet Sr just before Nigel Mansell was due to use it, a fine deployment of psychological warfare.

Also in Mexico, one of my drivers posted an impressive lap time in practice, but before the team could congratulate him on the exploit he came in prematurely and immediately he screeched into the pits leapt out of the car and legged it to the nearest toilet. Having had supper with him the previous evening, the reason was apparent.

Another well-known story is the Cadwell Park flood in '76, when the toilets overflowed on to the track, causing the race leaders to spin off. One of the drivers is reputed to have said 'I was pissed off!'

The most notorious example of a bog were the toilets at Interlagos, which ceased to be during an early grand prix when a commando unit led by the intrepid chief mechanic at Lotus, Bob 'The Vicar' Dance, used an acetylene bomb to show the teams' (all of them) displeasure at having to cater to their needs in this dank, door-less dimly lit Hades.

The fact that you had to perch precariously on the seat-less cracked porcelain bowl was probably the reason why there was a surplus of, how can we state delicately, human waste, all over the floor, walls, bowls and anything vaguely associated with the place. The ceiling was probably clear of it, but there lurked enormous half-seen tropical insects, possibly poisonous, definitely unpleasant. The Vicar's acetylene bombs are still

a legend, as attested by the wide grin when you mention it to the old lags, but the Interlagos one was the equivalent of the Tzar Bomba, the biggest thermonuclear device ever exploded.

After the not-so-innocent bystanders had backed off to a safe distance and the fuse was duly lit, we had our flabber thoroughly gasted when after a deep, dull boom the ceiling of the convenience levitated about five feet, all four walls promptly collapsed outwards, bricks whizzing away like shrapnel, and the levitating roof then decided that it would return to earth again with a resounding crash onto the resulting rubble.

It is interesting to note how Brits could look so guilelessly innocent when questions about this incident were being asked. The next year we were all pleasantly surprised to see the new comparatively

as far as we know. The worst case was also a grievous infringement of The Hague Human Rights Convention, with the forbidding 'Madame Pisse' barring the entrance of many toilets in France and Belgium, demanding money for the opportunity of solving a pressing natural need.

Resourceful teams sped up the process by paying a block-booking fee for the whole team for the duration of the event.

But the Brits had a particular problem with this procedure, probably because of lack of toilet training Continental style, where all have been indoctrinated to pay for clean, well-maintained conveniences, or to nonchalantly relieve themselves against any close wall or bush.

The most contentious place was at Spa Francorchamps, which eventually culminated with a mass showdown of the rebellious British teams lining up outside 'Les Toilettes' and hosing all the walls, despite their prude attitude about these matters.

Portaloos sunset

Tracks in towns, like Pau, Monaco and a lot of American races had the modern plastic one-piece portable toilets. This also seems to have been a magnet for the crews bearing duct tape, as it seemed to provide at least one occurrence per race of hapless drivers and other team members being taped up inside them.

The only chance of escaping was to implore any passer-by to untape the unit, it being swiftly learnt that trying to batter

the door open was prone to make the Portaloos fall on its side, with all that entailed.

One also has to mention the alternative at the Paris-Dakar rallies, where rather than an enclosed foetid bog, you had an entire desert at your disposal at the nightly bivouacs – preferably downwind from where you would be erecting your tent.

The downside, of course, was a blatant example of 'the tragedy of the commons' where a goodly amount of the participants seemed to be utterly unfastidious and would neglect to bring a shovel to the site chosen, resulting in a faecal minefield if you were not in the vanguard of the users. A useful spur to press on and arrive early.

But I did manage to score one for technology when testing a pair of infrared goggles intended to see bikers in the dust-clouds when in the pack, and discovering they were very useful in navigating the turffield at the bivouac at night.



Bog standard: the diversity and quality of race circuit toilets around the world has always been a major topic of conversation in the paddock

palatial surroundings we had, so this rather heavy hint was apparently taken.

But lest we think that this was a feature only in non-European contexts, there were equivalent swamps in many a track in Europe, too.

LM pee

When Le Mans had the old garages, with no electricity allowed in the pits and your average spectator leaning over the roof balconies flicking the ashes of their cigarettes over the refuelling cars just below them (probably just to thumb their noses at health and safety), apart from the smell of petrol sloshing about from the milk churn and funnel refuelling kit, you could always identify the labyrinthine passageway behind the pit by the ammonia stench of uric acid and urea as everybody seemed to relieve themselves in the dark. Although, luckily, only the liquid component,

The toilets overflowed on to the track, causing the race leaders to spin off



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Eric Broadley

Our columnist shares fond memories of the recently-deceased Lola founder

My first love was aeroplanes, as a kid. Fast cars and racing cars were also on my radar but it wasn't until I saw a picture in *Autosport* of the stunning, just-announced, Lola GT that racecars really took hold. It's still amazing to me that 30 years later I became joint managing director of the company that produced the ground-breaking automobile that so grabbed my attention, working alongside Eric Broadley – its designer, Lola Cars founder and subsequently my co-managing director – who died in May.

The Lola Mk6, to give the GT its correct model number, was the first 'big-banger' closed coupe to follow the mid-engine pattern only recently set by Formula 1. Typical of Eric in setting out his own design vision, it employed a number of then-unique features. Although the MK6 never achieved the results it deserved through lack of resource and the unreliability of contemporary American V8 racing engines, it established Lola in this racing arena and the transition via Ford money to the super-successful Le Mans-winning GT40 is well-documented. Just as remarkable, after barely eight years from the modest company start-up, was Lola winning the Indianapolis 500 with Graham Hill and the T90, the first of many successes in Indycar racing, with the USA subsequently becoming a mainstay of the company's earnings.

Natural engineer

Largely a self-taught engineer, Eric was very practical and capable, 'hands-on' in this respect, despite his frequent lost-in-thought professorial demeanour. I was told that he carved the intricate wooden patterns for the brake drums of the pretty little Mk1 sport racer that launched a part-time enterprise into the business that it became, as well as being chief fabricator and welder. I still had occasion to see his abilities in this respect much later. It was not unknown, for example, for Eric to disappear for a few days and then turn up with a wind tunnel or styling model that he had crafted himself at home tucked under his arm.

I have no doubt that this attitude created the insistence on quality of engineering that, with only a few exceptions (generally caused by lack of time and other pressures), earned Lolas the epithet of being 'the Rolls-Royce of racing cars'. He also had a

very good eye for line, which was evident in many of his creations, although he was happy to use input from those pattern-makers and professional car stylists whom he trusted.

Most usefully, Eric had the ability, using his trademark lateral thinking, for coming up with an engineering solution to a seemingly impossible situation that could dig all concerned out of the crap – a great gift for an activity as packed with traps to fall into as motor racing! If you are familiar with the film *Flight of the Phoenix*, wherein, following a plane crash in a desert, a lash-up of an aircraft is created from the wreck allowing the surviving occupants to fly out to safety, then Eric would be the man to make it happen! Ironically, my having used this analogy, it was his constant search for the holy grail of suspension geometries taking precedence over the rapid advances in racing car aerodynamics that compromised some of his later

employing 120 people at its height, to most it was like a family, albeit one of dedicated, hard-working and skilled people. As with most families, it had its ups and downs and Eric could be sufficiently single-minded to squeeze out those whose views did not accord with his. One noted senior designer commented to me rather ruefully, after suffering such a fate, that 'Eric might be quiet, but he certainly has teeth, doesn't he?'

Formula 1 folly

In contrast, Eric had a remarkable propensity for being ripped-off by certain characters that the rest of us could see from a mile off were just out for what they could get. It frustrated the hell out of the management team and led to my own enforced departure, when the final Lola attempt at F1 was looming. It was one Broadley gamble too far and caused the downfall of the company when it went disastrously wrong.

Eric has been criticised for the way this project went – or didn't, as it happened – but his thinking was correct in that this presented probably a last opportunity to get into Formula 1 as a constructor and team, F1 being where the best chance lay of a viable business for the future. Always a risk-taker and determinedly independent, he unfortunately greatly underestimated the task and the funding required, being ill-advised by some who should have known better and who fed Eric what he was so keen to hear. It should be remembered, however, that prior to this sorry episode the company that he and original business partner

Rob Rushbrook (who for a long time turned Eric's concepts into manufacturing reality) created together became an iconic racing car marque. It provided significant employment for over 40 years, earned many millions of pounds in exports, trained a great deal of young engineers – some of whom subsequently went on to become prominent in the Formula 1 arena – flew the flag for British engineering and won countless races worldwide, including some of the most prestigious.

I shall miss the wry grin and the dry humour. None of this RIP stuff, however. Eric will be wanting a project to be getting on with.



Lola's Eric Broadley had an extremely good eye for a racecar's lines, which resulted in some stunning machines, such as the glorious T70 sports racer

work, and caused some friction with the designers and the customer engineers alike.

It was his preference always to innovate than develop that on occasion prevented even more success; the T360 FATlantic/F2 was a lovely-looking and very quick car, but Eric came up with a completely different design as a follow-up which was as bad as the T360 was good. Nevertheless, the respect for his creativity and sheer brain power remained, as did a personal liking for him, even from those with whom he disagreed.

Eric being an informal, if usually pretty shrewd, character, the company followed his lead. Despite

It was not unknown for Eric to disappear for a few days and then turn up with a wind tunnel model that he had crafted at home tucked under his arm



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Disruptive influence

Is the era of people actually owning and driving cars now coming to an end?

It may be unusual to write a column in this magazine that is nothing to do with motorsport. However, the subject of this piece does have massive implications for the technologies and businesses of racing, and I feel it is better for the readers of *RE* to make up their own minds about how it will ultimately affect them.

The subject is a report titled: *Rethinking Transportation 2020-2030 – The Disruption of Transportation and the Collapse of the Internal-Combustion Vehicle and Oil Industries*, by James Arbib and Tony Seba. The authors are both academic specialists in the field of disruption technologies and have developed methods for modelling them. In applying these techniques to transportation and energy, they come to the conclusions that electric vehicles (EVs) and autonomous vehicles (AVs) will have far-reaching effects on major industries such as automotive and oil, and that society will demand a transition to what they call Transport-as-a-Service (TaaS) starting in 2020 and complete by 2030. Driving this revolution is simply consumer economics: 'By 2030, within 10 years of regulatory approval of autonomous vehicles (AVs), 95 per cent of US passenger miles travelled will be served by on-demand autonomous electric vehicles owned by fleets, not individuals, in a new business model we call "transport-as-a-service" (TaaS)', the report says. 'The TaaS disruption will have enormous implications across the transportation and oil industries, decimating entire portions of their value chains, causing oil demand and prices to plummet, and destroying trillions of dollars in investor value – but also creating trillions of dollars in new business opportunities, consumer surplus and GDP growth.

'The disruption will be driven by economics,' it adds. 'The average American family will save more than \$5600 per year in transportation costs, equivalent to a wage raise of 10 per cent. This will keep an additional \$1 trillion per year in Americans' pockets by 2030, potentially generating the largest infusion of consumer spending in history.'

Horseless carriage

To those that are sceptical about this conclusion I would recommend watching the lecture by Tony Seba on the key technology cost curves that are driving this: www.youtube.com/watch?v=Kxryv2XrnqM. I'll also try and summarise the reasoning behind their conclusions here.

At the start of the lecture above, Seba shows a 1900 photograph of 5th Avenue, New York, showing a street crowded with horses and carriages and he invites: 'Where's the car?' There is one. The next

photo is the same street in 1913, crowded with cars. 'Where's the horse?' There's just one. Man's preferred mode of transport for over 6000 years is obsoleted in cities in just 13 years, along with the associated industries, such as hay and farriers.

In 1985 AT&T asked McKinsey to predict the take-up of mobile phones and the effect on its landline business. McKinsey predicted 900,000 mobile subscribers within 15 years. It turned out to be 109 million and AT&T missed out on trillions of dollars of business as their landline business collapsed. As Seba says: 'It is usually experts and insiders who deny disruption.'

The trigger for this disruption is the achievement of AVs reaching Level 5 autonomy. It is anticipated that Level 4 will be attained in 2019. Once Level 5 is reached, the cost of providing ride-sharing (Uber, Lyft, Didi etc.) drops dramatically, and providers will offer services at a price tending towards cost as they compete for market share.

End of the ICE age

At the same time, EVs will be available with 200+ mile range for under \$30,000 – the average price of an American automobile. With predicted lives of 500,000 to one million miles (2.5 to five times an ICE vehicle) and 10 times the utilisation of an individually owned car, the cost will be four to 10 times less per mile than owning a car. Revenue sources from advertising, data monetisation, entertainment, and product sales to customers will keep down the price for trips.

Adoption will start in cities and radiate outward to rural areas. Non-adopters will be largely restricted to the most rural areas, where cost and wait times are likely to be higher and where population density is too low to attract a critical mass of TaaS services. There are also the very rich, a small group of people who already pay over five times the average price for a car and are not motivated by road travel economics. However, they may be motivated by the efficient use of time to use TaaS. Finally, there are always those who will not change to TaaS for personal reasons, such as distrust of new technologies, or a desire for personal freedom.

Here are some figures and implications. The car fleet will decline in numbers by 80 per cent, and 95 per cent of passenger miles will use TaaS. Economic effects will be massive. In the US, \$1 trillion/year will be freed up for consumer spending, creating new businesses and jobs. Around 70 per cent fewer cars and trucks will be manufactured each year, with total disruption of the automobile value chain: parts, dealers, maintenance, insurance, etc. Oil demand will drop by 30 to 40 per cent compared

with business as usual. The price will drop to around \$25 per barrel. The effect on oil industry asset values (much of the industry's shale and tight oil, and offshore fields then become uneconomic) will affect the US, UK, Norway, Nigeria, Canada and Venezuela.

Wealth and safety

Environmentally, tailpipes disappear on EVs and so emissions of CO₂, NO_x, and PMs are drastically cut as renewables continue to gain the major share of electricity generation. The moment AVs demonstrate greater road safety than human-controlled vehicles, insurance premiums for the latter will increase such that it will become uneconomic to use them. The potential is there to massively reduce the 1.2 million lives lost and 50 million serious injuries/year globally, with the associated healthcare costs. Even the need to police roads will almost be eliminated, as an AV is programmed to be law-abiding.

Brazil, India and China, the countries where 50 per cent of the world's population lives, are finding it impossible to cope with the overwhelming number of new cars on their roads, and have already embraced the concept of TaaS, gearing up their industries to compete for the business it generates.

Seba describes four ways new technologies and products disrupt existing businesses: First, there's

Society will demand a transition to what is called Transport-as-a-Service (TaaS)



Autonomous cars like this Google effort have been the future for a long time. Now the future is almost here



Will all motorsport soon be like historic racing, with little relevance to what is happening on the public highways?

Big Bang: when launched, a new product is better, faster and cheaper than mainstream products. Example: Google. Second; *Architectural:* a new product radically changes the way products and services are produced, managed, delivered and sold. Examples: distributed solar PV and batteries. Third, *From Above:* A new product is initially superior and more expensive, but gets cheaper at a faster rate than the market, while improving performance. Example: Smartphones. Then, *From Below:* A new product is initially inferior to mainstream products, but improves its performance while decreasing costs at a faster rate than incumbent products. Example: Personal computers.

Fast curves

Every technology has a cost curve; when a set of technologies converges they create opportunities for entrepreneurs to develop disruptive products and services. When combined with new business models to deliver value to the customer, the whole basis of competition is changed. At a certain moment the tipping point on the S-curve of market adaption is reached and exponential growth occurs.

The process of disruption is accelerated when there is open access to technologies, increasing the speed of development and reducing the cost of entry. Conceptual innovation brings totally new ways of doing things, such as TCP/IP and block chain, and further accelerates the process.

The four technology areas that are bringing TaaS about are: energy storage, EVs, AVs, and solar energy – photo voltaic (PVs). Seba describes the technology cost curves that have converged to generate the tipping point.

Energy storage: to reach this tipping point, the battery in an EV must endow it with 200+ miles range. For a 10 times utilisation of an owned car, it will need to travel 300 to 350 miles per day, over 10 to 15 hours, and so charging must be accomplished in the remaining 9 to 14 hours. In the next two

years, a number of 200+ mile range EVs are due to be launched at around \$30,000. An immediate example is the 2017 Chevrolet Bolt, offering a range of 283 miles for a price of \$37,500. It is rumoured that Foxconn is developing a \$15,000 EV.

Charged up

Seba accounts for battery life, lithium and other key materials' availability, and carries out cost sensitivities based on best and worst case scenarios. Tesla and BYD use different lithium chemistries and also different critical materials. Tesla's Gigafactory has a capacity of 50GWh per year and plans to increase this by 22.5GWh per year. BYD is building battery manufacturing plants with a total of 34GWh per year; Foxconn and LG Chem are joining forces to build 22GWh per year; Samsung, Nissan, TDK, Apple, Bosch, and VW are also getting into the EV battery manufacturing business. For a 200-mile range, EVs require around 100kWh batteries, and the projected battery manufacturing capacity can supply more than one million cars per year. Using the prediction that the vehicle fleet will fall by 70 to 80 per cent, this is already sufficient capacity to supply all the cars needed.

EVs: an all-electric powertrain has around one per cent of the moving parts of an ICE powertrain. EVs have already shown powertrain life at 2.5 times that of a piston engine, and this is projected to extend to five times. Both the extended life and low maintenance costs drastically reduce cost per mile.

AVs: the key technologies of AVs are: GPS – readily available at low cost. Sensors – particularly LIDAR, which has fallen in cost from \$70,000 in 2012 to \$250 in 2016, and the next generation is predicted to be less than \$100. Computing – in 2000, one teraflop of computing cost \$46m. In 2016, 2.3 teraflops were being offered by NVIDIA for \$59. In 2018 it is predicted that eight teraflops will be available at a price below this. The essential hardware for AVs is already affordable. The cost of

AVs will be further reduced by the need for far fewer models, almost no need for branding, as with taxis, and a much-reduced need for expensive options to fulfil the dreams of owners.

Solar energy. Firstly, PV is a technology not energy. The installation of PV, to gather solar energy has doubled in capacity every two years since 1990, and has experienced a 200 times cost reduction since 1970. Seven more doublings over the next 14 years will bring 100 per cent electrical energy generation capacity from solar.

Can it do this? By 2020, rooftop PV at three to four per cent interest rates will cost less than the transmission of conventionally generated electricity. PV+storage (for example, Tesla Powerwall) will cost less than transmission by 2022, stranding all the utilities' generating capacity. It is predicted that grid parity will be achieved over 80 per cent of the world in 2017.

These costs equate to oil at \$10 per barrel and natural gas at \$5 per barrel equivalent. Bring these cost reduction trends together and transport per mile in the developed TaaS system will be up to one tenth that of owning and driving a car, saving the consumer \$5600 per year.

Figures country-to-country will vary due to variations in the current and future tax on car ownership. Currently in the UK, taxes account for around 25 per cent of the total real cost per mile. TaaS costs, with zero tax on electrical energy, would be around one tenth, of which around 35 per cent would be tax. Could a UK government increase the percentage tax on transport? Could it tax the sun's rays? If VAT were applied to the price per ride of TaaS, then VAT would be recoverable on all the costs of providing that service.

Racing ahead

The revolution that is coming is major, and will disrupt many industries and businesses affecting us all. When? Arbib and Seba predict that it will be complete by 2030. 'The only certainty in life is death. The uncertainty is when.'

As with all revolutions, TaaS offers both threats and opportunities and this will also be the case in motorsport. Will there still be automobile and oil industries to support motorsport? Will Silicon Valley be interested in promoting TaaS using motor racing? Will motorsport become like horse racing – the province of the wealthy for the entertainment of those passionate about the sport, and the gamblers?

Up until now, electrons have been used to move bits (information) around on a large scale. In the future, an intelligent electric-powered TaaS system will use electrons to move atoms (us) around.

I can only offer the advice Steve Jobs was once given by a famous Canadian ice hockey player, when he asked him what made him a such great player: 'Other players skate to where the puck is. I skate to where it will be next.'



The revolution that is coming is major, and will disrupt many industries and businesses. When? It's predicted that it will be complete by 2030

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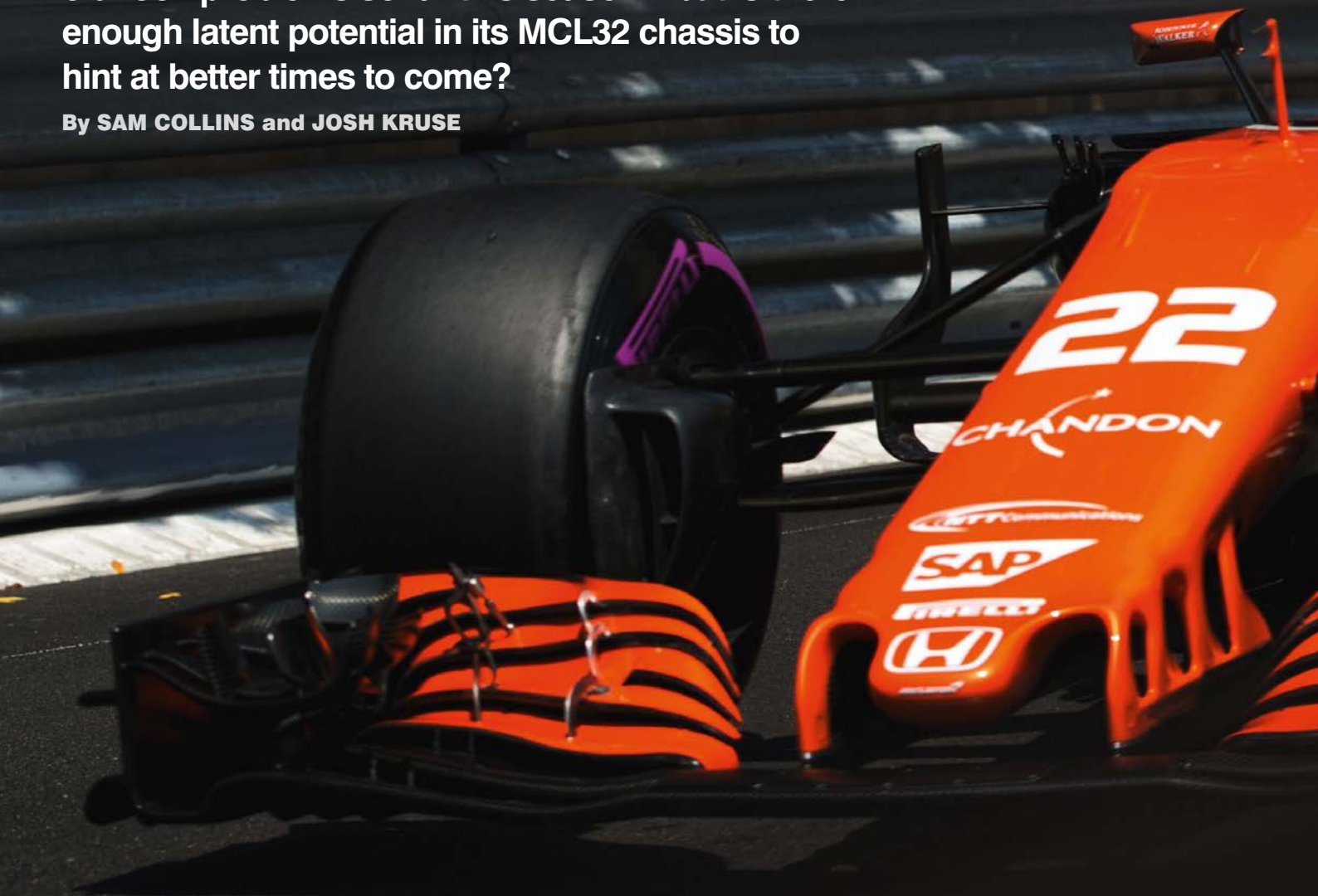
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Burnt orange

The new-look McLaren team has continued with its old-look problems so far this season – but is there enough latent potential in its MCL32 chassis to hint at better times to come?

By SAM COLLINS and JOSH KRUSE



At the time of going to press the season was eight races old and McLaren had scored just two world championship points in Baku. However, there are signs that the chassis itself is rather good

There is something of a new feel around the McLaren F1 team in 2017, as there is within the wider McLaren group. For 35 years Ron Dennis led McLaren after it merged with his Project 4 Racing team in 1980. But just before the end of last season he was removed from his role at the top of the organisation by other shareholders in what some have described as a *coup d'état*.

With Dennis gone major changes have taken place all over the McLaren organisation.

CEO Jost Capito has left after just five months in the job and long-term team manager Dave Redding departed the team shortly afterwards. Meanwhile, Zak Brown, McLaren's new executive director, has made other changes, including the naming convention of the cars. Thus the 2017 McLaren Formula 1 car is the first in 35 years not to be called an 'MP4-XX' (MP4 refers to McLaren-Project 4) and instead it bears the name MCL32.

In overall terms the car is fairly conventional, following some of the directions seen on the

MP4-31 of 2016. However, the 2016 season did not go particularly well for McLaren, it finished sixth in the constructors' championship and its best placings were a pair of fifths in Austin and at Monaco. There were undeniably issues with the MP4-31. Both of the team's drivers complained during the season that while the car had good balance, it lacked grip and performed badly in medium and high-speed corners in particular. So that needed to be sorted first. 'We took the conscious decision at the end of



'We're more competitive from a chassis point of view than we were last year'

last year to try and really understand where last year's car's limitations were,' Matt Morris, chief engineering officer at McLaren Racing, says. 'So we did a lot of track testing towards the end of last year, gathering data and trying to understand the car. That has actually slowed our development down on the 2018 car. A lot of other teams started developing the [2018] car in the wind tunnel quite early last year, so we have actually started on the 2018 car quite late as a result of this. The philosophy [of the MCL32]

was built around what we understood to be the limitations of last year's racecar, so we were really focussing on the aerodynamic efficiency and on the vehicle dynamics.'

One area identified early on in the development of the MCL32 was its overall weight. The new technical regulations introduced at the start of the 2017 season have not only seen downforce and grip levels increase significantly but also the minimum weight of the cars increase to 728kg, the

TECH SPEC

McLaren MCL32

Monocoque: Carbon-fibre composite, incorporating driver controls and fuel cell.

Safety structures: Cockpit survival cell incorporating impact resistant construction and anti-penetration panels, front impact structure, prescribed side impact structures, integrated rear impact structure, front and rear roll structures.

Bodywork: Carbon-fibre composite, including engine cover, sidepods, floor, nose, front wing and rear wing with driver-operated drag reduction system.

Power unit: Honda RA617H (see page 15).

Transmission: Carbon-fibre composite main case, longitudinally mounted; eight forward and one reverse gear; electro-hydraulically operated seamless shift. Differential; Epicyclic differential with multi-plate limited slip clutch.

Clutch: Electro-hydraulically operated, carbon multi-plate.

Suspension: Front – Carbon-fibre wishbone and pushrod suspension elements operating inboard torsion bar and damper system. Rear – Carbon-fibre wishbone and pullrod suspension elements operating inboard torsion bar and damper system.

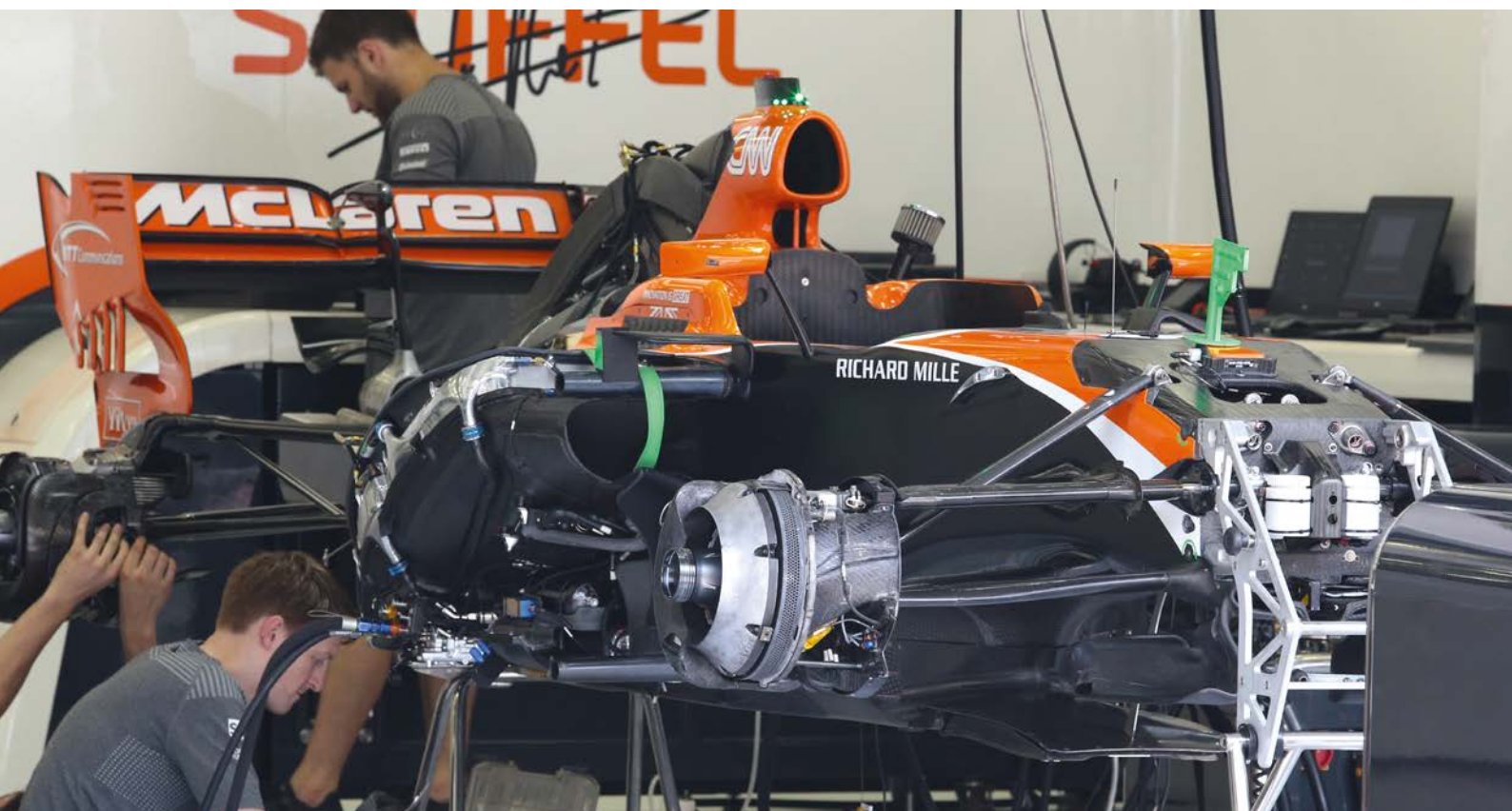
Brakes: Akebono brake calipers and master cylinders; Akebono brake by wire rear brake control system; carbon discs and pads.

Steering: Power-assisted rack and pinion.

Electronics: McLaren Applied Technologies; including chassis control, power unit control, data acquisition, sensors, data analysis and telemetry. McLaren Applied Technologies dashboard.

Cooling system: Calsonic Kansei water and oil cooling.

Weight: Overall vehicle weight 728kg (including driver, excluding fuel). Weight distribution between 45.3 per cent and 46.3 per cent.



As part of a concerted effort to get weight lower in the car (by both McLaren and PU supplier Honda) the coolers, including the charge air cooler, are housed in both of the sidepods

'We passed the crash test a few weeks before we went to winter testing, so it was getting pretty close

highest level ever seen in Formula 1. Yet despite this, weight and weight distribution was still very much on the minds of the McLaren engineers. 'It was a concern when the regulations came out,' says Morris. 'Obviously the loads go up with the bigger tyres and increased aero, so ultimately things have to get bigger – the suspension components have to get bigger. So, we knew it was going to be a concern, and we dealt with it very well. We have made everything strong enough [so that] the wheels don't fall off the car! But also, it finished up with more ballast than what we had last year, so I am surprised when I hear that other people have struggled. But then that sort of says that we have actually done a better job than them.'

Uncertain loads

While there was no doubt that the loads through the car would increase, the amount of that increase was not certain until pre-season testing, far too late to do anything about it. The reason for this was that Pirelli, the sole tyre supplier in Formula 1, had been unable to conduct any representative testing with its new tyres. Some running was conducted by



Suspension components are notably larger than in 2016 due to the much higher loads they must withstand this season

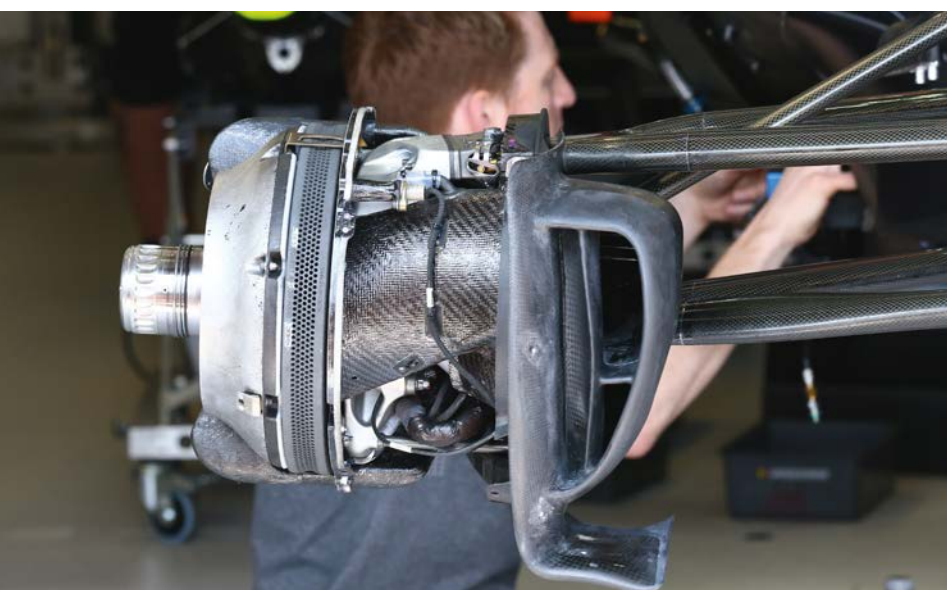
Red Bull, Ferrari and Mercedes using adapted mule cars based on 2014 and 2015 chassis, but the results were inconclusive. Pirelli used data supplied by teams to develop the 2017 tyres and say that the data was pretty accurate. Some in the paddock have said that the tyre data supplied by the Italian company was little more than a 'best guess', but Morris suggests that this was not really the case. 'We had quite a lot of information from Pirelli,' he says. 'We knew what the aerodynamic regulations were, we didn't really know what sort of load we were going to generate, but we had a good idea, and we were

quite conservative when calculating the new loads. We've got such good simulation tools these days that actually it's quite easy once you know the grip the tyres are going to generate, once you know what the aero loads roughly are going to be. It's quite easy to design everything.

'In the past, if you go back 10 years, you tended to take a bit of a guess and then test it in R&D labs to see if it worked,' Morris adds. 'Whereas these days, our tools are so much better now that we're very confident and we actually do very little R&D testing, because we trust the tools so much. We calculate what



Front bulkhead showing torsion bars and inboard suspension pick up points. In common with the rest of the 2017 Formula 1 field the MCL32 uses pushrod actuated suspension at the front and pullrod at the rear



The front brakes on the MCL32. McLaren is unique amongst the Formula 1 teams in that it uses calipers from Akebono. Braking distances have reduced with the introduction of the higher downforce regulations this year



McLaren says it has invested much time in developing the aerodynamics around the bargeboard space and it sees this newly opened up avenue as an area of further exploitation during this season and in years to come

‘Out of all the new regulations, it is the bargeboard area which has actually been the biggest change’

loads the suspension needs to accommodate then we just get on and design it, and then 99 times out of a hundred it works.’

Some teams decided to counter the uncertainty over the tyre data by building a large amount of adaptability into the car, but McLaren apparently did not go as far in this direction as some of its rivals. ‘We did build some flexibility in there, but we did a lot of work towards the end of last year trying to understand what the tyres really wanted,’ Morris continues. ‘Ultimately, if you build adjustability into the car it costs you in terms of weight and design freedom, so we really tried to avoid that. There were a few things in terms of suspension geometry subtleties that we had options on, but in terms of the base car architecture, we chose one route and went for it.’

Shifting mass

It was not just the total weight of the car that was a concern, but where the weight was located. The technical regulations restrict the weight distribution to a narrow window, so the centre of gravity height becomes a focus. ‘It is one of the key factors that you have to consider when you’re laying out a Formula 1 car,’ Morris says. ‘From a chassis point of view it’s something that we put a big focus on for this year, and also pushed Honda as well in the same direction. I think what we have done a good job across the team, both the chassis and the power unit team, in getting the centre of gravity down and also just general weight saving. That in itself brings you ballast benefits as you can put the ballast on the car where you want. Also, it gives you a centre of gravity benefit because obviously you can put the ballast at the lowest point. Speaking to some people at other teams, quite a lot of them have struggled just to get the car under the weight limit, where we’ve not been anywhere near that. We’ve had a lot of ballast to spend; either on reducing the centre of gravity or on suspension systems or aero upgrades, so it’s been quite a good position to be in.’

In terms of suspension, the MCL32 is fairly conventional, with pushrod actuated front torsion bars and a pullrod actuated rear (as is every 2017 F1 car). But the internal suspension layout is more complex, though Morris is unwilling to tell us much about its operation.

During pre-season testing the FIA issued a technical directive that restricted certain



'If you build adjustability into the racecar it costs you in terms of weight and design freedom, so we really tried to avoid that'

types of suspension systems many teams were using, which were designed to change the rear ride height at different speeds. 'That had a little bit of an impact on us,' Morris says. 'I mean, it's not really stopped us doing anything that we were doing, it's maybe stopped some of the development items that we had in the pipeline. It has sort of closed one door but there are other ways of getting to the same end game, if you like, and that's the great thing about

Formula 1, the rules change, and because we've got so many bright, passionate engineers, they are like, "Okay, how do we find another way to do whatever we were doing and still stay in the regulations?" It's changed a little bit of what we've done, but it didn't affect the racecar performance in any way.'

The biggest changes to the technical regulations for 2017 were related to aerodynamics, with a new package of bodywork

rules designed to make the cars aesthetically more pleasing as well as significantly increasing downforce. A lot of work has been put in to the front ends of all of the cars and McLaren is no different, with the swept back multi-element front wing suspended from the nose of the car by a pair of panels full of what could be described as slots, though Morris plays down the importance of this distinctive feature of the car.

'In terms of aerodynamics, the nose is not a big player, it's sort of something that you decide on and then design the front wing and the car around it, rather than it being an aerodynamic enabler,' Morris says. 'You see that across the entire grid, there's not often people changing noses a lot during the year.'

Crash and learn

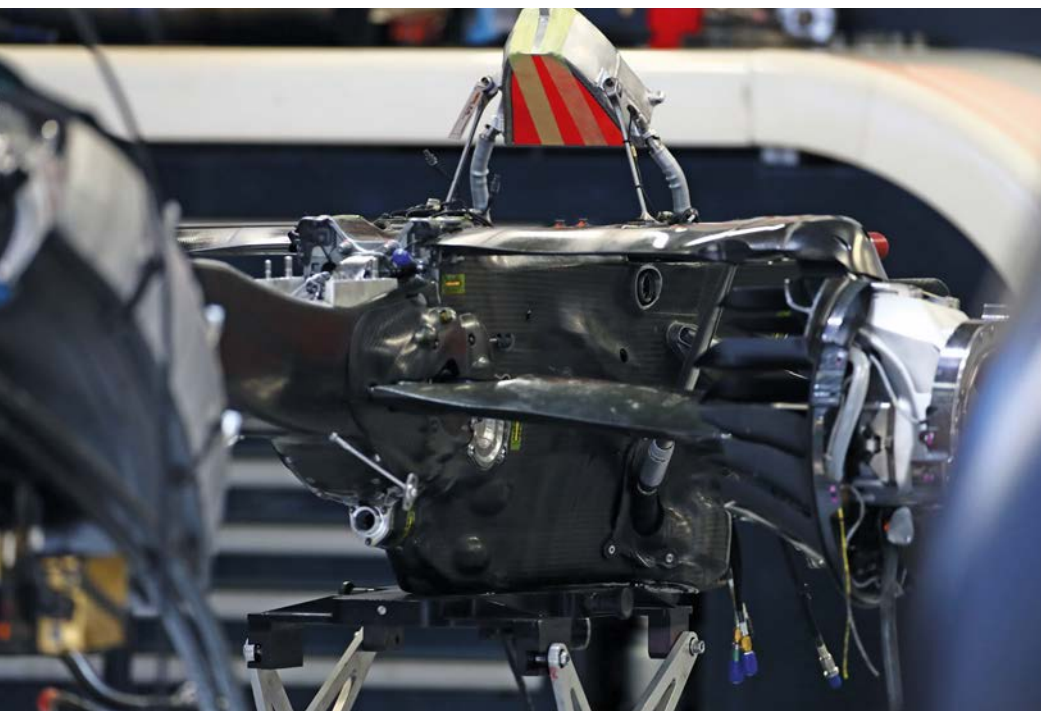
'The biggest challenge with the nose is just getting it through the FIA crash test,' Morris adds. 'It's been a little bit easier this year because the minimum nose length has increased, so in previous years everybody was designing the shortest nose you could get in the regulations. When you have a short nose, you then have to absorb the energy over a shorter distance, so it makes it more of a challenge, whereas when the nose is longer, you can absorb that energy over a longer period, therefore you're not pushing to the maximum g levels that you have to stay below. So that's the first challenge.'

McLaren is believed to have conducted its crash tests at the Cranfield Impact Centre in the early months of the year, but the team apparently pushed the design of the nose structure and the timetable right to the limit. 'It's always quite a traumatic time during the year because we always leave it until the last minute, like we do with everything,' Morris says. 'That doesn't give you a lot of margin to do modifications. I think we passed the test a few weeks before we went to winter testing, so it was getting pretty close. But it's just one of those things you almost push too far knowing that you may as well come at it from a failure point of view, then you'll finish up with something that's just legal from a crash point of view, and that's the lightest variant that you can produce.'

Nose duct

Like many cars on the 2017 grid the McLaren features a duct in the nose, with air scooped from the underside and fed via a channel to the upper side of the car. 'I think most people tend to have this, it's just about controlling the losses that get generated, and moving the losses from one area and putting them into another area,' Morris says.

In terms of overall performance it is the swept back (by regulation) front wing



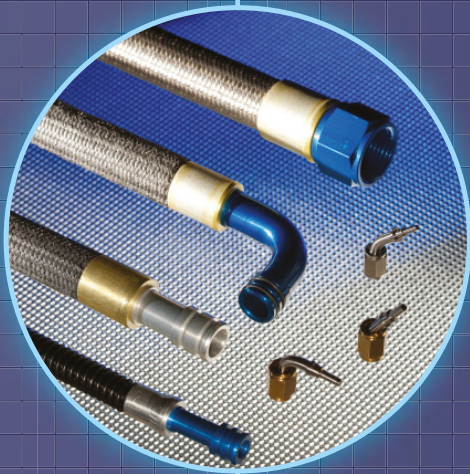
Composite transmission casing. The eight gears within it are selected via an electro-hydraulically operated seamless shift



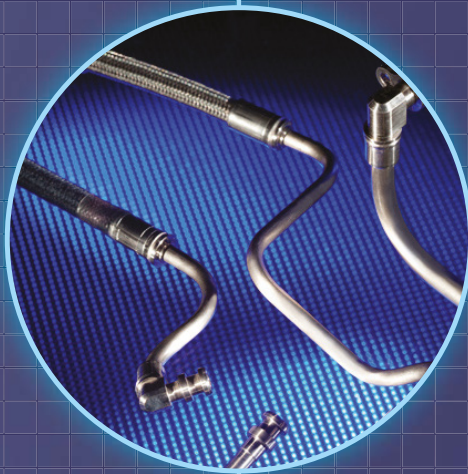
Note slots in the panels from which the front wing is suspended. McLaren says front wing treatment carries over from 2016



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The total time the engine is at full throttle has increased significantly



There are no coolers high up and on the centreline of the car so the MCL32 does not need extra ducting within the roll hoop

T-total

From the outset of winter testing an array of small T-bar winglets started to appear on the rear of Formula 1 cars up and down the grid, and the McLaren is no exception, with a biplane solution linked at the outer end with a semi circular section.

'It's a bit of a silly thing, really,' says Morris. 'It's annoying because everybody knew, so when the new rules were written, there's a little box that was missed. When you're moving all the boxes around, there's a little box that wasn't covered, which is that slot. Towards the end of last year, most of the teams realised it was there, and we actually went to the technical

regulations meeting and said, "listen, we've missed a trick here, we just need to change one number in the regulations, just to cover this." And it sort of shows you the madness, sometimes, that rather than just say, "okay, let's change it," some said, "we're not going to agree," and it was like; okay, everybody's going to turn up with these little wings and what have you.

'It's a direct downforce generating tool, but it's not that powerful,' Morris adds. 'So some circuits, like here [Monaco], everybody will be running them, maybe elsewhere some people will take it off, but yes it is just a downforce adding tool.'



The MCL32 has followed the F1 fashion for 2017 with a T-bar fixed to the trailing edge of the engine-cover fin. McLaren's example is a biplane and the team tells us it's there to generate downforce, though it admits it's not a powerful device

that Morris points to as a key performance differentiator, and something that despite the rule changes has at least in part carried over from the MP4-31. 'Although the regulations have changed quite a lot it's mainly just the box getting bigger, and a slightly different shape, than what you have been developing. In terms of the front wing philosophy, and how it affects the car, it's not really changed,' he says.

'We've got a philosophy that we've had for the last couple of years now, since Peter Prodromou joined us as head of aero, and we tend to stick with that,' Morris adds. 'If you look at our front wing concept, yes it's bigger, but actually it's a very similar concept to that we were running last year, as well.'

Barging through

In the wake of the front wheel there is another area of major aerodynamic development and again one that has been opened up by the new regulations. 'Out of all the new regulations, it is the bargeboard area which has actually been the biggest change,' Morris says. 'It's sort of opened up a new area, almost that we've not been allowed to develop in the past, and it's an area that we've invested a lot of time in developing. It's also quite a critical part of the car, the interaction between the front and rear of the car, so obviously all the airflow coming off the front wing is then dealt with by that whole area, and then manages to flow to the rear of the car.'

'So this is a very important and quite powerful area, and I think if you look at other teams, it's an area that is being, and will be, developed through the course of this year and beyond,' Morris adds. 'It's quite young in its development, whereas front wings, we've developed in a box for quite a few years now. But that bargeboard area is a new playing area. We do pay attention to everything on the racecar, but this is certainly an area where we see good performance potential.'

Wake up

Despite the opening up of new areas of technical development, the 2017 technical regulations have come in for some criticism because of the ever increasing level of aerodynamic complexity of the Formula 1 cars, something many believe is reducing the quality of the racing as cars are too sensitive to running in the wake of other racecars.

'The new regulations obviously brought more aerodynamic load, it has increased by quite a high percentage,' Morris says. 'I think that also tends to make the aero characteristics a bit more peaky, so that's just something that you have to manage and you have to try to develop around. It's quite easy to add dirty downforce, but having something that's more controllable,



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'We decided the best compromise was to keep the coolers nice and low'

and the drivers can make the most of, is the bigger challenge with these regulations.'

One of the other impacts of the new aerodynamic regulations – as well as the introduction of wider tyres – is that the total percentage that the engine is at full throttle has increased significantly, and that has wider implications than just those directly influencing the power unit itself. 'The cooling requirements have changed this year, but not by a massive amount. Cooling is an interesting subject because yes, the full throttle time is higher, but

then the average speeds are higher as well. So there's obviously more air going through the car, so some of that balances out, and again, it was one of the items that we had to do a lot of simulation on,' Morris says.

The MCL32 houses coolers in both sidepods, including the charge air cooler. Unlike many teams on the grid McLaren has not utilised coolers on the centreline of the car fed by ducting on the roll hoop. 'You're always in a trade between air and packaging, so obviously with the bodywork regulations you tend to

avoid [space] above the engine and the top of the engine cover, which is sort of free space,' Morris says. 'So you can put coolers there. We've put coolers there in the past, which then allows you to shrink the sidepods even more, but if you put heavy coolers up there it affects your centre of gravity. So with that trade between aero packaging and centre of gravity we decided that the best compromise was to keep all the coolers nice and low, so that's why we've not got anything above the engine.'

Lap time gains

Looking over the whole racecar that same trade-off applied in different areas of the car has resulted in the characteristics that Morris highlights as the best qualities of the MCL32. 'The two elements I'm most proud of the team achieving is the centre of gravity height and weight, because I just know that other teams haven't achieved what we've achieved – and that's lap time. You can talk about how much aero delivers in terms of performance, but if you're overweight that's a pretty simple sum to do in terms of lap time. Also, the centre of gravity translates into lap time, so that's a great trait of the car. I think also, from an aerodynamic point of view, and a vehicle point of view, we've made a car that's very driveable, which was backed up by Jenson Button getting in it for the first time [his one-off race at Monaco]. It was clear we had done a good job in making a well-behaved car. A question that we always ask the drivers after every debrief is "what do we need to do to make the car go faster?" It's always the same answers; more aero load, lower centre of gravity, and better ride.

'But I think the good thing this year is that last year we struggled with high speed performance, and we were quite open about that, that was a big weakness of the car,' Morris says. 'We spent a lot of time towards the end of last year trying to understand why that was and where that was coming from. We have done a good job of getting rid of that aspect. That's the big difference, and that's why we're more competitive, from a chassis point of view, than we were last year.'

Power woes

But not everything about the MCL32 is ideal. The power unit is still causing problems (see p22) and eight races into the season McLaren was sitting near the bottom of the table having scored just two points, despite some solid performances in qualifying. The team is clearly looking to move back up the grid and return to a situation where it is capable of winning races again, something it has not done since 2012. Things might have changed at McLaren, but there is still a great deal of work to be done before it is back to where it belongs.

Pronto-print

Here's an insight into the mind of Neil Oatley, who was the chief designer behind five championship winning McLaren's during the 1990's and is now the director of Design and Development. 'The quicker we can iterate, the faster we will be. One of my biggest challenges is to convert ideas into real parts in the shortest time available. In the '80s, we used to manufacture one front wing a year and now we manufacture five completely new designs. It's unlikely that the wing will remain the same from one race to another. Using rapid prototyping

and 3D printing we can bring components to the car quicker.'

In January this year, McLaren joined forces with Stratasys, global leaders in 3D printing. Under this partnership Stratasys revamped McLaren's suite of 3D printing solutions by installing the latest FDM and PolyJet machines, doubling the capacity within McLaren. 'We introduced a new front wing on Fernando [Alonso]'s car in Australia this year, but we needed a rear wing to go with it,' Oatley says. 'We had one in the pipeline that was scheduled to start in Russia a month later. However, we needed to bring it forward by two races so we discussed different manufacturing techniques which led us to 3D printing. That design was run on Friday in China, so we manufactured a rear wing within two weeks, which is impressive.'

Time fuse

The majority of McLaren's 3D printing is done on FDM (fused deposition modelling) machines where thermoplastic filament is heated to a semi-liquid state, extruded and deposited in fine layers along an extrusion path; building a part from the bottom up. The versatility of this process means it can manufacture structural components that can either be used for tooling or carbon fibre composite parts for the car or wind tunnel model.

Then there is Polyjet 3D Printing, which again builds a part up in layers but uses tiny droplets of liquid photopolymer which is then cured by UV onto a build

tray. This process can print up to six different materials at the same time, generating a single part which can be made up of a variety of colours and hardnesses. This is particularly useful to visualise the design of components such as a steering wheel, which has over 45 buttons controlling 600 performance parameters and is upgraded every three months.

'Polyjet is relatively new to us so we're still experimenting with its capabilities at the moment,' explains Oatley. 'However, we can print designs at low cost within a few hours which helps us to visualise intricate parts and promotes discussion.

'FDM allows us to manufacture tooling which we use extensively and compared to traditional methods, this process is taking days off jobs, which means we can get components one race earlier.'

Trackside 3D

The capabilities of 3D printing are becoming so important within a race weekend that teams are now taking 3D printers trackside. McLaren shipped a Stratasys FDM machine to Bahrain this year for the very first time and will continue to use it to print small car components at the track for the rest of the season. 'Of course, you have to make parts that are feasible with the materials and time you have available at the track,' says Oatley. 'However, most of the parts that come to the car are relatively small, but adding them all together across a season can lead to a significant gain.'

Gemma Hatton



Stratasys Trackside Printer. This FDM machine has been used at the circuit by McLaren already this year and the technology is becoming common in F1

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Infernal combustion

This season was meant to be the year Honda came good in Formula 1, but its new power unit has once again failed to deliver. *Racecar* delves deep inside the RA617H to find out why

By SAM COLLINS

The removal of the performance upgrade token system presented a great opportunity for Honda to take a major step forward

Soichiro Honda, the founder of the company that bears his name, once said: 'Many people dream of success. To me success can be achieved only through repeated failure and introspection. In fact, success represents one per cent of your work, which results only from the 99 per cent that is called failure.'

For a man who believed that racing improved the breed he would look at the current efforts of his company with great interest, because Honda's return to F1 has been defined by failure. The 2017 season has brought this into acute focus, particularly as the McLaren cars fitted with the Japanese power unit failed to score a single point in the first seven races of the year. Even Sauber, using an obsolete Ferrari power unit, has points on the board.

This season was meant to be the year it all changed for Honda. The new technical

regulations forced every manufacturer to create completely new power units, and the removal of the performance upgrade token system seemed to present a great opportunity for Honda to take a major step forward.

Honda's 2017 power unit, dubbed the RA617H, has very little in common with either the RA615H or the RA616H used in the previous two seasons. Indeed, the only major similarities with the combustion engine is that it is a turbocharged V6 mated to a hybrid system featuring an exhaust energy recovery system and a kinetic energy recovery system. 'Our target was to dramatically redesign the power unit for better thermal efficiency,' Yusuke Hasegawa, head of the Honda F1 project and it's chief engineer, says. 'Another major objective was to reduce the overall weight of the unit and lower the centre of gravity of it. So it was very clear that we had to have a completely new design

for the RA617H. Almost everything is new or substantially modified, beyond the things which are fixed by the regulations. We also introduced a new combustion system in order to produce more power. So, from an overall package point of view we have made a decent step forward.'

Fully loaded

One major challenge that all the power unit designers in F1 had to tackle was structural, as the loads passing through the cylinder heads and crankcase have increased by at least 20 per cent in 2017, and as fully stressed parts it's clear that all the load carrying parts would have to be made both stiffer and stronger. But with a brief of making the power unit lighter, too, this presented a major challenge for the Honda R&D engineers at Sakura City, Japan. As F1 power units have a total minimum weight limit of 145kg this might suggest that the RA616H was



TECH SPEC

Honda RA617H

Capacity: 1.6 litres

Cylinders: Six

Bank angle: 90-degree V-angle

Number of valves: 24

Maximum speed: 15,000rpm

Max fuel flow rate: 100kg/hour
(above 10,500rpm)

Fuel consumption: 105kg 'lights to flag' regulated fuel capacity limit

Full injection: Direct injection, single injector per cylinder, 500bar max

Pressure charging: Single-stage compressor and exhaust turbine, common shaft

Fuel and lubricants: BP Castrol

Hybrid system: Integrated Hybrid energy recovery via motor generator Units; crankshaft coupled electrical MGU-K; turbocharger coupled electrical MGU-H.

Energy store: Lithium-Ion battery, between 20 and 25kg; maximum energy storage, 4MJ per lap.

MGU-K: Maximum speed, 50,000rpm; maximum power, 120kW; maximum energy recovery, 2MJ per lap; Maximum energy deployment, 4MJ per lap.

MGU-H: Maximum speed 125,000rpm; maximum power, unlimited; maximum energy recovery, unlimited; maximum energy deployment, unlimited.

somewhat overweight, it is unlikely that much of this weight saving came from the battery, as this has a minimum weight of 20kg and a maximum of 25kg, but weight savings could be made in many other areas of the unit such as the MGUs and the ancillary parts like pumps.

'We have not had any issues with the increased loads passing through the engine, so that is a good point of this project,' Hasegawa says. 'It is true we did not have certain data on what the loads would be but we had some good simulation data, so that let us have some targets and it has not been a big problem. Our trade-off between being too safe in terms of the loads and being overweight, or being too light and marginal on reliability, has been pretty good. We took a reasonable compromise and I think we got it just right, especially in terms of stiffness. We did not change the material we use for the crankcase but we did a lot of optimisation work

to get the best solutions. So from a structural point of view I think we are pretty good. I am really pleased with this area of our project.'

But it was not just reducing the overall weight of the power unit which was a major target of the RA617H project, lowering the overall centre of gravity was a priority, too. The technical regulations give a minimum power unit centre of gravity height of 200mm above the reference plane, and the RA616H centre of gravity was some way above that.

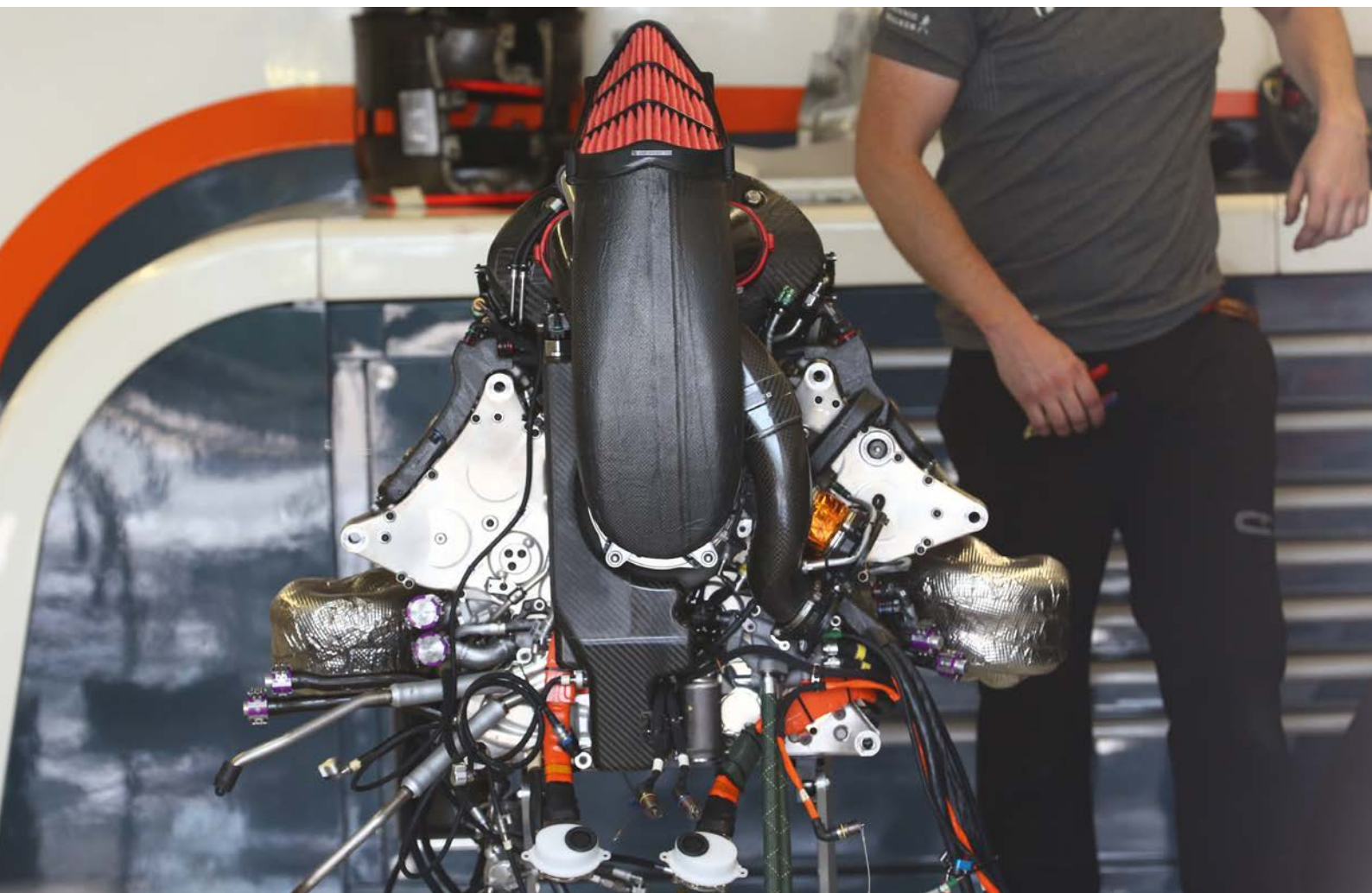
Gravity central

Moving the MGU-H lower in the car was key to getting the centre of gravity lower. Honda has, since it entered Formula 1, used a split turbocharger concept with the compressor toward the front of the V6 engine and the turbine at the rear with the MGU-H sat in between, all three components linked by a

common shaft. 'I can't give you the exact details, of course, but the centre of gravity on the RA617H is some centimetres lower,' Hasegawa says. 'Last year the compressor was positioned just too high up in the car and that had a detrimental effect on car performance. The compressor was installed in the V of the engine in 2016, but this year we have made the turbine, MGU-H and compressor layout longer so now only the MGU-H sits between the banks of the engine. This makes the internal combustion engine slightly longer than the 2016 one, if you include the turbocharger, but what this allowed us to do was lower the MGU-H dramatically. It's a massive change on the centre of gravity and allows us to lower it by centimetres. That is the best thing about this power unit, it is very lightweight and has a low centre of gravity.'

Improving the thermal efficiency of the power unit is really the key to increased





The RA617H. Improvements over the 2016 PU include a lower centre of gravity, thanks to the MGU-H being moved, while the ICE features a completely new combustion concept

performance in the current era of Formula 1 so it is no surprise that this was another major target for the RA617H. Limits on fuel flow (100kg/h) and total fuel consumption (105kg) mean that extracting the maximum amount of energy from the fuel is critical, and this has seen all four power unit manufacturers extensively researching technology in this area. The result is that compression ratios have risen dramatically, to diesel-like levels. The RA617H is believed to have a compression ratio of somewhere between 16.5:1 and 18:1. Such high compression ratios and the quest for great efficiency have also seen diesel style pre-chamber ignition being investigated by all the power unit manufacturers.

'We have developed a similar technology for the 2017 V6 engine and that means that we

have a completely new combustion chamber concept, but I cannot reveal too many details of this new technology,' Hasegawa tells us.

'We deliberately don't reveal much about our combustion system,' he adds. 'But I can say that we are trying to develop such systems [high compression ratio/pre-chamber ignition] for mass production, and obviously what we are doing in racing should be relevant to our mass production, too. The lessons we learn in racing can transfer, but the environment is different, because production cars do not have dedicated fuel like we do in F1. In general technology terms, what we learn in Formula 1 is shared within Honda R&D, we are not doing technical papers yet. But, of course, inside HRD there is a lot of sharing going on.'

Fuel's gold

The fuel used in the Formula 1 V6 engines is crucial to getting the greatest efficiency. As the current generation of engines typically have a very lean burn, specially formulated anti-knock additives in the fuel are crucial to good performance. Honda had developed all of its previous power units using Exxon-Mobil fuel specifically developed for use with the Honda V6, but ahead of the 2017 season a very late switch to BP Castrol fuel was needed, after

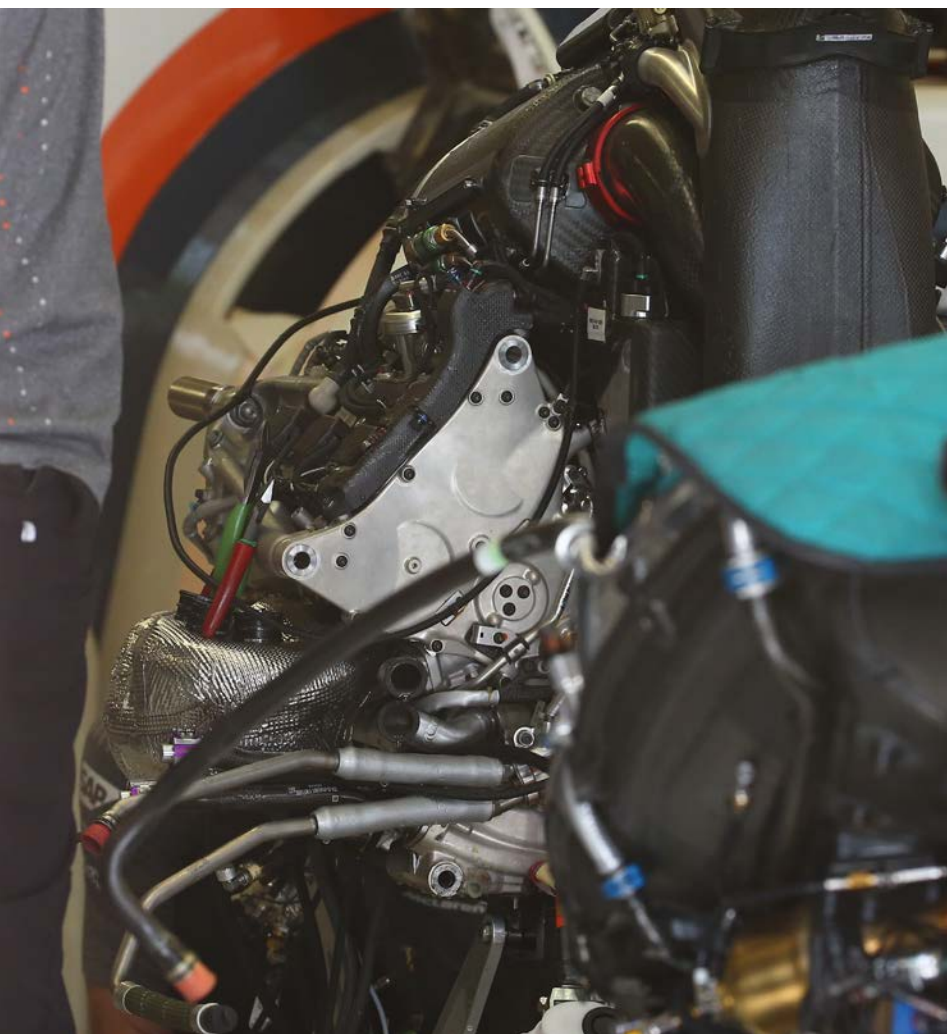
McLaren signed a new partnership deal with the British petrochemical giant.

'We started the project with the new combustion concept on the mono-cylinder engine,' Hasegawa says. 'The timing is not exact as we always have research projects ongoing and they are not always targeted at introduction in a particular season. But I think you could say around last May we started to finalise the 2017 concept. When we were doing that work on the mono-cylinder we were of course using Exxon-Mobil fuel. That made us really concerned in terms of performance when the switch happened, we had to ask BP to modify the fuel to suit our engine. The engine was already done, so they had to modify the fuel, but we are very grateful for the work they did.'

It seems that the real focus of the RA617H was performance, but this emphasis perhaps exposed something of an Achilles heel in terms of reliability; just six races into the 20 race schedule and the McLaren-Honda drivers had used up their maximum allowance of just four turbochargers and MGU-H per season. One of the two McLarens had also exceeded the maximum number of energy stores and control electronics permitted.

Many in the industry have openly been wondering why, in its third F1 season of the

'We took a reasonable compromise and I think we got it just right, especially in terms of stiffness'



One of the major changes to the power unit is the relocation of the compressor to the front of the engine block

current era, Honda is still suffering so many reliability problems, but these issues are apparently not easily predicted.

'I have to be blunt, we didn't do a good job in terms of reliability, but technically speaking some of the areas where there have been issues were fine on the dyno,' Hasegawa says. 'When we tested them on the bench there was no problem, but in the car with the transmission and the tyres the behaviour in some areas is completely different. So on the dyno you don't see big lateral or vertical accelerations, but in the real car this has an effect.'

New challenges

The rework of the layout of the power unit to lower the centre of gravity may also have had unintended consequences in terms of reliability of some parts, notably the MGU-H. 'The MGU-K and MGU-H themselves have actually largely carried over from the RA616H, at least conceptually, but there are of course small differences in packaging. The thing you have to remember is that these parts do not work in isolation, the whole package has changed, so sometimes we are finding new things and we have to investigate,' Hasegawa says.

But despite its reliability troubles Honda's engineers are not discouraged and are pushing

hard to improve the situation, though they have no doubt that what has been delivered to date is simply not good enough.

Yet they also know where the performance gains will come from. 'It is clear that the ICE, specifically the engine power, is the biggest issue and is the biggest area with room for improvement,' Hasegawa says. 'There are a number of reasons for this but in short we simply did not have enough time to prepare for the introduction of this very complicated new technology in the engine [the new combustion solution]. So we are focussing on that now, but we also understand that we need to improve all areas of the power unit, and keep improving all areas until we are winning races.'

Positive signs

Soichiro Honda would probably have a lot of respect for this situation. In 2014 Honda could barely get its Formula 1 power unit to run, in 2015 and in 2016 it slowly improved. In 2017 at least one McLaren-Honda is a regular in the top 10 qualifying shoot out, something which seemed almost unthinkable at some points in the 2015 season.

Maybe, just maybe, Honda's getting close to the end of that 99 per cent of failure its founder once spoke of, then?



Honda's F1 facility in Milton Keynes in the UK. The Japanese organisation expanded the workforce here in September 2016

Seeing beyond 2020

The future of Formula 1 power units is unclear. A new set of technical regulations is due to be introduced in 2021, but there remains great uncertainty about what shape they will take. Some in the sport have called for units which are far less complex, while others have even suggested a return to normally aspirated V8s.

'The discussions, of course, are ongoing, but there are two things we are expecting,' Hasegawa says. 'Firstly, Formula 1 power units will still have a very high level of technology, it must remain the pinnacle of technology, and secondly the technology must also have relevance to production cars. If it is different to that and there is a very low level of technology we will be very disappointed. Having a hybrid system is part of that, it is necessary, and I think all of the manufacturers have the same opinion on it. [But] I know there are some other opinions out there, some saying that a normally aspirated V8 engine would be a better idea, for example.'

Spec savers

Suggestions have also been made about increasing the amount of spec parts shared between the PUs with the MGUs frequently mentioned as potential common parts.

'The power unit must be a Honda power unit. Of course, that does not mean some parts cannot be common or supplied externally, actually that is normal even in mass production,' Hasegawa says. 'Sometimes we purchase in motors, for example. Under the current regulations if every power unit shared the same MGU-K, for example, it wouldn't have a big effect due to the regulatory restrictions, right now we all achieve the same performance at the moment, more or less. If those rules are relaxed and it was an area which offered technical development and performance gains, then we would absolutely insist that we could develop our own. It depends on what the rules are.'

The outline of the new technical regulations have not yet been released and it seems that there is no consensus over the form they will take. But for some the clock is ticking. 'I think we need to have real clarity of the 2021 regulations by the end of 2017, or early in 2018 at the latest. If there is to be a drastic change then we need time to prepare. The limit would be before the summer break in 2018,' Hasegawa warns.

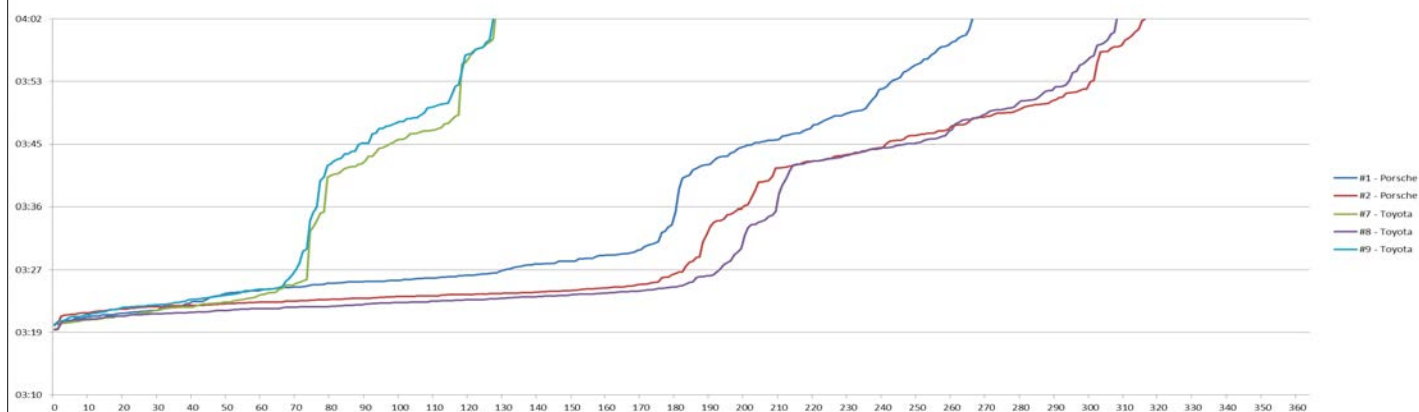
Strike three!

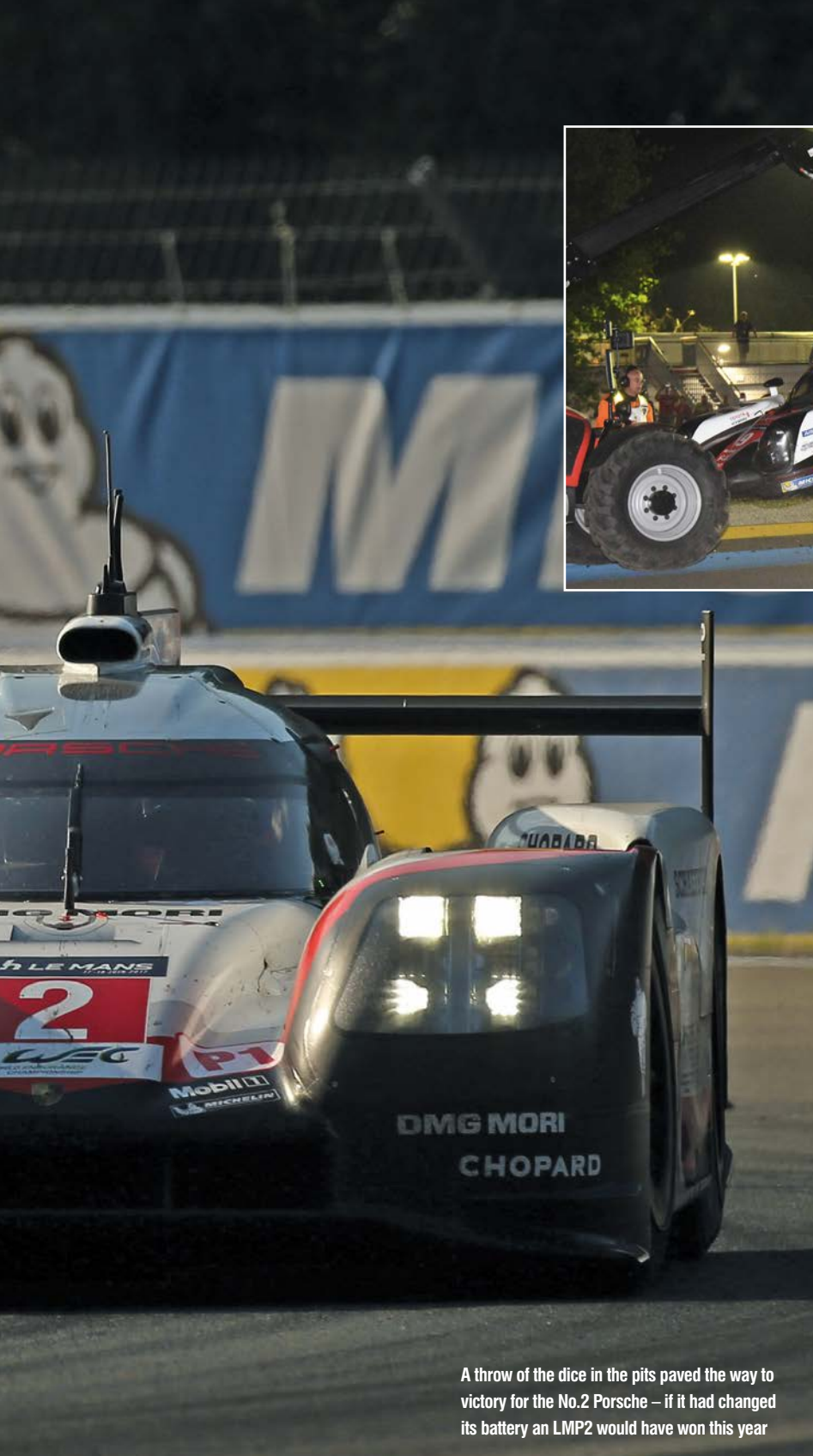
Porsche took a third successive win at Le Mans this year – but the hybrids were very nearly upstaged by the LMP2s. We crunch the numbers from an extraordinary race

By ANDREW COTTON and PAUL TRUSWELL

The gamble worked and the Porsche then ran reliably to the end of the race

Rising average lap times





A throw of the dice in the pits paved the way to victory for the No.2 Porsche – if it had changed its battery an LMP2 would have won this year

A strategic decision taken by the Porsche team on Saturday afternoon delivered the manufacturer its 19th victory overall at Le Mans, its third in succession and one that means it will keep the Le Mans trophy. The odds were stacked against it, though, as it was slower over a single lap, did not have the downforce to challenge the Toyota in wet or dry conditions, and had only two cars; for the first time Toyota entered a third and therefore had more options strategically.

But ultimately the race result came down to a strategic risk taken by the Porsche team when

it had the option to change the battery of the No.2 919, following a front hybrid motor failure, or not changing it. Toyota, with the failure of a similar component, did not have that option, and so finished the race eighth overall.

The build-up to the race had been extraordinary. The test day was dry throughout, and Toyota was comfortably quicker over a single lap than Porsche. Kamui Kobayashi set a time of 3m18.132s, 3.3s faster than the quickest of the Porsches in Earl Bamber's hands.

TMG predicted that it could set a qualifying lap in the 3m15s bracket, far quicker than

Toyota once again endured a miserable Le Mans. The No.9 car was taken out after a coming together with an LMP2 (above) while the other two TS050s suffered from various mechanical maladies

anything Porsche could manage and that, in part, was what set off the rumours about Porsche leaving at the end of the 2017 season. Three seconds in outright pace is a lot to make up in a stable set of regulations, and would require a new battery, hybrid system, chassis and engine, none of which are believed to be on the table yet. Porsche's 2018 car is in development, but whether or not it has all of that and can close that gap is another matter.

Hot laps

There was no rain between the test day and the race, which meant that the track was in a unique condition for the cars during first practice on Wednesday. With no rain and a heatwave that hit the circuit from Monday of race week, it was a tough build-up to a race and another potential problem for the cars and the strategists. With temperatures predicted to rise above 34degC on Sunday afternoon, teams worked out their tyre strategies and driver stint times, which would be limited for cars that were not fitted with air conditioning systems. This being racing, there were a number of alternatives for that strategy; in Toyota's case it had an air conditioning system, but it cools the batteries rather than the driver, so does that count?

What was also interesting was that, because of the support races, the circuit was closed all day on Thursday. That meant a lot of running with race rubber on the track, and no public access on the section from Tertre Rouge to the entrance to Porsche Curves. According to Dunlop, this was 'worth seconds' in qualifying, and partly explained the pole position lap of Kobayashi in the Toyota TS050. Once again, the Japanese driver beat the simulated lap time when he became the fastest ever around the fabled 13.629km circuit at 3m14.791s, an average speed of 251.9km/h.

Neel Jani was third fastest in his Porsche, a full 2.4s slower than Kobayashi, but on the



'It is the toughest race in the world and not a demonstration run'



The Jackie Chan DC ORECA LMP2 that finished second overall. Its drivers had been instructed to look after the brakes from the start of the race

long runs Porsche believed that it had a chance against Toyota with tyre management. In the heat, both manufacturers were affected although Porsche believed the Toyota would suffer more than it would. In the cool of the night, Toyota would clearly have an advantage, according to both the manufacturers, and that was going to be the deciding moment of the race. By Sunday morning, if Toyota had opened enough of a gap, it could then start to cruise to the flag, and deal with the unusually high ambient and track temperatures.

The race unfolds

The race for overall and LMP1 honours consisted, broadly, of three phases. Initially it was a contest between the Toyota of Conway, Kobayashi and Sarrazin and the Porsche of Neel Jani, Nick Tandy and Andre Lotterer. The second phase, after the retirement of the Toyota, concerns the period when the No.1 Porsche had a comfortable lead for more than 10 hours, but it is interesting to look at its pace relative to that of the two cars delayed by front motor changes: the No. 2 Porsche driven by Timo Bernhard, Earl Bamber and Brendon Hartley and the No. 8 Toyota of Anthony Davidson, Kazuki Nakajima and Sebastien Buemi.

The final phase covers the last four hours, after the retirement of the Porsche of Andre Lotterer following an engine failure, and follows the chase by the No.2 Porsche to hunt down the LMP2 Jackie Chan DC Racing ORECA of Oliver Jarvis, Thomas Laurent and Ho-Pin Tung.

Throughout the race, both Toyota and Porsche stuck rigidly to a plan to change tyres every three stints. In the early stages of the race

Evolution of gap between Toyota No.7 and Porsche No.1 up to lap 150

Time of Day	Driver #7	Driver #1	Lap no.	Gap
16:16	Conway	Jani	22	2.4s
17:25	Kobayashi	Tandy	40	28.7s
19:31	Kobayashi	Tandy	76	47.0s
21:21	Sarrazin	Lotterer	102	22.2s
22:30	Conway	Jani	120	28.0s
00:15	Conway	Jani	150	1m 11.2s

Evolution of gap between Porsche No.1 and Porsche No.2; lap 168 to lap 317

Time of Day	Driver #1	Driver #2	Lap no.	Gap
01:50	Tandy	Bamber	168	1h 05m 41s
04:30	Lotterer	Hartley	212	1h 03m 01s
06:15	Jani	Bernhard	237	1h 03m 27s
10:30	Tandy	Hartley	307	1h 00m 16s

(Note: the MGU change for #2 cost 1h 05m 10s in pit lane)

Evolution of gap between Oreca No.38 and Porsche No.2; lap 319 to lap 367

Time of Day	Driver #38	Driver #2	Lap no.	Gap
10:08	Jarvis	Bamber	288	14m 30.1s
11:30	Jarvis	Hartley	309	11m 41.2s
13:00	Laurent	Bernhard	333	3m 45.2s
14:00	Tung	Bernhard	349	-23.1s
15:00	Tung	Bernhard	366	-4m 11.3s

(Note: change of lead happened on lap 348 at 13:54)

this meant 39 laps, or about 2h 15m driving for each driver on a single set of tyres.

In the first triple stint, it was Jani versus Conway, and during the third segment, Conway was able to extend the margin by 13 seconds. Close analysis of the data reveals that Jani lost out in the 'slow zone' that had been established in the Porsche Curves to deal with the recovery of the Roman Rusinov G-Drive ORECA after its crash with the Proton Porsche. Or, more accurately, it lost out in the braking area into

this slow zone, and the acceleration out of the slow zone. Amazingly, Jani lost two seconds on Conway on six successive laps each time he passed through the Porsche Curves.

As Nick Tandy and Kamui Kobayashi took over the Porsche and Toyota respectively, the gap was 28s and over the next 2h 10m, the Japanese driver was able to open a further 18s margin. Stephane Sarrazin took over from Kobayashi at 19:35, and five minutes later, Andre Lotterer took over from Tandy. With air

Slow zones

Incident No.	Reason	Sector	From time	To time	
1	36 off Mulsanne Corner	5 - Mulsanne	15:21:30	15:25:30	
2	26 stopped after crash with 88	8 - Porsche curve	16:17:45	17:03:00	
3	43 off at Dunlop Chicane	1 - Dunlop	18:02:00	18:09:30	
4	Tyre debris (from 95) at Indianapolis	6 - Indianapolis	18:24:00	18:29:00	
5	28 off at Indianapolis	6 - Indianapolis	18:37:30	18:42:00	
6	47 off at Dunlop Chicane	1 - Dunlop	19:41:00	19:49:00	
7	82 off at 1st chicane	3 - 1st chicane	20:01:30	20:52:15	Note: also required SZ at Sectors 1, 2 and 4 to move equipment
8	43 off at Indianapolis	9 - Ford chicane	20:57:30	21:06:00	
9	60 off at Mulsanne Corner	5 - Mulsanne	21:45:15	21:50:30	
10	49 off at Indianapolis	6 - Indianapolis	21:51:45	21:54:30	
11	43 off at Porsche Curves	8 - Porsche curve	21:56:15	21:59:15	
12	Debris from no 98 after Mulsanne	6 - Indianapolis	22:15:45	22:27:30	
13	66 off at Indianapolis	6 - Indianapolis	00:11:28	00:18:52	<i>Note this SZ became SC</i>
14	7 stopped past Arnage	7 - After Arnage	01:10:30	01:16:50	<i>Note this SZ became SC</i>
15	25 at Dunlop	1 - Dunlop	01:12:00	01:16:50	<i>Note this SZ became SC</i>
16	49 stopped at Porsche Curves	8 - Porsche curve	02:32:45	02:40:00	
17	92 stopped at Ford chicane	9 - Ford chicane	04:03:00	04:17:30	
18	50 off at Mulsanne	5 - Mulsanne	04:05:45	04:10:45	<i>Note this SZ was simultaneous with previous</i>
19	34 off at Porsche	8 - Porsche curve	05:28:30	05:33:15	
20	90 off at Porsche out	9 - Ford chicane	05:37:30	05:41:00	
21	40 off at Indianapolis	6 - Indianapolis	06:29:30	06:35:00	
22	83 off at Indianapolis	6 - Indianapolis	06:37:15	06:42:00	
23	22 off at Indianapolis	6 - Indianapolis	07:38:45	07:45:30	
24	Repair guardrail 2nd chicane (90/51)	4 - Between chicanes	08:02:00	08:13:00	
25	1 stopped before Mulsanne	5 - Mulsanne	11:24:45	11:30:30	
26	23 off circuit after Arnage	7 - After Arnage	11:31:30	11:39:30	
27	45 gravel Mulsanne Corner	5 - Mulsanne	12:57:45	13:02:30	



The No.1 Porsche led Le Mans for 10 hours and looked certain to win before an engine failure ruined its race

temperatures still in the high 20s, and track temperatures over 30degC, Lotterer was able to cut into Sarrazin's lead to the tune of 24s in 26 laps. It was not an advantage that he could sustain into the final stint on the used tyres, though, and the gap stabilised for the final stint before the cars were handed back to Conway and Jani at 22:20.

In the cooler, dark hours, the Toyota really stretched its legs, Mike Conway regularly lapping over a second per lap quicker than Jani, and opening up a gap of over a minute by the time the first safety car period was called at just after a quarter past midnight.

Ultimately, the decisive moments came on Saturday evening. At 18:30, Bamber pitted the

No.2 Porsche with a front motor failure and Porsche made a quick calculation. If it changed the battery, it would have meant a longer stop and it would have no chance of overtaking the LMP2 cars, assuming that it remained reliable. However, by leaving the battery untouched, they risked it being damaged, and so risked another long stop to take out the repaired motor, and reach the battery too.

'When the car came in, we knew that the initial damage was caused by the front axle drivetrain failure,' said team principle Andreas Seidl. 'Since we couldn't switch on the hybrid system before replacing the entire front axle, we couldn't diagnose 100 per cent if the inverter or battery also got damaged as a consequence.

Therefore, we had to decide if we risk first to change the front axle only, and then switch on the hybrid system afterwards and check if all was fine. This is what we actually did, and it saved us the race win. If the battery was also damaged, we would have changed the entire front axle, and then we would have had to open up the car again a second time.'

The gamble worked, and the car then ran reliably to the end of the race, but it had rejoined in 54th position, having lost one hour and five minutes, 19 laps to the leaders. It had seemed that it would not be in contention for the win, and Porsche's attack was limited to a single entry.

Toyota's LM curse

There is an old Le Mans saying that a team needs three cars to win: one to crash, one to break down, and the other to win. Toyota almost followed that to the letter. The drama started just before 11pm when the No.8 car pitted from third position with a hybrid failure, a broken tooth in a gear. This may have been caused by running over a kerb; Xtrac noted a similar rare failure in the gearbox of the Rebellion No.31 LMP2 car on Sunday morning and told the other competitors running its products to stay off the kerbs.

The Toyota design meant that to access the MGU, the battery had to be removed, leading to a far longer stop. Whether the battery needed to be changed or not, Toyota didn't have the option to leave it in, and so changed it as a precaution. It lost almost two hours in the process, and with

it went any chance of overtaking the LMP2 cars. Fastest lap of the race was no consolation for another failed attempt to win at Le Mans.

Before dawn the race was all but over for the Toyota team as two incidents hit its remaining two cars. One of these saw the luckless Nicolas Lapierre collide with a Manor LMP2 car into Turn 1. Lapierre had damage to the rear left of the TS050 and, on the way back to the pits, the tyre delaminated and took out the hydraulics.

Shortly afterwards came the retirement of Kamui Kobayashi through clutch failure. The team brought Kobayashi into the pits under the safety car, and when he got to the end of the pit lane he was stopped by a marshal. French driver Vincent Capillaire then stepped forwards, gave the thumbs up to the Japanese driver who, seeing the figure in orange and black and mistaking his driving suit for marshal's overalls, took that as a sign to leave the pit. The team

instructed him to stop, and having jumped the red light, he was forced to make a start using the engine, rather than the hybrid system, which destroyed the clutch. Again, arguably, this was a failure of design, as the clutch could have been made robust enough to cope with such a start, or the car could have gone back into pit lane mode and started on hybrid as intended.

Cruise control

From 1am onwards, it seemed that the race comfortably belonged to Porsche. The (so far) untroubled 919 reduced its pace, keeping off the kerbs and taking no risks in the not inconsiderable traffic (the attrition rate in the race was the lowest-ever, so there were many cars for it to overtake).

The No.2 Porsche had now reached 21st overall, ahead of the leading GTE cars, and was lapping around 10 seconds per lap quicker than the leading LMP2 entries. That translated to 0.9 laps every hour – second place overall, and importantly, a Porsche 1-2 in the double-points scoring WEC Championship, was within Weissach's grasp – provided the track stayed clear of slow zones and safety cars.

It was the victory parade that Porsche may have dreamt of, but it quickly turned into a nightmare as the pre-chamber ignition, new to

the cars this year in order to improve efficiency (see RE V27N7), led to its third engine failure at Le Mans in 2017. 'We need to analyse first the two engines which failed during the Le Mans week,' says Seidl. 'It seems that all the extra load which we introduced this year with pre-ignition system and so on simply brought the engine to the limit under Le Mans race conditions.'

'Simply, the tough competition made us both go to and sometimes above the limits. For everything we decided this year we had to weigh between performance, reliability and serviceability. We should not forget that Le Mans is in the end a test bed for future technologies and even with all the testing you do, the toughest conditions you only experience during the race. It is the toughest race in the world and not a demonstration run. It is part of the game that you also have failures.'

Although so-called 'jet-ignition' works in Formula 1, the fuels there are tailored to the requirements of the engine, while in the WEC, a standard fuel is used, making the job much, much harder for the engine department.

Even if Lotterer could get his car back to its pit, it was far from certain that it could be repaired. The next car back, Olly Jarvis in the Jackie Chan DC Racing Oreca, was 14 laps adrift, and it would take nearly an hour for this car – by then being driven by Thomas Laurent – to overhaul the lap tally already accumulated by the stricken Porsche 919.

But it did so, and the mighty No.38 made history by being the first LMP2 car to lead the 24-hours. It sat atop the lap chart for 29 glorious laps before the recovering No.2 Porsche swept past into the lead, going on to win.

LMP2

For two and a half hours the LMP2 car of the Jackie Chan Racing team led the Le Mans 24 hours. For a while many hoped that it could take a rather unlikely, yet famous win. Oliver Jarvis, Thomas Laurent and Ho-Pin Tung eventually took the class win, and second overall.

On raw pace, the LMP2 cars were not close to the hybrids in qualifying or on race pace, and with their 75-litre fuel tanks could not complete more than 10 laps each stint, or 40 minutes. It was a gruelling schedule for the mechanics throughout the 24 hours, particularly in the high temperatures. The cars each had 16 sets of tyres for the race, with between 38 to 40 pit stops to complete. And these were customer tyres, no confidential tyres allowed, and rival tyre makers are permitted to take tyres from each other to check they are one of the three homologated compounds for the season, too.

From the test day it was clear that the ORECA had the advantage, with 13 of the 14 ORECA's filling the top spots with either ORECA 07 or converted 05 chassis. The quickest non-ORECA was a Ligier, 3.7s off the fastest time, and that led to manufacturer representatives seeking to play a special 'joker' in its aero kit to close the

On the long runs Porsche believed that it had a chance against Toyota with tyre management

LMP2 driver analysis				
1st				
38: Jackie Chan DC Racing Oreca 07				
Driver	Ho-Pin Tung	Thomas Laurent	Oliver Jarvis	
Rating	Gold	Silver	Platinum	
No of laps	116	126	122	
Driving time	7h 27m 24s	8h 11m 01s	7h 26m 20s	
Best lap	3m 28.632s	3m 29.727s	3m 29.305s	
Average of best 20 laps	3m 31.027s	3m 30.841s	3m 30.960s	
2nd				
37: Jackie Chan DC Racing Oreca 07				
Driver	David Cheng	Tristan Gommendy	Alex Brundle	
Rating	Silver	Platinum	Gold	
No of laps	92	139	131	
Driving time	6h 00m 57s	8h 43m 50s	8h 27m 47s	
Best lap	3m 33.115s	3m 30.348s	3m 29.418s	
Average of best 20 laps	3m 34.926s	3m 32.059s	3m 30.545s	
3rd				
35: Signatech Alpine A470				
Driver	Nelson Panciatici	Pierre Ragues	Andre Negrão	
Rating	Platinum	Silver	Silver	
No of laps	126	97	137	
Driving time	7h 55m 44s	6h 11m 10s	8h 52m 58s	
Best lap	3m 30.691s	3m 33.074s	3m 31.814s	
Average of best 20 laps	3m 32.210s	3m 34.372s	3m 30.551s	

Time spent in pits LMP2						
Class pos.	No	Team	Car	Stops	Time	Longest stop
5	32	United Autosports	Ligier	36	44m 32.900s	1m 46.221s
3	37	Jackie Chan DC Racing	Oreca	37	45m 29.418s	2m 00.044s
1	38	Jackie Chan DC Racing	Oreca	38	49m 46.195s	3m 21.733s
6	40	Graff	Oreca	36	49m 46.782s	2m 40.402s
4	35	Signatech Alpine Matmut	Alpine	40	54m 11.025s	4m 06.544s
7	24	CEFC Manor TRS Racing	Oreca	37	54m 14.965s	4m 37.203s
2	13	Vaillante Rebellion	Oreca	38	57m 02.186s	4m 21.414s



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gap. Its request was refused by all the other manufacturers on the grounds that it would be balancing the performance by allowing one manufacturer to introduce a free upgrade.

The regulation joker allows for each of the LMP2 manufacturers to make one update to the homologated car within the four year period, but it is not very clear whether or not this is solely for the WEC racecar, the Le Mans kit or for the IMSA series.

Even before the race the ORECA teams had faced mechanical issues. They prepared for a change of the carbon brake pads and discs for the first time in many years, as the calipers in

the ORECA were apparently too small to house the endurance racing pads needed to do the 24 hours, and the 32mm brake discs were not up to the job either. One ORECA team also pointed towards a shortage of spare parts. Others saved their brakes for the race. There was a possibility to run the whole race with them, but only with careful brake management.

One of the problems with the brakes in the high temperatures was that they went off with little or no warning, as experienced by the Signatech team on Sunday afternoon as it chased the final podium position. Andre Negrao went straight on at Mulsanne Corner when he found himself with a long brake pedal and the team had to subsequently change the brakes.

This left the Jackie Chan Racing ORECA to take the class win. The JDC team had instructed its drivers from the start to manage the brakes, lifting and coasting into Tertre Rouge and into the Porsche Curves. Jarvis compared it to driving the Audi R18 before the team introduced the automatic cut for the fuel allowance. The team

also took great care of the gearbox, not using first gear where possible, particularly over the kerbs at Arnage, and still had to cope with a failing clutch towards the end of the race.

P2 reliability

The fight for LMP2 honours was truly remarkable. No fewer than 25 cars took the start, and all but four of them were there 24 hours later. It is true that some had troubles along the way, but many didn't, as the table of pit stop times shows. For the first six hours of the race, the Rebellion ORECA seemed to hold the advantage, but by this stage only seven cars were on the lead lap, and the opportunities for those that had fallen back seemed limited.

The problem that did affect all the class, however, was the restricted stint lengths – most cars would only manage 10 laps per stint, and were therefore looking at stopping every 40 minutes. The ability to stretch this during safety car periods or slow zones could prove decisive.

GTE

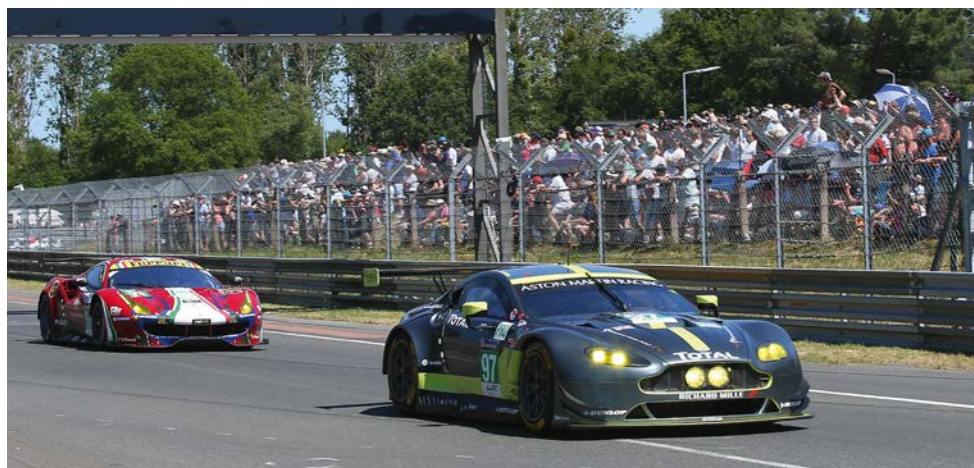
The GTE-Pro class seldom disappoints at Le Mans and this year it thrilled the crowds with much less of the acrimony that surrounded last year's race. The dreaded Balance of Performance was as close to perfect as anyone could wish for, and there were an astonishing 52 changes of lead in the class; each of the five manufacturers that started the race led at one stage or another.

The No.91 Porsche was in contention for the race win, but dropped out of the battle with a puncture with one hour remaining and then a nail-biting finish between the No.97 Aston Martin and the No.63 Corvette was only resolved as the cars began their last lap.

The problem for Aston Martin Racing, as the last three hours of the race unfolded, was that their leading contender, the car driven by Darren Turner, Daniel Serra and Jonny Adam, would need an extra stop for fuel before the end of the race, compared with the schedule for the No.63 Corvette, which had pulled itself into contention with a clean and uneventful (so far) drive from Antonio Garcia (suffering from a back problem; he did not drive during the last three hours of the race), Jan Magnussen and Jordan Taylor. Rather than leaving it until the last possible moment for the 'splash and dash' and risk being caught out by a safety car, Aston brought Jonny Adam for the short stop on the same lap as the Corvette, the two cars leaving the pit lane nose-to-tail with just over three-quarters of an hour of the race to go.

Despite the fact that Jordan Taylor had new tyres on the Corvette, 2016 British GT champion Adam noted that his tyres were delaminating, and made his overtaking move out of the Ford Chicane in front of the packed grandstands at the start of the last lap. The Corvette suffered a puncture and in its limp home to the flag also lost the second place to the Ford GT being driven by Harry Tinncknell.

No fewer than 25 LMP2 cars took the start and all but four of them were there 24 hours later



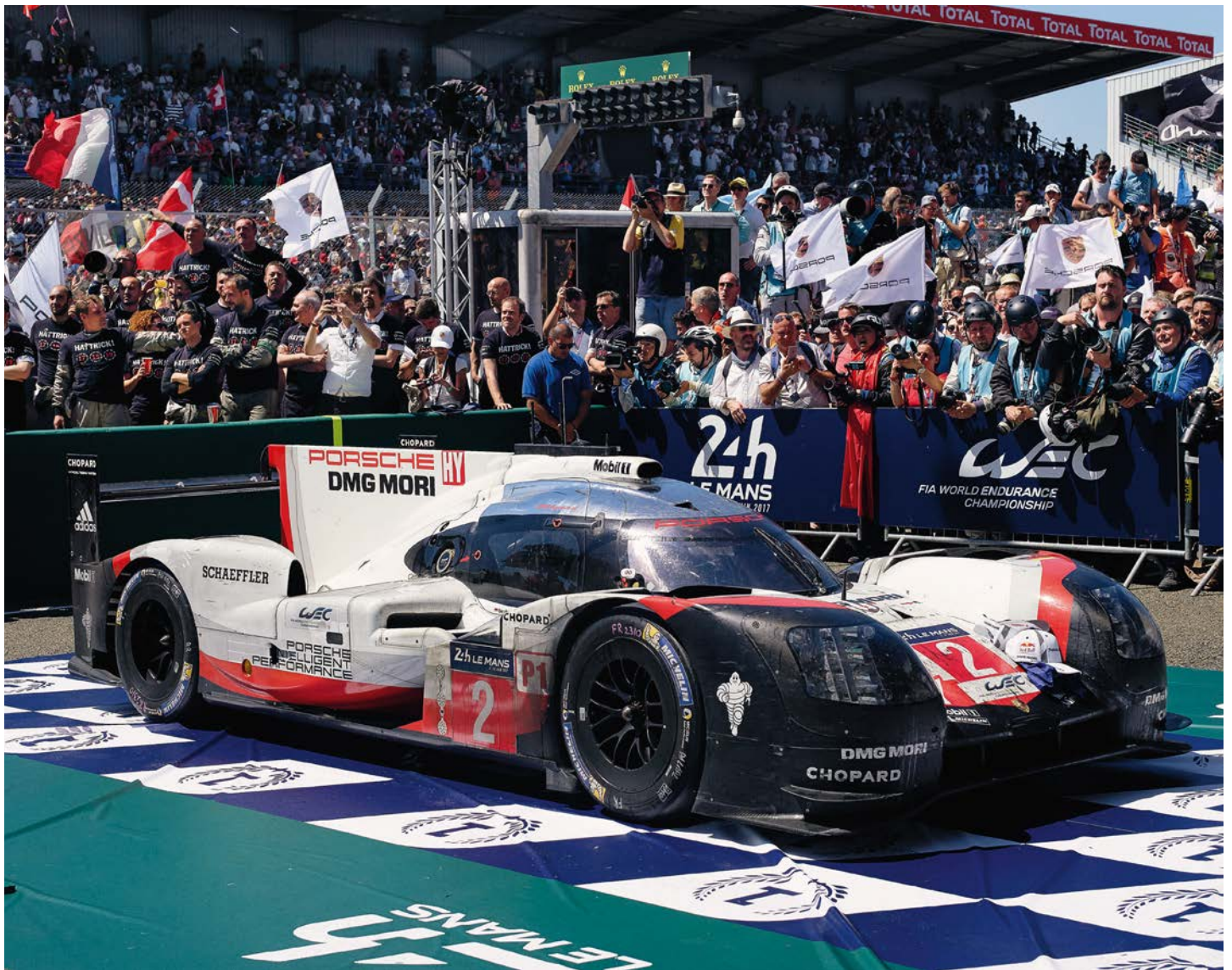
GTE-Pro was a highlight this year with great racing and few BoP issues. The No.97 Aston Martin took a last gasp class win



The No.63 Corvette came close to winning in GTE but a puncture dropped it to third after losing the lead on the final lap

GTE Pro race analysis

Class position	No.	Car	Laps completed	Best lap	Average of best 20%	Top speed
1	97	Aston Martin Vantage	340	3m 50.950s	3m 52.646s	303.0 km/h
2	67	Ford GT	340	3m 51.438s	3m 52.990s	301.3 km/h
3	63	Chevrolet Corvette C7.R	340	3m 51.156s	3m 52.778s	304.7 km/h
4	91	Porsche 911 RSR	339	3m 51.549s	3m 52.918s	302.2 km/h
5	71	Ferrari 488 GTE	339	3m 51.846s	3m 53.497s	303.9 km/h



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Body of evidence

With bespoke bodykits allowed for Le Mans the four LMP2 constructors took a variety of approaches to the problem of optimising the aero around the Circuit de la Sarthe

By **ANDREW COTTON** and **SAM COLLINS**



The Dallara's Le Mans spec trailing edge – its low drag kit was perhaps the most extreme



WEC spec rear of Dallara – Gurney was removed for Le Mans kit (see previous image)

When the new LMP2 regulations were introduced at the start of the 2017 season, each of the four selected constructors had to homologate the bodywork for its car. This homologated bodywork would be fixed for the entire period right up to the end of the 2020 season.

No changes would be permitted apart from in two scenarios; first a Le Mans specific kit, and then in some circumstances an evolution kit could be introduced, as long as all the other manufacturers agreed. The first time that the Le Mans kits were seen was at the test day, two weeks ahead of the famous race itself. These kits are cost capped at €10,000 and they are also homologated.

Drag act

The Dallara low drag kit was perhaps the most distinctive, with an entirely new front bodywork section featuring much longer front wheel pods, allied to a lower rear wing and the removal of a Gurney along the trailing edge of the engine cover. It worked in as much as

it was clearly very low drag, the three examples of the Italian constructor's car topped the speed trap, with the fastest of them exceeding 341kph. It was significantly faster than any other LMP2 car and even faster than the only non-hybrid LMP1 entry.

However, the drivers of the Dallaras reported handling problems with the racecar and they were noticeably slow in the corners. To rectify this the Dallara teams started to experiment with running the base aerodynamic package rather than the Le Mans kit and by the time of the race all three Dallara runners had abandoned the low drag bodywork; this lost the cars around 10kph in top speed but notably improved the handling and ultimately the lap time.

'In the wind tunnel and with CFD, [the Le Mans kit] produces a very good combination of low drag and enough downforce to do Le Mans,' says Luca Pignaca, chief designer and EU racing business leader at Dallara. 'Of course, it didn't work as we expected it to work and we are trying to understand why this happened. It is front downforce



Dallara low drag nose next to WEC spec high downforce example; latter in foreground

that we are missing; it is not there. We have to come back with [reducing] rear wing, so total downforce goes down, and the drag goes down too, so we have very high speed, and not enough speed in the corners.

Away kit

Pignaca adds: 'We suggested the medium downforce kit, with the lowest possible drag so the top speed was not bad, but it is not the ideal kit

for Le Mans. It is a more comfortable car to drive than with the Le Mans kit, but it does not work properly. If it had, we would have been more or less the same downforce, but higher top speed, and I think we would have been in front. We have to understand why we have this problem and will organise a full scale aero test, and make it into an opportunity.'

Riley and Multimatic joined forces to create the Mk30 LMP2 car, which

The Dallaras topped the speed traps, the fastest exceeding 341kph



Ligier Le Mans kit. There were few changes from WEC spec beyond a lowered rear wing



Ligier in WEC spec. At Le Mans it struggled for both straight-line speed and downforce



Riley Multimatic's Le Mans low drag kit. This shows extended top panel arrangement



The Riley Multimatic had a lower wing position with no Gurney on trailing edge of body



Riley's new rear wing endplate had reshaped upper section and a lower wing position



Riley Multimatic's low drag nose was not enough to help this draggy car at Le Mans

carrying too much drag and it was the slowest LMP2 through the speed trap.

Notably, the Riley Multimatic also struggled in the corners, suggesting that it may also lack downforce, or is a bit overweight. The car finished the race 20th and last in its class.

Minor tweaks

Ligier's Le Mans kit was, curiously, very minor indeed. The cars lacked front dive planes (though these are optional parts anyway) and had a slightly lower rear wing.

The package proved to be uncompetitive with the Ligiers down on top speed compared to the Dallaras and ORECAs, while they

were not as strong in the corners as the latter either.

As a result of this Onroak, the division of the Everspeed group responsible for designing and building the Ligier JSP217, asked the race organisers if they could introduce some new parts for the race (see Le Mans analysis) but this was not allowed, while it also appears the request to introduce new parts was too late anyway. A minimum of 15 days is required between the homologation of an update and the first time the updated car is presented at scrutineering, except in cases of *force majeure*, at the discretion of the Endurance Committee.

made its first European appearance at Le Mans. Its low drag kit consisted of clip-on front wheel pod extensions, an extended upper panel behind the front wheel pod, new rear wing

end plates and a slightly different tail section. During the test session ahead of the race the car was dogged by a fuel system issue, but the runs it did complete made it clear that it was

Old dog, new tricks

ORECA chose to develop its existing 05 chassis to produce its new-breed LMP2, the 07. The result? It almost won Le Mans outright. Here's the inside story of a remarkable racecar

By GEMMA HATTON



Four chassis manufacturers were selected to deliver new LMP2 cars for 2017: Dallara, Riley Multimatic, Ligier and ORECA. It was the last of these that was the most interesting, as ORECA had a long-standing relationships with the majority of the P2 teams competing in the WEC, while it had set up an office in the US to deal with the anticipated US market in the IMSA series.

The company was clearly confident, yet it is the only one of the four makes that did not secure a manufacturer deal in the US. Dallara partnered very early on with Cadillac and concentrated its development there, Riley partnered with Multimatic, which itself had been approached by Mazda and Ligier partnered with Nissan, running GT3 engines.

Although ORECA didn't have a manufacturer deal, it still raced well in the opening races of the IMSA series, the Rebellion team ably demonstrating the WEC package at Daytona and Sebring in January and March. Meanwhile ORECA concentrated on making the most of

its contacts in Europe and selling its WEC cars, fitted with the Gibson normally-aspirated engines that power all WEC P2s.

At Le Mans, ORECA's aero kit was clearly far superior, leading its rivals to point out that its development budget was all aero, while theirs was spent developing new cars. A clear indication of this was that while the Dallara showed incredible top speeds at Le Mans during the test day, it was because the Italian manufacturer's bodykit was inexplicably missing front downforce. The rear was trimmed, the top speed was there, but the lap time was not. Instead, it was the ORECA that dominated the test day, qualifying and the race.

Kung fu P2

For the first time in history, LMP2 made it on to the overall podium, with the two ORECA's run by Jackie Chan DC Racing claiming second and third position overall (following the exclusion of the Rebellion Racing ORECA after a starter motor failure and bodywork modification to

address it). Although this was partly due to the demise of the LMP1s throughout the race, there is no question that LMP2 has made significant gains in terms of both reliability and performance. This year's Le Mans pole for LMP2 was over 11 seconds faster than 2016, with the highest top speed recorded at 337km/h – 27km/h faster than last year.

Within this field of much faster cars the ORECA's are, arguably, in a league of their own. The top nine in qualifying were ORECA's, with the Dallara in P10, 2.4s off the class pole. 'We knew Dallara were joining LMP2 this year and we have a lot of respect for them as a company as they are a global leader in manufacturing customer racecars,' says David Floury, technical director at ORECA. 'Therefore, we really wanted to challenge them, so we put a lot of effort into developing the best car possible.'

The primary advantage ORECA had was the fact that this year's ORECA 07 was based around the ORECA 05's monocoque (which was itself based on the ORECA-built Rebellion

Within this field of much faster LMP2 cars the ORECA's are arguably in a league of their own

The Jackie Chan DC Racing ORECA 07 not only won P2 at Le Mans but was also second overall and came close to a famous outright victory

TECH SPEC



ORECA 07 LMP2

Chassis: Carbon fibre and honeycomb monocoque

Engine: Gibson GK-428 4200cc, normally aspirated 90-degree V8. Power output – 603bhp, max revs – 9000rpm

Suspension: Double wishbone with pushrod; adjustable shocks specifically developed by PKM.

Tyres: Front – 30-68/R18, Rear – 31-71/R18

Gearbox: Xtrac 6-speed sequential. Pneumatic paddleshift system

Brakes: Ventilated carbon discs with six monobloc calipers

Bodywork: Carbon and Kevlar light lamination

Lubrication: Dry sump, staged oil pump

Electronic control unit: Cosworth

Dimensions: Front track – 1.57m; rear track – 1.55m; wheelbase – 3m

Weight: 930Kg

This has led to concern among the other manufacturers, in particular Ligier. The manufacturers are allowed to re-homologate their cars once within the four-year homologation period, but it is not clear under what circumstances they may do so. For example, is the Le Mans kit different to the WEC kit, and where does IMSA's BoP sit with the update programme? Any update presumably must be adopted globally, so would IMSA need to do a new BoP?

Ligier concerns

IMSA allows only the high downforce specification bodywork from Europe, but the performance deficit at Le Mans, says Ligier, must be addressed immediately if it is to sell cars, and it applied to have a separate 'joker' between the Le Mans test and the race, that was outside the homologation update. This was rejected by all the other manufacturers in the class.

'Basically, BoP is to me something that you need to have when you have styling constraints to be considered, like in DPi,' says Floury. 'Or different engine technology, like in diesel and petrol, or when you start from a car that is production based and you need to balance different racing cars because of their heritage. But in LMP2, we all started with the same regulation and white sheet of paper. In this case, I don't think that BoP is something to be considered. The back-up plan in the regulation is that you can re-homologate your kit, but it is once in four years. If someone feels that he has a performance deficit, he can do this option, which Ligier tried to do between the test day and the race, but the other three were firmly

R1 LMP1 car), while it also shared mechanical components from the 05. 'Our concept was to design a completely new car around a base of existing components, thus allowing the teams who own an ORECA 05 to update it to the 07, by trying to control the cost of conversion,' explains Floury. 'Obviously, Riley and Dallara did not have a base to work from this year. Ligier, however, had the opportunity to do the same. They could have carried over their JS P2 chassis, rather than designing a completely new one, so we went two different routes.'

Five into seven

There are also associated costs with developing a completely new chassis, and ORECA felt that the increased cost did not equate to enough of a performance gain, hence its decision to re-invent the 05 – a decision that was made very early on. 'The 05 was conceived in record time with 2017 in mind, which is why it had a width of 1.9m instead of 2m, to meet what we knew of the 2017 rules at the time [2014],' says Floury.

Although this strategy compromised performance over recent years, particularly at twisty circuits, it allowed the 07 to evolve from a strong and proven base. As Christophe Guibbal, ORECA 07 project manager, says: 'As the monocoque did not require any major developments, we could concentrate more on refining the other elements to which the new rules offered lots of room for improvement.'

The first track tests took place at Paul Ricard circuit, on the doorstep of the ORECA factory, in November 2016. The cars had to be developed to run on Michelin, Dunlop and in the US on Continental tyres, which was one of the major hurdles for the manufacturer as each has very different characteristics for handling and set-up.

Now that the cars have all been homologated the chance to change them has become extremely limited, and more than a little confusing. 'You can't develop your car much further. By now, the potential of your LMP2 car should already be exploited to around 95 to 97 per cent,' explains Floury.



The ORECA 07's front bulkhead. Monocoque was carried over from previous 05 ...



... Which in turn was based on Rebellion R1 LMP1 car. R1 bulkhead is shown above



Le Mans spec body front wheel opening. The LM bodykit was cost capped at €10,000



WEC Spec front wheel opening. It's forbidden to mix and match aspects from each kit



The Le Mans spec rear has a smaller gurney to promote higher straightline speeds



Gurney on the rear of the WEC spec 07 is much larger. ORECA develops aero in CFD

opposed to it. It was the FIA and the ACO's call to accept it or not, but at the end of the day it is just a back-up plan to allow a manufacturer to catch up.

'Clearly we all started with the same regulation, and to develop the ORECA 07 we worked hard because we knew that the competition level would be high with the other manufacturers, and their experience was very high,' Flourey adds. 'We took on the challenge and cannot be blamed if we have done a good job, [they] shouldn't level things to the low side. We had discussions in the TWG to discuss the regulations together and the back-up plan in terms of one manufacturer having a deficit of performance [and] the possibility to re-

homologate the kit, and the conditions are clear as well, so it is surprising that people are starting to discuss what we all agreed.'

So, in order to upgrade, it appears that a manufacturer must show that it has a clear performance deficit, which must then be recognised by the other manufacturers, and then accepted by the ACO and the FIA before an upgrade can be put in place.

From the start of the LMP2 programme, engine supplier Gibson was clear that the cars would be capable of running at Le Mans in excess of 330km/h – and they actually reached almost 340km/h. This was a headache for the engineers setting up the cars, particularly around tyre performance. Stints at Le Mans were

less than 40 minutes long, and tyres needed to be at least double-stinted and in some cases triple-stinted to make it to the finish on the prescribed allocation (16 sets for around 38 pit stops during the 24 hours).

But with the car only six months old, there were other problems for the teams to overcome, too, not least with the brakes. The ORECA 07 was designed with 32mm brake discs and, according to teams, the pads that could be fitted into the Brembo calipers were only just sufficient to complete the 24 hours of the race.

The JDC team had to order its drivers to lift and coast into Tertre Rouge and the Porsche Curves to save its brakes and try to avoid a four-minute stop to change the carbon brakes. This

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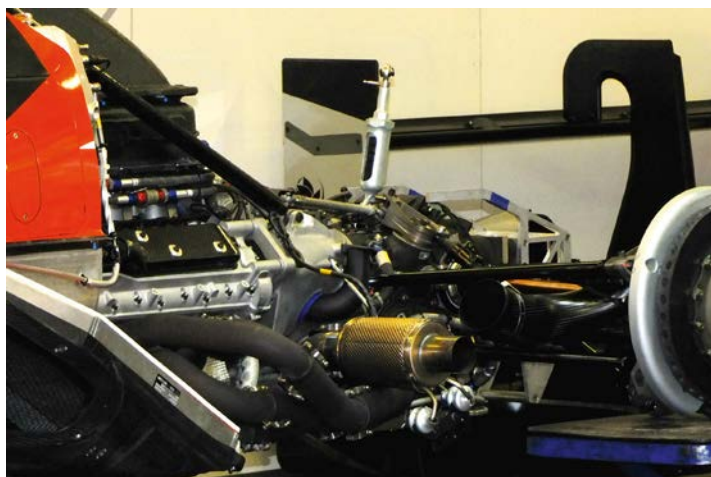
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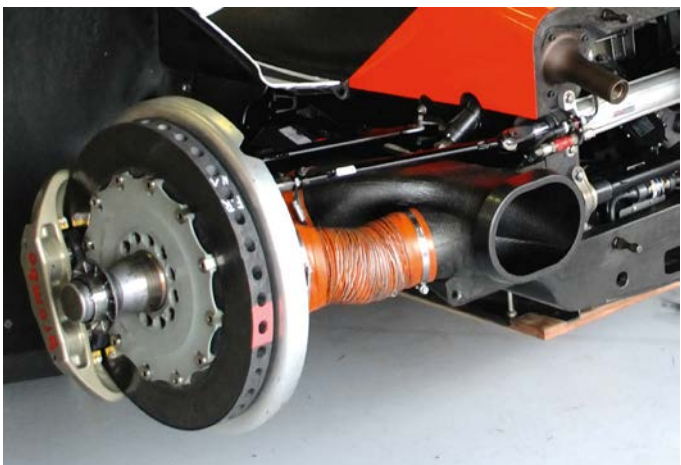
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ORECA 07 runs double wishbone front suspension with pushrod actuated torsion bar



Gibson 4.2-litre V8 engine is a common feature of all the new WEC LMP2 racecars



Protecting the front brakes was an issue at Le Mans due to a problem with pad life



ORECA 07 has been the P2 car of choice for the majority of teams racing in the WEC

is clearly an area that the ORECA organisation will need to work hard on for 2018.

But otherwise the performance of the car was impressive. 'It is well balanced, easy to drive, which is important for the amateur drivers, and you have the reliability, because at Le Mans you need to be reliable,' says ORECA owner Hugues de Chaunac. 'When you see six ORECA cars in the top nine, that is fantastic. We have a good compromise between performance, reliability, and a car that is easy to service by a team. This car is less than six months old, but next year there will be no more problems. We have to work on the brakes to see what we have to do, but it will be solved for next year.'

The Le Mans aero kit itself is, like the rest of the car, heavily restricted not only in what can be done, but also in how much it costs. 'For this race only, the FIA and ACO have allowed LMP2 manufacturers to homologate a specific kit for which the price is regulated and cannot exceed €10,000,' says Flourey. 'This kit's main objective is to reduce resistance in order to reach a good top speed and to improve performances at Le Mans. As for the ORECA 07, its kit essentially comprises new aerodynamics elements, both front and rear. They were mainly developed in

CFD, got tested and validated on Le Castellet track in November 2016, as part of development tests, and homologated in December 2016, as stipulated by the FIA. Additionally, it is important to note that rules and regulations do not allow a mix of Le Mans and Sprint kits.'

Rare bits


After development and tooling the €10,000 limit does not leave a lot of room for the production or for profit. The teams had to be careful about how they approached the manufacture of the kits, and it was no surprise that parts were limited at Le Mans, though no one went short.

'We have bits and pieces on the front, side and rear of the car,' says Flourey of the Le Mans aero kit. 'It's small differences everywhere all over the car, it's not one side or the other or one big topic, it's small details everywhere. You have to look at the global picture because you have to keep the aero balance in the correct window for these tracks, everything is linked, you cannot work on only one side of the car, so you have to really look at the big picture.'

'We do all the aero development in house,' Flourey adds. 'Everything on our own CFD and our own CFD facility, and in the simulator close

to the Ricard circuit. Through the years we've developed very good skills, tools as well to guide us. It takes a lot of work but it seems to be helping. We worked a lot on correlation between the track and CFD. We've developed a lot of our own CFD process and methodology. Now we, more or less, always have a decent correlation but it is still improving. It was already satisfying on the ORECA 05, and the 07 is another step, but for sure the new P2 rules have changed [what needs working on] on the car significantly as well, which needed to be taken on board when setting targets for this year.'

While Dallara is dominant in the US with the Cadillac engine, ORECA has won at Le Mans, and there are rumours that Penske will run with the car at the Petit Le Mans in October, in WEC trim ahead of a full Honda programme in 2018 in the US. There are also rumours that Joest will also run a private ORECA in the US, fitted with an Audi RS5 engine.

ORECA was quietly confident of its business model from the outset, and despite not landing a manufacturer contract in the US, it appears to have played its game perfectly. After all, it says a great deal when a Le Mans class-winning team laments not taking victory overall. 

'We took on the challenge and cannot be blamed for doing a good job'

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Rouge awakening

With VW out most of the smart money was on Citroen's C3 to run away with this year's WRC – so why is the French firm rooted in fourth and last spot in the teams' standings?

By MARTIN SHARP

Citroen has had a rough ride thus far in 2017 with just one win to its name and a string of retirements. C3 is pictured on Rally Italy, in Sardinia



When Volkswagen pulled out of the WRC at the end of last year, many pundits predicted the new Citroen C3 WRC would take over the mantle of the previously dominating VW Polo WRC. After all, what other manufacturer team had a similar budget and the rallying expertise, experience and victory-record to match the Hanover operation?

It seemed like a reasonable argument. But, so far, for various reasons, the predictions of the pundits – aside from one win in Mexico – have come to nothing (see box out) and Citroen has experienced perhaps more than its fair share of accidents. The question is, how much of this is actually down to quirks of the car itself?

The C3 WRC project started when two engineers began initial design work in April, 2015. Two became three, and from September that year the percentage of the Citroen Racing workforce dedicated to the C3 WRC was then increased progressively to 100 per cent.

Before its 2017 Monte Carlo debut the team had completed 9500km of pre-season testing, over 10 sessions since the first C3 WRC test car appeared in April, 2016.

Great expectations

But technical director Laurent Fregosi freely admits Citroen has taken more risks in the development of this car, including using lots of new components: 'If we speak about parts, the carry-over from the DS3 WRC [its predecessor] is very few, but of course we have designed the new car with all the experience we have from the DS3, so some parts are the same philosophy, and in this case you can see some similarities, but not a lot of carry-over.'

The car has an all-new Sadev transmission, a decision taken both in order to properly package the system into the C3 shell, and also because for 2017 an active centre differential is allowed. 'As we had to redesign the gearbox you try to incorporate in the design all the experience you have, so at the end even if the philosophy of some parts are the same, the parts are all different,' Fregosi says.

Ground speed sensors are not permitted, making central active differential control potentially more complicated, but Fregosi says 'it's not such a problem because the regulations allow us to have the four wheel speeds to control the diff ... but only for this. To control the engine we have only one wheel speed [to monitor], so we cannot do traction control; but it's quite open on the centre diff to do what we need with the [four] wheel speed sensors.'

Fregosi does, however, concede that Citroen Racing spent much time optimising the active

TECH SPEC

Citroen C3 WRC

Engine: In-line four cylinder, 1.6-litre, turbo direct injection.
Bore x stroke: 84.0 mm / 72.0 mm. Max power: 380bhp (280kW) at 6000rpm. Max torque: 400Nm at 4500rpm.

Transmission: Four-wheel-drive; 6-speed sequential gearbox; mechanical front and rear self-locking hydraulically-controlled central differentials.

Clutch: Cerametallic twin-disk.

Suspension: MacPherson; Citroen Racing dampers.

Steering: Power-assisted rack and pinion

Brakes: Front – ventilated disks, 370mm (tarmac) and 300mm (gravel), Water-cooled four-piston callipers (tarmac). Rear – ventilated disks, 330mm (tarmac) and 300mm (gravel), four-piston calipers.

Wheels and tyres: 8 x 18in for tarmac, 7 x 15in for gravel and snow. Michelin tyres.

Dimensions: Length – 4128mm; width – 1872mm; wheelbase – 2540mm.

Weight: 1190kg minimum; 1.350kg with crew

centre differential's control maps in order to provide the drivers with an easy, forgiving car when there is a sudden change in grip.

Fregosi also says that centre diff control is more critical on tarmac than on gravel. 'You have wheelspin, even on tarmac, and the effect of the wheelspin is much more important on tarmac than on gravel,' he says. 'Even if we have less wheelspin it can be a problem on tarmac.'

The team uses different, specific, active centre diff maps for each event and, similarly, different damper diagrams. 'The only thing is that the difference between one rally and the other is bigger than we had with the DS3 WRC, which had become very refined because we have had many years with it,' says Fregosi.

New engine

Although Citroen Racing has extensive experience of a 36mm diameter inlet restricted version of the DS3 WRC's global engine in the WTCC C-Elisee, it was decided the C3 WRC power unit would be a new design. 'In making a new engine we have taken [WTCC] experience; we have been able to improve and implement it in the engine of the WRC car,' Fregosi says.

The cylinder block is new, machined from solid aluminium alloy and its bore diameter is increased from the DS3 unit's 82mm to the FIA maximum 84mm. Hence, this results in a shorter stroke to complement running at higher maximum power rpm, courtesy of the two millimetre larger diameter inlet restrictor.

Incidentally, the team's engine manager, Patrice Davesne, says he is particularly proud of his work to reduce internal friction.

Maximum inlet pressure is retained at 2.5bar, hence the new unit produces maximum

The C3 is the first WRC car to have fundamentally different front suspension set-ups for gravel and tarmac

'The effect of wheelspin is more important on tarmac than on gravel'

torque at about the same rpm as its DS3 predecessor while, courtesy of the bigger restrictor, there is more power further up the range. Yet this wider power curve between maximum torque and power has not caused problems for the Citroen team drivers. 'We have more power than torque, so it can be more difficult to manage, but it's not a big complaint that I hear from our drivers; they are happy to have more [power],' explains Fregosi. He adds that the same engine mapping is used across all engines, adjusted to suit events, of course.

Suspension set-ups

The amount of available space in the DS3 and C3 front wheel arches is similar, and 2017's greater front suspension design freedom has resulted in improved wheel travel options for the C3. However, the C3 WRC is the first World

Rally Car since the category arrived in 1997 to have fundamentally different front suspension set-ups for gravel and tarmac. Asphalt specification C3 WRC MacPherson front struts incline rearwards to help manage longitudinal movement of the car and enhance stability. In contrast, the gravel spec front struts angle forwards to optimise wheel travel.

Damper units are designed and built in-house. The team worked with Ohlins on the damper set up of its WTCC car and now the Swedish company helps it in the WRC.

But has that WTCC experience influenced the team's approach to its rally car? Certainly, its asphalt chassis performance is there or thereabouts, but witnessing the car on gravel does point to some, perhaps worrying, characteristics, particularly on rebound. And the question must be asked; why have Citroen's

Craig Breen and Chris Meek both been sidelined on two of the five gravel rallies so far with smashed gearboxes after heavy compression contact with the ground in places where rival cars had sailed through with no problem?

Rough and tumbled

Meeke's experience in Sardinia was telling. On SSS he bounced his Citroen off a bank, which flicked it on to co-driver Paul Nagle's side of the car. It continued down the stage on its side, then hit a parapet and was flicked into a massive roll. Rival cars took similar lines to that of Meeke's C3 at the location of his Sardinian shunt without problems, but it seems the Citroen's dampers rebounded into big oversteer, which kicked the back out to clobber the bank and produce this most unusual of accidents.

Yet while boss Citroen Yves Matton admits his car is not the easiest to drive at the limit he has said this is getting 'better and better.'

Fregosi adds: 'We have changed the damper specification, but it's the same parts; just changing the set-up – the damper diagram – but it's a normal job; we did it already for the DS3. The only thing is that it is a new car and before we had some feedback to improve from one rally to another; so it's bigger [more work].'

Fregosi admits the team cannot identify whether the additional downforce enabled by the 2017 aero package changes the way the damper diagram works: 'We don't really know. We have had to change the diagram with this car. On big bumps we arrive with more speed.'

An intriguing development with most of the new WRCs is that tyre inner treads are wearing more than expected on gravel rallies. It is possible that extra downforce is creating more negative camber, but Fregosi explains that this circumstance is not new to his team: 'We had it also last year [with the DS3], for example in



New regulations have meant improved wheel travel for the C3. Its dampers are made in-house by Citroen with Ohlins input



It was thought that new regs which gave more power further up the range thanks to a bigger restrictor would make C3 hard to drive. But its drivers have had no throttle control issues

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‘When you lose the front splitter off this car it has much more of an effect than when you lose the rear diffuser’



Some of the aerodynamic parts have proven fragile, especially the front splitter. Note the large 2017-spec wing and diffuser

C3 – P4

Fortune has rarely smiled on the Citroen team as the first half of the 2017 WRC season unfolded.

A series of unfortunate incidents during events masked the C3 WRC's potential, while controversy over the true nature of that potential has reigned.

Lady Luck certainly didn't shine on the team on the Monte Carlo Rally; unpredictable handling blighted the cars on the Rally of Sweden, Kris Meeke's engine let go in Corsica while he was leading, and questionable spring/damper settings in Argentina made the cars difficult to control.

Craig Breen drove last year's DS3 WRC to fifth on the 2017 Monte, then scored three more fifth places with the C3 WRC in five rallies. Meeke won in Mexico, but by season mid-point Citroen Racing stood fourth

of the four manufacturer teams that are running the new 2017 World Rally Cars.

Indeed, by then Breen's measured approach gave him 43 drivers' points against Meeke's 27. Team boss Yves Matton had looked beyond immediate top results when engaging the consistent Breen as a factory driver at the start of the 2016 season; that has paid off, so far.

But there's not much else positive to report. The French team is a massive 147 manufacturer points down on championship leader M-Sport, with its Ford Fiesta, at the time of writing, while Breen is seventh and Meeke is 10th in the driver rankings.

This, remember, is the team which won eight of the last 14 manufacturers' titles and nine of the last 13 drivers' championships. Clearly something is wrong.



The spring and damper settings on Rally Argentina made the cars difficult to control. Meeke rolled his C3 as a result

Portugal. Perhaps, [it is because] you have the camber? For us we have it especially when we are using soft tyres with high speed.'

As mentioned, most of the teams with new World Rally Cars are suffering similar inner tyre tread attrition at front and rear on gravel and there is a general consensus that some further development by Michelin may alter this characteristic in the future.

Fragile or agile?

One development problem that raised its head while testing this – uniquely three-door – WRC version of the five-door C3 was undue attrition to key aerodynamic addenda, particularly the front splitter, an important element in the aerodynamic package of the C3. 'The main downforce is given by the rear wing; and at the front we have to work a lot on the front splitter, to try to have enough downforce to have the good balance with what we have with the rear wing,' says Fregosi.

Rear diffusers have also been damaged. 'Of course; it is so close to the ground. What is more critical, though, is when you lose the front splitter it has much more effect than when you lose the rear diffuser,' Fregosi says.

Modifications have been made to help the C3's front splitter survive. But in the first half of this WRC season this expected aerodynamic addenda attrition has not been evident across all the top teams, as Hyundai Motorsport boss Michel Nandan confirms: 'I was expecting more aero parts to be destroyed, and if you look at the start of the season, okay we destroyed parts but not as much as I was expecting. It's survival really. You lose some bits but I was expecting more, also for the other cars. There's not so much. I would expect more, because when we did the tests last year, well we destroyed quite a lot. But on tests you are on the same road; you remove a lot of stones and you dig into the track a little bit as well. So, no I have to say we don't destroy too much.'

In Sardinia, while recent Citroen signing Andreas Mikkelsen was getting to grips with the car. He stalled the engine while hand-braking the tight hairpins, thereby losing time. All teams must conform to the same technical rules, of course. Hyundai Motorsport and M-Sport appear to have addressed the engine stalling issue through attention to the centre differential and engine ECU maps, yet it does seem this is just one of the technical areas which the Citroen team – and, to a lesser extent, Toyota Gazoo Racing – needs to address.

Perhaps only then will Citroen be where all the pundits expected it to be this year, filling the void left by Volkswagen?



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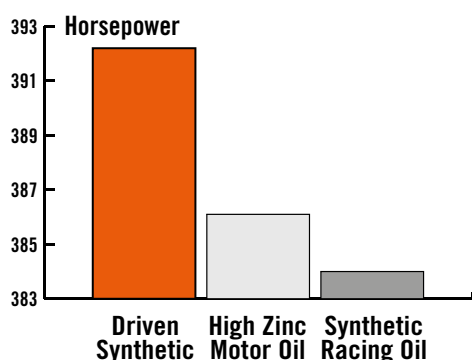


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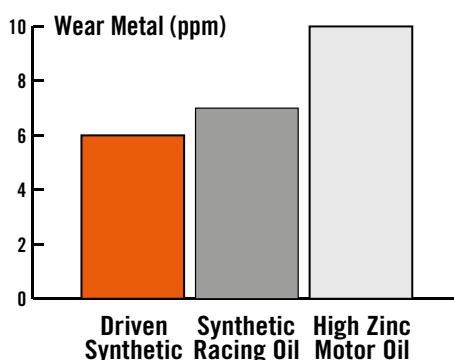
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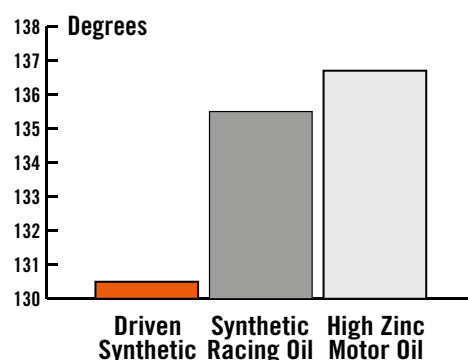
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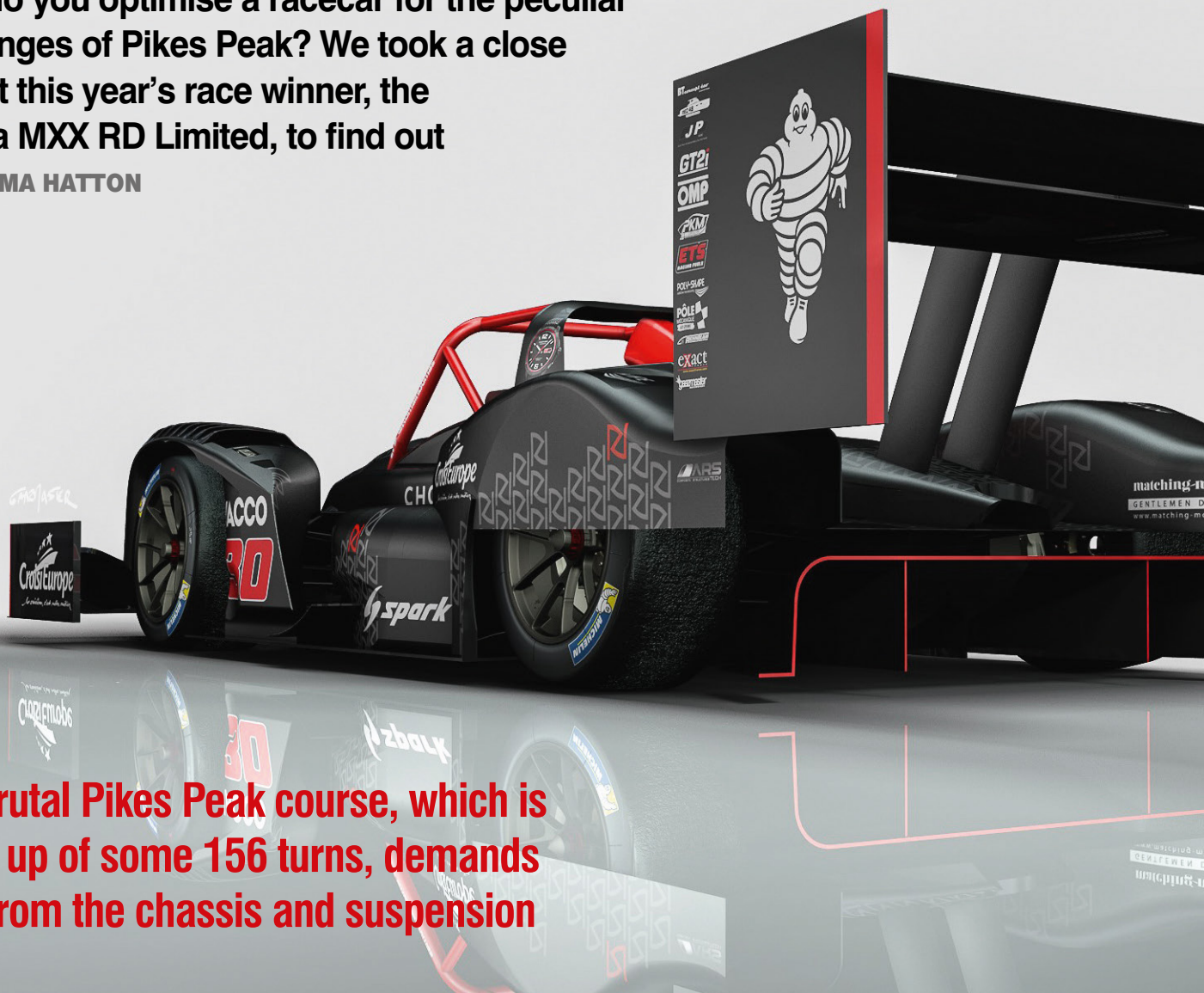


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Peak performance

How do you optimise a racecar for the peculiar challenges of Pikes Peak? We took a close look at this year's race winner, the Norma MXX RD Limited, to find out

By GEMMA HATTON



The brutal Pikes Peak course, which is made up of some 156 turns, demands a lot from the chassis and suspension

The world-renowned Race to the Clouds is an annual hillclimb to the summit of the 4300m Pikes Peak mountain in Colorado. Competitors have to climb 1400m around a narrow public toll-road with precipitous drops to meet them should they stray. It's quite a challenge.

This race is also the most diverse form of motorsport in the world, because aside from some safety requirements, there are minimal restrictions. 'It is the best form of motorsport, in my opinion, because it is unlimited. There are no rules; you need one rollcage, one seatbelt, one fire extinguisher, and that's it,' says Romain Dumas, this year's winner and also the winner in 2014 and 2016. 'You can do whatever you want in terms of power, weight, wheelbase, tyres;

you can even compete on two, six or even eight wheels, all within the same event.'

In his fifth visit this year, Alpine LMP2 driver and twice overall Le Mans winner (with Porsche and Audi) Dumas was taking on the mountain in a reinvented Norma MXX RD Limited.

Apart from the carbon monocoque, which is the very same as last year's winning M20, nearly every other element of the car has been developed. The all-wheel drive system has been optimised with the addition of a new Sadev SLR 6-speed gearbox, the switch to carbon brakes has saved approximately 20 to 25kg compared to last year's car, while the 4-cylinder 2-litre Honda Engine from HPD has a newly integrated turbocharger and intercooler to compensate for the effects of the lower air

density at high altitudes, which can reduce engine power by up to 30 per cent.

'Pikes Peak is a very difficult race because it is like nothing else,' Dumas says. 'First of all, you need a car that can perform for 20km and perform reliably, because you only have one chance. On top of that, you need a car to perform both at the start line, which is at 2800m height and 20degC ambient temperature, and then at the finish, where you are at 4300m and the temperature has dropped to 0degC. Despite the lower air density at high altitudes, you also need to maintain power all the way through the run – which is why electric cars are quickly becoming famous at this event.'

The narrow track itself provides even further challenges, with the first 10km a series of quick



Norma has proven to be a strong base car for Pikes Peak and it won with Romain Dumas driving this year and last. There are few straights and in the thin air at altitude drag is not too much of an issue – hence the fitting of that huge rear wing



Norma M20 tub has been developed into a no-holds-barred Pikes Peak machine. Suspension has been optimised to ensure that the aero platform remains stable through the lower section while mechanical grip is still good at the top of the mountain

TECH SPEC

Norma MXX RD Limited

Chassis: Carbon fibre FIA-homologated monocoque from the Norma M20 (which won the 2016 Pikes Peak hillclimb).

Engine: 2-litre 4-cylinder Honda K20 engine developed by HPD with turbo and intercooler. Power – 570bhp.

Brakes: Carbon fibre disc brakes (saving 20 to 25Kg over originals).

Transmission: All-wheel-drive with a front and rear differential on either axle. Sadev Type SLR 6-speed pneumatic paddleshift gearbox.

Suspension: Double wishbone, pushrod. 4-way adjustable dampers developed by PKM Consulting and based on Ohlin TTX36. Uprights developed by Poly Shape through additive manufacturing; each unit weighs 2.3Kg.

Aero package: 2.35m wide front wing and 2.1m wide rear wing, swan neck mounted. Turning vanes on the underside of the front floor to increase downforce.

Wheels: Magnesium BBS.

Tyres: Michelin 18in hillclimb tyres with a super soft compound for rapid temperature generation.

Fuel: Specially developed by ETS.

Dimensions: Length – 5.1m; Width – 1.98m. Height (with roll-cage) – 1.1m. Wheelbase – 2.5m.

Weight: 770kg.

fourth and fifth gear curves while the last 5km sometimes requires first gear. The faster corners also require downforce and power, both of which are significantly reduced at these altitudes. 'Also, at the start, the track surface is relatively smooth, but because it snows almost every day at the top, it's very bumpy there, which makes it difficult to achieve an optimised set-up because every 3km there is a different challenge for the engine and chassis,' explains Dumas. 'The driving style has to be completely different. You usually only drive at 80 to 85 per cent, as you cannot take the risk of pushing to 100 per cent, because you'll end up in Colorado Springs, which is about 2000m lower.'

New for this year there were Michelin tyres especially designed for hillclimbing. They utilise

a super soft rubber compound which helps to generate temperature and therefore reach the optimum working range quicker. 'The tyre side is also very complicated, because they have to work and offer consistent performance throughout a wide range of temperatures from 0degC to 20degC ambient,' explains Dumas. 'The construction also needs to cope with the rough and bumpy roads found at the top.'

Smooth operator

The suspension has been developed by PKM Consulting which started with the three-way adjustable Ohlins TTX36 dampers from last year's Norma M20. 'We installed a two-way adjuster on the rebound side to achieve a four-ways adjustable damper and our specific



'You need a good distribution of downforce on both of the axles'

blow off to cope with the bumpy sections of the track,' says Paul-Etienne Berthe from PKM. 'We adapted the spring stiffness, damping ratio and third element stiffness to this specific track in accordance with the new aero balance.'

The spring/bump-stop balance was also heavily investigated to ensure that aerodynamic stability was maintained throughout the first sector and mechanical grip throughout the last, where the downforce is at its lowest due to the high altitudes. 'The unlimited nature of Pikes Peak has allowed us to develop a regenerative damper that is also an adaptive damper, and the plan is to introduce this as soon as possible,' Berthe says.

To help optimise the aerodynamic package Dumas challenged five former members of the Rennteam Uni Stuttgart Formula Student Team to put their university knowledge into practice in professional racing. 'The air density at the finish line is only around 0.72kg/m^3 , which is a

lot less than the 1.2kg/m^3 at sea level,' explains Simon Eser, one of these former students. 'Consequently, the aerodynamic forces are significantly lower which means that not only is the downforce lower, but the drag forces as well. The unlimited nature of the Pikes Peak hillclimb gave us the chance to build an aero package with a very high downforce coefficient so that even at these low air densities, the aero package would still produce downforce. Furthermore, the combination of low air density and absence of long straights reduces the importance of developing a low drag design.'

Mountain-air

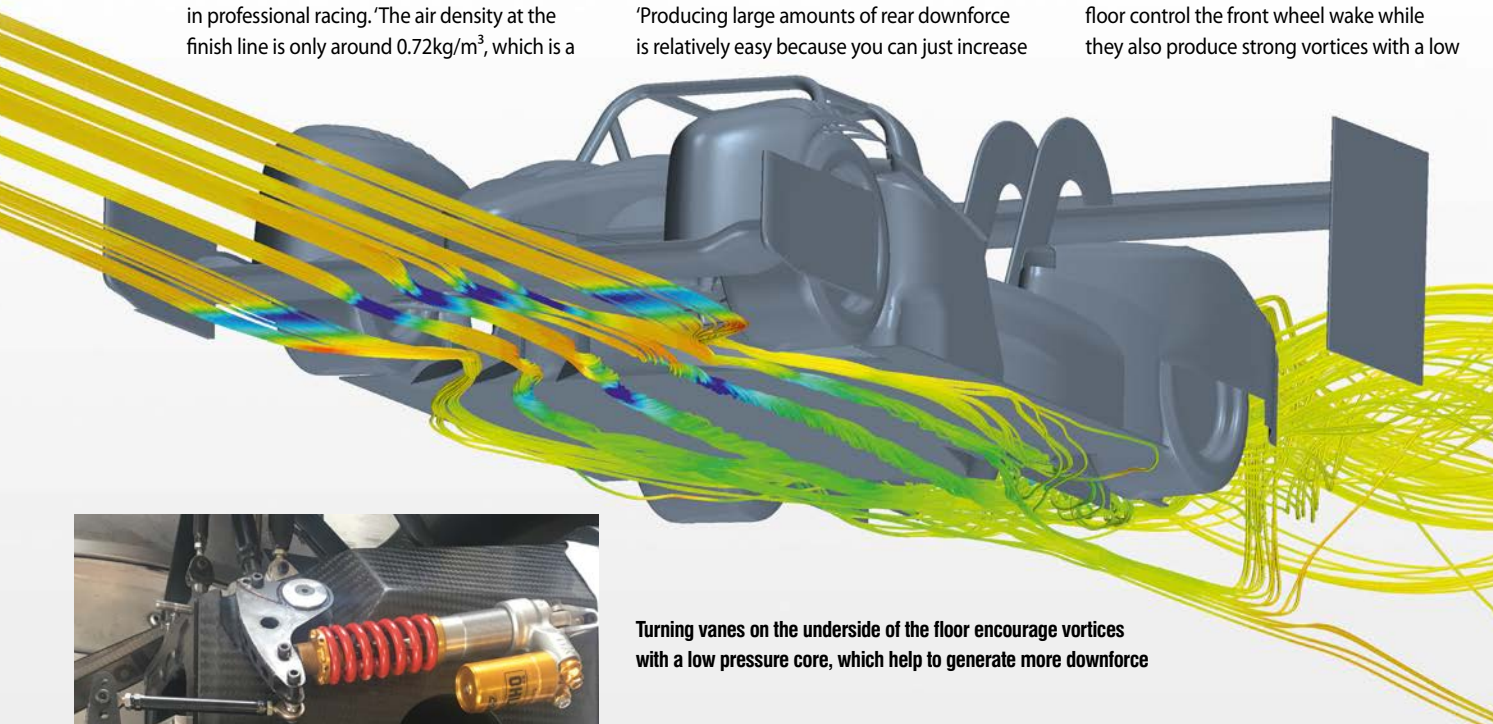
Self-developed lap time simulations were used to determine the initial minimum lift/drag ratio required throughout each development step in improving the performance of the car. 'Producing large amounts of rear downforce is relatively easy because you can just increase

the size of the rear wing,' Eser continues. 'However, to build a quick racecar, you need a good distribution of downforce on both axles. Therefore, our primary focus was to find front downforce whilst maintaining a sufficient amount of airflow into the radiators, and also keeping a good ground clearance to cope with the bumpy track.'

Winging it

The front wing consists of two elements and is 2.35m wide, making it wider than the front tyre edges. The outboard section of the front wing has been designed to generate a strong front wing endplate vortex, which is unobstructed and can therefore flow around the front tyre. This not only improves front downforce but also helps manage the flow towards the floor.

Turning vanes on the underside of the floor control the front wheel wake while they also produce strong vortices with a low



Turning vanes on the underside of the floor encourage vortices with a low pressure core, which help to generate more downforce



To deal with the bumpy and rough track (at the top of the course at least) PKM Consulting has modified the Ohlins TTX36 shocks from last year's car to produce clever 4-way adjustable dampers



The front wing endplates help to generate strong vortices which flow around the front of the tyres. The aero package has been developed with help from a cadre of former Stuttgart Formula Student team members



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'By effectively only putting material where strength is needed, we have been able to produce a much wider and bigger upright than last year'

pressure core, hence increasing downforce at the leading edge of the floor.

The rear wing also has two elements and is mounted via a swan neck arrangement similar to that seen in LMP1. The 2.1m span increases downforce at the rear, balancing that at the front. To reduce cost and to speed up manufacturing, the rear diffuser was carried over from last year and the wheel arches are from the Norma LMP3 racecar, with several modifications.

'All our development was conducted in CFD, where we not only computed straightline cases, but also analysed the flow in the yawed, steered and rolled conditions. We also simulated an aeromap to set up the ride height, spring rates and bump-stops to ensure a good aero balance throughout the entire speed range,' Eser says.

Improving the performance of one area of a car often requires you to develop other areas

as well. For example, the more efficient aero package, together with the specifically designed Pikes Peak Michelin tyre, combine to give superior grip. The wheels have also increased in size from 13in to 18in, allowing for larger and more effective brakes, prompting the switch to carbon brakes for the first time.

'All of these factors mean that the loads going through the uprights are much higher than we've previously seen,' explains Frederic Impellizzeri, Automotive and Motorsport Business Unit manager at Poly Shape. 'The biggest technical challenge was to achieve the right loading case to design the uprights to withstand these loads, but also be as light as possible. We used a new design approach which suits additive manufacturing perfectly, called topology optimisation, where the uprights were designed from scratch using titanium.'

Mountain topology

Topology optimisation is a mathematical approach that optimises material layout within a given design space, for a given set of loads and boundary conditions such that the resulting layout meets a prescribed set of performance targets. The software uses iterative calculations to remove chunks of material from areas where there is no mechanical stress and, therefore, no strength required. Also, because it's an additive manufacturing process, the flexibility enables any shape to be created, so the optimum design can not only be achieved, but manufactured as well, resulting in the uprights weighing 2.3kg.

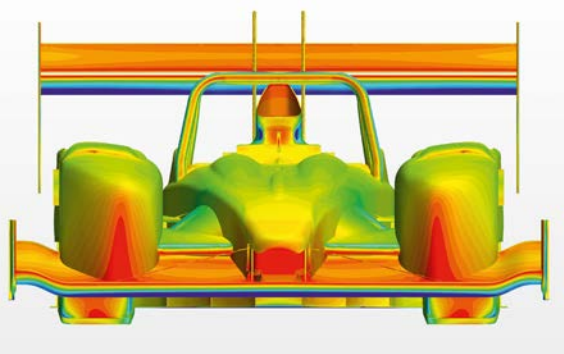
'By effectively only putting material where strength is needed, we have been able to produce a much wider and bigger upright than last year, whilst minimising weight.'

Impellizzeri says. 'This biomimetic design approach also avoids any stress concentrations that you often find on the sharp or angled geometries of billet machined components.'

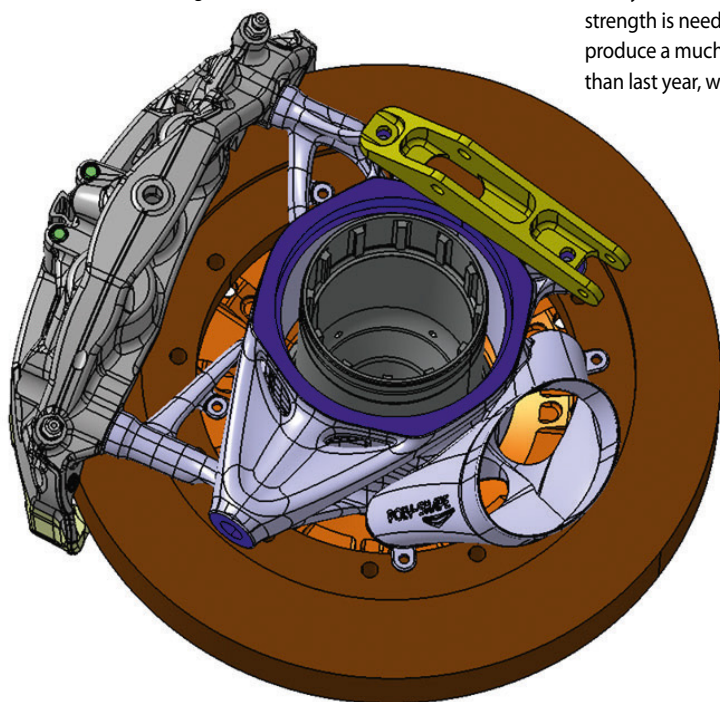
The track has high demands on the chassis and suspension, which is why Poly Shape improved the fatigue resistance of its uprights by implementing a high isostatic pressure (HIP) heat treatment after the routine stress relief heat treatment. HIP is where components are heated in a high-pressure chamber with an inert gas, usually argon. Subjecting the material to pressure from all directions, in addition to the increased temperature, allows plastic deformation and creep, helping to reduce porosity within the component.

Peak practice

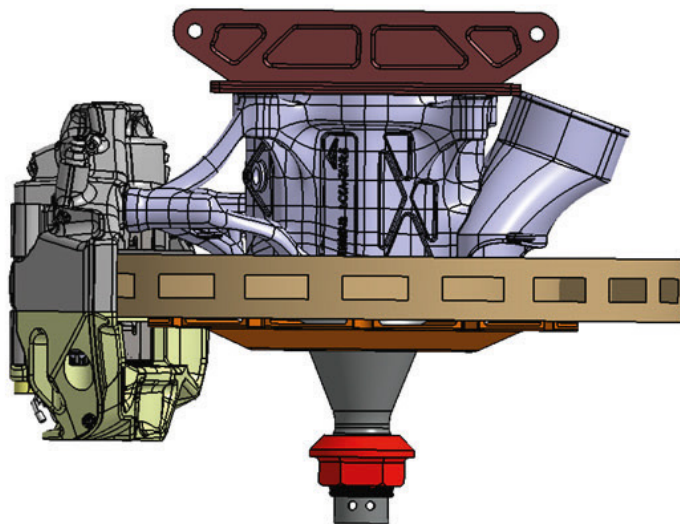
Additive manufacturing also allowed the parts to be produced very quickly, which was essential, as Dumas wanted to complete a test programme, which demanded short lead times. 'It's always the same, when you are a private team. You are very small, which often means things are ready at the last minute. An extra three or four months would have been nice to have,' Dumas says. 'We tested at a small airport in the south of France because it's a narrow track with a hairpin. It is very difficult to simulate the Pikes Peak track with the change in altitudes and so on, but at least we tested at a track with a relatively similar layout. The uprights designed by Poly Shape are incredibly intricate and lightweight and it was the first time they had designed an upright for the particular demands of Pikes Peak.' Poly Shape completed the entire process from design to production of the uprights in just a few weeks.



The unlimited regulations and high altitudes at the Pikes Peak hillclimb require an ultra-high downforce package and this has resulted in a front wing on the Norma which is over 2m wide



Above and right are CAD versions of the wheel assembly. Brakes have been upgraded to carbon to deal with the increased demands of better tyres and extra aero load



AM company Poly Shape has developed the uprights from scratch using a new technique called topology optimisation. Made of titanium, these now weigh just 2.3kg



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Rear view

It was a concept that was all but forgotten by grand prix car builders for close to 20 years, yet by the end of the '50s mid-engined racecars had burst back on to the scene, and they were there to stay. Here's the curious story of this interrupted evolution

By FORBES AIRD



Auto Union was successful with its mid-engined racecars in grands prix in the 1930s, but it took two decades for the concept to return to the top level of single seater racing

Once upon a time, monsters strode the earth. Their roar was deafening, the ground trembled when they passed, and their breath stung the eyes. Little creatures could only hide, and bide their time. Then a great cataclysm convulsed the earth, and all the lights went out. Many lives ended, frozen in their tracks or incinerated. A few of the monsters survived for a while, but they were enfeebled. One sub-species, largely isolated by an ocean from the turmoil of the times, remained robust but grew notably lopsided, a deformity brought about by their insistence on only ever turning to the left. But the breed was doomed. Now the tiny creatures began to creep out of their lairs in garden sheds and back alley lock-ups. Through a quirk of mechanical genetics, these little creatures were

of a configuration notably different from most of the monsters – they had their engines behind the driver. The future was theirs.

For a time, sometimes decades, sometimes entire eras, things grind along. Then everything changes. Catastrophic events on a large scale – like asteroid impacts or world wars – inevitably reshuffle the deck. Evolutionists call this punctuated equilibrium. Now, if you want punctuation, the arrival of a hypersonic rock the size of Gibraltar will fit the bill. So will the aftermath of five years of violent armed conflict, culminating in a couple of atom bomb blasts.

As an example of equilibrium, Mike Hawthorn's 1958 F1 world-championship winner, the Ferrari 246, had a specification identical to that of the 1938 European Championship-winning Mercedes W154, 21

years earlier: engine at the front, the fuel load at the rear, wire wheels, drum brakes, a ladder frame and IFS, plus De Dion rear suspension.

Then came the punctuation. The following year, 1959, the world championship-winning car – the Cooper T51 – was entirely different. It featured a mid-mounted engine, fuel and driver carried amidships, cast magnesium wheels, disc brakes, a multi-tubular frame, and independent suspension at all four wheels.

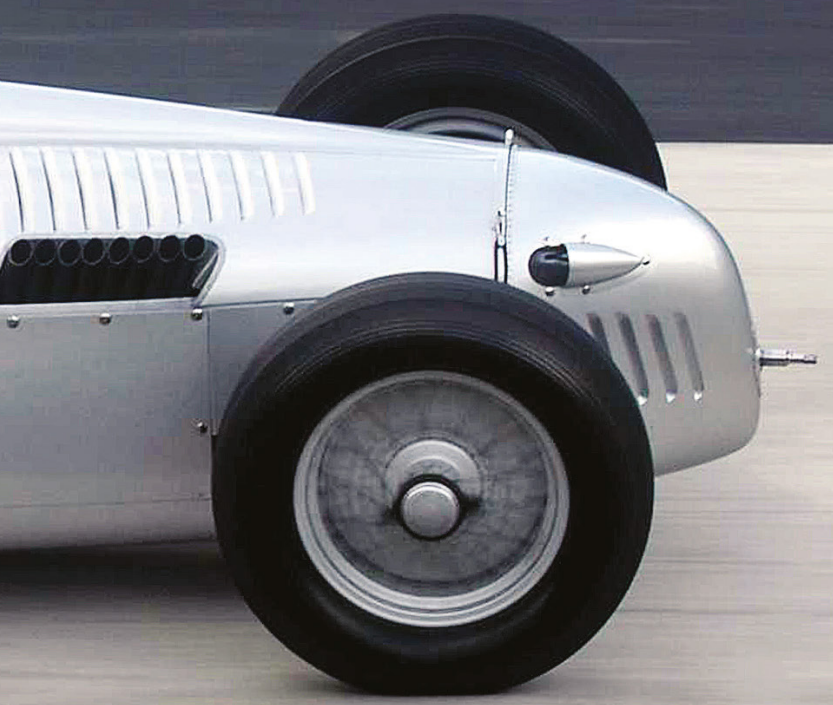
Back-pedalling

Such shifts seem sudden at the time, a veritable thunderbolt. After all, you don't get from a Ferrari 246 to a Cooper T51 by an evolutionary process of refinement – creationists have a field day with this sort of thing! But retrospection brings the realisation that the harbingers

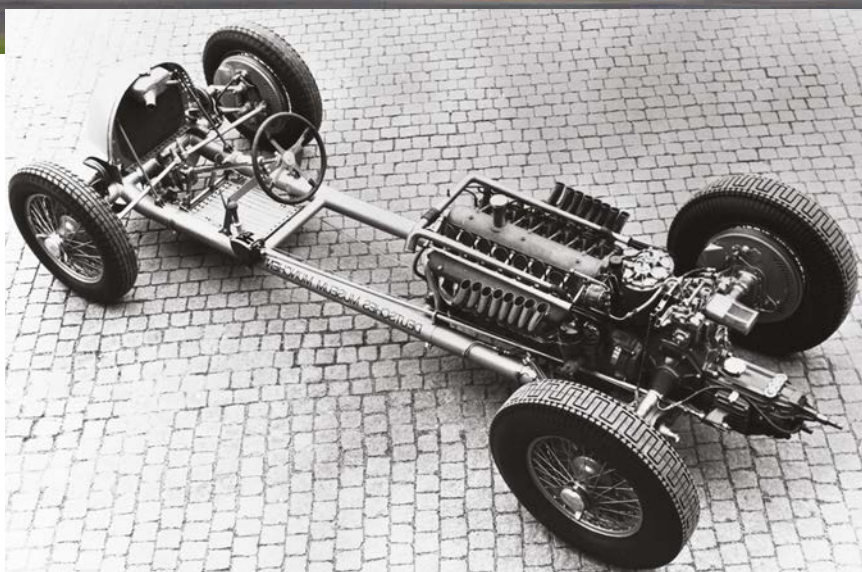
Racecars with the engine at the back have been around almost as long as there have been racecars



Compare and contrast: there are clear similarities in design for the Ferrari 246 (above), which won the World Championship in 1958, and the 1938 European Championship-winning Mercedes (below)



While Auto Union stuck with the mid-engine concept throughout the 1930s, Mercedes-Benz produced a string of more conventional cars, including the W25, the W125, and the W154 (pictured)



Naked Type C Auto Union. The suspension was trailing links at the front and swing-axes at the rear and this meant this beast of a car, which also packed a 550bhp V16 engine in the back, was far from easy to drive

were there all along. Just as the precursors to modern mammals, including us, co-existed with dragonflies the size of Cessnas and lizards as big as buses, a little digging reveals that racecars with the engine at the back have been around about as long as there have been racecars.

You don't have to dig very deep to find one obvious example – one of the end-times monsters, the pre-war Auto Union. The behaviour of the early (1934-1937 Type C) AU's bred the belief, indeed the utter conviction, that monsters cannot be housebroken – that a rear/mid-engined car must have savage oversteer, uncontrollable by anyone other than a driver as skilled as Bernd Rosemeyer. In those days it was a *well known fact*.

The real problem with those first Ferdinand Porsche-designed Auto Union's was mostly



The Eberan-Eberhorst designed Type D Auto Union was built for new regulations introduced in 1938. De Dion suspension replaced the swing-axle of the Type C and the handling was much improved



While Bernd Rosemeyer was the only driver to truly master the Auto Union Type C, Tazio Nuvolari (above) was very quick in the Type D – perhaps because of his unusual induced-understeer driving style

the suspension system, comprising trailing links at the front and swing axles at the rear. Edmund Rumpler had introduced swing axles on his road-going Tropfenwagen (teardrop car) back in 1921, and had previously patented this design. Porsche himself held a patent on a front suspension system which comprised paired parallel trailing links at each side, working transversely mounted torsion bars.

This configuration places the front roll centre invariably at ground level, and the rear one a bit above the axle centreline, which worked serviceably well on early Volkswagens and was tolerably okay even on early Porsches, if you paid close attention. But the AU's enormous 19in wheels (22in for high-speed circuits) pushed the rear roll centre up to somewhere near half a yard high, with consequent severe

jacking. Together with acute camber change, this could produce very nasty bouts of trees-sky-trees-sky-trees. Trying to pipe 545bhp through very narrow tyres didn't help much either.

Further excavation unearths another Tropfenwagen, more swing axles, and another Porsche connection. In 1923, Benz engineers Wagner and Nibel built what is arguably the first mid-engined road racecar, using an essentially unchanged Rumpler chassis, though with its wheelbase stretched a bit to accommodate a 2-litre, DOHC in-line six, in place of the Rumpler's four-cylinder engine. This Benz Tropfenwagen enjoyed a modest degree of success in hillclimb events in the 1920s, sometimes driven by one Adolf Rosenberger. In 1931, Rosenberger became a partner in, and provided financial backing for, Ferdinand Porsche's independent design consulting firm. It was he who championed the design then known as the P-wagen (P for Porsche) which, when taken up by the newly-formed amalgam of Wanderer, Horch, DKW and Audi, became that same 1934 to 1937 Auto Union Type C.

Backpacking

One rung up the ladder in our archaeological dig, we can perceive the effects of a shift in the environment – a rules change for 1938 that demanded a new design. Porsche had charged

a hefty fee for the P-wagen plans, but by now Auto Union was financially troubled, so it decided to dispense with Porsche's services and to do the job in-house. The 1938 car – the Type D – was thus principally the work of AU engineer Robert Eberan-Eberhorst. Together with some artful re-packaging, Eberan-Eberhorst banished the perfidious swing-axes, providing instead a De Dion tube, laterally located by a low-mounted Panhard rod. With camber change eliminated, and the rear roll centre dramatically lowered, the handling was transformed. The beast was partly tamed.

Had it not been for World War II we might have seen more examples of this interim species than the Type D Auto Union (the enigmatic Type E, and the Alfa Romeo 512) now that the genus had been, if not exactly house-broken, then at least partly domesticated by Eberan-Eberhorst. A scarcity of fossil specimens is a common problem with archaeology. But near the top of our ladder, just under the surface, lies a debris field positively littered with arrowheads, all pointing to the future.

Catastrophes may extinguish a dominant species, but they do not necessarily determine its successor. There is an intriguing thesis, popularised in a fairly recent book by Jeffery Schwartz (*Sudden Origins: Fossils, Genes, and the Emergence of Species*, Wiley NY, 1999), that

The Auto Union Type C's enormous 19in wheels pushed the rear roll centre on the car up to somewhere close to half a yard high

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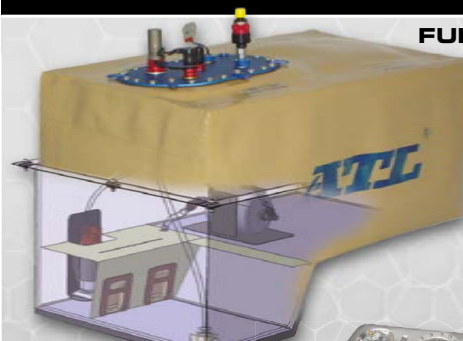
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The 1960 Cooper T53 Formula 1 car. Cooper reignited the rear-engine revolution in the late '50s with its championship-winning T51 of 1959



With the bike engines chain-driven their location aft of the cockpit was the obvious solution for the 500cc Formula 3 cars

refutes the disputations of the Darwin deniers about sudden origins. The notion (here greatly simplified) is that all individuals carry within them a number of recessive genes that only get 'expressed' – as geneticists put it – if two individuals with the same recessive gene should breed. The mutant offspring of such a union is usually not viable or, if so, labours under a handicap – blindness, for example. But occasionally the mutation confers a benefit – possessing an opposable thumb, say.

An individual so favoured would have an advantage throughout his/her/its life, but the beneficial characteristic would only be passed on to a future generation if that individual finds a likewise advantaged mate. The probability of such a mating is a matter of statistics,

depending on the size of the population, and the fraction of it holding the trick gene – it's all a matter of numbers then. Maybe, just perhaps, it's the same with racecars?

Breed apart

There is no suggestion here, of course, that racecars actually mate with each other, they don't do it in the road (though it may sometimes seem that way, especially at the first corner!), but they do proliferate. Here, the mechanism of 'genetic' diffusion is human agency: a certain new design configuration convincingly demonstrates its fitness within a new environment to enough people that the new idea multiplies, and rapidly deposes the previous paradigm. That process is a mode of

evolution addressed by neither Darwin, who adequately accounted for the incremental steps in the evolution of organisms, nor LH Pomeroy, who did the same for racecars. Rather it is how you get from a stegosaurus to a stoat, and from the architecture of the Mercedes W154 to that of the Cooper T51, in a seeming blink of an eye.

Little creatures

The critical size of transmuted population was achieved in the late 1940s, by the swelling numbers of 500cc Formula 3 cars, powered by motorcycle engines. Using the near-universal chain-drive, the obvious packaging arrangement was to mount the engine behind the driver. The 500 Club, which wrote the rules for that original Formula 3, was founded in 1946, and had its origins in the pre-war hillclimb specials, several of which also had bike engines. Due to concerns about adequate cooling, however, many (perhaps most) of these were front-engined, which involved some awkward drive train arrangements! And of the handful that did pioneer the now-classic architecture, many used the dreaded swing-axes.

A key element of the new environment in which these little creatures were to thrive was the existence of dozens of RAF and USAAF bomber airfields now lying disused in the UK, having made their contribution to the violent upheaval of WWII. After the usual bureaucratic government foot-dragging, they became venues for amateur motor racing. Despite their seemingly long stretches of straight pavement

By the late '40s and early '50s there were hundreds of 500cc Formula 3 cars

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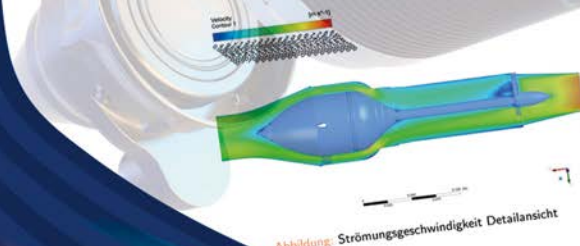


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The Lotus 25 of 1962 took the mid-engine concept to the next level with the introduction of fully-stressed monocoques in to Formula 1

(a fully laden Lancaster or B-17 needed about 1000 metres to take off), the artificial circuits cobbled together from these runways and perimeter roads were a far cry from the settings for the road races where, a decade or so earlier, the monsters had often thundered: flat-out blinds on roads miles long, (usually narrow, sometimes bumpy, and often tree-lined), followed by a clumsy trundle around the fountain in the village square, then another blast of hard acceleration and more sustained very high speed running. Their front-engine/fuel at the back configuration – with consequently high yaw inertia – fitted them well for that environment, but they weren't much use in the twisty bits. There the little creatures frolicked.

Cooper-sonic

By the late '40s and early '50s, there were hundreds of 500cc F3 cars – the Surbiton works of Charles and John Cooper alone turned out about 300 of them, and there were literally dozens of other 500cc racecar makers. As a racing class, F3 was enormously popular – grids of 30-plus were not unknown, and these boasted such drivers as Stirling Moss, Peter Collins and even one Bernie Ecclestone.

The Coopers avoided the treacherous swing-axes by what was surely a fluke: expedience rather than calculation led them to use the widely (and cheaply) available Fiat 500 'Topolino' front suspension ... at both ends! This amounted to a pair of wishbones at the bottom, and a transverse leaf spring that provided both

the springing medium and the top links. The geometry thus delivers equal, near ground level roll centre heights at both front and rear, although with a slight rear weight bias, and equal sized tyres front and rear, so the Coopers were still somewhat disposed to oversteer. Also, camber compliance was a bit iffy, and rear toe-stiffness was dodgy in the extreme, but with a paltry power output (about 45bhp) and, above all, freedom from jacking, they offered a convincing visual demonstration that mid-engined racecars can be managed by mere mortals. And many were watching.

Rear drive

These little creatures reached reproductive maturity remarkably rapidly, and begat successive generations, each bigger and stronger than the previous one. From their 500cc ancestors, they grew first to 1100cc, then to 1500cc. The Cooper's conception reached its full, adult size of 2500cc just in time to propel Jack Brabham's 1959 T51 to their mutual F1 championships. Now everyone was watching.

One of those observers was Colin Chapman. His contemporaneous Lotus F1 car, the slim and svelte 16, could hardly be called monstrous (published values of its dry weight vary from 720lb, which is impossibly light, to 980lb, which seems improbably heavy), but its front-engine layout was outmoded, a skeuomorphism from those days of the monsters.

Chapman implicitly acknowledged this by announcing the following year the birth of

the 18 – the first mid-engined car born in the Lotus stable. Following a further change in the environment – a rules change in 1961, reducing engine size to 1500cc – the intense energy radiating from the brain of Chapman and his formidably talented retinue of mechanical minds brought about a stunning genetic modification: the creatures became exoskeletal. The stressed-skin Lotus 25, which propelled Jim Clark to the 1963 F1 World Championship, arguably represented the apotheosis of the mid-engined racing car, at least until the creatures began to sprout wings.

Market forces

Chapman then lit the fuse to the time bomb that was to blow everything up. Abandoning all protective camouflage, he festooned his progeny with advertisements, thus introducing the breed to the disease called 'the marketing department'. And although the little creatures were, despite this, to grow ever larger and stronger – exceeding at times even the awesome power of the monsters of yore – the object of the life-form that had emerged and had begun to evolve was no longer that it should scamper about simply to amuse itself while others watched on. The game was now all about amassing wealth.

The archaeologists of the future will find the peak of the animal called 'Racecar' smothered under an avalanche of contracts, rulebooks, and money. What starts with a bang, ends with a whimper.



Such shifts seem sudden at the time – you don't get from a Ferrari 246 to a Cooper T51 by a process of refinement

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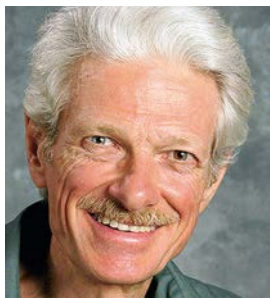
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Putting some bounce into the steering return

Examining the reasoning behind installing springs in a steering rack

QUESTION

I recently saw a rear-engined Renault that had centring springs built into its steering rack. I've never seen that before. Why did they do this? Is this a good idea, or a crutch for bad design?

THE CONSULTANT

I don't think they're a bad idea. There are other ways to make the steering seek a vehicle centreline centre, but they aren't necessarily better. The most common way is to use some front view steering axis inclination (SAI) combined with some positive front view steering offset (ISO term) or scrub radius (SAE term). This causes both front wheels to gain positive camber with steer and lift the car at the lower ball joints – or more precisely, at the steering axis/ground plane intersection. That induces a gravitational centring force in the steering: the car tries to follow gravity by straightening out the wheels. This gets us the centring force with no added parts, but it also produces adverse camber change with steer on the outside front wheel. This effect increases as we add SAI.

Steering offset is also a mixed blessing. It makes longitudinal (x axis) forces feed back more through the steering. That increases the driver's ability to sense where the front wheels are because he/she can feel them going over bumps. It also increases the driver's ability to feel any pulsation in the front brakes, and increases the possibility of a sharp impact breaking the driver's grip on the steering wheel, or even injuring the driver's hands.

Self-centred

In combination with caster, steering offset makes the car roll out of the turn with steer, and increases load on the inside front and outside rear tyres. In moderation this can be good. In excess, it can make the car twitchy. The optimum amount will depend on the car, the track, and driver preference.

At speed, caster combined with trail produces a centring force due to tyre drag, and a force trying to steer the wheels out of a turn or down a lateral slope. In moderation, this is good because it helps the driver sense lateral

force at the front tyres. How much of this is desirable will vary with driver preference.

Caster combined with trail also produces a de-centring force at low speeds and when the car is stationary. In extreme cases this will make the front wheels flop over to either side when the steering wheel is released, as is often seen with dragsters. In less extreme cases, at parking speeds the steering will have a normal feel at small steer angles but the force at the steering wheel will lighten and then reverse as we steer further from centre. Since most cars don't do this noticeably, this will feel odd to a driver who isn't used to it. Centring springs can reduce or eliminate this effect.

Spring time

I did a brief search for Renault Dauphine, Caravelle, R8, or R10 alignment specs and came up dry, but I think I remember reading back in the '60s that they had around eight degrees of caster. I drove an R8 in 1966. I didn't know it had centring springs. I thought the steering feel was good: well weighted; appropriately geared; communicative, especially of lateral force; no odd quirks. I also remember that the front wheels tilted more than usual in the direction steered, indicating a lot of caster.

Rear-engined Renaults aren't the only cars to use centring springs. Corvairs have a torsional rubber bushing where the Pitman arm meets the relay rod. That would give a little centring effect, in addition to some vibration isolation. It's common to see a pair of gas shocks on the tie-rods of 4WD trucks. Those mainly provide damping, but there's also a little centring force from the gas springs.

With pullrod suspension, it is possible to arrange the geometry so the front end lifts as the wheels steer, with a lot less camber change than is created by SAI. This is also possible with pushrods, but not as easily.

Added adjustability

The nice thing about centring springs is that they can easily be made as stiff or soft as desired, allowing the centring force to be tuned as needed without changes elsewhere in the system. They allow SAI, steering offset, caster, and trail to be optimised for other design objectives, without any need of compromise to obtain centring force. Then again, it's usually possible to get very good steering without centring springs. So they're not about to become universal, but they shouldn't be dismissed as a bad idea or a crutch either.



Rear-engine Renaults of the 1960s, such as the Dauphine pictured here, sometimes used centring springs built into the steering rack to help the wheels return to the straight-ahead position. It's an unusual approach, but it has its benefits

These centring springs can easily be made as stiff or as soft as you desire

De Dion woes in the 1930s

Why did the Mercedes W125 suffer with speed-sapping wheel judder in the turns?

QUESTION

I'm designing a Special and considering using De Dion rear suspension. I know many successful cars used it in the '50s and it would appear to have good camber properties. However, I recently learned that Mercedes had a problem with it in their racecars of the 1930s. Apparently the cars had a tendency to 'judder' while cornering, particularly on bumpy surfaces. This caused Mercedes to revert to swing axles for their W196 in the '50s. However, Alfa went from swing axles to De Dion when developing the 159 from the 158. Maserati used De Dion with great success. What's the story with this judder thing? What causes it? Is it an inherent problem in De Dion systems?

THE CONSULTANT

The phenomenon we call judder is basically wheel hop, most often during lateral acceleration (cornering). It doesn't necessarily happen just on bumpy surfaces.

De Dion suspension is like beam axle suspension, except that the final drive unit is mounted to the sprung structure as in an independent suspension, with jointed shafts going out to the wheels. Compared to a live axle, there is a reduction in unsprung mass, and driveshaft torque does not react through the suspension. The system gives 100 per cent camber recovery in roll, if we disregard roll due to tyre deflection. Camber does not change with ride height. Thus, camber does not change adversely as the car traverses humps and dips in a corner, or when the driver is compelled to lift off the throttle when cornering hard.

Judder in cornering can occur with beam axles, swing axles and De Dion suspension, or even independent systems other than swing axles. It is sensitive to tyre properties and grip level. It is sensitive to compliance in the system. But most of all it is sensitive to roll centre height or lateral jacking coefficient. I have seen it in swing axle cars, including a VW Squareback and a Mk3 Triumph Spitfire. I have also seen it in Chevrolet Chevelles with live axles on rubber-bushed triangulated four-link suspensions.

The Mercedes version of the De Dion had a De Dion tube with a swivel in the middle and a sliding block for lateral location that moved in a slot in the rear face of the final drive. The tube assembly had to be able to twist freely because its ends were located by one simple trailing arm each. The system couldn't move in roll unless the tube could twist. This geometry gave more than 100 per cent camber recovery in roll: it caused the rear wheels to theoretically lean into the turn a bit. The geometry also gave a roll centre considerably above the height of the sliding block, which was roughly at hub height.


The track was narrow by modern standards at only 55in, and the tyres were very tall. According to Denis Jenkinson's book on the W125, rear tyre section was always 7in but the rim diameter varied according to the circuit: 19in, 22in, and 24in rim diameters were used. Front rim diameter was always 22in. With the middle choice of rear rim diameter, allowing half an inch of tyre deflection, the height of the sliding block would have been nearly a foot and a half. The roll centre height would then have been around two feet! A line drawn

from the contact patch centre to the roll centre would have been at nearly a 45-degree angle to the ground. I don't know how well they were able to control clearances and deflections in the tube assembly, but there must have been considerable lateral compliance in those tall and narrow wire wheels.

So that's why it juddered. A De Dion system with a roll centre no higher than a foot or so should be fine. Auto Union, on similar tyres and wheels, went from swing axles to De Dion for the Type D, with a much lower roll centre, and it appears not to have had any such problem.

Swing low

Mercedes, like so many other manufacturers, switched to De Dion suspension to remedy the bad handling it had experienced with swing axles, in its case on the W125's immediate predecessor, the W25. The W125's problem could possibly have been solved by just substituting four parallel links for the trailing arms. That alone would have lowered the roll centre to the height of the sliding block, and also would have eliminated the need for the swivel joint in the tube assembly. It would have been desirable to lower the roll centre further, but it's hard to say whether that would have been necessary to eliminate the judder. In any event, the problem was clearly the result of detail misapplication of the De Dion design concept rather than the concept itself.

I think probably Mercedes' reverting to swing axles for the W196 was driven more by marketing than by engineering; all its road cars had swing axles at that time. But to make swing axles work at all, it had to adopt the 'low pivot' version of the design also used later by Porsche. Even then, the cars were touchy to drive and required complex rear ride height control to minimise camber change as the fuel burned off. According to Stirling Moss, the cars were not bad, but you had to be very smooth and never lift abruptly when cornering. 

Mercedes switched to De Dion suspension to remedy the bad handling it had with swing axles



The potent Mercedes W125 of 1937 was plagued with a handling trait that saw the rear wheels hopping in the corners

CONTACT

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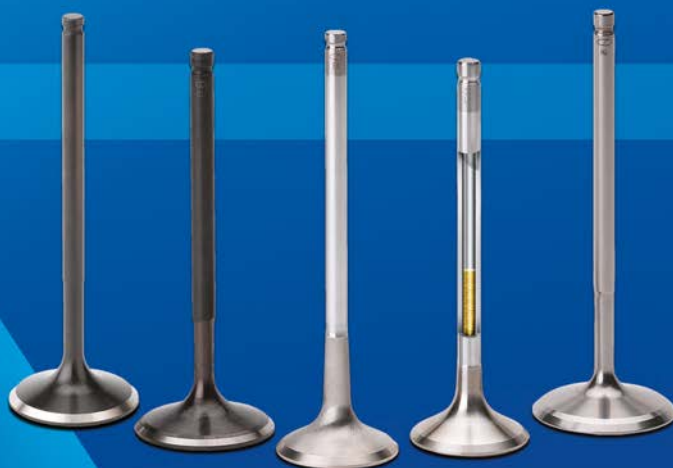
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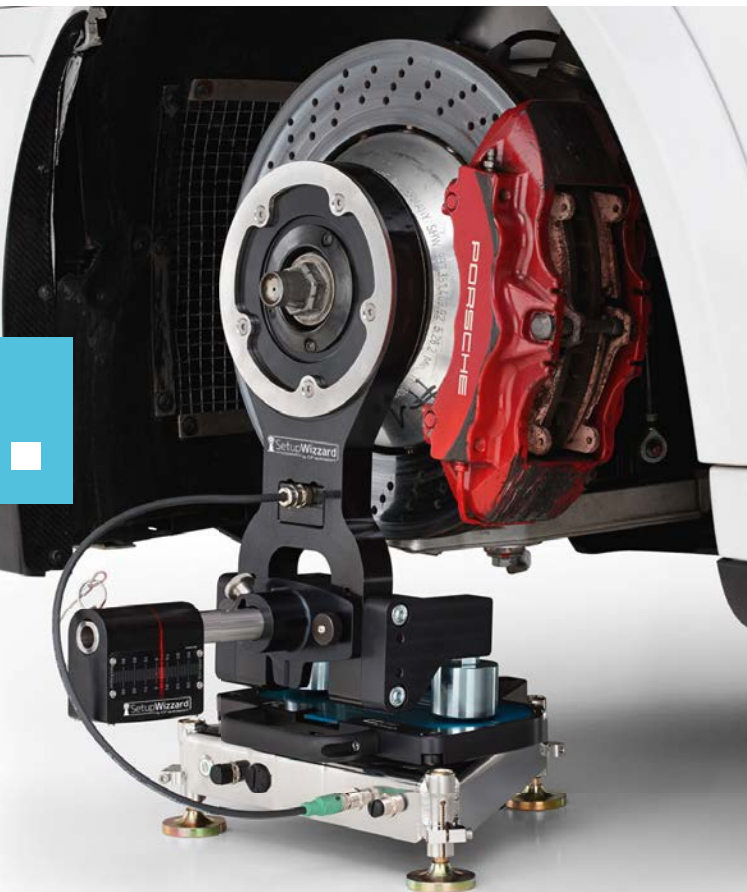
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Optimising the aero on a Nissan GT-R

Our 'Ring racer study concludes with some more potent tweaks

Our current MIRA full-scale wind tunnel project car, the Nissan R35 GT-R of London-based Australian Anthony Gaylard, will be used to attempt a sub-seven minute lap of the Nurburgring's Nordschleife circuit. The car is road legal and has been assembled and developed by UK-based Litchfield Motors, featuring 1000bhp, Ohlins-tuned suspension, Alcon brakes and an aerodynamics kit based on NISMO GT3 components. But with uncertainty about the car's actual aerodynamic characteristics – in particular its front to rear downforce balance – prior to coming to the wind tunnel, our session provided valuable data and insights on attaining that all-important balance with the highest possible downforce level.

The previous instalments, in our June and July issues, examined the GT-R's baseline data and focussed on the measures to improve the balance. Initially rear downforce was reduced by lowering the rear wing angle to minimum, and significant improvements were then made at the front with simple cooling system ducting. After these modifications balance was much improved, from a starting point of modest front lift to more than 32 per cent of the total

downforce on the front end, as the results in **Table 1** show. However, the balance target was 45 per cent front, given that the static weight split was roughly 50/50 front to rear. So in this final instalment we will examine the remaining configuration changes that brought the car very close to the balance target.

Front end mods

Having obtained some front downforce gains from front cooler ducting that also yielded drag reductions, it was time to move onto modifications that were going to be less efficient in terms of incremental drag to downforce ratios. However, with 1000bhp available drag was not a primary issue. The first of these modifications was to fit front wheel arch Gurneys. The splitter sides protruded from the wheel arch perimeters by about 30mm, so the Gurneys were made that width at the base, tapering to zero at the height of the top of the upper dive plane. The effects are shown in **Table 2** as Δ or 'delta' values in 'counts' where one count is a coefficient change of 0.001.

As hoped, the wheel arch Gurneys brought a useful benefit, but as expected they were not very efficient, with 29 counts of downforce for

17 counts of drag, a ratio of just 1.71:1 where efficient gains are thought of as having a ratio over 3:1. Nevertheless, 25 counts (14.7 per cent) extra front downforce brought the car's aero balance to just over 35 per cent front in absolute terms. Curiously, the front wheel arch Gurneys added an unexpected rear downforce increment, too.

Next, small fences were added to the ends of the splitter. **Table 3** shows that these small fences were less effective and less efficient than the wheel arch Gurneys, but they did produce a further forward balance shift. While part of that balance shift was due to a small gain in front downforce, it was also partly due to a somewhat bigger reduction in the rear downforce, which cannot have resulted solely from the mechanical leverage of this forward-located device alone. There was clearly a contrast here with the wheel arch Gurneys, which would have created more *outwash* at this height and which added rear downforce, with the end fences which would have created more *upwash* at the same height and which reduced rear downforce.

Lastly, taller rectangular splitter end fences were tried, and at the same time the small



With 1000bhp available drag was not a primary issue with this car



The R35 GT-R's aerodynamic set-up was significantly improved during its MIRA session



This front wheel arch Gurney helped with balance, but the mod was not very efficient

Table 1: The aerodynamic coefficients and balance after last month's modifications

	CD	-CL	-CLfront	-CLrear	%front	-L/D
After front duct modifications	0.385	0.522	0.170	0.352	32.47%	1.358

Table 2: The effects of front wheel arch Gurneys

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
Δ , counts	+17	+29	+25	+5	+2.86%	+13
Δ , %	+4.4%	+5.6%	+14.7%	+1.4%	-	+1.0%

*Absolute rather than relative difference in percentage front.

Table 3: The effects of small splitter end fences

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
Δ , counts	+6	-3	+4	-8	+1.02%	-26
Δ , %	+1.5%	-0.5%	+2.1%	-2.2%	-	-1.9%

*Absolute rather than relative difference in percentage front.

Table 4: The effects of tall splitter end fences

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
Δ , counts	+19	-5	+15	-20	+3.11%	-72
Δ , %	+4.7%	-0.9%	+7.7%	-5.7%	-	-5.3%

*Absolute rather than relative difference in percentage front.



Adding these small splitter end fences produced some extra downforce at the front end



Larger splitter end fences added upwash to join flow off undersides of lower dive planes

gaps between the top corners of the dive planes and the front arches were also taped over, with the results shown in **Table 4**. These had a similar but larger effect than the small, triangular fences but again added a very useful front downforce increment. The overall values are shown in **Table 5** and indicate the balance was now at almost 39 per cent front, getting somewhat closer to our target.

Chassis rake

Having left adjusting the chassis rake until the car was somewhere near its target balance value, three rake adjustments were then made using shims under the rear tyres, respectively raising the rear ride height by 6mm, 10mm and 16mm, and the results are grouped in **Table 6**. The first two increments yielded essentially linear gains at the front, with small losses at the rear, while the final 6mm of additional rear ride height produced a very different result, with rear downforce *increasing* and no change at the front. Overall, though, the balance was in excess of 42 per cent front and, at the +10mm rear ride height setting, was

approaching 43 per cent – which is very close to the 45 per cent front target.

Moving to the diffuser, this was divergent in top view as well as side view, but the divergent sides were also inclined from the vertical, so it was decided to mount the strakes fore and aft, as wide apart as possible while remaining vertical. This divided the diffuser into roughly equal thirds at the exit. The results in **Table 7** show a modest effect with rear downforce increasing and balance shifting slightly rearwards. However, with no drag increase, this small but useful increment could be traded against a bit of wing angle, which always adds drag.

Summary

The data culminating from all of the described modifications is summarised in **Table 8**, and shows that balance was between 41 per cent and 42 per cent front, although it peaked closer to 43 per cent front. However, as mentioned in our first instalment in the June issue, the GT-R's splitter was provisionally mounted higher than it could be, and, if lowered as much

Table 5: The overall data after the front end modifications

	CD	-CL	-CLfront	-CLrear	%front	-L/D
After front end modifications	0.423	0.542	0.211	0.331	38.97%	1.282

Table 6: The effects of increasing the rear ride height, as values in counts

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
+6mm RRH	+1	+10	+15	-5	+1.92%	+19
+10mm RRH	+2	+9	+15	-6	+2.02%	+15
+16mm RRH	+6	+8	0	+8	-0.52%	0

*Absolute rather than relative difference in percentage front.

Table 7: The effect of diffuser strakes

	Δ CD	Δ -CL	Δ -CLfront	Δ -CLrear	Δ %front*	Δ -L/D
Δ , counts	0	+3	-3	+6	-0.83%	+7
Δ , %	0	+0.5%	-1.2%	+1.8%	-	+0.5%

*Absolute rather than relative difference in percentage front.

Table 8: Aero numbers after all the modifications described

	CD	-CL	-CLfront	-CLrear	%front	-L/D
After all described modifications	0.432	0.572	0.238	0.334	41.56%	1.323



Strakes, which divided the diffuser exit into three parts, added some rear downforce

as practicably possible, would significantly increase front downforce. With the rear wing at its minimum angle to achieve the balance figures reported here, it would be simple to add wing angle to balance a more potent splitter to generate more total downforce with a similar or possibly more forward balance. Thanks to Anthony Gaylard, Iain Litchfield and all the team at Litchfield Motors.



CONTACT

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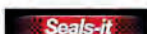
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Taking control

ECUs are no longer purely engine management devices – these complex units can now often control the entire system on a modern racecar. We talked to those at the cutting edge of this technology to find out more

By GEMMA HATTON



The Engine Control Unit (ECU) is often described as the brains of a modern racecar, and with the continued demand for increased functionality from these boxes, they are indeed quickly becoming the central core of any racing vehicle. They are, then, nothing less than vital.

Throughout four seasons in F1, the TAG-320 ECU from McLaren Applied Technologies will have covered the equivalent distance of a return trip to the moon, whilst continuously monitoring and controlling the major systems of the cars. All this information is captured by over 200 sensors, which together with on-board processing produces over 1000 parameters of data. Aside from safety systems, this ECU

is one of the few main components that is a standard part in all the Formula 1 cars on the grid. Therefore, this one box has to not only deal with the complexity of the Formula 1 power units, semi-automatic gearboxes, throttle by wire, clutch by wire, onboard data logging and telemetry, but all the variants of these systems across the Formula 1 field, as well.

'The Formula 1 ECU, the TAG-320, is arguably the most complex racing ECU ever produced,' says Richard Hull, motorsport business development manager at McLaren Applied Technologies. 'The ECU can handle up to nine different applications, which was revolutionary when the unit was introduced back in 2013. The TAG-320's capabilities allow teams, engine

manufacturers and the FIA to have applications that all interface and work together.'

This unit's processing performance and input/output capabilities has also made it a viable option for autonomous vehicles, and it is also used in other race series such as LMP1.

In an effort to close the functionality gap between LMP1 and LMP2, the governing bodies introduced Cosworth as the electronic supplier for all LMP2 competitors across the World Endurance Championship and IMSA WeatherTech SportsCar Championship for this year. This not only reduces costs, but also helps to secure the sustainability of these categories. Therefore, the chassis and engine control, together with the logging and display



A Cosworth ECU is at the heart of all the new-breed LMP2 cars (Ligier pictured), looking after chassis logging and gearbox control as well as the traditional task of engine management

Below: GDi80 from GEMS is one of the smallest ECUs on the market, weighing in at only 456g. Size and weight of ECUs is increasingly an issue



'The Formula 1 ECU, the TAG-320, is arguably the most complex racing ECU ever produced'

units are all Cosworth products, with only the wiring harnesses and other electronic hardware designed by the team or manufacturer.

'Nowadays, ECUs do a lot more than just engine control. Although that's their main function, they also need to look after the chassis logging, gearbox control, the displays on our steering wheels as well as newer aspects such as variable valve timing and traction control,' explains Rob Jarvis, ECU technical manager at Cosworth. 'ECUs have evolved a lot from just controlling the fuel and spark. You also need to consider things like Direct Injection, which a lot of people are moving into, as well as dual turbocharging and Piezo injectors – it's quickly becoming a very complex unit.'

Box of tricks

The reason ECUs have taken on more roles outside of engine control is primarily down to the development of more powerful processors. 'In addition to the complexities of modern engine systems such as Direct Injection, cam timing and turbocharging, ECUs such as our EM80 also do the gearbox shifting,' says Mike Skinner, technical director at General Engine Management Systems (GEMS). 'Ten years ago, we would have had a separate gearbox module which you would then attach to the ECU, whereas now the ECU controls this function as well. Gone are the days where we would supply up to four different boxes for our rally cars, now one box is sufficient along with a small power management unit and a display.'

The following three modules are essentially what make up the Cosworth electronics for the LMP2 car: 1) A MQ12Di engine control and logger unit; 2) IPS32 power distribution unit; 3) CCW Mk2 steering wheel. There is also a RSP20 switch panel and an RLU removable USB logger which stores data from both the Power Distribution Unit (PDU) and ECU. The design ethos of this system was to develop multiple layers, to allow the various manufacturers access, whilst controlling and standardising what functions and settings can be modified by the teams. Therefore, the engine manufacturers control the engine mapping, the chassis manufacturers govern the traction and gearbox control and the teams can change the logging of the MQ12Di, the steering wheel settings and calibrate sensors. The governing bodies can access the entire system and measured data





Every car on the F1 grid has at least one thing in common – the TAG-320 ECU from McLaren Applied Technologies. This controls and monitors all major systems via 200 sensors



Cosworth CCW Mk2 steering wheel is a part of its LMP2 electronics package. The firm's ECU feeds information to it

‘Teams are constantly looking to optimise data to help make decisions faster’

whilst some channels are hidden, depending on whether you are a member of the team, engine or chassis manufacturer.

The same applies in Formula 1, as Hull explains: ‘The TAG-320 unit allows teams and manufacturers to develop their own strategies using their own Simulink models, safe in the knowledge that the bank-level security measures we have implemented protect their IP. A feature called ‘parameter discovery’ allows the various applications to communicate and interface without having to reveal the inner workings of each process.’

High security

Security is a particular concern throughout the lower professional categories of motorsport where all the cars are required to be standardised to ensure a level playing field. ‘You still want the engine to work as well as it can, but the challenge becomes making an ECU that teams can’t fiddle with because you don’t want someone to gain an advantage by simply tuning the electronics differently,’ Skinner says. The software is often locked, and the scrutineers and manufacturers have tools that can plug in and check that the ECUs firmware is what it should be. This can also be done with the calibrations, so it’s very difficult for teams to hack in and modify anything without being detected.

With motorsport now demanding so much functionality from today’s ECUs, the consequent

increase in interference and noise needs to be accounted for. F1’s TAG-320 units have up to 66 general purpose 0-5V analogue inputs along with a whole host of other inputs including ignition switch, lap trigger and thermocouples.

LMP2’s MQ12Di has 37 analogue inputs, with 16 digital inputs as well as the eight injectors for the 4.2-Litre V8 engines and the individual coils, cam and crank sensors. ‘There are quite a lot of inputs which means there is a lot of noise, voltage and current going through the same box, so you need to take into consideration all the potential interference,’ says Jarvis. ‘We’re continually investigating and testing components such as injectors and coil packs with various engine manufacturers to constantly improve and help teams run what they want to now, and in the future.’

Sound advice

The most effective way of minimising this interference is through appropriate installation and component placement. The high current drawing components within the PCB will have specified tolerances from the chip manufacturers on their specific locations on the board. The casing is also designed to reduce the effect of electrical interference from the car’s telemetry and radio communication.

Temperature can be another enemy for electrical components and was a particular concern at this year’s Le Mans where ambient





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'The last thing you want is a large unit that you can't fit into the car'



As well as F1, TAG-320 is also used in LMP1 and autonomous vehicles. It is capable of monitoring over 1000 parameters of data

temperatures were consistently exceeding 30degC. But again, the correct installation is essential to minimising any issues here.

'All our boxes are proven for 24-hour racing,' says Jarvis. 'You do have to keep an eye on the battery voltages and temperatures, especially when running in the heat of the day because the ECUs can get quite warm, especially if they're driving multiple injectors.'

'But our ECUs run perfectly up to 70degC,' Jarvis adds. 'It helps that in LMP2 the cockpits are cooled and this is where the units are mounted, because you don't want to sit your ECU in a sidepod right next to the radiators where it is exposed to higher

temperatures and minimal air flow, so installation is a very important consideration.'

The constant evolution of ECUs is forcing manufacturers such as Cosworth to develop innovative solutions that increase the capabilities of their boxes whilst conforming to the demands of modern motorsport, such as minimising weight. One area of development is to reduce the amount of loom wire throughout the car as this not only adds weight but also the requirement for high quality wiring increases costs. This can be achieved through the use of CAN or LIN based systems, where several CAN networks are used for different systems as well as LIN control.

Yes we CAN

Jarvis says: 'Ideally, you want to avoid the situation where you have one CAN port with everything on it because it could overload the CAN port and if a device causes an issue on that CAN port it can potentially take down the whole racecar. Therefore, companies are now looking into running multiple CAN buses, with one being redundant so that if there are any wiring or box issues, you can switch and utilise the other CAN.'

Among the many new developments in ECU technology, designing a box that can work with the high voltages from piezo



This Cosworth ECU has over 37 analogue inputs as well as injector, coil, cam and crank sensors



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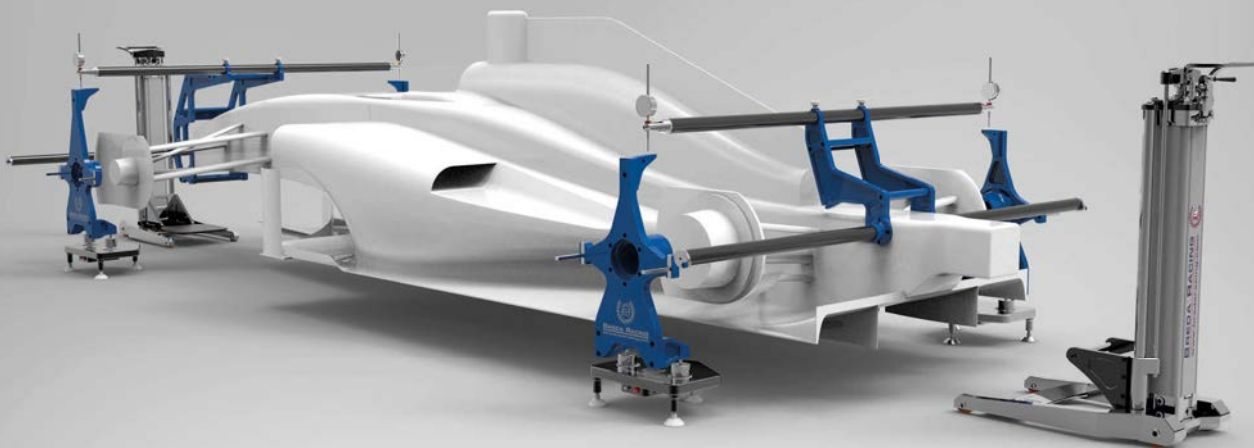


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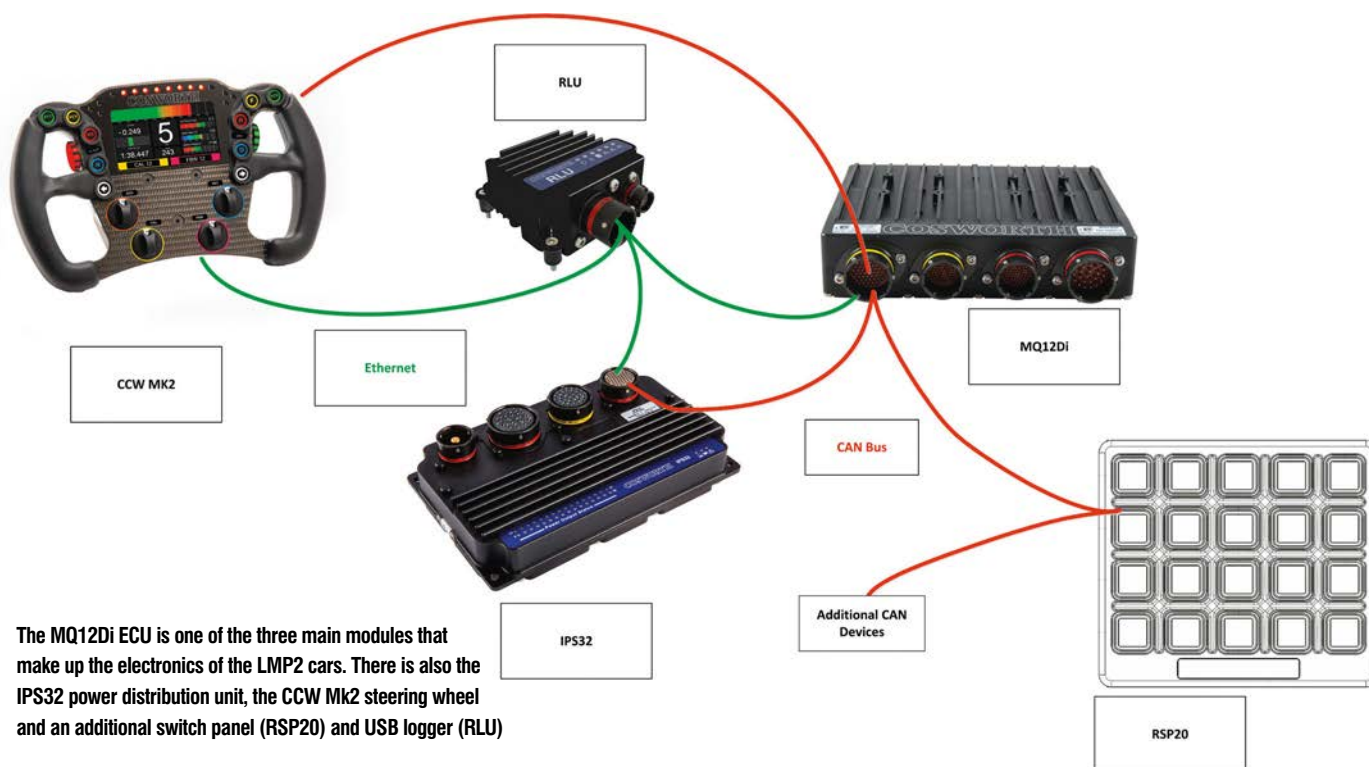


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The MQ12Di ECU is one of the three main modules that make up the electronics of the LMP2 cars. There is also the IPS32 power distribution unit, the CCW Mk2 steering wheel and an additional switch panel (RSP20) and USB logger (RLU)

Power with control

On top of ECUs increasing their capabilities outside of engine management, recent developments in engine technology, such as Gasoline Direct Injection (GDI), have also increased the complexity of engines, demanding even more from ECUs. 'GDI is injecting the fuel directly into the engine, rather than into the air inlet system and as a result the injection time has to be much shorter,' says Mike Skinner of GEMS. 'Therefore, you need high flow rate injectors which run at much higher pressure, such as 200bar instead of 5bar. The injectors also need to open very quickly and that's achieved through having a high voltage. Approximately 80V allows a high rising current within the injector which enables it to snap open incredibly quickly and then you have the injection period.'

In a simple ECU with port injection, the injector drive is likely to be a basic MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor). This is a type of transistor where the amount of voltage changes the conductivity and therefore it can be used to amplify or switch electronic signals. In this case, the MOSFET turns on, opens the injector and switches off. However, with a GDI injector there are many different phases to the injection process and because it takes place so quickly the ECU has to conduct extremely high-speed calculations to maintain effective control

injectors is at the forefront, and this is something Cosworth has researched.

Cosworth's LMP2 MQ12Di weighs approximately 1.02kg, compared to F1's TAG-320 weighing in at 1.35kg. Smaller ECUs can be found in other professional race or rally applications, such as the EM80 from GEMS which weighs in at 385g. The weight, however, is directly proportional to the functionality.

The continued growth of sensor inputs so that teams can monitor everything on the car, is forcing electronic suppliers to move towards single box solutions. However, this requires larger connectors, which is the main restriction when trying to reduce the ECU's size and weight. 'You always have to consider the effect of weight in the car. The last thing you want is a large heavy unit that you either can't fit into the car, or you need to ballast the car to counteract it,' explains Jarvis. 'When you're utilising military grade spec connectors, and the number of digital, analogue and communication (i.e. Ethernet, CAN, LIN) ports are increasing, the connector size gets bigger and bigger. The amount of information required and the sensors you need to connect with the ECU is what typically dictates the size of the box.'

Little GEMS

The GDi80 unit from GEMS is one of the smallest on the market (456g), because it was designed with the primary focus of minimising weight. 'When we first started making ECUs around 25 years ago, they would end up the size of a brick,' explains Skinner. 'Then the chassis engineers wanted us to take weight out of the units because it was no longer reasonable for the electronics to be so heavy when teams were shaving grams off the suspension.

However, this weight is restricted by connector size, which now makes up a significant part of the volume of the box. This is why the boxes are often longer and wider, because that is the only way the connectors can fit in. Engine engineers are constantly beavering away to innovate their engines and then they will require some sophisticated electronics. We are always at the mercy of the actuators and sensors that are available.'

Future trends

As for the future of this technology, as ever trends are difficult to predict. However, ECU performance will continue to improve, resulting in faster and more sophisticated control. 'We'll also see the general trend of hybrid powerpacks,' says Skinner. 'We're working on the interface between the electric and internal combustion engine for some niche manufacturers and the design of both parallel or serial hybrid systems. This is already being achieved in F1, where they essentially have a hybrid turbocharge system where the impeller and turbine are connected electrically.'

Hull says: 'Teams are constantly looking to optimise data to help make decisions faster. This is why vTAG was developed in Formula 1 to allow teams to create virtual parameters off the ECU to enrich this data even further. We also feel that utilising the technology to improve the entertainment is a key part of motorsport's future. Technology has driven us this far and we are now in a position where we are asking; "is motorsport a technology leader or an entertainment product?" We believe that you should be able to use the technology to drive the entertainment and engagement with modern motorsport.'

It's very difficult for teams to hack in and modify anything without being detected



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2020 vision

The ACO announced its new regulations for the 2020 season at Le Mans – but in doing so it's thrown up as many questions as answers when it comes to LMP1-H. *Racecar* investigates

By ANDREW COTTON



This year LMP1-H is allowed two bodykits – pictured is Toyota running with its high-downforce example at the WEC season-opener at Silverstone. Future cars will be allowed just one type of bodykit for a season. Other changes include the requirement to complete the first kilometre after a pit stop on electric energy alone, plus the allowance of fuel development

The ACO and FIA used the Friday press conference at Le Mans to outline their clear vision for the future. Whether or not this turns out to be a success is another matter, but although the vision was light on detail, there were some illuminating highlights, including a change to the cockpit shape and volume, driver seating position, and the allowance of fuel development.

As expected, the number of bodykits available to manufacturers during a season has been further reduced to just one for the year, limiting wind tunnel development, which has

itself reduced from 800 hours to 600 under the new rules. It seems clear, following the opening races of the 2017 season, that bodykits will be designed for Le Mans, and then scaled back for the rest of the season. This will make life interesting, not only for the development of the tyres, but also in changing weather conditions where applying the requisite downforce may not be an available option.

The change in driver seating position and size of the cockpit will affect the aero concept of the LMP1 cars. Seating position will be a 55-degree position from horizontal rather than

the 35 degrees currently in use. Assuming the FIA has responded to the SAE paper that was produced in March in full and covered in this magazine by Peter Wright earlier this year (May issue, V27N5), the shoulder and seat belt positioning will also be changed, as will the seat pad thickness and stiffness which will go a long way to protecting the driver's back and pelvis in the event of a frontal impact. With the increased cockpit volume, and increased gap between the driver's head and dashboard, there will be major aero implications for the teams to overcome within the new regulations. Stiffer



Each hybrid must complete 1km on EV energy alone during each stint

front and rear end crash tests will also lead to changes in the monocoque design.

Active aero could include DRS but could also include ride height reduction at speed, although details on what would be introduced and viability studies were not in evidence at the presentation. A reduction in brake cooling is designed to limit the development in brake technology, although it seems likely that manufacturers will merely invest in more robust materials. A limitation will also be imposed on the number of staff, from 65 to 50 on track at the WEC races (Le Mans will remain free of the restriction), and a limitation

of power units from five to four is proposed. Finally, the FIA also wants to limit the number of gearboxes to just two in 2020.

Electric drive

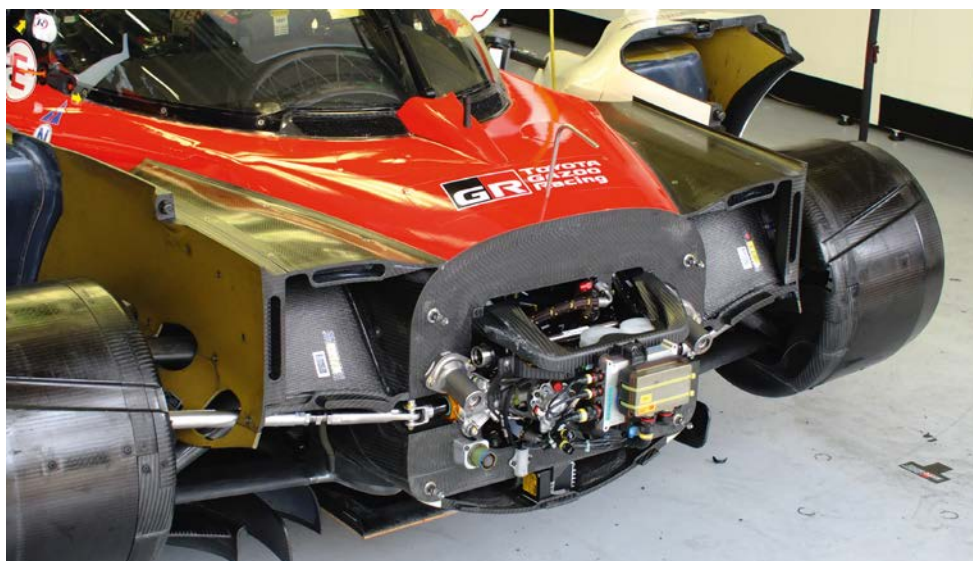
However, while Peugeot – which is thought to be considering a return to LMP1 – was looking for a decrease in hybrid from 8MJ to four, and thereby a reduction in development cost, the ACO and FIA plan appears to fly in the face of this. In a bid to make the hybrid deployment more relevant to road cars, each hybrid must complete 1km on EV energy alone during each stint. That must be done at racing speed, and

it is here that the majority of the budget will need to be spent in the early days. It is for this reason that there is no reduction in hybrid energy storage; the FIA confirmed that a large system would be needed to complete this 1km, and so it even considered going up to 10MJ, presumably to allow cars to travel further on EV.

The LMP1 cars will be plug-in hybrids under the new regulations, although both the governing bodies have not yet figured out how they will charge them – at the same time as refuelling or not? With a charging unit on the other side to the fuel rig – or even where the charging point will be? Will the fuel rigs have to carry the charging cable? Will it be a magnetic contact, or a connector?

Hybrid future

On the subject of reducing the hybrid capacity, the FIA's technical director, Bernard Niclot, was adamant: 'It would have been in total contradiction with the 1km on electric mode,' he said after the presentation. 'This 1km is very important. With one ERS and 4MJ, you cannot do it. To be consistent with this, you need it to be more. The technology is there, and exists, why should we decrease? What is the future of the automotive industry? We believe that hybrid is the future, and plug-in hybrid technology is even more essential. It is key for the next 20 years, so that is what we want for motorsport, to bring its heart to this, and make the system work in extreme conditions. We said this is the key, and that is why it was logical to continue



There is to be a reduction in the brake cooling which is aimed at limiting the development of expensive braking technology



Wind tunnel testing has been further restricted – from 800 hours to 600 – while moveable aerodynamics are to be introduced in the shape of DRS flaps on the front and rear wings



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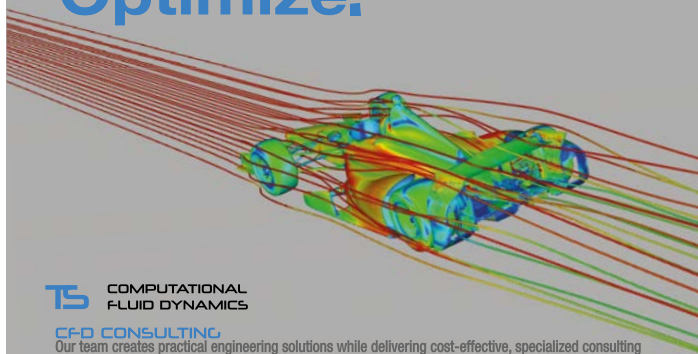
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Refuelling stops might also include battery recharging from 2020 onwards, but it has not yet been made clear how this will work or where the leads and connectors would be sited

with 8MJ, and at one time we said 10MJ, but the costs would be high and the value is not there, it was much more important to do this zero emission section.'

On the question of how the recharging of a battery would be included in the pit stop sequence there were few details. And teams wondered also, who would supply the connectors? Would they be a standard supplier to prevent costly development work in fast-charging to gain seconds? Niclot said: 'You will have a mechanical plug but we have not defined it in detail, but I think it will be a plug and when you have the connection, then you can start to charge. We think it will take a few seconds, less than 10seconds.'

Fuel charges

And will the cars charge at the same time as refuelling? 'We don't like it too much, but this is something that we have to study in detail because if you have the connection on one side, and the fuel on the other side, you will not create an arc between them,' says Niclot. 'You imagine that it is terrible, and maybe it is not. The first reaction is to say that you refuel, and then you have to recharge, but we have

not studied it. We have to speak with facts and not speak of what we think. Fast charging is developing very fast in the US.'

So, it seems that the development of a plug-in hybrid system is a new area of development for the LMP1 manufacturers, who have spent millions on developing 8MJ hybrid systems that can recharge out on circuit through MGUs.

Road relevance

The decision to run a hybrid system on EV alone for 1km was, said the FIA, to reflect motoring trends that it can see coming in the near future. Towns and cities have already started to ban certain fuels, and could in future only allow electric cars into the city centres. This would mean that cars would drive to the city on efficient ICE modes, and then complete the journey on EV. What relevance this actually has in a racing environment is open to question; 'Who will notice?' asked one engineer. 'It is not as though it will run that 1km alone, so there will be engine noise from the other competitors, so what's the point?' The only solution is to make the plug in technology road relevant, but then how will that fit without investment in connector technology?

The development of the fuels was another key announcement that was made, but it seems to have been thought through more with Shell in mind than Total. Shell is better geared to developing specific fuels, in a similar vein to the way it has Formula 1. However, it is Total that will take the fuel contract at the end of the 2017 season. Will fuel become a performance factor once again? The proposed 2020 rules will integrate 'other types of evolved fuels in close collaboration with the fuels strategy'. That could lead to a development war in engines for the 2018 season, and now past 2020. The introduction of new energies was also flagged up, although again there was no detail on what, or who, would be an interested party.

Two for one?

While the hybrid manufacturers, Toyota and Porsche, contemplated the new proposals, thoughts were turning towards the LMP1 non-hybrid category that could make up the majority of the LMP1 field in 2018. Rules already outlined are widely available, but there is still no confirmation of key elements such as DRS. One idea mooted was to take the LMP2 cars, give them open bodywork development and open

The changes in the driver seating position and in the size of the cockpit will also change the aero concept of the LMP1 cars

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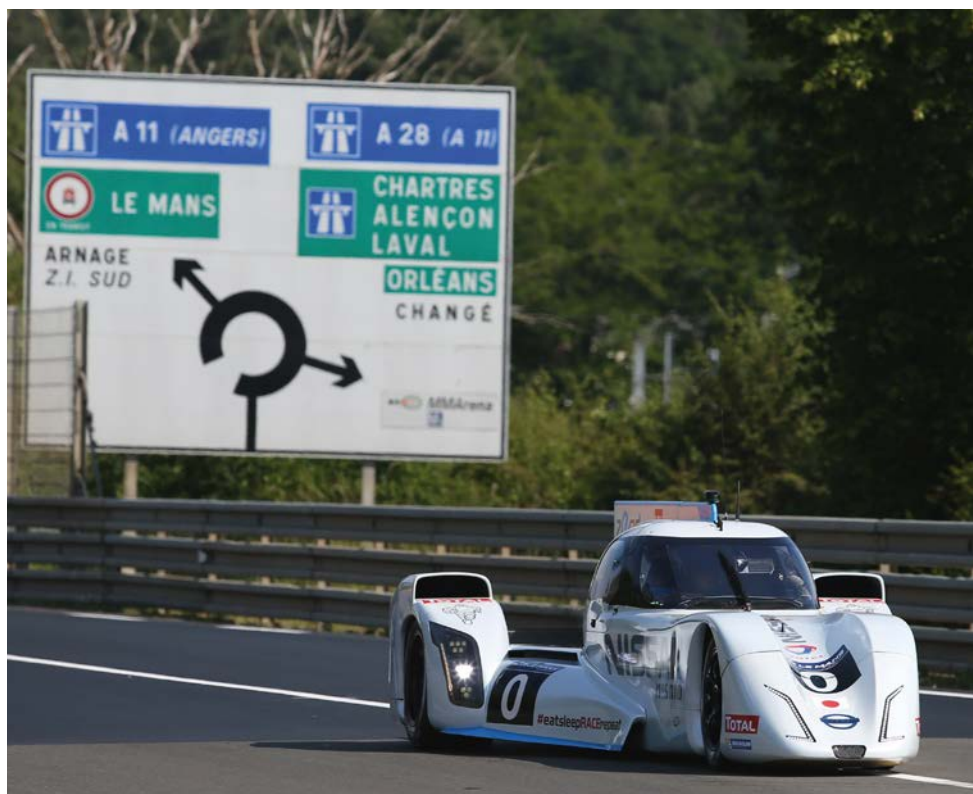
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Nissan's Zeod did an entire lap of the 8.5-mile circuit and also hit 300kph on electric power only at Le Mans back in 2014

engine development, as well as confidential tyres. The already tightly homologated LMP2 cars were qualifying at 3m25s at Le Mans, and also raced 11s slower than the LMP1-Hs, leaving a window for the new racecars.

'If you take an LMP2 car as a base and then open it, find an engine that is viable that is better than the one in the LMP2,' challenges the FIA's Endurance Committee chairman Sir Lindsay Owen-Jones. 'If it is not faster than LMP2, why join? The window between LMP hybrids and LMP2 is not that huge, because the LMP2s have hugely progressed in their latest format. When you say that it would be great and simple, non-hybrid cars, actually when you ask people to draw or design a thing, they find it difficult to imagine how to do it better than the current LMP2. It is a very good car. If you open up the engine manufacturing side of it, you have to have people step forward to do that, and it is not obvious that there are people out there who are producing better than the present LMP2 engine. You could do more sophisticated aero than an LMP2 car, but whether you really want to do that to your LMP2 class, and whether there is the space to do something that is satisfactory and interesting is the subject of debate. I asked someone if you could put a turbo on one, so we understand the idea, but if there is a breakthrough, it would probably be a super LMP2. We are very aware of that and it is a fine line to tread.'

Ginetta continues to develop its LMP1 and believes that the window between the current LMP2 cars, effectively just over an hour slower than the LMP1-Hs over 24 hours according to the results this year, is plenty. Owen-Jones refused to be distracted by stating an overall target lap time for the LMP1 non-hybrid class. 'I don't think that it is just a question of lap time, it is where the lap times are done, what you think the safety issues are,' he says. 'We said to average three laps but once you really start to analyse small sections of the total lap, you can see a car is accelerating faster, and another car would do it in a different way; lap times are not a good way to address the issue.'

Wiggle vroom

So, the conference threw up as many questions as answers. The ACO gave a clear global view of its hybrid regulations, but the target was clearly to increase technology rather than to address the issue of bringing in a third manufacturer. Peugeot representatives at Le Mans were unimpressed, and clearly the FIA and ACO were not interested in a plan B to accommodate new manufacturers into a non-hybrid class, having clearly said *non* to the concept of adopting the new DPi cars from the IMSA series in the US.

Whether Peugeot decides that entry to Le Mans is vital to its strategy or not, there is a lot of wiggle room within these regulations before they will be rubber-stamped.



Active aero could include DRS but could also include ride height reduction at speed



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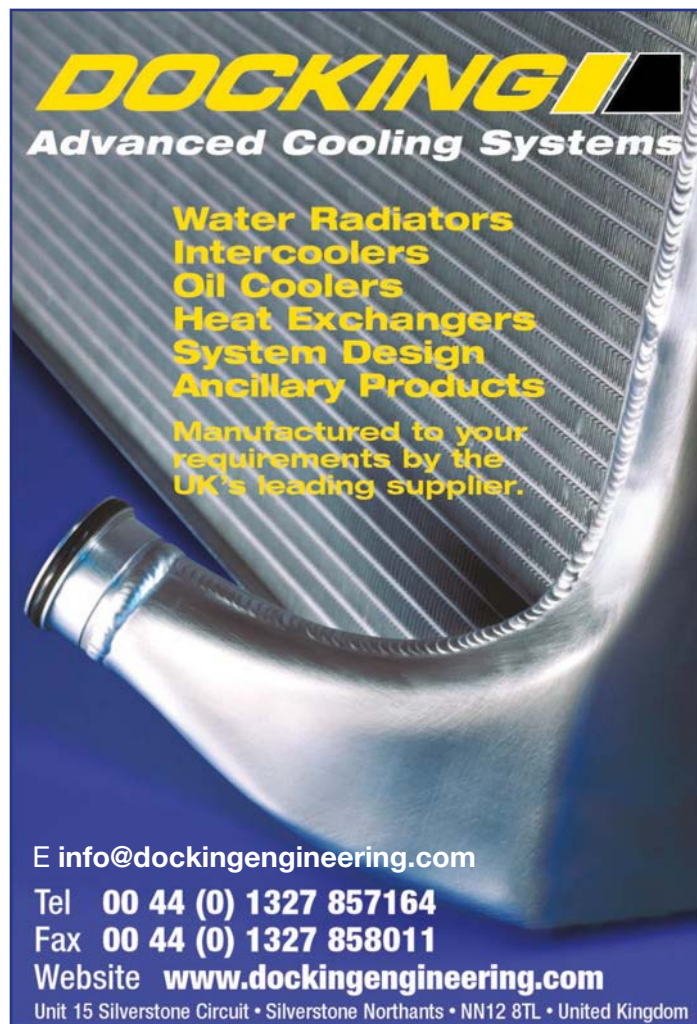
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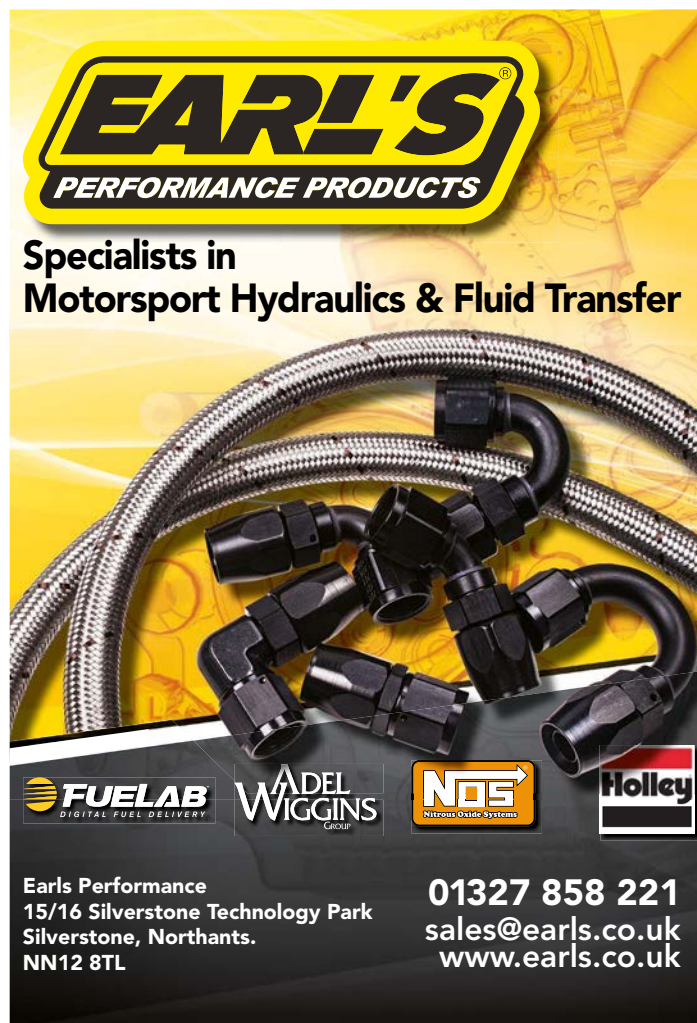
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No quarter given

While a quarter car model works well for dampers, what happens if you use a bit more of the car? *Racecar's* numbers man investigates

By DANNY NOWLAN



The first step in specifying dampers for your F3 car is to get on your bike – the bicycle model of the racecar, that is. But can we go beyond a quarter car?

One of the most useful tools for specifying a damper is the quarter car model. It is breathtakingly simple and is an excellent start point for mathematically quantifying what a damper can do. It also gives you a reasonable start point. However, I was chatting to a no-nonsense Texan colleague of mine and he made the point that cars don't exist in quarters, they exist in wholes, and he suggested I should have a look at this.

So I re-looked at the bicycle car model and have now come up with something that will light the way and provide some food for thought. This is what we'll be discussing in depth in this article.

To kick this discussion off, let's review the full equations of motion of the bicycle car model – which is illustrated in **Figure 1**.

The full equations of motion are also shown. For simplicity, I am going to remove the aerodynamic and the applied longitudinal

forces (**Equation 1**). But don't worry, there is a method in all this madness.

It goes without saying that since this is a bicycle model the spring rates will be double what they are on an actual car. The exception to this is if you are dealing with a third spring or monoshock. Also, we are dealing with wheel rates here. So the first thing we are going to do here is to take a leaf out of the quarter car model approximation and assume the tyre spring

EQUATIONS

Equation 7

$$\omega_h = \sqrt{\frac{k_f + k_r}{m_t}} = \sqrt{\frac{2 \times (120 + 100) \times 10^3}{550}} = 28.3 \text{ rad/s}$$

$$\xi = \frac{c_f + c_r}{2 \cdot \omega_h \cdot m_t} = \frac{2 \times (5000 + 5000)}{2 \times 28.3 \times 550} = 0.64$$

Equation 8

$$\omega_p = \sqrt{\frac{a^2 \cdot k_f + b^2 \cdot k_r}{I_y}} = \sqrt{\frac{2 \times (1.593^2 \times 120 + 1.107^2 \times 100) \times 10^3}{500}} = 41.33$$

$$\xi = \frac{a^2 \cdot c_f + b^2 \cdot c_r}{2 \cdot \omega_p \cdot I_y} = \frac{2 \times (1.593^2 \times 5000 + 1.107^2 \times 5000)}{2 \times 41.33 \times 500} = 0.915$$

Table 2: Eigenvector and eigenvalue analysis

	1	2	3	4	5	6
Value	503.79	301.3	55.66	-16.9 +/- 44.7i	32.4	10.81 +/- 27.15i
Mode	Front tyre	Rear tyre	Heave/front tyre	Pitch/front tyre	Pitch/rear tyre	Heave
Freq (rad/s)	503.79	301.3	55.6	47.8	32.4	29.22
Z	N/A	N/A	N/A	0.353	N/A	0.37

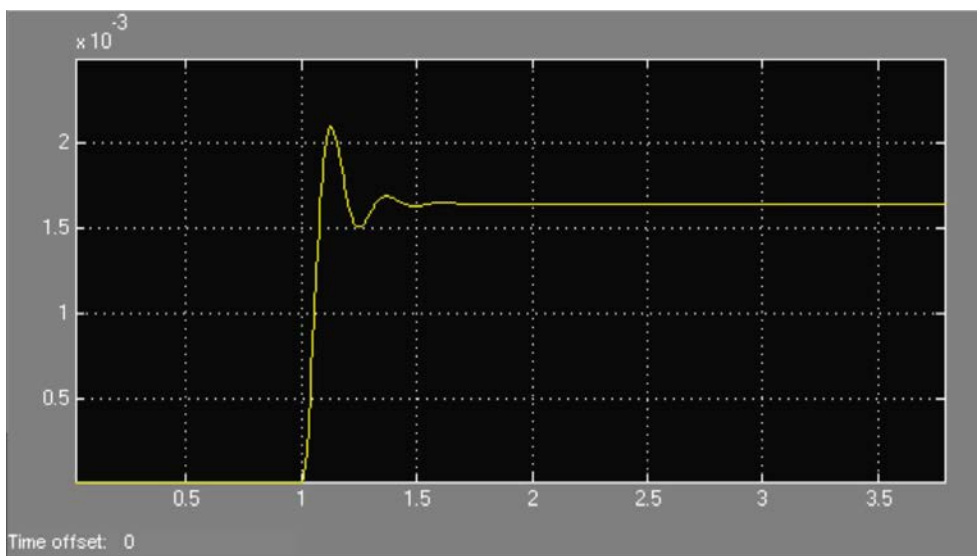


Figure 2: A Simulink model was set up to investigate the response to step input with heave with a load of 50kgf applied



Figure 4: Step input response of pitch to a moment of 500Nm. There is still an initial overshoot here but it is much reduced

Table 1: F3 parameters

Parameter	Value
Total vehicle mass	550kg
ly	500kgm ²
kf	120N/mm
cf	5000N/m/s
kr	100N/mm
cr	5000N/m/s
a	1.593m
b	1.107m
mtf	20kg
mtr	30kg
ktr	240N/mm
ktr	260N/mm

for our car are shown in **Table 1**. Crunching the numbers for our approximation, for heave see **Equation 7**. For pitch see **Equation 8**.

So, on the surface, it would appear that the system is very well damped.

When we compare this to the eigenvalues and eigenvectors of the proper bicycle car model, a most interesting story is revealed. The results are shown in **Table 2**.

Oscillatory behaviour

So, it looks like we have done a very good job of predicting the natural frequencies for both heave and pitch. However, we have done a very bad job of predicting the damping ratios.

Here is where things are not so clear cut. If we look at **Table 2**, modes 3 and 6 act in pitch. Note how mode 3 is a purely real number. That means there is no oscillatory behaviour there, it will die out immediately. So these two modes will play into each other. The same thing will happen with modes 4 and 5.


To confirm the above, a Simulink model was set up to investigate what would happen with a step input. A step input response of 50kgf was applied to the centre of gravity. Its response is shown in **Figure 2**.

When **Figure 2** is investigated there is an initial overshoot, however the heave response very quickly settles to a steady state deflection within 0.5s. This is entirely consistent with a damping ratio of almost 0.7. A step input of 500Nm was also applied to the model. The pitch response is shown in **Figure 3**.

Like with heave there is an initial overshoot but it is much reduced and the settling time is in the order of 0.2 – 0.3s. Again this is all indicative of a highly damped system as shown by the initial approximation.

All about heave

For completeness this set-up with zero downforce was run through the ChassisSim shaker rig toolbox. To say the results were interesting was an understatement. These heave input results are shown in **Figure 4**.

As can be seen the heave resonant frequency of 4.25 Hz compares very favourably with natural frequency of 4.5 Hz for our approximation. 

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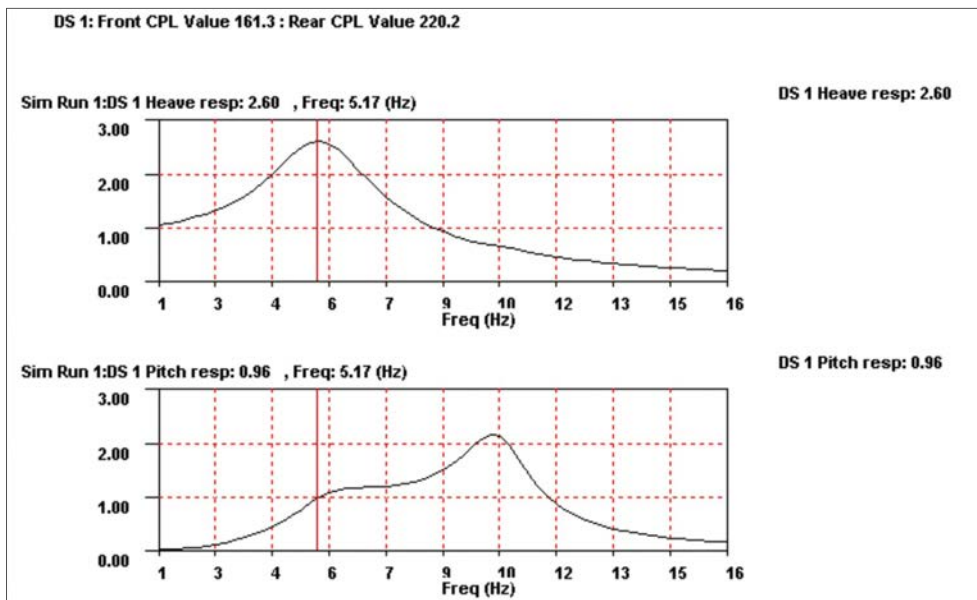


Figure 4: Step input response of pitch to moment of 500Nm. Heave frequency compares favourably with natural frequency

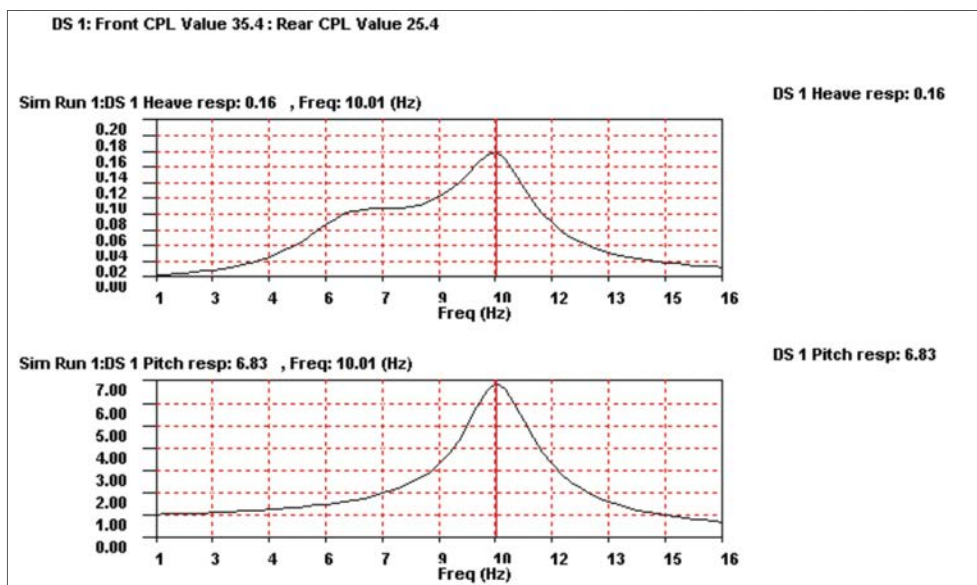


Figure 5: Pitch input results. In this case the resonant frequency in pitch was 10Hz against a natural frequency of 6.6Hz

EQUATIONS

Equation 9

$$\omega_f = \sqrt{\frac{120 \times 10^3}{112.75}} = 32.62 \text{ rad/s}$$

$$\xi = \frac{c_f}{2 \cdot \omega_f \cdot m_f} = \frac{5000}{2 \times 32.62 \times 112.75} = 0.681$$

Equation 10

$$\omega_r = \sqrt{\frac{100 \times 10^3}{162.25}} = 24.83 \text{ rad/s}$$

$$\xi = \frac{c_r}{2 \cdot \omega_r \cdot m_r} = \frac{5000}{2 \times 24.83 \times 162.25} = 0.62$$

Unfortunately the pitch results didn't compare as favourably. This is shown in **Figure 5**.

In this case the resonant frequency in pitch of 10Hz plays a natural frequency of 6.6Hz. However, in this case the resonant frequency is being driven by the unsprung mass that we have ignored. This shows two things. Firstly, this is an approximation and it isn't going to be perfect. Secondly, this is just a start point and it doesn't replace tools such as the ChassisSim shaker rig toolbox to refine what you have.


Sim sins

What we have seen here is an interesting bag of results. On the surface, because we have ignored the effect of the tyres and have set the cross terms in **Equation 3** to zero, we have certainly committed a number of analytical sins. However, the results that have been shown have been more than ample to get us in the ball park. But more importantly, this is an analytical tool that readily lends itself to hand calculations and an Excel sheet. This gives you a keen sense of the numbers, rather than being completely at the mercy of your computer aided engineering tool of choice. That is a good thing.

To ensure completeness here it would also be prudent to contrast this with the results of the quarter car model. The numbers for the front are shown in **Equation 9** and the numbers for the rear are shown in **Equation 10**.

This is a most interesting set of numbers. The front quarter car has done a pretty good job of predicting the natural frequency in heave and has replicated the damping ratio of the bicycle model. The rear agreement is not as good. This doesn't mean the quarter car model analysis is irrelevant. What it has shown is the perennial problem, that always exists in high downforce cars, that there is a mechanical imbalance that is being dictated to by the aero. Also, as a start point for specifying your dampers, it still has great relevance, just because it is so simple. However, what we have just discussed takes this analysis to the next step.

Food for thought

In closing, our approximation of the bicycle model is an interesting tool that warrants further application. While we have certainly cut some corners to come up with something that is simple, the results shown here provide considerable food for thought. In particular the correlation between the natural frequencies and the eigenvalues and step response certainly provides a moment for pause. However, the thing that this analysis technique has going for it is its simplicity, and you can hand calculate the numbers. This is in and of itself worthy of both further investigation and application. 

The front quarter car has done a good job of predicting natural frequency in heave and it has replicated the damping ratio of the bicycle model

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Interview – Takuya Takahashi

Dome and away

Dome's president tells us about the new outward-looking business philosophy he's introducing at the legendary Japanese racecar builder

By **SAM COLLINS**



'My goal is clear. We will finish on the podium at Le Mans in the next five years'

Dome's DNA stretches back to 1965, when Minoru Hayashi built his first racecar, a Honda S600. Over the next decade he constructed a number of other competition vehicles until in 1975 he formally founded Dome. The company went on to become the leading private racecar constructor in Japan to the point that in the mid-1990s a very serious attempt to enter Formula 1 was made. In more recent years Dome has developed a series of Le Mans prototypes and Formula 3 cars and it was also responsible for the development of Honda's GT500 Super GT cars up until 2013.

But in 2015 it was announced that Hayashi would be retiring from Dome and that the company would be changing hands. Its composites facilities had already been sold off while the highly regarded Furusha wind tunnel had been acquired by Toyota. The new owners then took control of the business and appointed Takuya Takahashi as president of the organisation. 'Dome was acquired by a motorsport enthusiast who loves racing,' Takahashi says. 'Hayashi-San was thinking of closing the company when he retired. He had actually announced this intention. He would rather that Dome was closed down entirely rather than struggle on without his leadership. However, the new owner persuaded Hayashi to sell it to him and keep it going. So now I am running the company day to day – this annoys my wife a lot as I have been retired for seven years, and she does not want me to spend so much time at work!'

Second Dome

To re-launch the company – now known as Dome 2.0 – a new facility was constructed in Maibara, Japan. The two-storey structure has a floor area of 3100sq.m and features a large design office, race bays, extensive stores, a machine shop and inspection areas. Yet, just over a year after it was opened in the spring of 2016, it is now clear that the facility is too small. 'The factory is already limited on space so we are looking at opportunities to grow,' Takahashi says. 'I think within the next 18 months we will be expanding significantly.'

Dome's current product line-up consists of an FIA F4 car, the Cheetah junior car (see March issue, V27N3), a composite seat with integrated cooling for endurance applications, as well as the design and production of the Super GT GT300 Mother Chassis base package. But these are just the projects that Dome is willing to make public, and it is clear that there is actually a lot more going on at the factory.

'Our trade mix is about half motorsport and half production car, and that makes things very sustainable in terms of business,' Takahashi says. 'When we relaunched the company as Dome 2.0 we set some new objectives and it has been a lot of work. To define what the new ethos of the company is you need to look back at the history of Dome. Hayashi-San loves Japan, and under his management the company really had a very local outlook. I think the work he did to build the

company over the last 40 years was great, but attempts at overseas co-operation were limited.

'Motorsport is an international industry, and that means we need to be more internationally focussed and that means more overseas cooperation. Dome 2.0 is an international company not a domestic-focused organisation. We are trying to do a lot more overseas, there are conversations going on with partners, we are doing research, things will happen in the next year or so.'

So does this mean pushing its Formula 4 chassis in new overseas markets? 'While Formula 4 might seem our obvious export product there are three other companies offering products and that makes the competition very high in terms of prices, but we are trying,' Takahashi says.

Civic duty

In early 2017 it was announced that Dome would be entering the Super Taikyu series, a Japanese multi-class championship similar to VLN in Germany. Unusually for a company well-known as a constructor, it was revealed that the team would be using the JAS built Honda Civic TCR. The TCR class has just been launched in Japan and Takahashi saw it as an opportunity to relaunch Dome's in-house racing team.

'Even though the new Civic model has been launched I didn't want to wait for a new shape TCR to come, I wanted to get going immediately,' Takahashi says. 'I was on vacation in Italy and I paid a visit to JAS. We talked and I thought about buying a car. Hayashi was very surprised when we announced the TCR project, he was a little angry, actually, he called me and said "you are buying a kart; that is not a racing car!" He went on



One of Dome's newer creations is the neat little Cheetah junior racecar, while it also currently builds its own Formula 4 chassis

to say that it is not the spirit of Dome to buy someone else's car, the spirit of Dome is to build your own.

'We have done this, though, because we see that there is a big boom in TCR, globally and in Japan. GT3 has seen prices sky-rocket and I think as a result of that TCR and GT4 will be major areas of activity in the next couple of years. I wanted us to learn about it rather than doing the traditional Dome thing of just building our own cars and never really evaluating someone else's car, I wanted to understand more about TCR.'

East to Ouest

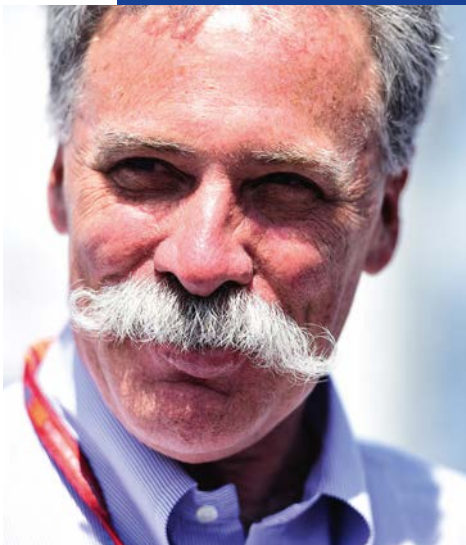
Dome's in-house racing team has previously contested the Le Mans 24 Hours and competed in both classes in Super GT, so perhaps TCR is a bit of a come down, but the team seems enthusiastic about getting back to the track. Takahashi cannot go into too much detail as to where this all might lead, though. 'I can't really answer what the plans are for the team, we are just learning, putting the racing team back together. Doing TCR, it's really a warm-up, I can't really answer the question of what it is a warm up for, though,' he says – but rumours are rife in Japan that the team is about to re-enter GT500 with Honda.

But something that has almost been a constant in Dome's history is a halo-project of some description. Often it has been a Le Mans prototype, but Formula 1 and IndyCar have also been on Dome's radar in the past. Recently, an attempt at becoming the sole Formula E chassis supplier was abandoned (see *RE* December 2016, V26N12) leaving Dome without an obvious headline programme. So what now?

'We are trying to find a new halo-project, but these things don't happen overnight,' Takahashi says. 'We are talking to a lot of people who want to cooperate and work with Dome, so I think you will find out about some things coming up very soon. My goal is clear, Hayashi has raced in Le Mans 18 times, and he never managed to finish on the podium, so I am going to do it. We will finish on the podium at Le Mans in the next five years. It would make Hayashi very upset, taking 40 years and not achieving it, and I want to do it in five.'

Beyond racing, the new management at Dome has also set itself a new target as a business. 'We should become the number one racing car constructor in the Asian market,' Takahashi says. 'Lots of European and American companies are seeping into Asian markets like China, we are closer to those markets than the others and we need to build our market there to be the clear and number one choice in the whole of Asia.'

XPB



Formula 1 chairman **Chase Carey** was the official starter for this year's Le Mans 24 Hours. F1's new owner, Liberty Media, has made it clear it would like to see greater cooperation between international motorsport series, especially when it comes to avoiding calendar clashes for big events. The ACO said Carey's role as starter symbolises the start of a new relationship between it and F1.

Former McLaren Formula 1 CEO **Jost Capito** has rejoined Volkswagen, where he had led its all-conquering WRC team until 2016 as head of the motorsport division. He is now managing director of Volkswagen R and Volkswagen Zubehor. The former is VW's competence centre for design- and performance-oriented products, while the latter develops and markets vehicle accessories.

Australian Supercars outfit Mobil 1 HSV Racing has terminated the contract of team principal **Adrian Burgess**, who joined the squad from Triple Eight Race Engineering in 2014. **Matthew Nilsson** has taken on the role of acting general manager of motorsport while the team looks for a replacement for Burgess. Meanwhile, **Rob Starr** has now stepped into a strategist role for the organisation on the race weekends.

Formula 1 has appointed **Nigel Kerr** as finance director (motorsport) where he will take responsibility for financial strategy, reporting directly to managing director (motorsport) **Ross Brawn**. Kerr is to take up his new post on August 1. For the past 15 years he has run the financial operations and strategy for a number of Formula 1 teams, including BAR, Honda, Brawn and most recently Mercedes, where he was chief strategic officer.

RACE MOVES

NASCAR Truck series crew chief **Kevin Bellicourt** was fined \$5000 after the GME Racing-run Chevrolet truck he tends failed the post-race height checks at the Charlotte Motor Speedway round of the third-tier NASCAR series. Bellicourt was also suspended for one race while the team was docked 10 points in the drivers' and the owners' standings.

Formula 1 has hired two former F1 engineers to help it frame its future regulations. Former Williams, Toyota and Lotus aerodynamicist **Jason Somerville** has joined as its head of aerodynamics, while former BAR, Honda, Brawn and Williams engineer **Craig Wilson** is now head of vehicle performance.

Justin Alexander has replaced **Richard 'Slugger' Labbe** as crew chief on the Austin Dillon-driven Chevrolet at NASCAR Cup outfit Richard Childress Racing (RCR). Alexander moves from RCR's No.2 Chevrolet in the NASCAR Xfinity Series. Labbe, had been with Richard Childress Racing since 2011. RCR said that Labbe 'is leaving the company to pursue other opportunities'.

NASCAR Xfinity Series crew chief **Randall Burnett**, most recently with JTG Daugherty Racing, has taken **Justin Alexander's** place within RCR's Xfinity operation (see above). Burnett had been replaced by veteran **Ernie Cope** on JTG Daugherty's No. 47 Chevrolet.

Hendrick Motorsports NASCAR car chief **Ron Malec** has been honoured with the Brian Lunneiss Lifetime Achievement Award. The award is for mechanics who demonstrate remarkable achievements during their career. Malec has been seven-time Cup champion **Jimmie Johnson's** car chief since the latter arrived in NASCAR's top division in 2002.

NASCAR Cup crew chief **Rodney Childers** has been fined \$10,000 for a safety violation at the Charlotte Motor Speedway's Coca-Cola 600 event. The No.4 Stewart-Haas Racing Ford that Childers tends was found to have a lug nut improperly installed at post-race inspection.

Respected British club racing reporter **Dud Candler** has died at the age of 71. Candler had reported at events in the south of England for both the weekly motorsport titles – *Autosport* and *Motorsport News* – since the mid-1970s.



OBITUARY – Eric Broadley

Eric Broadley, the founder of Lola and a visionary racecar designer in his own right, has died at the age of 88.

A former quantity surveyor, Broadley was a self-taught engineer with a hands-on approach. His first car, the 1100cc Mk1, was an instant success and from there Lola went on to build cars for just about every formula you might care to mention.

Among these were iconic sportscars such as the luscious T70, a bevy of spectacular Formula 5000s, and a host of other racecars for everything from Formula Ford to Group C and Formula 1.

There was plenty of success, too, including three Indianapolis 500 wins – the first of these with Graham Hill back in 1966.

And while it's always supposed Lola didn't quite crack Formula 1, it should be noted that Broadley certainly made his mark in grand prix racing: first with the Reg Parnell-run Bowmaker Lola Mk4



cars in 1962, and then with the 'Hondola' – the 1967 Italian Grand Prix-winning Honda RA300, which was based on a Lola design. There was also the points-scoring Larousse Lolas of the late

1980s and early 1990s.

It was not just great cars that came through the doors at Lola's Huntingdon premises and its former homes in Bromley and Slough, though. There were also the talented engineers and designers. People like John Barnard, Tony Southgate, Bob Marston, Patrick Head, Ralph Bellamy, Mark Williams, Ben Bowlby, Bob Marston and Julian Sole, to name just a few.

Our own columnist, Mike Blanchet, was also at Lola for many years – he was joint MD with Broadley, in fact – and his personal tribute can be read on page 7.

Eric Broadley 1928-2017

XPB



Former F1 driver **Jos Verstappen** has taken on a role with Red Bull. The father of current Red Bull Formula 1 ace **Max Verstappen** is to act as a talent scout for the Austrian organisation, bringing to bear his knowledge of both karting and the junior single seater formulae. Verstappen's first scouting mission was at the Pau Formula 3 race in May.

RACE MOVES – continued

NASCAR Cup crew chief **Adam Stevens**, tyre changer **Jacob Seminara** and tyre carrier **Kenneth Barber**, were all suspended for four races after a tyre came off the Joe Gibbs Racing No.18 Toyota driven by **Kyle Busch** during the Dover round of the series.

NASCAR has announced the inductees for its 2018 Hall of Fame class. The famous five are NASCAR's first race winner **Red Byron**, crew chief and car owner **Ray Evernham**, serial Truck series winner **Ron Hornaday Jr**, well-known journalist the late **Ken Squier**, and engine builder and team owner **Robert Yates**.

Jim France is to be given the Landmark Award for Outstanding Contributions to NASCAR. France is vice chairman/executive vice president of NASCAR and is also chairman of the board at the International Speedway Corporation (ISC). He helped build the sport with his father **Bill France Sr**, the founder and first president of NASCAR, and brother **Bill Jr**, NASCAR's former president, chairman and CEO.

Frank Arthofer has been appointed global head of Digital and New Business at F1. He joins Formula 1 after spending more than a decade in leadership roles in sport, media and technology. Most recently Arthofer played a key role at Boston Consulting Group's Media and Technology practice.

Michael Cobb is the new president and chief executive officer of the SCCA. An SCCA member, who has competed in its Autocross and Solo championships in the past, Cobb was previously chief marketing officer for Gold's Gym.

Doug Duchardt, the executive vice president at Hendrick Motorsports, was set to leave the NASCAR organisation at the end of June. Duchardt has been a part of the Hendrick team since 2005. Hendrick does not plan on filling the position after his departure and his responsibilities will be split among other personnel, including its team president **Marshall Carlson**, chief financial officer **Scott Lampe** and vice president of competition **Ken Howes**.

Bathurst-winning race engineer **Geoff Slater** made a one-off return to the Australian Supercars series when he looked after the BJR-run car of **Macauley Jones** at the Hidden Valley, Darwin, round of the championship. Slater left Tekno Autosports at the end of last season and is now looking for a full-time race engineering post outside Australia.

PFC Brakes engineers **James Borner**, **Darin Cate**, **Paul Rankin**, **Mark Wagner** and **Don Burgoon** (the founder of PFC who died in 2015) have been awarded with the 51st annual Louis Schwitzer Award, which recognises innovation in racing technology at the Indianapolis 500. The award was for its 'uniform matrix' carbon disc and pad assembly.

Prodrive's David Richards to take on MSA chairman role

Prodrive founder David Richards is to be the new MSA chairman, succeeding BTCC boss Alan Gow at the head of UK motorsport's governing body.

In this role, which Richards will take up on January 1 2018, he will be tasked with deciding the direction of the MSA, which represents over 30,000 competitors, 750 clubs and 10,000 volunteers and officials.

Richards is boss of famed motorsport engineering concern, Prodrive, which he set up in 1984. Prodrive has been successful in the World Rally Championship with Subaru and has more recently run Aston Martin's international sportscar racing programme. Before setting up Prodrive



David Richards is to replace Alan Gow as chairman of the MSA in January next year

Richards was an international rally co-driver, winning the world championship sitting alongside Ari Vatanen in 1981. In his business career he has also spent time in charge of Aston Martin, while in F1 he has been team principal at BAR and Benetton.

Richards said: 'Having started out as a competitor and more recently run my own teams in a wide variety of motorsport categories I'm honoured to be asked to chair the MSA. I'm looking forward to this new challenge and trust my 50 years of experience, in almost every facet of the sport, can now be put to good use.'

Alan Gow said: 'I have known David, as both a friend and as a previous business partner, for over 25 years. I have no doubt [he] will take on this new role with great enthusiasm and I'm delighted that he is my successor.'

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Interesting times

Politics has once again muddled the waters for the UK motorsport industry

What a great start to the summer: exciting, close racing in Formula 1, stunning battles at Le Mans, the BTCC just getting better all the time and M-Sport leading the World Rally Championship. We could even enjoy the fun of Alonso getting close to success in the Indy 500. This kind of action will certainly bring back the fans, giving motorsport a great future.

Now for UK motorsport businesses: what on earth are we doing to ourselves in the UK? This started when the Brexit vote split the country and brought about a change in Prime Minister. The recent General Election then showed another clear split in the political choice – half the country voted for one style of government, and the other half a different one.

It's a long time since we have had such polarised options and results in the UK: remain or leave; austerity or spend; Conservative or Labour; and finally, hard or soft Brexit. No wonder many business people are confused.

This complex situation is the reason why the MIA is hosting at Sahara Force India, on July 13, a Business Growth Conference to help motorsport and high-performance engineering businesses plan their way through to success. Over 250 people will hear successful business leaders, from large and small companies in our sector, who have a clear vision of the future. I strongly suggest you attend to meet others from our business community and share views from which everyone can benefit. This is a vital time to work closely together and not become isolated. See www.the-mia.com for more.

Stronger together

Motorsport Valley UK has achieved much to be proud of and has so much more to offer in the future. Historically, strong business clusters, such as ours, bring stability in difficult times. The community works closely and collaboratively, strengthening one another, staying agile and awake to change. By staying close and sharing knowledge you get to know of problems before they arise, and hear of opportunities earlier than those outside. At times like

these you should work closely with your suppliers and even with your so-called competitors. The MIA helps to bring this business community together, increasingly fighting, on their behalf, against ill-advised government plans and policies. Government can make a positive difference but you must grab their attention, and our growing membership shows plenty of people in this business support our efforts.

Winston's wisdom

My practical advice to all in business is just KBO! Churchill used this tactic often when challenged by confusion and chaos: 'Keep Buggering On' was his advice to the country at large. Confusion has a strange way of resolving itself, given time and determination. So, I recommend KBO to you. The

up and follows through on every export enquiry – your prices have never been so competitive. Look into new adjacent markets for your services or products – there is financial support to help you deliver automotive innovations, check out Innovate UK: www.gov.uk/government/organisations/innovate-uk – and find a way of collaborating with others to secure funding.

Also, check out the generous R&D tax credits in the UK. Assume you are not yet getting your full credit, get a specialist to work hard on your behalf. If you haven't yet secured your tax credit for the development work you are doing, then do it now, go to the MIA website for our easy to understand R&D tax guide (www.the-mia.com). This is easy to claim and helps you pay for staff or equipment when developing solutions. Make sure you get as much as you can.

Pricing right

Be careful with cash and protect your margins, keeping a close eye on any import cost increases that may affect your suppliers. Don't wait for them to increase their prices, you know where they import from so you know how the currency rate will affect their costs. Be ready for them to rise.

Also, don't be slow to change your selling prices – you can always reduce and discount these later when times change, and they will. Work hard on keeping your best staff, spend a little more on their training to

secure their loyalty, and reward them well.

You have the benefit that you and your customers operate in the global business of motorsport and not just the local one. This international spread gives more stability to your future business. This really should encourage you to step forward and attack the opportunities that will arise during this admittedly confusing, but also quite exciting, period.

Come along on 13 July to Sahara Force India, and discuss this future with colleagues. You will be stronger by working closely with your friends in your own community, and don't forget, KBO – times will improve, I promise.



M-Sport flying high in the WRC is just one of the highlights of a great season of motorsport so far, but while the show is pretty good the business in the UK faces plenty of uncertainty

motorsport ethos is to just get on with it, and now is clearly the time to do just that.

Don't get distracted by inaccurate waffle from politicians, media, polls or pessimistic forecasters – focus on finding the positives and the new opportunities that are arising. I'm pretty sure government will be more supportive and generous to innovative businesses which export from the UK. They need the strength of this business community to help in their negotiations with the EU.

If the EU are willing to listen, then they will agree that it's in our mutual interest to retain a strong business platform for trade in the future. Be sure to go hard for exports, make sure your company chases

Don't get distracted by inaccurate waffle from politicians, media, polls or pessimistic forecasters – focus on finding the positives

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Reflecting on Le Mans

The 85th edition of the Le Mans 24 hours was, to my mind, a classic. There was drama in the failures of the manufacturer cars, there were the usual accidents, there was an incredible pole position lap from Kamui Kobayashi and, at the end of it, a strategic decision based on risk management delivered Porsche victory over the LMP2 privateers. Yet post race the talk was all about how complicated these cars have become and that the technology should be dragged back somehow, that the manufacturers should hang their heads in shame and it's someone's fault at the ACO and in the FIA that there were technical issues. Sorry, but all I can say to that is, bullshit.

The technical changes since 2016 have been mainly aero, and what happened at Le Mans was that Porsche and Toyota really pushed the boundaries within the regulations. Porsche introduced a new pre-ignition system that, apparently, accounted for three failures. There was no fire to turn the engine, said one team insider, which pretty much points to only one thing. Are engine failures a new phenomenon at Le Mans? Of course not, so please stop bleating about that one.

Let's then have a look at the hybrid failures that were experienced by Porsche and Toyota. Both had front motor failures, which can happen as Audi experienced on numerous occasions. The front motor on the R18 was housed in the cockpit, so when that went bang, as is not unheard of, the cockpit floor could become something of an oily swimming pool, particularly if a driver braked and rode a kerb at the same time. What could have been a 'disaster' for the race, an LMP2 winning overall, was averted as Porsche considered the competition, and unlike Toyota, elected not to change the battery at the same time. That meant risk, but also a chance at overtaking the remaining P2 cars. Toyota had to change the battery as it could not reach the front motor without doing so, and finished ninth.

For me, the big failure of Toyota's own making was Kamui Kobayashi's retirement. The Japanese was invited to leave the pit lane by a driver whose overalls were similar to those of a marshal. Kobayashi left, as a marshal's instruction supercedes almost everything, but the team told him to stop. By then, the ICE had started, and when he did get the all-clear to go, due to the programming in the car he was forced to pull away from standstill using only the clutch, which was not designed to perform that task. That was a failure of design, again, not unheard of at Le Mans, and certainly not exclusive to Toyota.

The big problem was that there were only two manufacturers, five cars, and all failed in some way. The

ACO's press conference on Friday came up with a new set of regulations (see Tech Update) which, in my opinion, failed to address that problem. Dr Wolfgang Ullrich was in the paddock as Oliver Jarvis led the race overall in the Jackie Chan Racing ORECA LMP2, and I jokingly pointed out that this is what happens if Audi does not turn up. Yet it was a serious point. I can't see the WEC thriving on only two manufacturers, and unless there is a third that agreed with these regulations and will sit alongside (not instead of) the two that are already there, the rules will lead to failure. In the paddock, I couldn't find a soul who thought that these regs were a good idea.

Chatting to the ACO technical director Vincent Beaumesnil after the race I wondered how they would slow down the LMP2s for 2018, given that the tyre manufacturers will bring more performance, and teams will have a year of learning and understanding with their new cars. With 75-litre fuel tanks and stint lengths of around 35 minutes, cutting the fuel allowance is not an option, and the cars already run on customer tyres. His response was interesting: 'Why should we cut their pace?' Well, very simply, if P1 non-hybrid cars do come in 2018, they have to find a place between the LMP2s, and the LMP1-hybrids, a gap of around 11 seconds in qualifying. They are going to have to be capable of lapping in 3m16 to 3m18 seconds and be reliable to be able to finish above

LMP2, although the LMP2s were an hour slower than a reliable LMP1-H over the full race distance so there is room there.

Sir Lindsay Owen-Jones, President of the FIA's Endurance Commission, was adamant that if an alternative engine should be selected for LMP1 non-hybrid and fitted to an LMP2 chassis, it should necessarily be faster than the Gibson. They already have those in the US. When Pipo Derani's turbo boost strategy failed at Sebring in the Nissan-powered Ligier LMP2, he was nearly two seconds faster than the pole position time overall! These cars are already capable of lapping much quicker. More open development around the bodywork, the engine, the suspension, the tyres and with all-professional driver line-ups, an invitation to constructors such as Dome, BR and Gibson to build chassis, and the variety is back.

There is a way to maintain the high technology of LMP1, as well as boost manufacturer involvement. LMP1 non-hybrid must be given the encouragement to grow and must welcome manufacturers. New regulations are open for discussion, I hear. But I hope they will make much more sense than the proposed 2020 hybrid regulations, which could cost the ACO and FIA its two remaining manufacturers.

ANDREW COTTON Editor

LMP1 non-hybrids have to find a space between P1- hybrid and LMP2

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