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Formula 1 2014

Full regulations analysis

Grid car-by-car examination

This was the most keenly anticipated Formula 1 season for many years. This was the season when the sport moved into a new era, with more powerful hybrid systems and 1.6 litre, V6 engines. The teams and engine suppliers moved away from the V8 engines and started with a clean sheet of paper.

From before the start of the season there were questions that were being ignored. What happened if one engine supplier found itself far behind the others? Renault Sport's Rob White said that there was no provision for going back and helping out, sports car style. However, that is exactly what happened – there was a change to the regulations to help those who had got it wrong at the start. And, that was the correct decision. From the start, the suspicion was that Renault was likely to have got it right, Mercedes was powerful but had reliability problems, and Ferrari was far behind. In the end, Mercedes produced a dominant package, Renault did manage to overcome a series of embarrassing failures at the start of the season, and Ferrari struggled to make up the lost ground at the start of the season.

It was a period of development and learning, one that would never be cheap, and by the end of a bruising season, two teams were in administration, others were raising serious concerns about their own viability, and the whole financial structure of Formula 1 was in the public domain. There was talk of three car teams for 2015, but the loss of teams will hurt the sport. The increase in costs was no surprise to anyone. This was a period of learning about new technology, and it was never going to be cheap. Can more be done to distribute the wealth more fairly? Certainly, but that should have been discussed and agreed long before the loss of hundreds of jobs.

In this supplement, we look back on a season where the best teams and constructors were tested. Some were more successful than others, but this season was always going to be different to the tight competition of 2013. What needs to happen now is that more teams don't go to the wall, and Formula 1 retains its variety.

ANDREW COTTON
Editor, Racecar Engineering

A difficult season

No secret was made that it could be a tough 2014 F1 year – low noses, cooling issues, you name it – and so it has proved

By SAM COLLINS

As was made abundantly clear at the first official test in Jerez at the start of the 2014 season, Formula 1 was facing what may be its toughest ever year. The arrival of new twin hybrid power units with a 1.6-litre direct injection turbocharged engine at their core, coupled with a completely rewritten rulebook, has changed the game significantly.

'It's been a massive job to accommodate all the changes to the power unit – it's the biggest change I've witnessed in the sport since I started in 1990,' said Force India technical director Andy Green at the launch of his team's design. 'On top of that, if you add the development that comes with it during the season, it's going to take some managing.'

Despite this, the most discussed rule change was one of the more minor details in the technical regulations governing the car's dimensions. For 2014, the cars have to be fitted with a nose tip which is no more than 185mm high, a substantial reduction over the high noses of recent years.

The FIA had hoped that this would bring back the low nose look of the 1990s and improve safety, but the result was rather more unsightly, with many teams having rather prominent front sections. The chassis around the driver's legs and feet is now also significantly lower, due to a regulated drop in maximum height at the front bulkhead, introduced for the same reason.

These 'finger' or 'brewer's droop' noses have been universally criticised, even by those who designed them. 'It is not a strictly technical matter, as we all design a car that gives the best performance, regardless of the styling,' says Red Bull's Adrian Newey. 'But I think that the shape of the cars is all part of the excitement of Formula 1, and it is a shame that they are unattractive and that the rules have forced ugly solutions.'

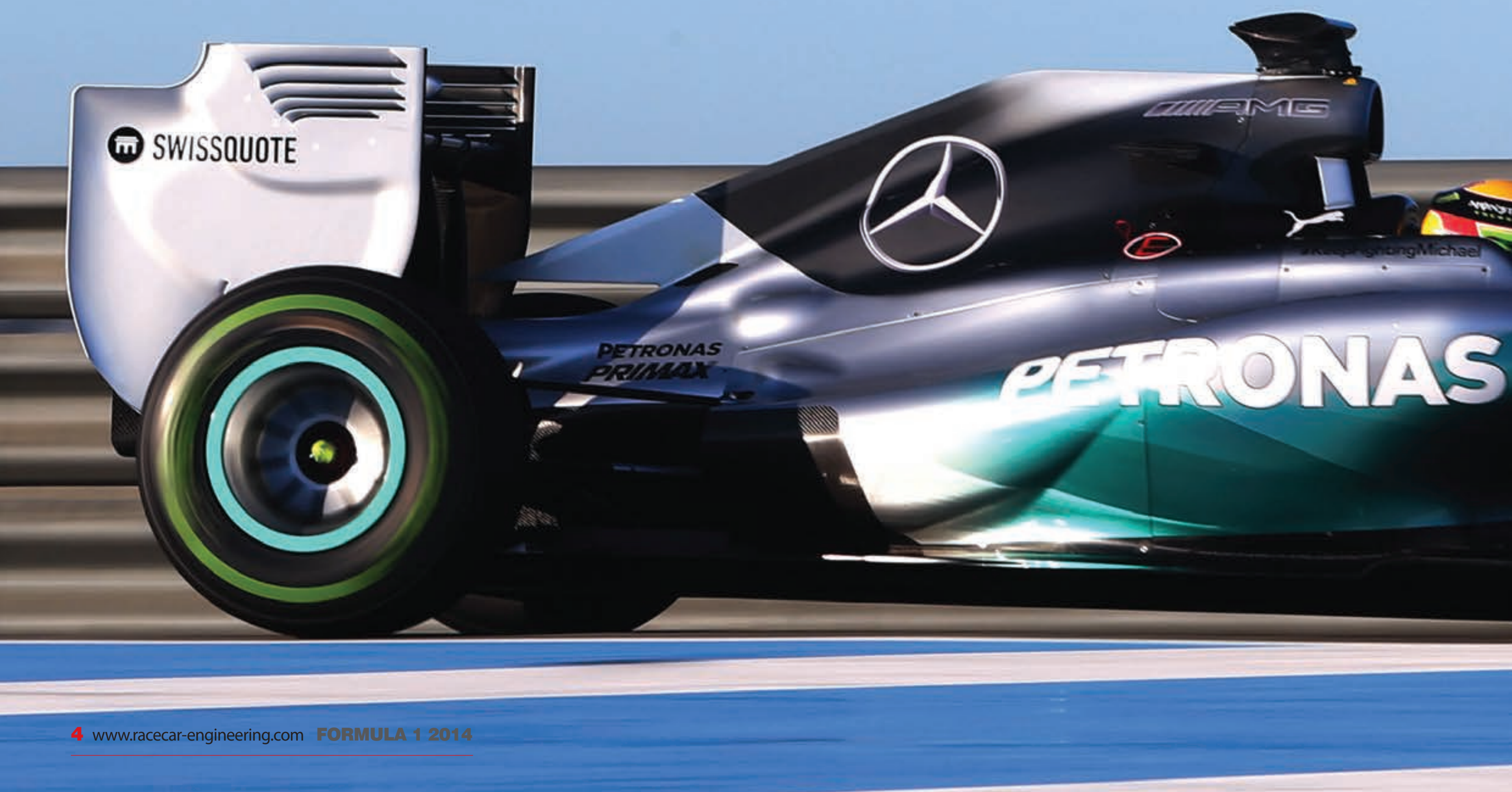
The noses are a crucial part of the car's structural design, as they also form the front impact structures, but despite the wide range of shapes on display – from the rather more elegant looking Ferrari, Mercedes and McLaren designs to the extreme twin structure Lotus, it seems that this is not an area of great aerodynamic importance.

'There is a different nose on every car, and there is not too much similarity between any of them,' says Ferrari technical director James Allison. 'The nose rules allow quite a lot of geometrical freedom, so of course you explore that. There are such big variations between the cars because it is not that much of a sensitive area. There are lots of solutions that work.'

It seems fairly clear that the rule-makers at the FIA had not realised that the nose regulations would make the cars quite so ugly, and according to some there have been some other unintended consequences. The nose tips now sit lower than the the rear crash structure found on all of the cars, and Newey among others raised fears that this could lead to cars being lifted up by one another.

'The regulation on the noses was introduced following some research by the FIA, which suggested that it reduces the chances of the cars being launched, like the accident Mark Webber had at Valencia a few years ago,' says Newey. 'I must admit I am concerned that the opposite may happen and that cars will "submarine". If the following car hits the back of the one in front square on, it will go underneath it and the driver will end up with the rear crash structure in his face – which is a much worse scenario.

'There are some accidents we have seen over the years that make you wonder if a low



nose would have made it worse, not better. Like all of these things, it might be worse in some scenarios, but it may help in others. I don't think the low noses will stop cars launching in all scenarios either. If the following car hits the rotating rear wheel, it will get launched regardless, like Patrese and Berger at Estoril in 1992 or the two Minardis at Monza the following season – they were low nose cars that got completely launched.

'For me the low noses have introduced more dangers than they have cured.'

Newey's fears proved unfounded during the season but the reaction to the look of the new cars was enough to prompt a rule change for the 2015 season which should in theory improve the look of the cars somewhat.

Beneath the nose sits a region which was less obviously different to previous seasons, but far more important in aerodynamic terms. The rule changes here were fairly simple, limited to a slightly stiffer front splitter (tea tray) and a narrower front wing.

'The front wing in the centre is very similar in its philosophy, as we still have the FIA central section and the vortex that comes from it,' says Toro Rosso technical director James Key. 'But the endplates are now right in the centre of the tyre. If you look at 2008, the endplates channelled airflow inside the front wheels – inwash – and from 2009 to 2013 it became clear that as much outwash as possible was good. Now it's right in the middle and the question we are all asking is: do you go one way, the other, or do you try to encourage both? It's very complicated, and these areas are very much up for development.

'The whole area around the brake duct is also substantially different in aerodynamic terms, even though it may not look like it. Yes, losing the beam wing at the rear of the car is significant, but fundamentally it's just a loss of load. The front wing and lower chassis, however, are surprisingly different.'

The airflow in that area in the car feeds the cooling ducts in the sidepods, and cooling is one of the biggest challenges with the new power units. Some claim that they require as much as 125 per cent more cooling than the 2.4-litre V8s used until 2013.

'Cooling has been the biggest challenge,' says Green. 'Most of last summer was taken up trying to understand the cooling requirements of the power unit, and how best to optimise it in the chassis. There's a lot more to cool and you are weighing up the performance of the power unit versus the performance of the chassis and aerodynamics, and trying to hit the optimum on each one of them. We've had to develop a new toolset to examine, analyse and optimise it.'

Heat rejection

It is apparent when looking at the cars that the three different power units used in 2014 have very different cooling demands. While the Renault-engined cars have notably more cooling than the 2013 designs from the same teams – apart from Red Bull.

'You have to make up for the amount of additional cooling devices that you have had to put on the car in some way,' says Key. 'It's hard to compare to 2013 because the heat rejection from the engine is obviously less, as it is much smaller. But you have the charge cooling which is an added complication, and then you have the turbo, which adds heat to the mix, and then with the ERS cooling there is a significant increase. While there is not a huge amount more demand on air to the coolers, you have a lot more cooling circuits.'

The Mercedes teams also seem to have somewhat increased cooling, but the Ferrari cars appear to have less than the 2013 designs.

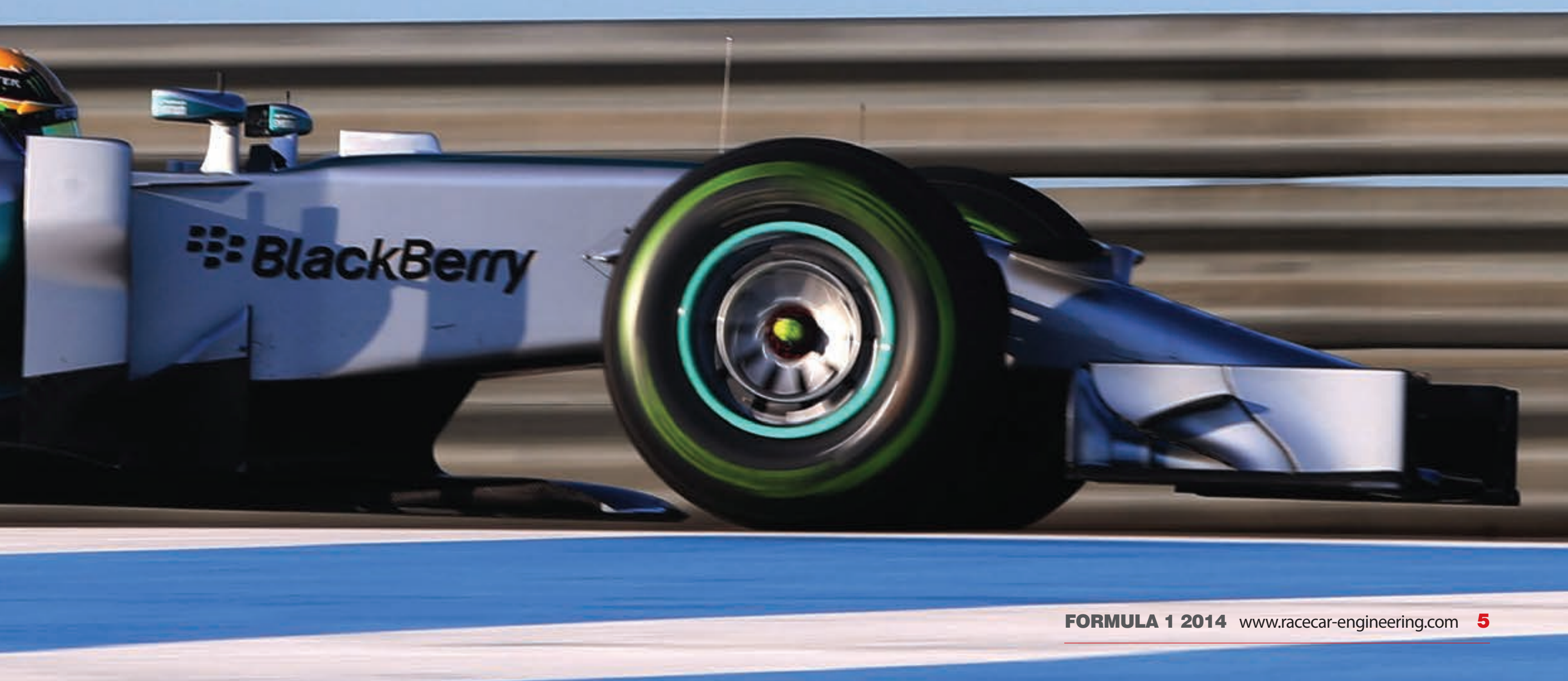
While the thermal management of the power units is a challenge, the teams seem to feel that the overall challenges of the layout are more difficult to overcome, especially in terms of overall vehicle weight. Force India in particular has been unable to get down to the 690kg weight limit. This is largely because the power units on their own are significantly heavier than the old V8s, and when the additional subsystems required to operate them are added – such as the aforementioned cooling circuits – the weight goes up even more.

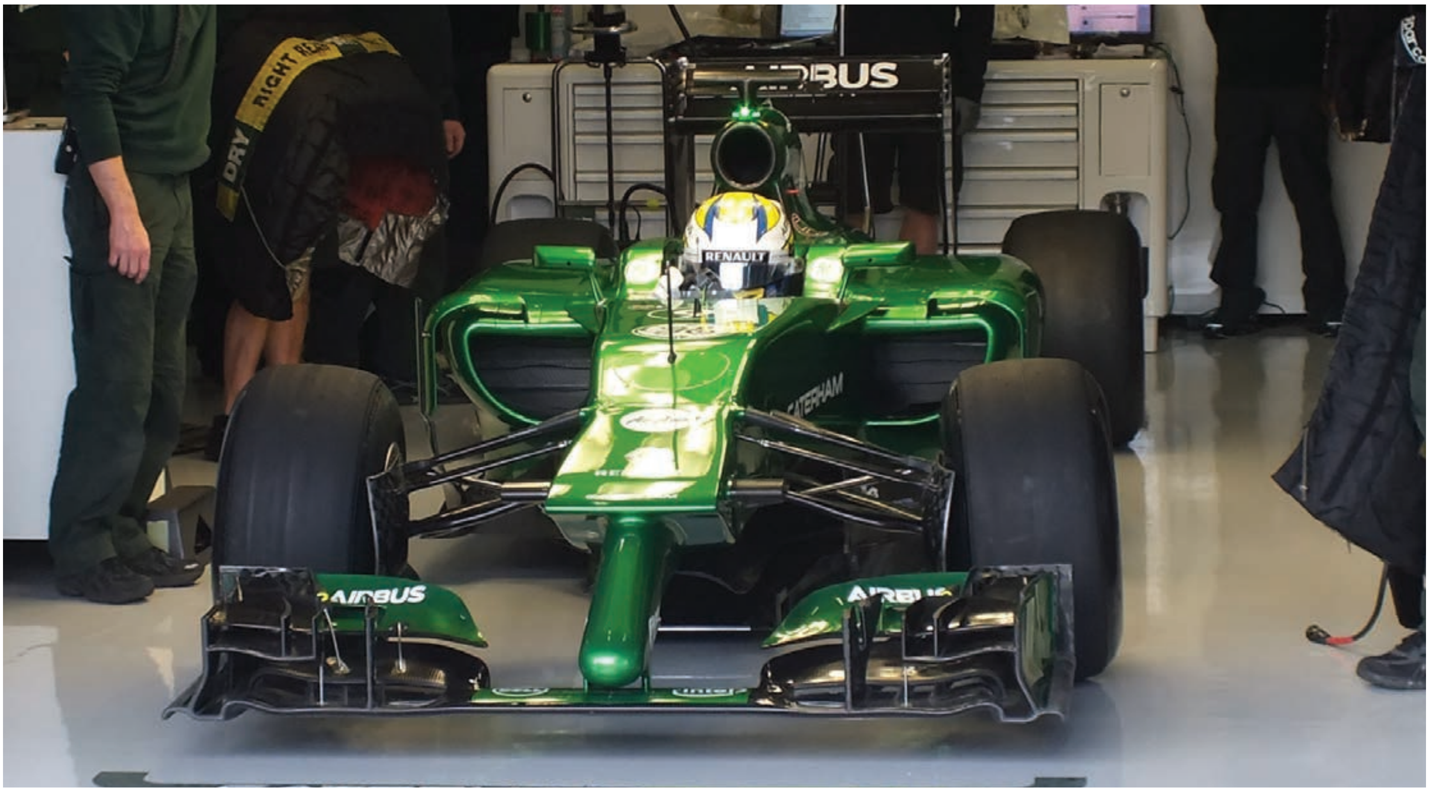
'Getting to the weight limit is a big challenge, and we have had to work really hard to get it under control,' says Key. 'We should be OK with our car. The problem is that the regulations evolved a lot over the 12 months before we rolled the car out, but the weight was agreed early on. If we re-did it all again, we would probably look at doing something different in terms of rules, and it will probably change in 2015. Once you have managed to get to the weight limit, only then can you can start to look at CofG height and weight distribution. It's proved quite tough to hit the weight limit.'

The technical regulations also restrict the front-to-rear weight distribution, and the weight applied to the front and rear wheels must not be less than 314kg and 369kg respectively. 'You don't really want the fixed weight distribution regulation at a time like this, but it is there and you have to respect it,' adds Key. 'You have to design around the window and make sure you are in it. You do not just want to be at one end of it either, so you may tweak your front wheel centre line a bit and look at all of the masses in the car and move it about as you develop.'

But it is not just housing the weight within the car that is giving the designers headaches – it is also the issue of packaging the power unit components in a way that allows them to

"You don't really want the fixed weight distribution regulation at a time like this, but it is there and you have to respect it"





Caterham achieved respectable mileage in the first two tests, which the team attributed to the car's larger cooling capacity

operate correctly. This is especially true in terms of the battery, which must by regulation be mounted in the monocoque underneath the fuel cell. With a 35 per cent reduction in fuel consumption year on year, the large battery pack takes up much of the volume left from the reduced tank size. 'It has been bloody complicated for us to get it in the car,' says Key. 'The battery and fuel cell determine the chassis length, but you make up for that with the smaller engine size. The thing that has more impact overall is the bell housing and gearbox casing being designed to accept turbos. That's more influential on the wheelbase, and for us we are marginally longer than in 2013.'

The power unit energy store has become something of a focus for many teams, not least Red Bull Racing. Chief technical officer Adrian Newey was unhappy that he has been forced to mount the battery pack in front of the engine, rather than behind it as he did with all of his previous hybrid F1 cars.

'It's a shame that we chose to have the batteries and KERS components around the bell housing on our previous cars, and could not carry that over,' he says. 'It allowed us to put the weight at the rear of the car and get the layout we wanted in terms of engine position and wheelbase. This has now been removed and the battery now has to be in front of the engine and under the fuel tank. I think that is a shame, and the only freedom beyond that is whether you carry the KERS control unit in the fuel tank as well or under the radiator ducts.

'It was done on safety grounds, but I'm not sure how putting a battery under the fuel tank is safer than putting it under the engine. Putting the battery under the fuel tank is uncharted territory. Remember, Boeing had an absolute nightmare with the batteries on the Dreamliner – it grounded the planes. These batteries can suffer thermal runaway through impacts, and other causes that are difficult to predict. Once they go into that, then it is very difficult to control that fire – frankly it's a case of putting it in the pit lane and watching it burn.

'I don't think it is a driver safety concern, but overall it is a danger. The voltages are also very high and large DC voltages are very dangerous. So for the whole pit lane, the safety aspect is a very big challenge with these cars.

'Another big challenge here is the supply chain. As soon as you work with outside manufacturers, battery suppliers and electric motor manufacturers, you realise that they do not work to motorsport lead times. They don't work in days and weeks, they work in months and years – so it is not a problem you can get out of quickly.'

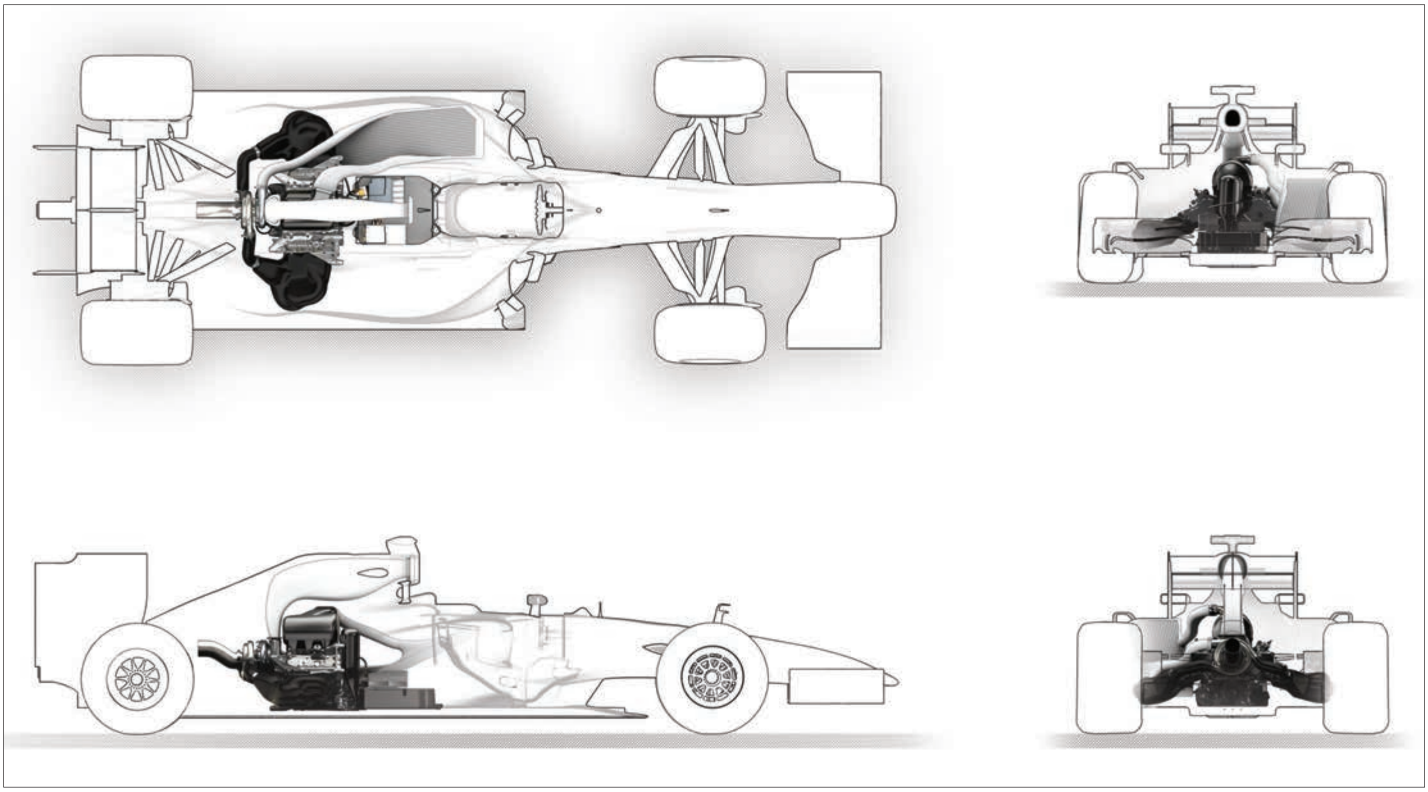
Once the power unit is actually installed, the teams then have to get them to actually run. And as was made very clear at the first pre-season test in Jerez, this is far from an easy task. 'The biggest challenge of these cars is the electrical side,' adds Newey. 'It's hugely complicated, and crosses several disciplines. When you look at hybrid production cars, they have years of development before they hit the market. They are not really designed to be taken apart – they are almost sealed for life.

'The F1 environment is very different to that. Unlike previous years, with a KERS problem you could carry on. Now if you have one, it means you have to park it at the side of the road.' Indeed, battery problems saw the Renault-powered cars all sidelined for a significant amount of time at the first test.

One of the challenges all of the engine manufacturers had to overcome related to electromagnetic interference created by the high voltage system on the car, though the only obvious sign of this from the outside was some distortion on the onboard camera footage from Ferrari engined cars. 'The important thing is to recognise that everywhere there is electricity, there is the possibility of interference between one current source and another,' says Rob White, deputy managing director (technical) of Renault Sport. 'The physics of it is simple, and the electromagnetic interference is most common where there are big currents that change rapidly.

'The currents in and out of the MGUs are big and change rapidly. In the power electronics to control the MGUs, there are high frequency switching circuits, and the switching action from one polarity to the other can create the

"I am not sure how putting a battery under the fuel tank can be safer than putting it under the engine. It is uncharted territory…"



Packaging the power unit is a challenge, not least due to its high cooling demands and high weight. The units are proving to be unreliable in testing, leaving many 2014 F1 teams struggling to even get their cars to run on track

conditions for induced electrical currents. When you change the current rapidly in a wire, the wire next to it will see a change in magnetic flux and a current induced in it. If you have a big power cable next to a small signal wire, the induced noise can be the equal or bigger to the signal it is supposed to transmit, which will cause trouble for the whole thing.

'The sensors by their nature are sensitive, low voltage, low current devices, and any sensor or sensor wire sited next to a big, rapidly changing current source will be at risk of sending a false signal.

'It's a lot about the harnessing and shielding – it's something that has to be resolved as part of the commissioning of the car.

'It's a bit a case of pulling yourself up by the bootstraps – if the signal going into the control system is not clean then the control system cannot respond correctly.'

During the season the subject of suspension design came to the fore, teams had been spending substantial funds during recent seasons on developing complex interconnected suspension systems, and as talk about power unit installations and reliability died down they became the centre of attention.

There was much discussion in the media about a ban on 'FRICS' in Formula 1, but many of these reports were overstated or generally inaccurate. The name 'FRICS' (Front to Rear Inter Connected Suspension) is simply the latest product of Formula 1's tendency to give every sub system of the car a new name, usually a complex sounding acronym, and the discussion of it being banned is basically incorrect.

FIA warning

Shortly before the German Grand Prix, the FIA issued a communication to all Formula 1 teams regarding interlinked suspension. It says: 'Having now seen and studied nearly every current design of front to rear linked suspension system we, the FIA, are formally of the view that the legality of all such systems could be called into question.' It went on to explain that the front to rear aspect of the systems, which can give some degree of pitch control may breach article 3.15 of the technical regulations, ie:

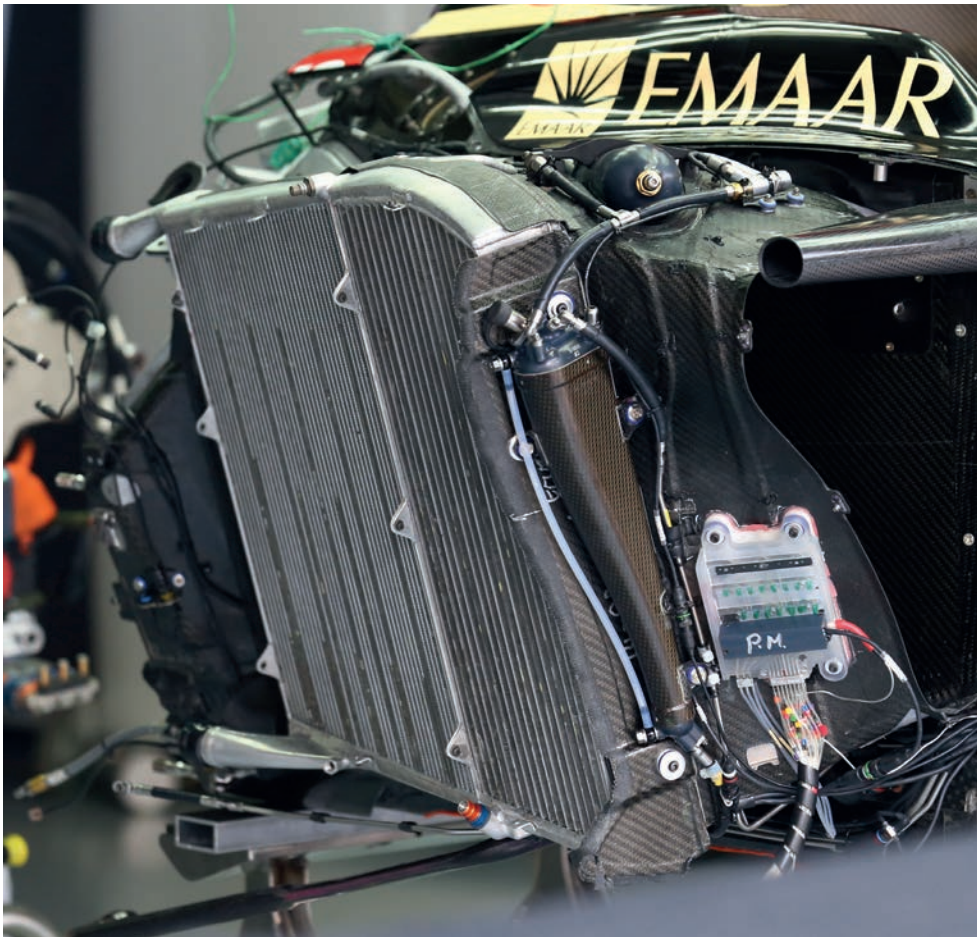
'Any specific part of the car influencing its aerodynamic performance must be rigidly secured to the entirely sprung part of the car (rigidly secured means not having any degree of freedom) and must remain immobile in relation to the sprung part of the car. With the exception of the parts necessary for the adjustment described in Article 3.18, any car system, device or procedure which uses driver movement as a means of altering the aerodynamic characteristics of the car is prohibited.'

It does seem difficult to understand quite how this regulation restricts a suspension system, but it was the same rule that saw the Renault F1-tuned mass damper outlawed in 2006. Interconnected systems do not clearly breach this regulation, and most teams feel that they are legal. 'The regulations are very stringent on what inputs a connection between the front and the rear of the car to work to, and in essence, that's limited to the vertical inputs through the tyres and that really restricts what you can do with them,' says Bob Bell, former Mercedes GP technical director. 'These suspension systems are complex and expensive but, because of those restrictions, they only have limited use. You still need a basically good car, using it will not get you out of a hole.'

Lotus technical director Nick Chester adds that his team did not introduce it for aerodynamic reasons. 'We brought it into the sport in 2007 and the basic concept of the system has not changed,' he explains. 'We have obviously continually optimised it to improve the ride. We did it primarily for a ride benefit and it worked well.'

These systems are simple in concept and have been detailed in Racecar Engineering more than once, but notably by Sauber's aerodynamic design engineer, Manuel Greiner, in RCE V23N3 (March 2013). The layouts link the springs (torsion bars) and dampers to one another in order to cancel out bumps or give the car better more stable handling and aerodynamic performance. The exact nature of how the interconnection is done varies from team to team. In the case of Mercedes it is fully hydraulic, but purely mechanical and even electronic systems have been used elsewhere in the past.

'It is no secret that everyone on the grid has an interlinked suspension system that incorporates Cambridge inerters front and rear,' Marussia's Dave Greenwood explains. 'The way you get all of those elements working together is a way you can get performance. You find a spot where the car has the most downforce and that's where you want to run it as much as possible. Then you have the way the car shifts going through a corner, and the way you make



The cooling system on the cars is proving to be a major packaging issue. Here on the Caterham CT05, two heat exchangers are visible, as is the lower side impact structure

the suspension work is to optimise where the car is in terms of ride height. That unit combines lots of elements that you would normally separate, it allows us to have something that gives us gains in ride and aero performance with as little weight as possible.'

Basically, what the teams are trying to do is keep the floor of the car, which generates substantial downforce, as flat as possible to give a consistent amount of aerodynamic load. This can also improve a car's handling and traction, though former Mercedes technical director Bob Bell downplays the impact of FRICS, as his former team dubbed it, and similar systems.

In reality FRICS, or interlinked suspension, is nothing new at all, the Lotus team has run it for the last six years and claims that the increase in popularity in such systems is down to improvements in computer technology allowing teams to optimise it more effectively. Tyrrell used a similar concept in the 1995 season on the 023 design and dubbed it 'Hydrolink,' but the technology was not yet fully optimised and it was dropped and largely forgotten.

That system was only used on the front of the car and provided enhanced and separated bump and roll. Tyrrell felt that the having that additional control was of more importance on the front of the car due to the greater degree of suspension movement there and its fundamental influence on the air flow under the car. It had planned to fit it to the rear of the car but apparently never did.

So, why did the FIA feel compelled to take action mid season after all, the front to rear interconnection systems have been in use in F1 for the last seven years, or – if you go back as far as the Tyrrell application – almost two decades!

Indeed, in 2014 every single car on the grid was fitted with a interconnection system of some description.

It seems that the FIA's communication was in response to a request from two teams wanting to clarify its legality for the 2015 season before integrating it into the new car designs. There was discussion in various F1 groups about banning the systems for next season as a cost cutting measure and possibly replacing it with fully active suspension in 2017. But some teams, including Lotus, argue that the costs of taking it off would be more significant than leaving it on. 'I think most teams, especially those that have had it for a few years are not developing it all that hard anymore,' says Lotus's Nick Chester. 'Some that are newer to it are arguing that they are developing it hard. For us, it is quite a lot of development hassle to remove it.'

For teams like Lotus, this will be a bigger challenge than it will be for some others. Force India is likely to be one of the biggest winners from the ban, though it will also be frustrated as it had just introduced an updated system to its car. 'We had an interconnected suspension system at the end of last year and we used the data from that to develop a new system for this car,' Force India technical director Andy Green reveals. 'We have used it in a couple of races (Shanghai and Barcelona), but it needed further refinement so we took it off and reworked it. We felt we could have raced it at Monaco, but we were not comfortable with the limits it was setting with respect to the tyres. Taking it off allowed us to explore a lot of different avenues.'

The FIA's communication followed a request from two teams wanting to clarify its legality for 2015 before integrating it into new car design

Points risk

Ultimately, FRICS has not been banned in 2014 or 2015 (yet), but if found on a car after the German Grand Prix it would run a high risk of disqualification and lost points. With every point hard fought for in 2014, it seems that teams felt that it was not worth the risk and they all removed the systems from the cars for the German Grand Prix in July.

Interconnected suspensions remain legal in other forms of motorsport such as LMP1 where Porsche is using a highly advanced system on its 919 Hybrid. Toyota and Audi are also thought to have similar systems.

Something else that features in both LMP1 and Formula 1 is brake by wire (controversially in the case of the former). To allow teams flexibility on energy harvesting strategies during braking, the 2014 rules allow for a semi-active electronic control of the rear braking pressure line. This BBW system allows the braking load to fluctuate between the engine braking effect of the KERS harvesting and pure friction braking – and indeed any combination of the two. This is not a first for motor racing – the GT300-specification Toyota Prius was fitted with two brake calipers on each of its rear wheels: one a conventional AP Racing hydraulic design, the other an electronically controlled unit from Project Mu. 'When you brake, the motor recovers energy from the rear wheels and that feels to the driver like engine braking,' explains Hiroto Kaneso, who designed the GT300 Prius. 'But when that KERS braking phase ends due to the battery being full, you lose that retardation. For the driver it is important to retain the brake feeling, and that's why we have the second caliper, so when the battery is full, the second caliper maintains that feeling and retardation. The second brake

Brake by wire has been a particular area of development this season and teams have struggled to master the technology. Early season failures are now a thing of the past

caliper is fully electronically controlled and operated with no master cylinder.'

Getting the feel right for drivers is a major headache for some teams, as well as making the systems reliable. At the first test at least two teams struggled to get BBW fully operational, leading to a few off-track moments. At the first race of the year a BBW failure on one of the Caterhams lead to a spectacular crash on the opening lap. The F1 BBW layout involves only a single caliper on each rear wheel, and has more complex inputs as can be expected.

'You just take the hydraulic inputs that the FIA specify, and work with an electronically-controlled hydraulic link to the caliper,' said Toro Rosso technical director James Key. 'At the same time you have some redundancy in there, so if you have a failure it should revert to a manual brake circuit. You have to account for any failure mode you can think of both mechanically and in software. It's a bit like a differential or a clutch, but the tricky bit is mapping it well.'

Mapping the systems is an area where some teams struggled all year to fully optimise. 'Brake-by-wire is massive for us in 2014,' says Williams chief test engineer Rod Nelson. 'You have control system mapping, driver mapping to get him comfortable, state of charge control, making sure the battery is topped up at the right time, and temperature and vibration – and that's just one system. The driver needs to have a good feeling of retardation vs pressure that is not steppy or moves around – it has to stay the same. He can adjust the bias forwards or rearwards as in the past, but we are also balancing how much energy he uses from the rears with how much we are trying to recover. It's key to the mapping and the brake setup that when you come off the brakes, there is no residual force that may give a little bit of instability or a lock up. Some drivers are very, very sensitive to this. We can model the brakes on the simulator, and we have done, but they are not straightforward as there is a thermal effect. The amount of stopping power the brakes have depends on the temperature of the brake, so that's an input we need to understand. We set a recovery target for each lap, so whatever a driver does not put in, the MGU does.

Softer braking

'We have had issues with losing brake-by-wire, and the driver ends up on his own. The pedal has a very different feel when that happens – it is much softer than you expect it to be. More significantly, the brake bias shifts substantially. If you come into a corner with a BBW failure, you'll get a wake-up call.'

It also creates a challenge for the caliper manufacturers such as AP, Brembo and Akebono, who have to develop systems to aid the braking effort at the rear, negating the need for the driver to constantly alter the brake bias, and also contributing in preventing rear lock-up.

The arrival of BBW in F1 means that now the only things the driver controls mechanically are the steering angle of the front wheels, and the pressure applied to the front brakes.

Every other system on the car is now drive-by-wire. This, say some, reduces the challenge for drivers, but increases it for engineers.

Ever since Pirelli returned to Formula 1 the tyres have been something of a centre of attention and controversy, but in 2014 they have generally been out of the spotlight. This is the result of a deliberately conservative approach from the Italian firm.

With so much focus on just getting the new power units to work, many teams have had very little time to understand the new Pirelli compounds and construction. At the first test, the Italian company brought along special winter tyres to cope with the highly abrasive surface at Jerez, as well as the cold conditions expected at the Spanish circuit. It also had some of the proper 2014-spec tyres on offer, although most teams were not interested at that point.

'The 2014 tyres are just as different to their predecessors as the 2014 cars, with the majority of our preparation work having been carried out by using advanced data simulation, as well as real on-track testing,' said a Pirelli spokesman. However, the on-track testing was conducted using the previous generation of car, which could not replicate the torque characteristics of the 2014 power units.

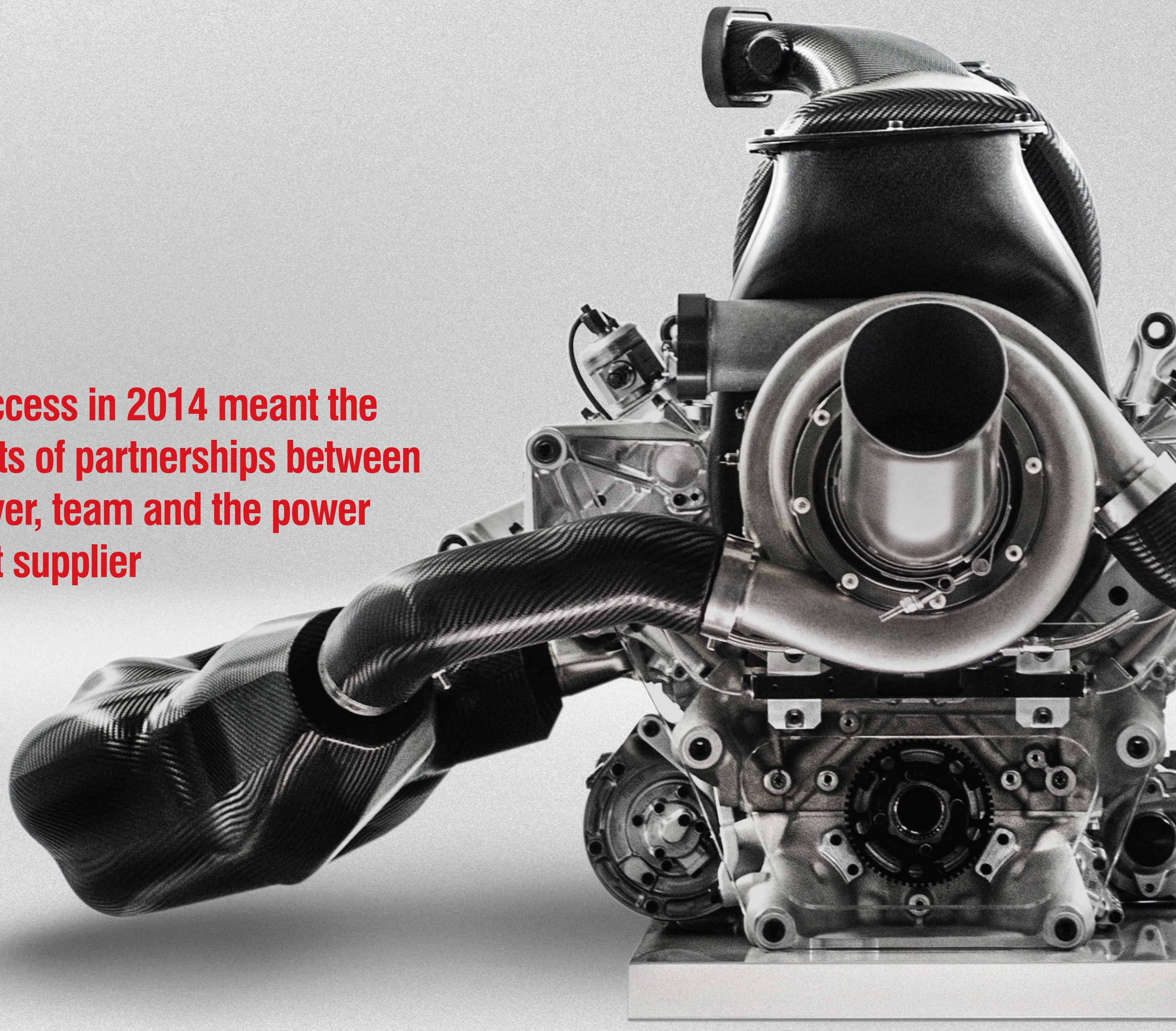
The new 2014 tyres have a new construction and new compounds, with slightly increased weight. The wet tyre has also a new tread pattern and a different compound.

Overall the result of the first season of the new regulations has had something of a mixed response from all concerned. The power units are felt to be too expensive, and some, including Bernie Ecclestone, are openly critical of them. Meanwhile the on track racing has generally been of a good standard however the performance advantage of one power unit supplier over the others has lead to a rather one-sided season.

Daunting prospect

From the start the new regulations looked like an uphill struggle for many Formula 1 teams and the season was a tough one. We sent Peter Wright to the first test of the season for his analysis

By PETER WRIGHT



Success in 2014 meant the fruits of partnerships between driver, team and the power unit supplier

Driving from Malaga airport towards Jerez for the first public tests of the new-for-2014 F1 regulations, I had little idea what to expect.

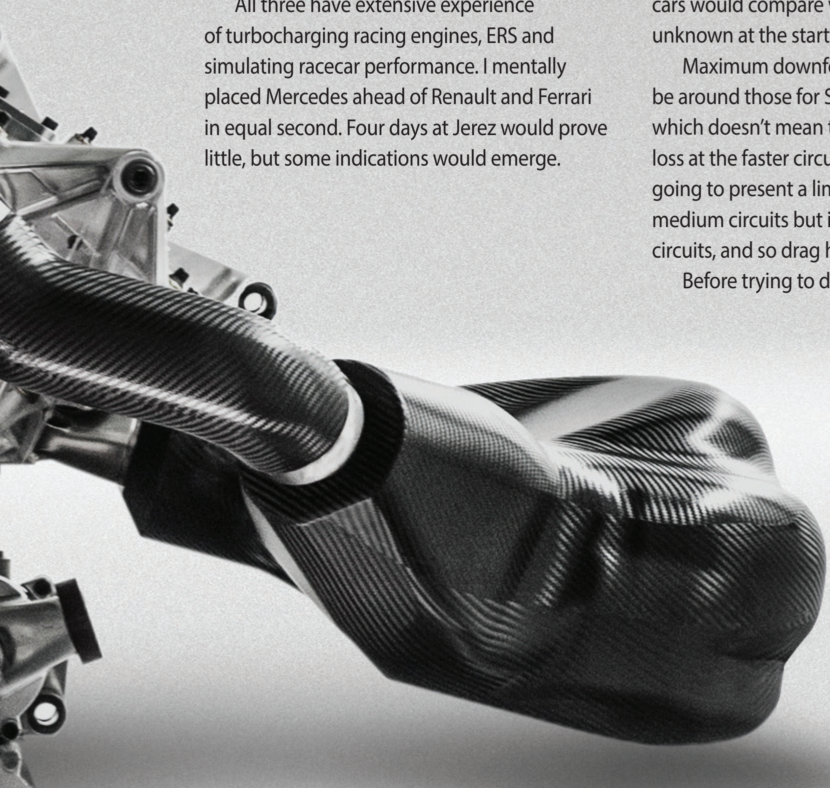
With radically new power unit (PU) regulations – you mustn't call them engines any more – and significant changes to the aero regs, making predictions about performance would be hopeless. Likewise, with cautious but information-less statements emanating from all three PU manufacturers, and it being quite clear that the true aero performance of the cars was unlikely to be evident at this first test, I set to musing about the fundamentals behind the development of the new PUs. Mercedes, Ferrari and Renault – how could they be rated according to industrial might?

Mercedes, as part of Daimler AG, lacks nothing in terms of R&D expertise in materials, combustion, and simulation, nor in resources. In Mercedes AMG HPP at Brixworth, they have a fully-resourced F1 engine and ERS facility, manned by the best of Cosworth and Ilmor. Mercedes had, by reputation, the most powerful 2.4-litre V8 of the last few years.

Renault's industrial resource is probably not as great as Daimler's, but without knowing how much of Nissan can be called upon, this may be unfair. Viry produced an adequately powerful and very fuel-efficient V8, and this expertise, I surmised, would be useful in 2014.

Ferrari, though small in itself, has so much high-performance powertrain experience, and has the might of Fiat, Fiat Research, and indeed all of Italy behind them.

All three have extensive experience of turbocharging racing engines, ERS and simulating racecar performance. I mentally placed Mercedes ahead of Renault and Ferrari in equal second. Four days at Jerez would prove little, but some indications would emerge.



The power unit with the best method of combusting fuel, sharing the released energy between pistons and turbine, with the least friction, heat and pumping losses, would achieve the highest output

To achieve the fuel consumption reduction target involved more efficient IC engines, more energy recovery, and a reduction in drag

Fuelling partnerships

Success in 2014, more than ever before, meant the fruits of partnerships between driver, team, and PU supplier. What exactly is it that they are all trying to do? The FIA has set the objective: to perform at close to existing levels while using a third less fuel. The last part of this is simple and clear: each car had an allocation of 100kg of fuel for each race, an average of two-thirds of what they used in 2013.

Meeting the first part, performance, is a bit more complex. To achieve the fuel consumption reduction target involves more efficient IC engines, more waste energy recovery, both kinetic and exhaust, and a reduction in drag. A reduction in mass would also contribute, but this quickly became impossible once all the new systems required were specified. The reduction in drag is to come from a reduction in downforce. When the regulations were finalised in 2011, no one knew how fast the cars would be in 2013, especially as the full exhaust blowing capabilities were not known. How clever the aerodynamicists would be in interpreting the 2014 bodywork regulations was also not known, and so just how the performance of the 2014 cars would compare with those of 2013 was unknown at the start of the current season.

Maximum downforce/drag levels looked to be around those for Spa and Canada in 2013, which doesn't mean there will be no downforce loss at the faster circuits. 100kg fuel was not going to present a limitation at the slow and medium circuits but it would be a factor on fast circuits, and so drag had to be reduced too.

Before trying to delve into how each driver, team and PU manufacturer set about meeting these objectives in a better way than their competitors, let us look first at how the FIA planned to apply these new and sportingly decisive regulations. Regulating the total quantity of fuel used requires both a means of regulating that quantity very accurately and a maximum flow rate rule, to prevent PU designers producing very high maximum power units for qualifying and the last lap of the race. These two measurement tasks can be performed by a single sensor, and the FIA, after an extensive search, sourced such a device from Gill Sensors, which will form the basis of both the 2014 F1 and WEC regulations.

The Gill flow rate sensor uses ultrasonic pulses to measure the velocity of the flow relative to the speed of sound in the fluid. With the mass flow output dependent on the bulk modulus, density, temperature and pressure of the fluid, sensors are independently calibrated with each fuel used by a team.

Because of this, each sensor does not have to be identical to the others (reproducibility) but must be repeatable. Early indications are that an accuracy of ±0.25 per cent was achieved. Very good, even in an application where everyone wants it to work accurately, but the real test was in the application where perhaps the user does not want it to be accurate. 0.5 per cent power equals around 0.07 seconds per lap or 3-4 seconds over a race distance. The sensor is mounted between the low-pressure and high-pressure fuel pumps and any return flow from the fuel injectors must be returned downstream of the sensor. The WEC uses up to three sensors per car – two to provide a reliable average reading, and one, if required, for return flow. In F1 the sensor must be mounted in the tank; in WEC on the outside of the car, beneath a cover.

The FIA ECU was set to monitor the 100Hz signal from the sensor along with RPM, and had to deal with any measurement of excess flow due to signal noise. This excess flow went into a virtual 'pot', and provided the flow is instantaneously below the limit at any given RPM, the 'pot' leaked out its contents at a prescribed rate. The 'pot' must not 'overflow'. The quantities and rates for this system were not yet decided at season's start, awaiting hard data from the cars, but it was planned to limit mean overshoots to less than 0.5 per cent. Attempts to use this method of smoothing the signals to gain extra flow rate are punishable.

The sensor also totalises the fuel flow. The value is zeroed after the parade lap and must not exceed 100kg at the finish line. The PU's ECU

and the FIA will be provided with the totalised value for each car, and it is up to the PU not to exceed limits. FOM TV also received the values such that they could be used in graphics to illustrate what was going on between competing drivers. Fans should be able to take this on, as most car drivers are used to using their 'range' displays to control driving in search of a fuel station.

By far the best way of understanding the complexity of the technical regulations and what they allow the PU to do is to study Appendix 3 of the Technical Regulations. The diagram titled 'Power Unit Energy Flow' explains it all and saves lots of reading, cross-referencing and head scratching.

Of particular note is the fact that the MGU-H and MGU-K are permitted to pass energy between them directly in a way that does not have to suffer the losses, which can be as much as 15 per cent, of intermediate storage in the energy store (ES), and with no limit on power.

In effect, this means that the turbo can be 'connected' directly to the crankshaft with similar efficiency to a train of gears, but under the control of the MGU control unit. To understand how this new and complex PU was to be used in racing, it is first necessary to understand – as far as is possible – exactly who controls what. The driver's throttle pedal is a torque demand. The regulation stipulates that the relationship between the pedal position and torque demand must be a fixed relationship, and that the driver may have two alternative maps – one for dry tyres, and one for wet. The PU software decides what mix of torque generators – ie engine and/or MGU-K – delivers the demanded torque. The FIA monitors this demand: the PU software output to the torque generators, the torque entering the transmission, and the torque going to the wheels. These last two are derived from new for 2014, homologated torque sensors.

The FIA's interest is traction control. They want to check that nothing about the torque control originates anywhere other than at the driver's right foot. They also want to check that the instantaneous, per-lap, and per-race limits on energy and energy flow rate (ie power) are adhered to, and it is the job of the PU software to achieve this. However the teams, via the drivers, do have some influence on the per-lap figures. At this point some numbers may be useful:

100kg/hr maximum fuel flow rate equates to 1.11MJ/second, or 1111KW, with a fuel of, say, 40MJ/kg energy density. This represents the input power of the fuel to the PU.

Note that the F1 fuel regulations do not specify any energy density limits. WEC uses a standard gasoline of 39.55MJ/kg. It is considered that the F1 fuel specifications limits what is possible to vary energy density, and this approach allows the all-important fuel industry partners to be involved in PU development. There are limited trade-offs between energy density and octane number, which is more important for efficiency than flame speed in these relatively low-revving engines compared to the V8s. 1-2 per cent variation in energy density is expected.

Although we didn't yet know specific details regarding MGU-H performance, it could theoretically produce 40-60kW power over and above the needs of the compressor. The actual output will depend on the acceptable backpressure of the turbine, which will impact the output and efficiency of the piston part of the engine.

Unsubstantiated figures doing the rounds indicate that the pure turbo-IC part of the PUs

(Above) exploded view of Renault's new F1 power unit; (left) problems for the Red Bull RB10 in testing at Jerez, as Daniel Ricciardo was forced to stop on the circuit, and a fire extinguisher was put on the case

are giving around 520cv, or 388kW. With, say, 50kW at full power from the MGU-H, this rises to 587cv. Therefore, with a 1111kW input fuel power, as a pure turbo-IC engine the efficiency would be 35 per cent, and as a turbo-compound engine 39.5 per cent. Pretty impressive if achieved. For qualifying, this is what is relevant, but for races where total fuel is limited, the total energy available matters more. 100kg fuel equals 4000MJ. At Monza, this is 75.5 MJ/lap over 53 laps, which can be turned into 29.8MJ at 39.5 per cent efficiency at full power. Ignoring part throttle PU use for the moment, we can put this 29.8MJ in a pot for use during an average lap. Bear with me!

It was always unlikely the MGU-H would generate any significant energy for storage in the ES, as it is always best to pass it directly to the MGU-K whenever there is a surplus, which is generally at full power.

The MGU-K is permitted to pass 4MJ/lap from the ES to the wheels at 120kW, which means for 33.3 seconds. This could certainly be used if there are 4MJ in the ES available. However, the ES can only receive charge from the MGU-K at 120kW for 16.7 seconds to meet the 2MJ/lap limit. It was always going to be a challenge to harvest 2MJ each lap but, for simplicity's sake, let's assume an average of 2MJ of energy was available each lap. Therefore total average energy per lap equals 29.8+2MJ = 31.8MJ.

The average race lap time at Monza is 89 seconds, so average power equals 357kW, or 479cv. This equates to 81.6 per cent of the maximum power of the turbo-compound engine, on average, or 70 per cent of the maximum power of the 680cv of the entire PU (remember: the MGU-K is limited to 120kW even if drawing energy from the MGU-H), on average. Drivers use around 70 per cent full throttle at Monza, so this makes some sense. These figures involve many assumptions, but are indicative of the race energy and power equations. The PU suppliers and teams will work the actual numbers to the nth degree and arrive at optimal settings for every part of every lap in qualifying and in the race, when there is a varying fuel load and hence car weight.

Qualifying presented a particular set of opportunities: the driver simply had to maintain the maximum throttle possible for as much of the time as possible and – though limited by the maximum fuel flow rate – he is not constrained by total fuel used during his fast lap. The guy who uses the most fuel is likely to be on pole! At the same time, he needs to start his fast lap with 4MJ available in the ES. It is unlikely that he will try and harvest all this on multiple warm-up laps, as this would be to the detriment of his tyres. He cannot charge the ES in the pits or garage during either qualifying or the race. So, for each of the Q2 and Q3 sessions, the ES needs to have been topped up to 4MJ at the end of the preceding session, leading to two or more hard-braking slowdown laps at the end of Q1 and Q2. A second lap on a set of tyres looks difficult in the time available, with the need to recharge the ES.

The race is far more complicated. The calculations above relate to an average lap. Conditions during the race vary enormously: wet/dry, safety car, fuel weight, race position, tyres etc, and will require a continuously evolving strategy for performance versus fuel use. The PU software is permitted to reduce power once full-throttle is applied and there is an excess of traction over wheel torque, so fuel can be saved. The driver can always lift early on the straight (the optimum technique for fuel saving) and he can short-shift. He is only likely to do this on instructions from the team and this is likely to to be communicated with a tone in his earphones, so he does it right.

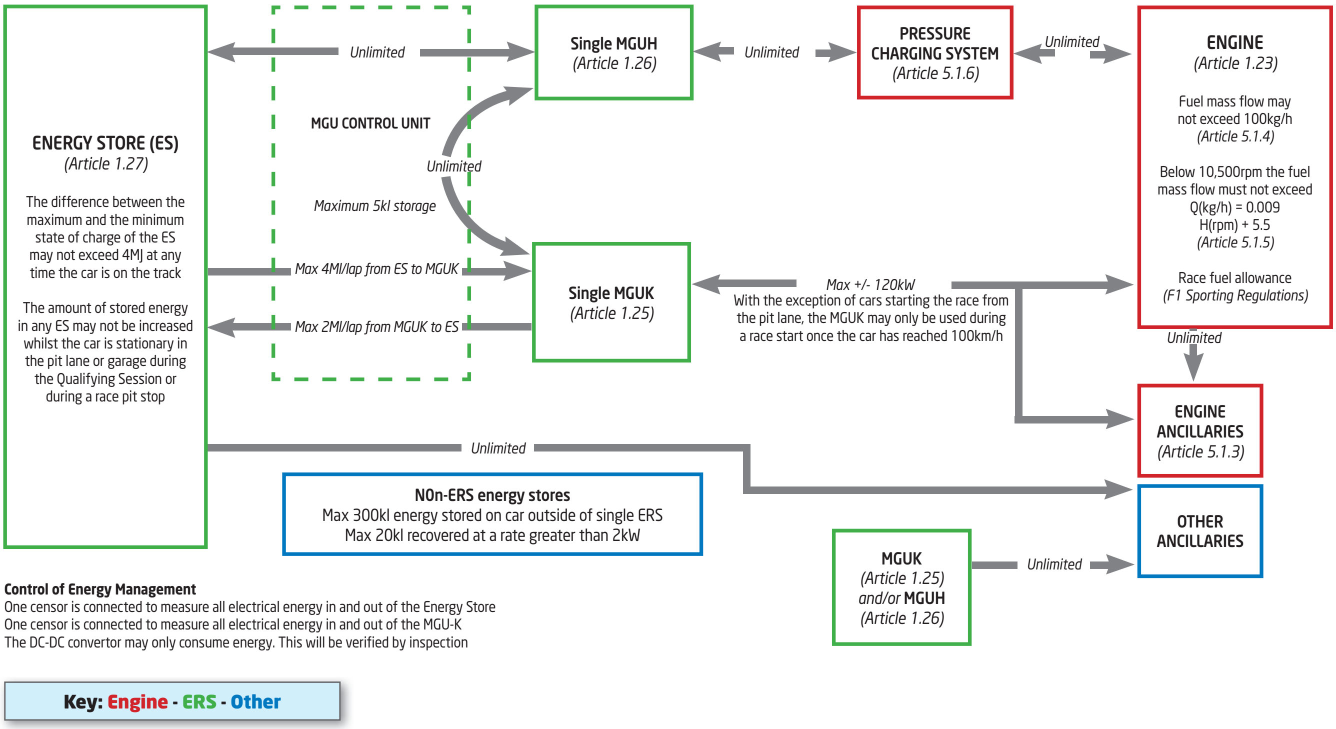
Although not in the regulations, it was at first believed teams would fit a boost button, LMP1 style, so that full power could be demanded regardless of the target fuel for that lap, for overtaking or preventing being overtaken. The excess fuel used would have to be won back. It is obviously easier to regain fuel budget overspent early in the race than the same overspend in the last few laps. Expect real-time strategy computing to be going on in the garage and back at the factory throughout the race.

The name of the game is simply 'performance per unit of fuel' and provided the fuel-used information is made available to

The driver can always lift early on the straight – the optimum technique for fuel saving – and he can also short-shift

↳

Power Unit energy flow



Points of interest

- The two throttle maps for wet and dry tyres were thought to provide enough scope for qualifying and the race. No software changes were permitted in parc fermé – the FIA can check every time the PU is fired up. Automatically!
- The FIA gathers around 100Gb of data at each event.
- Although the main engine ancillaries must be driven by the engine, other fuel and coolant pumps, the drive-by-wire throttle etc can be electrically powered from the ES. 48V is becoming the norm for this.
- The cars need a small startup battery to power up all the main systems. There is nothing to stop the PU being started by the MGU-K.
- All the core engines employ pneumatic valve closing. This doesn't make obvious sense from a weight, cost or reliability viewpoint, as 15,000rpm is well within the capability of steel springs. The only reasoning I could obtain for this was that pneumatic is what the designers know best these days.
- Although early on, no PU pictures show turbo waste-gates, there was much talk of them being fitted in case of MGU-H failure. The waste-gate exhaust would have to join the main exhaust pipe and if fitted, is probably hydraulically operated.

viewers in an understandable way, they will observe the performance and should be able to follow the game.

How each PU supplier and their teams have set out to achieve this best 'performance per unit of fuel' is pretty hard to determine. The level of secrecy, screens, shut garage doors, always meant little was seen of the PUs. When engine covers have been removed in plain sight, most of the PU is hidden beneath heat shields. Even if they were not, there is little to be learned from an assembled PU, as everything of interest lies inside the hardware and software, well out of sight. However, from observing the running and listening to the talk at Jerez, it was possible to see where the main challenges were and gain a glimpse of some of the solutions being tried. It was quickly evident that getting everything to work together in harmony was the greatest challenge and that, while Mercedes and their principal teams were on top of it, Renault, and Red Bull in particular, were not. Failure to do so quickly manifests itself as a reliability issue where powerful, hot, fast-rotating, high response-rate systems are involved. 'The team that comes up with the simplest, reliable strategy for looking after the powertrain can win,' said Pat Symonds. However, development will happen very fast and just who was really 'on top of it' only became evident in the racing environment.

If we put to one side the aerodynamic and tyre contributions to the performance, a) because they have been widely covered elsewhere; b) because aerodynamics, and probably final tyre specifications too are nowhere near definitive; and c) because the job of the engineers involved is not so different from previous years, even if the regulations have changed, then we can concentrate on powertrain performance, weight, and braking.

Powertrain output

The output of the thermal part of the PU, the turbo-compound engine, is all about efficiency. The manufacturer who finds the optimum way to combust the fuel, share the released energy between pistons and turbine, all with the least friction, heat and pumping losses, will achieve the highest output and be able to use it for the longest time. The additional output from the mechanically coupled MGU-K is pretty well a double-sized KERS system from last year. The battery ES, while able to output 10 times the energy of previous years, per lap, is only about twice the size, because it is sized by the power it must accept while charging and discharging.

However, with that power able to be turned on for much longer, cooling requirements for the storage, control and MGUs are significantly greater.

Cooling

In addition to the need to dissipate the greater energy losses in the more powerful ERS, the cooling system must also cope with the turbocharger's heat input to the charge air. For maximum power, the cooler the charge-air, the better will be the volumetric efficiency. However, at least under race conditions where performance/unit energy is paramount, this is not necessarily so. PU developers and their fuel partners know the optimum charge temperature for efficiency, and the system

can then be designed accordingly. Ferrari has determined that air-water-air cooling for the charge-air works best, and their teams' cars display by far the smallest radiator intakes. One would think the extra heat transfer interface would be less efficient, but type and construction of radiator (air-air versus water-air) comes into it and there is great progress being made into radiator core technologies.

Renault only specifies air-air; and Mercedes offers a choice of either.

Intriguingly, Mercedes split the compressor from the turbine, locating the former at the front of the engine and the latter at the rear. In between, mounted in the V, is the MGU-H being driven/driving the turbine and compressor via shafts. This arrangement allows all the cold parts and charge-air ducts to be mounted forward and the hot parts at the rear. The air-water heat exchanger is also mounted low down at the front of the engine. Mercedes studied literally dozens of layouts, analysing them for performance, efficiency and packaging, and built and dyno-tested quite a few before coming up with what they have built.

Response

Turbo engines have the reputation of providing the driver with turbo lag, ie a delay between throttle demand and engine response. Modern turbocharged road cars overcome this with tiny turbos, and variable geometry – not permitted in F1. The turbines on the new PUs use a larger turbine than is required, just to drive the compressor in order to extract energy from the waste exhaust gas stream, and so they have higher inertia. To meet the FIA's requirements that the PU responds to a torque demand within a certain time, the MGU-H is used to accelerate the turbine and compressor. The MGU-K can respond almost instantly and here the FIA will be watching to ensure fast torque modulation is not used for any form of traction control or even ABS at the rear wheels.

The 2014 witnessed the introduction of all-new, eight-speed gearboxes, with ratios that were fixed for the season, although in 2014 alone there was to be one change permitted to the homologated ratio-set.

The 2013 V8s needed seven speeds to cover the useable torque band, and it is considered that five or six should suffice with the wide torque range of the new PUs, so providing a range of options from eight ratios. Additionally, because the engine is generating almost constant power above the peak fuel flow RPM of 10,500, the RPM can be extended upwards to allow DRS or slip-streaming top speed increases.

The weight limit of 690kg always looked as though it would provide a real challenge, denying race engineers ballast to adjust the handling of the car. Two examples that illustrate the lengths to which designers have had to go is the replacement of aluminium oil and water pipes with carbon fibre ones, and then there was the dispute over turbine failure containment.

All the PU manufacturers have conscientiously ensured that their turbos are safe, but an argument over the wording of the regulation on the subject is really about the difference of over 3kg in the interpretation, hence the intense discussion.

Braking

With engine braking from the MGU-K increasing from 60kW of KERS in 2013 to 120kW, brake balance becomes critical, and the FIA has permitted a level of brake-by-wire to adjust brake pressure distribution. Two other issues have emerged. Firstly, the teams have reduced the size of the rear brakes, and a loss of MGU-K braking will lead to an under-braked, but fortunately stable car. Secondly, as the zero-shift transmission changes down during braking, the torque pulses to the rear wheels have become larger with a destabilising effect. Smoothing the shifts becomes important. The teams had to work hard on rear braking throughout.

Mercedes has split the compressor from the turbine, locating the former at the front of the engine and the latter at the rear

Out in front

Since the Silver Arrows era, Mercedes has built its F1 reputation. In 2014 it was unbeatable again

By SAM COLLINS

The Silver Arrows have a reputation for dominance. On every occasion that they have appeared in grand prix racing they have ended up being almost unbeatable. In the 1930s nobody but Mercedes-Benz and Auto Union had a hope of winning a race, and when the cars with a three pointed star on the nose returned to the championship in the 1950s it again dominated before leaving the sport prematurely.

Mercedes then came back to Formula 1 in the 1990s as an engine supplier, a role which saw it win many races and world titles with McLaren and Brawn GP. Then in 2010 it took over one of its customers, Brawn GP, and once again became a manufacturer team, but it was not until 2013 that its cars started to perform like the Silver Arrows of old. By 2014, however, the silver cars had returned to their default position and dominated the sport.

Its design, dubbed the Mercedes W05 Hybrid, has been described as a masterpiece of engineering, at some races it was able to lap over a second faster than any other design.

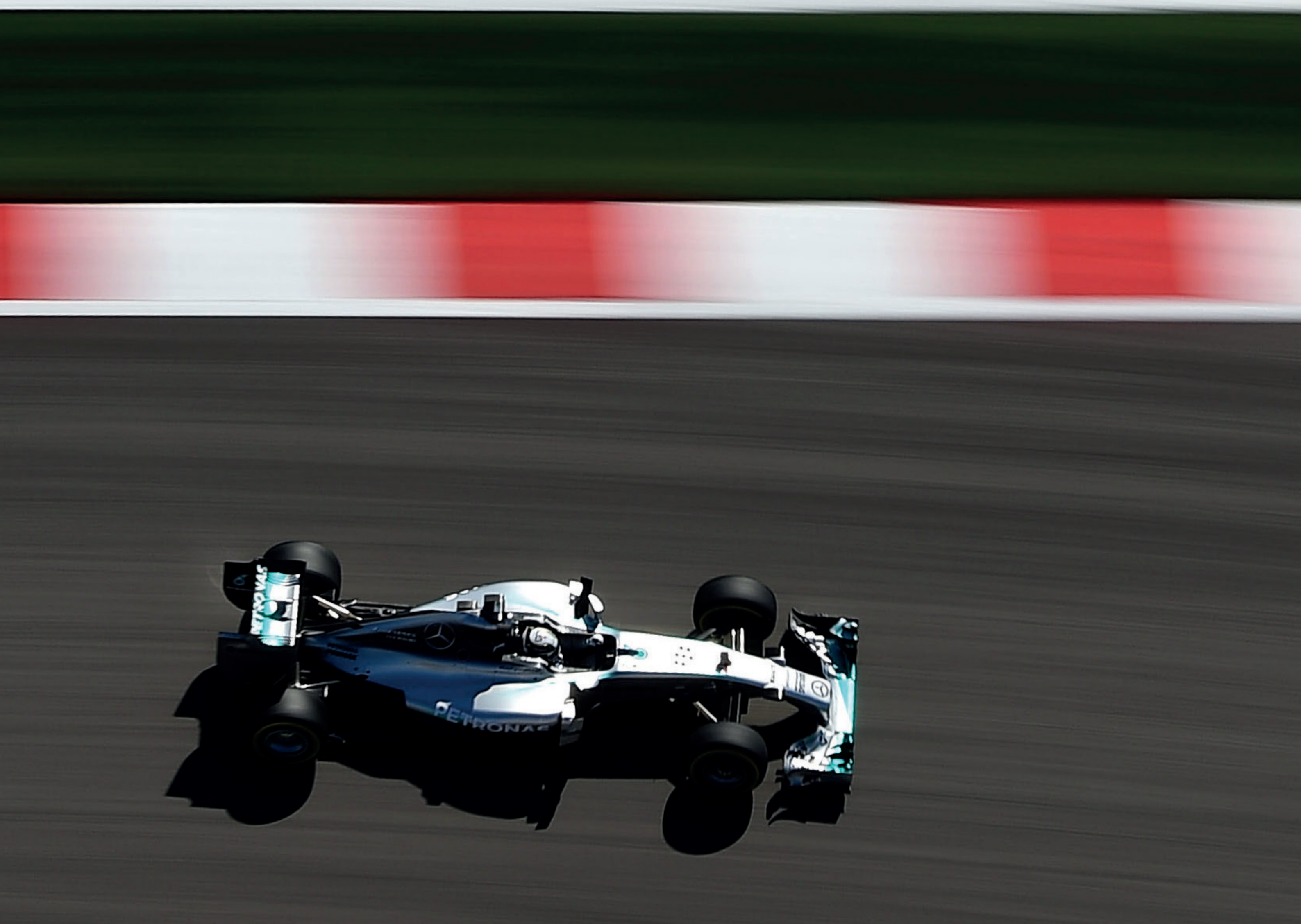
'The whole team has done a fantastic job on the management of the project and its delivery. We have hit our milestones and hit our targets. The new car is an elegant but aggressive design and, as is often the way, its beauty is much more than skin deep; the internal engineering of the car is extremely innovative and intelligent,' Mercedes technical director Paddy Lowe enthused at the car's rollout. 'This is by far the most complicated car we've ever built and the level of detail is incredible; it has been very well engineered on both the power unit and chassis

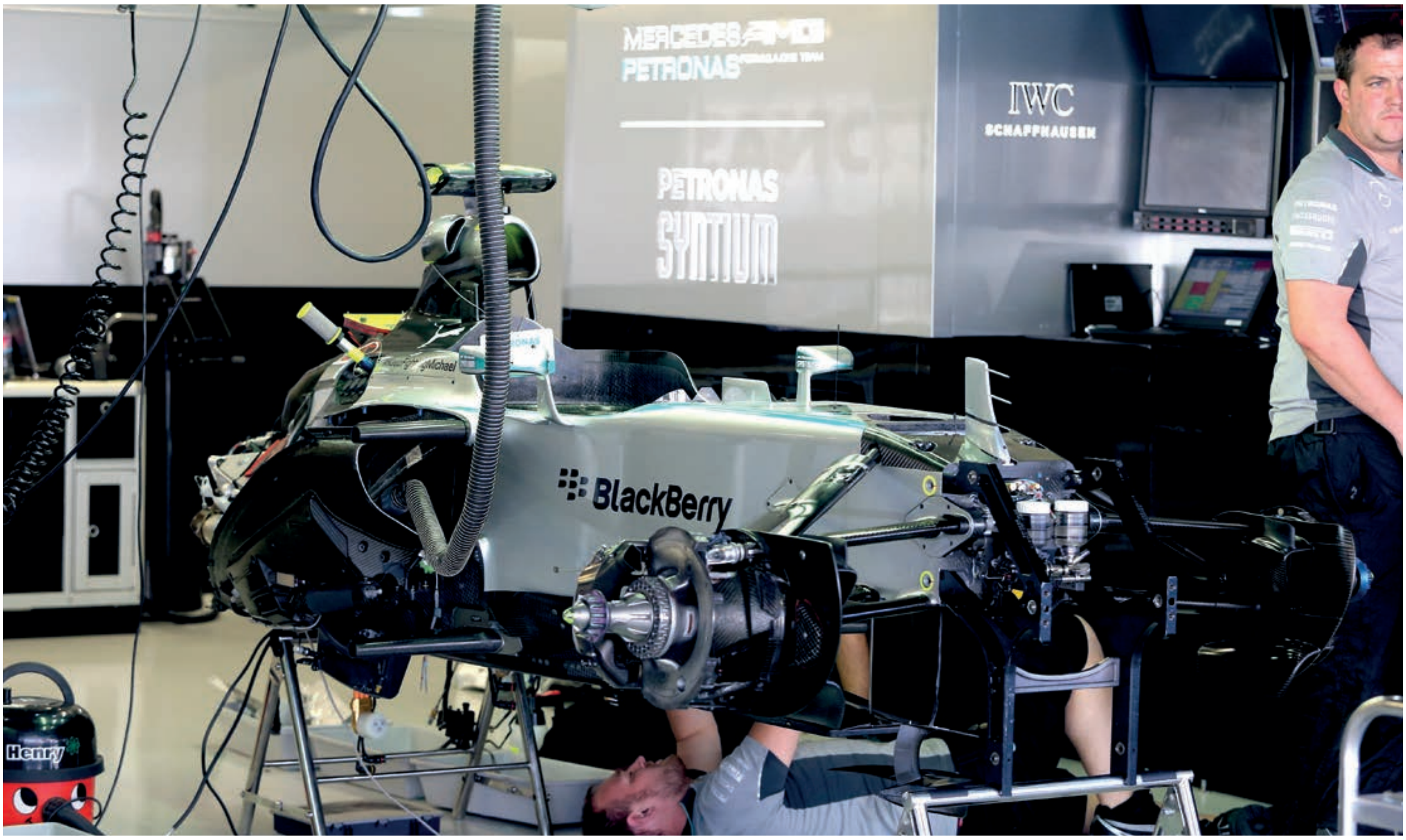
“Running a full race on 100kg rather than 150kg of fuel sends a great message about F1 technology”

side. Our preparation for the season was also strong, with plenty of lab work and a filming day at Silverstone before the first test. While it was a far less positive story in terms of reliability on that day, it allowed us to overcome some of the initial hazards with the new package, which was certainly useful in terms of hitting the ground running in Jerez.' From that point on, the Mercedes was essentially uncatchable. A few minor reliability glitches did little to give the other teams much hope. From the start the car was ominously fast.

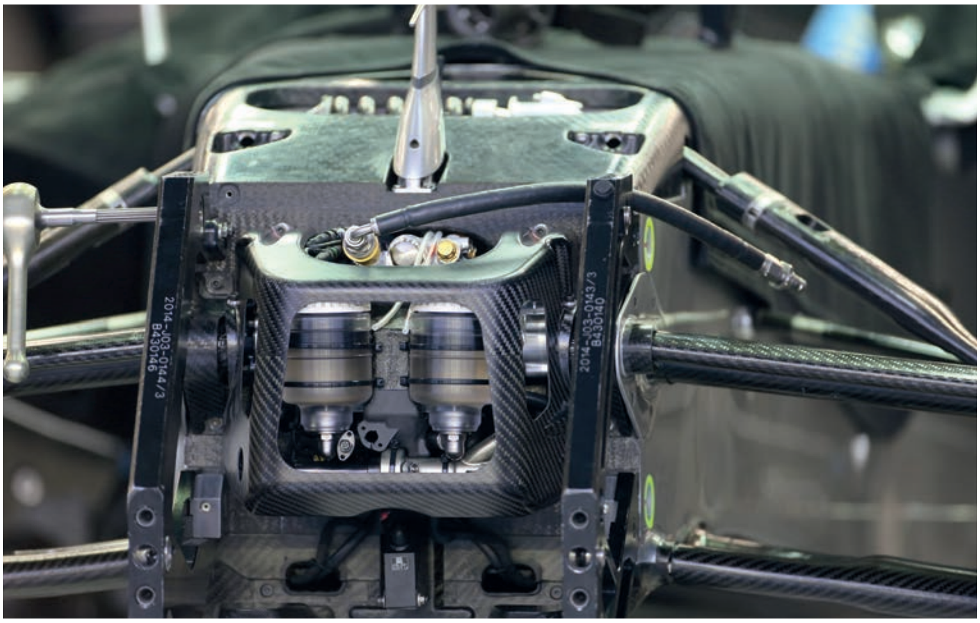
'For 2014 we have probably the greatest change in regulations in Formula 1 history. The headline is 'efficiency'. The fact that we can run a full race on 100kg rather than 150kg of fuel sends a great message about the technology we can deliver for F1 – and gives an important message to the automotive world in general. It's not simply about the fuel saved per car on a Sunday afternoon, it's about the technology itself. Over the years, we have seen how relatively small things filter through to the production world, not just in terms of the cars themselves but also what is seen as attractive.'

The performance advantage of the W05 set many people off looking for what may be its secret weapon. When they read the April 2014 edition of *Racecar Engineering* some thought they had found it. The car's power unit features a highly innovative turbocharger installation with the compressor mounted at the front of the engine, and the turbine at the rear with the MGU-H sat in between the V of the engine block on the clutched shaft between the two.

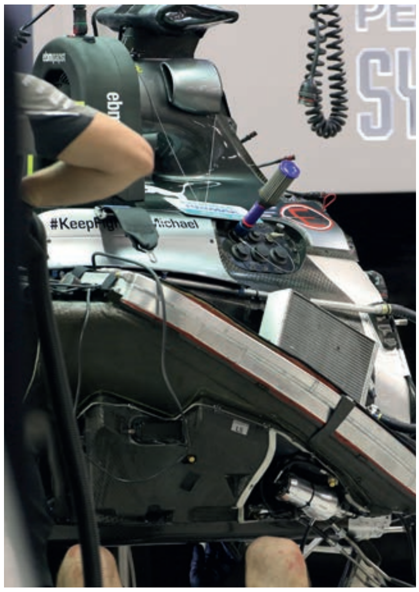




Brackley chassis engineers, above, have worked incredibly closely with those at Brixworth, where the power units are developed



Neat and tidy is the watchword at Brackley, as the W05's bulkhead sets an example



Elements of the car's design remain a closely guarded secret

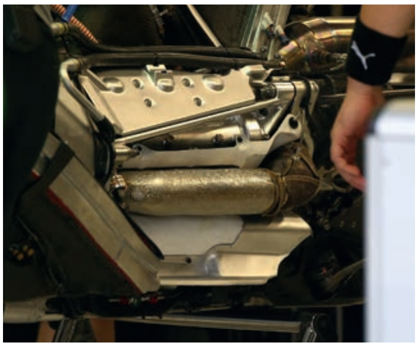
This undeniably offered both packaging and cooling benefits, but was not the real secret of the W05's success. Instead that came, as is always the way of things in Formula 1, from many other tiny details. The Mercedes engineers at both Brixworth, where its power units are designed and built, and at Brackley where its chassis are developed have clearly worked very closely together on the car. Looking under the skin, every sub system has been packaged in an incredibly neat and tidy way and the sheer level of integration on the car is something that impresses almost instantly.

This is particularly evident when looking at the side pod volumes when the car's bodywork has been removed – on most 2014 F1 cars the space directly beneath the side pod duct is cluttered with various electronic and hydraulic control boxes, but on the Mercedes this is all housed neatly in a carbon fibre case. This very neat and tidy philosophy carries throughout the car.

The exhaust system on the V6 engine has been designed to be as compact as possible to not only aid cooling but the overall aerodynamic package of the car. Its internal design remains a closely guarded secret though a technical paper published in the January 2015 edition of *Racecar Engineering* reveals tantalising details about how it could deliver more power overall as well as higher efficiency. Indeed the power unit had been said to be the most efficient gasoline power train of all time.

The car itself is fairly conventional in design terms with double wishbones all round, pushrods actuating the dampers on the front and pullrods on the rear. Both the V6 engine and transmission casing (which interestingly has a twin skin design) are fully stressed components.

Gearbox with its twin skin design – a fully stressed component



The engine – a few glitches but otherwise spot on

Ready to roll in the pit lane, with that low nose

The sheer level of integration on the car is something that impresses almost instantly

TECH SPEC

Chassis construction
Monocoque carbon fibre and honeycomb composite structure

Front suspension
Carbon fibre wishbone and pushrod activated torsion springs and rockers

Rear suspension
Carbon fibre wishbone and pushrod activated torsion springs and rockers

Transmission
Eight speed forward, one reverse unit with carbon fibre maincase

Clutch
Carbon plate

Dampers
Penske

Wheels
Advanti forged magnesium

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
Brembo carbon/carbon discs and pads with rear brake-by-wire

Steering
Power-assisted rack and pinion

Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
FIA SECU standard electronic control unit

Cockpit
Removable driver's seat made of anatomically formed carbon composite, Sabelt six-point driver safety harness, HANS system

Engine
Mercedes-Benz PU106A hybrid
ICE capacity 1.6 litres, six cylinders, 90deg bank angle, 24 valves
Max rpm ICE 15,000rpm
max fuel flow rate 100 kg/hour
(above 10,500 rpm)

Fuel injection
High-pressure direct injection
(max 500 bar, one injector/cylinder), Pressure charging: single-stage compressor and exhaust turbine
on a common shaft
max rpm exhaust turbine 125,000rpm

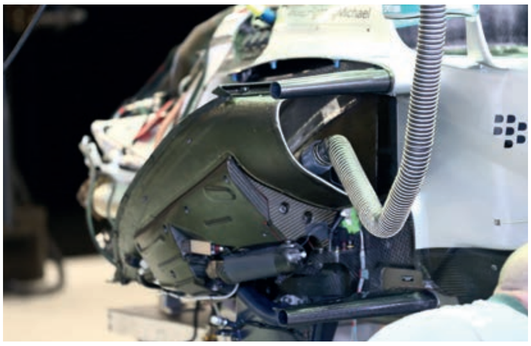
ERS
Mercedes AMG HPP

Dimensions
Overall length: 4800mm
Overall height: 950mm
Overall width: 1800mm

One of the most distinctive aerodynamic features of the W05 is its low nose; clumsily written new rules for the 2014 season saw many teams adopt oddly shaped front crash structures but Mercedes, along with Ferrari, instead adopted wider low noses for 2014, although Mercedes' original design struggled to pass the crash tests and an interim version had to be used until the Chinese Grand Prix. A third lightweight version was introduced at the Belgian Grand Prix later in the year.

Mercedes started the season with an advantage and carried it on through the development race in the season. Indeed at some points the gap extended even further, something the team are rightfully proud of. 'The image of the two Silver Arrows streaking away from the pack, in close battle with each other, that is something I will remember for ever,' says Lowe.

By the end of the year the rest of the field had closed up the gap but they were still ahead and in an exclusive interview, which can be read in the January 2015, edition of *Racecar Engineering* Lowe suggests that there is more to come in 2015.



Mercedes' very clean look extends to the side pod – the space beneath the duct devoid of the usual clutter of hydraulics

Re-building the teamwork

By mid-2013 the Williams F1 team was not performing and they knew it – but they have bounced back with style

In 2014 the Williams FW36 has been a regular sight at the front of the Formula 1 field regularly challenging the likes of Red Bull and Ferrari, and on occasion even the otherwise dominant Mercedes W05s. It is something that in recent years would have seemed highly unlikely.

In mid-2013 the Williams F1 team was enduring one of the worst periods of its existence; with half the season gone it had failed to score a single point. While the paintwork of the car harked back to the former glories of the Rothmans era, the logos on the car were few and far between – the biggest of them related to one of the team's drivers, Pastor Maldonado who looked likely to leave the team at the end of the season as the relationship soured.

Financially and technically the team was underperforming and everyone knew it. 'If I had been in charge of that I would have been fired,' a former Williams technical director admitted ruefully. It was into this environment that Pat Symonds arrived from Marussia to take up the post of technical director.

'When I really got into the team I saw a lot more than I had expected, and I was a lot more worried than I thought I was going to be – there were a lot more things to do than I realised,' he admits. 'There was a bit of an air of panic, the car was not good, and everyone was blaming aerodynamics which was partly true but they'd also sort of given up on other areas which was a shame because they should have done better.

'The pressure then was on the aero guys – a sort of "here's a new front wing, oh that didn't work, here's another." I think the trouble was that the results were so bad and there was no sort of direction of: "This is how we're going to get out of it." The idea seemed to be, "Well, if we just put more parts on the car, sooner or later we'll get something that's good."

'So we calmed that, thought our way through it. I hope I took away the blame culture and allowed people to innovate a bit.'

Symonds knew that things needed to change across the organisation, the team was clearly not functioning to its potential. 'I could see there were some damn good people there – they just didn't know quite what to do to make a winning team. There were some deficiencies, so I set about analysing what we had, where we needed to fill in – that's a process that takes some time.'

Working with the team's management – team founder Frank Williams and his daughter Claire, the deputy team principal and commercial director – Symonds restructured the whole team to become more effective.

Talent pool

'We made a conscious effort to go out and recruit some senior technical figures last year to complement the great talent pool we already had in house. These people have come into a variety of different departments – Rob Smedley (head of performance engineering), Rod Nelson (chief test and support engineer), Pete Vale (race team manager), Greame Hackland (IT director), Jakob Andreasen (head of engineering operations), Craig Wilson (head of vehicle dynamics), Shaun Whitehead and Dave Wheater in aerodynamics to name a few,' Claire

"The pressure was on the aero guys – a sort of 'Here's a new front wing, oh that didn't work, here's another'"

Williams adds. 'The restructure was to make sure that the right people are in the right places doing the right things.

'The impact of those changes we will see going forward as they continue to develop this year's car and then moving on to the FW37 project which has already commenced.'

With the new structure coming into place Symonds then had to turn his mind to the 2014 car design. 'The basic architecture was done when I arrived,' he says. 'The monocoque was completely laid out, a lot of the engine was too, but we made changes on the transmission and rear suspension, and then just concentrated on aerodynamics because there was only a basis laid out. That was where I spent most of my time in the first few months. I felt the design group were very functional, were very good indeed, so really we wanted to concentrate on aero – as always performance comes from there.'

One of the biggest challenges for Symonds with the aerodynamic programme was to work out exactly where the shortfall was coming from on the 2013 car. By understanding that he felt that he could then improve the 2014 design before the season had even started.

'The fact is that an awful lot of the performance of last year's cars came from the blown diffuser. It wasn't everything, and the basic aerodynamics of the FW35 were pretty poor anyway, but the blown diffuser was a disaster, so elimination of that definitely made my job easier. But I looked at the car when I arrived and knew there wasn't a quick fix. We had no chance of catching Sauber in front of us, and we knew that for someone to overtake us it would be a freak result – so to me the concentration was always on the FW36,' he explains. 'As a result, the aerodynamics of the FW36 are good. And that wasn't because I came along and said, "Well I think if we change this bit and this bit and this bit here it'll be better."

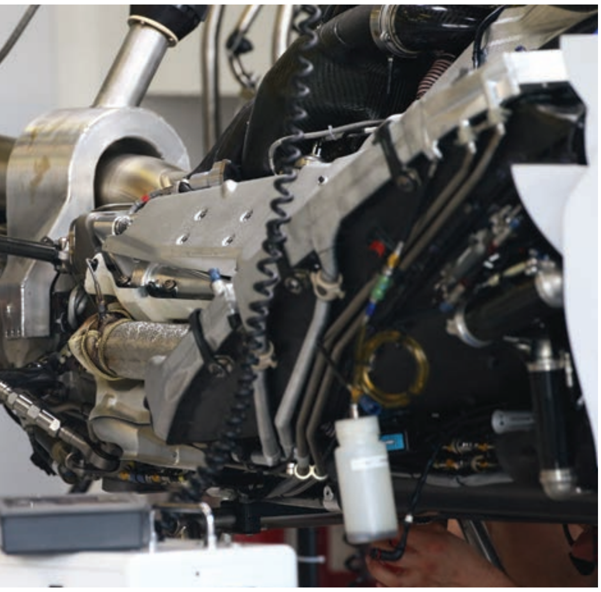
'It was much more because I said, "Look, just think about the way you're looking at your test results, think about what you need to do next. Don't be afraid to say you've got something wrong. Understand what went wrong and understand what went right and why they both have." With that sort of approach to things almost the same guys are producing a very, very effective car.'

Immediate improvement

Indeed, when the FW36 first rolled out at the Jerez Circuit in Spain during winter testing it was apparent almost immediately that the team had made a step in the right direction. The design itself seemed fairly conventional among the 2014 F1 field with push-rod-actuated dampers with torsion bars on the front suspension and a pull-rod-actuated layout at the rear. Williams had struck a deal with Mercedes to supply its power unit in 2014, which has since been firmly established as the class of the field.

Even with the experience the team had of developing and installing hybrid technology into competition cars having developed its own systems in 2009 and 2011, integrating the Mercedes power unit was still a challenge. 'It wasn't difficult because it was a Mercedes or anything like that, although there is a certain

Roll hoop of the Williams FW36 with cooling slots evident. Note the engine air intake with its hybrid safetly light



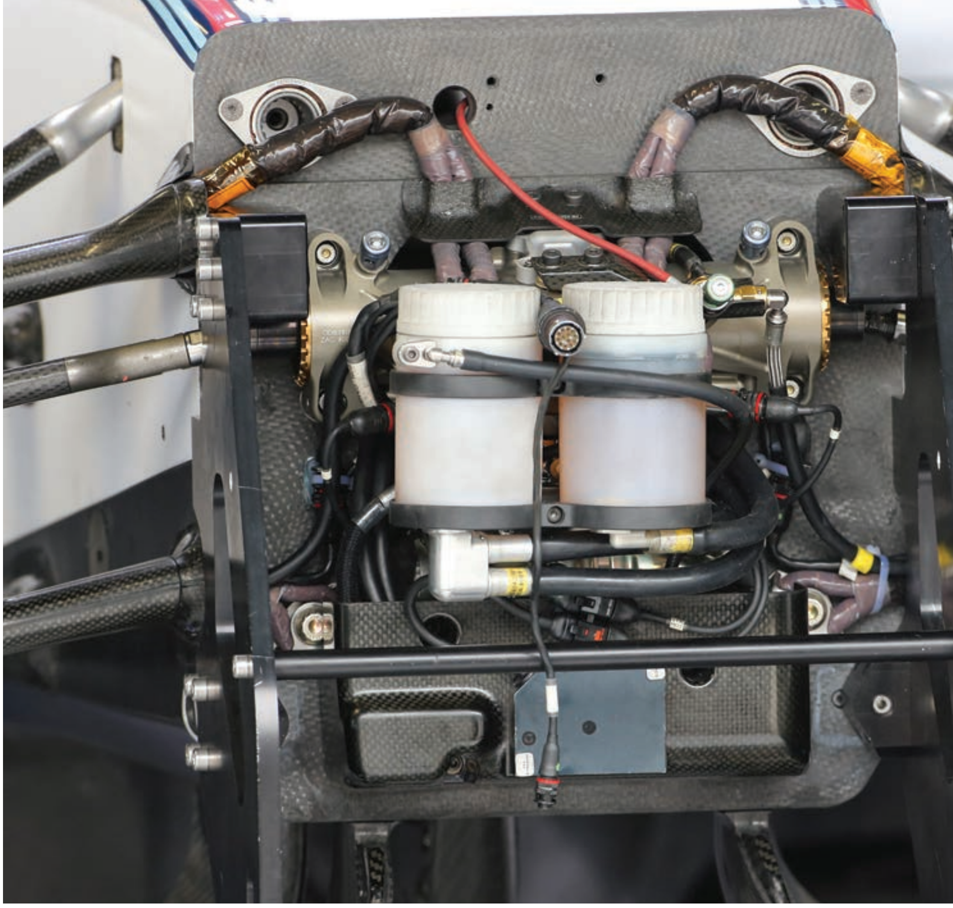
The team has experimented with the cooling system, but the only real change was pre-season between tests in Bahrain and Spain

amount of challenge involved with just working with a new partner at that sort of level.

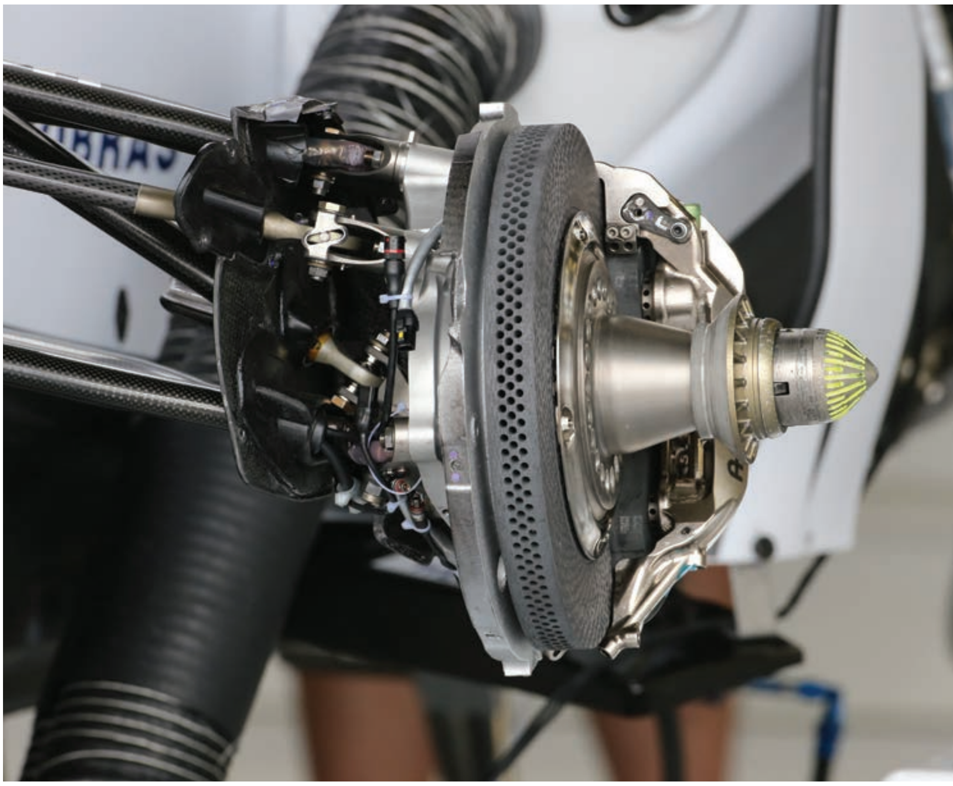
'But I think the main thing was the hybrid power units this year are so different to anything we have dealt with before that we really had to go back to square one and consider every aspect,' Symonds explains.

'Now I think that, generally speaking, to install a new engine is pretty much an engineering/design exercise if you like. What can become difficult is two things – understanding the duty cycle of the engine and also understanding how your engine supplier partners work. Of course we had to cope with both of those for the 2014 car. So the duty cycle of the engine was obviously going to be very very different to what we've experienced before. It took an awful lot of simulation to do and the understand the effects of that, particularly on heat rejection.

'Heat rejection is one of the banes of a chassis designer's life and for the 2014 cars there was an awful lot of additional work to do in that area, because although the heat rejection to water and heat rejection to oil were reduced,



Front bulkhead showing torsion bars and master cylinders

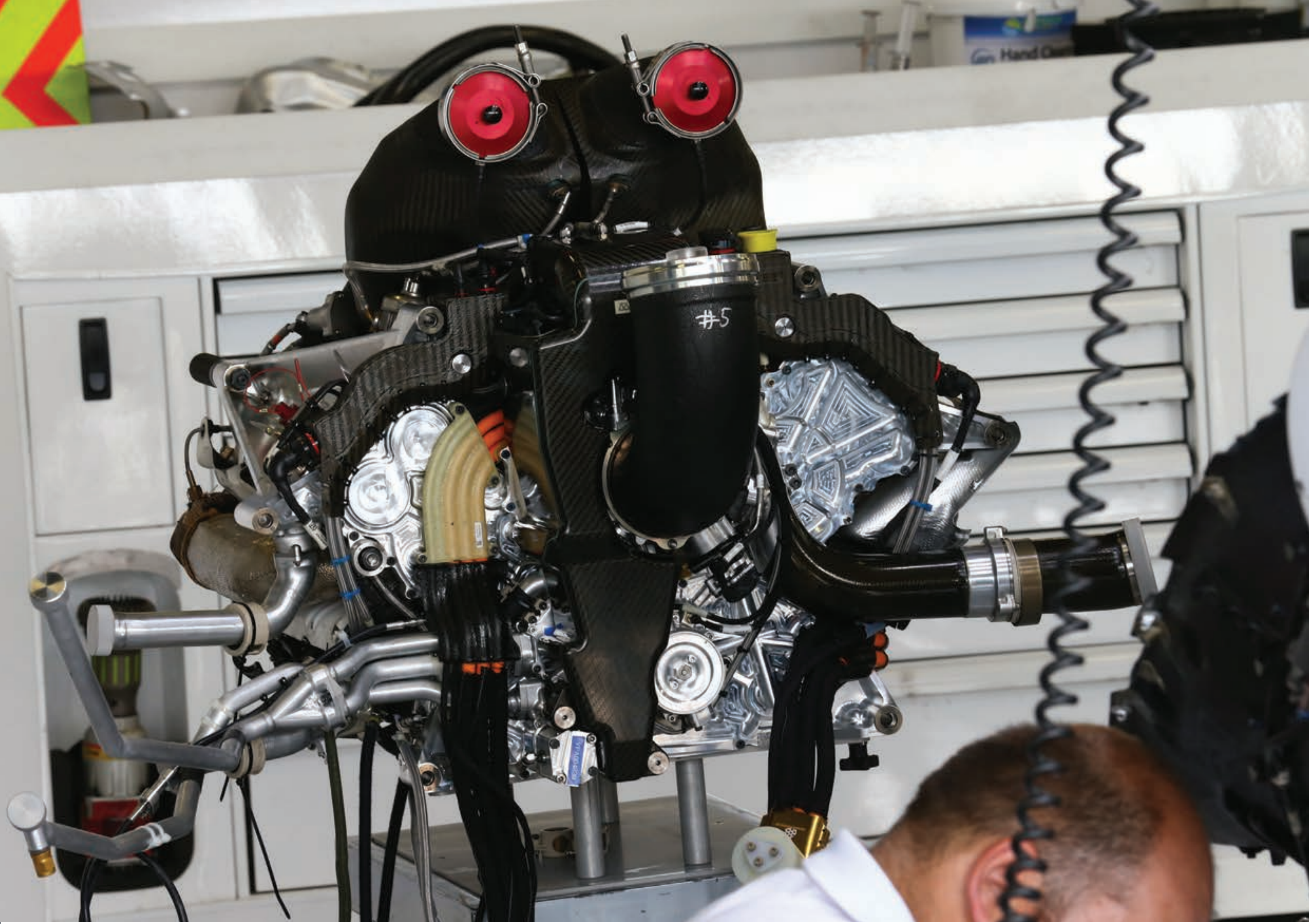


Left front brake setup with shrouding removed so that outboard front suspension pickups are visible

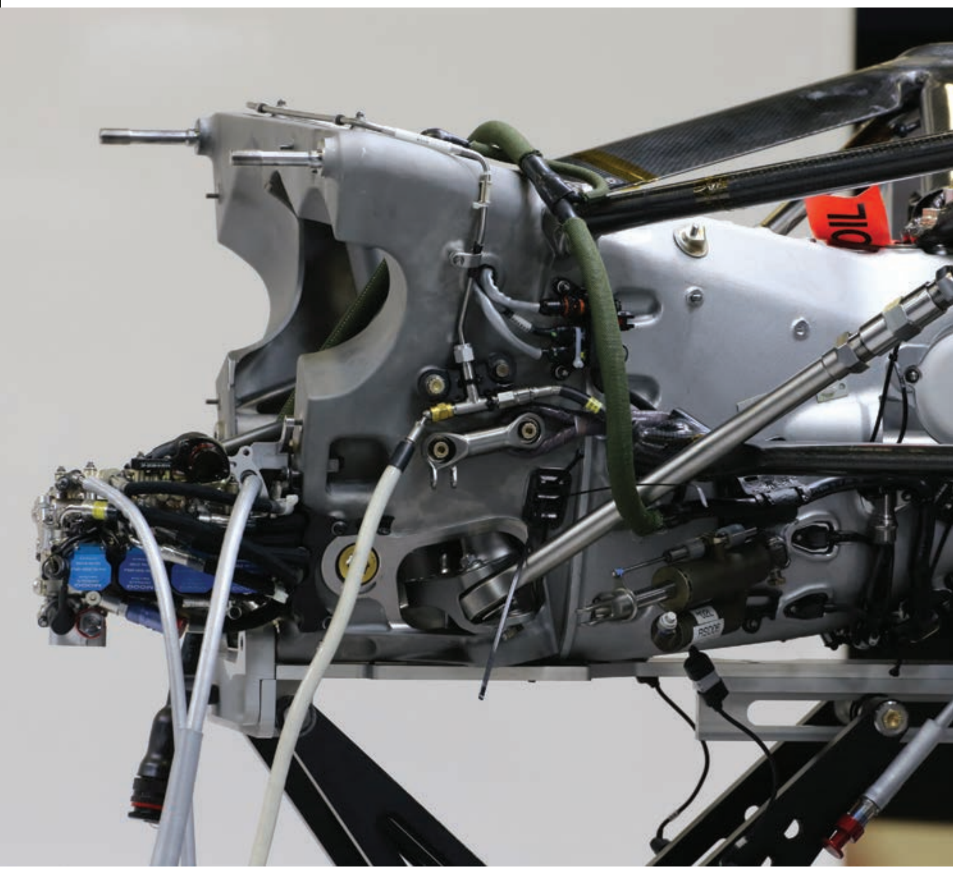
we now had charge air cooling to deal with and a lot more work to do on the ERS cooling so that was pretty difficult. And at the same time we had to get to know the people from Mercedes HPP and understand how they expressed things like heat rejection, so it was quite a challenge.'

To improve the integration, Mercedes HPP at Brixworth allowed its partners not only to use some of its facilities (the Williams transmission was tested on the rigs at Brixworth for example) but it also embedded some of its staff in each of the teams. They work with the car designers looking at every element that could impact the power unit's operation and performance.

'We have a number of dedicated people on the design side and have a dedicated contact point within HPP at Brixworth. He is our immediate point of contact for anything we need, whether it's CAD models, engineering information or discussions. We obviously also have now, a dedicated trackside team who work with us all the time at the circuit but behind our



Mercedes has the upper hand in terms of performance, but the turnaround of Williams' fortunes have had more to do with the restructuring than solely engine performance, notably the Mercedes powerunit features a split turbocharger with the compressor and turbine at different ends of the engine block, as above



The 8-speed gearbox was tested at the Mercedes facility in Brixworth as part of the technology partnership that Mercedes initiated with its customer teams. Note hydraulic block at front of gearbox

dedicated design contact of course there is the entire services of HPP at Brixworth that we can call on,' Symonds continues. 'I don't think helpful is the word for this, I think the word is essential. We couldn't work without having someone we could talk to on a daily basis and of course we have face-to-face meetings every couple of weeks as well. We still, however, need someone who can filter all of our requests throughout the organisation.'

And this approach has not prevented Williams from taking its own approaches to the installation of the power unit in some areas, notably the positioning and design of the intercooler in the left-hand-side pod of the car.

A different solution

'Mercedes will tell you what the heat rejection is, what the maximum temperatures are that you can operate at, and how you achieve those is entirely down to you as a chassis team. Our solution is different to that which works for Mercedes but one I think has worked very well for us. We use an air-to-air intercooler. Some teams, certainly the Ferrari teams and some of the Mercedes teams, do use a water-air intercooler and then an air-air, but I think our solution is the most efficient. We've run basically the same cooling configuration since day one. The only change we've made to the

The exposed rear end of the Williams FW36 – the metal transmission casing evident as is the composite rear crash structure. Note the neat rear upright designs

"plumbing" if you like is in Spain. There we resized the cooler slightly because we were able to actually get good heat rejection information from the Bahrain tests, and by the time we had made that and designed the parts, it was actually for fitment in Spain so we did a pretty major cooling system upgrade and we've done nothing since other than bodywork changes.'

One major change to the layout was tested at the Austrian Grand Prix where the intercooler was mounted behind the fuel cell, but according to the team that was a test of the 2015 cooling concept rather than a development for 2014.

"We did a pretty major cooling system upgrade for Spain and we've done nothing since then other than bodywork changes"

From the first race of the year, the FW36 proved to be a very strong package indeed, and as *Racecar Engineering* closed for press had finished on the podium six times, but the top step has proven elusive. The Williams unable to quite match the pace of the works Mercedes. Symonds feels that while the works team is much better funded and able to do more development, there are still areas of the car which are weaker than that of the front runners. 'I guess two main things are aerodynamics and tyre usage. I think we have an aerodynamic deficit to Mercedes and I think they're very very good at the way they use the tyres both in qualifying and in the race,' he admits.

Despite heading for the team's best finish in the constructors championship in over a decade, Symonds is not satisfied and feels that there is still much more to do. 'I am surprised by the speed of the turnaround, that's true. I didn't expect we could get this far up. Realistically I hoped we could get to sixth in the championship or something like that this year. But I know where I want to get to and that is a long way further ahead from where we are now. It's never one person: what it shows is that there was some quality there, it just needed direction as to how to turn that quality into performance. Each department was doing it individually but everyone was in silos and there was very little communication. The design department, the operations, the trackside operations, the aero and even to some extent the production, although production was, to be honest, a lot better. I really wanted people talking together more openly and while I haven't got as far as I wanted to go with that yet – I'd like everyone in one office. But what I have got is people who now like to talk to each other about what they're doing and they're not trying to score points over their colleagues or blame their colleagues, they're just getting on just trying to make everything better but there's a way to go yet,' he concludes.

Claire Williams has set a clear goal for the team moving forwards. Even with its Martini branding the team is still not the best-funded operation at the front of the grid by any stretch. 'Williams has always been a great example of a team that has not always had a huge budget and we have won championships.

'You only need to look at the 1990s when we had significantly smaller budgets than other teams and we were winning championships. I think it is a dangerous mindset that it is always about money, it would be great to prove again that you can win races in Formula 1 without big budgets,' says Symonds.

Work is well advanced on the 2015 Williams FW37, and it will be the first car that Williams has developed fully under the technical management of Symonds. The proof of his restructuring and influence on the team will only really be shown when, and if, that design reaches the podium for the team's first win since 2012.

TECH SPEC

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

Front suspension
Double wishbone, pushrod activated springs and anti-roll bar

Rear suspension
Double wishbone, pullrod activated springs and anti-roll bar

Transmission
Williams eight speed seamless sequential semi-automatic shift plus reverse gear, gear selection electro-hydraulically actuated

Clutch
Carbon multi-plate

Dampers
Williams

Wheels
RAYS forged magnesium

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
AP six piston front and four piston rear calipers with carbon discs and pads

Steering
Williams power-assisted rack and pinion

Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
FIA SECU standard electronic control unit

Cooling system
Aluminium oil, water and gearbox radiators

Cockpit
Six point driver safety harness with 75mm shoulder straps and HANS system, removable anatomically formed carbon fibre seat

Engine
Mercedes-Benz PU106A hybrid
ICE capacity 1.6 litres, six cylinders, 90deg bank angle, 24-valves
Max rpm ICE 15,000rpm
max fuel flow rate 100 kg/hour (above 10,500 rpm)

Fuel injection
High-pressure direct injection (max 500 bar, one injector/cylinder)
Pressure charging: single-stage compressor and exhaust turbine on a common shaft
max rpm exhaust turbine 125,000rpm

ERS
Mercedes AMG HPP

Dimensions
Overall length: 5000mm
Overall height: 950mm
Overall width: 1800mm

McLaren fight-back

After a disappointing season in 2013, McLaren changed its focus for 2014 but fingers still point at downforce and fuel issues

By SAM COLLINS

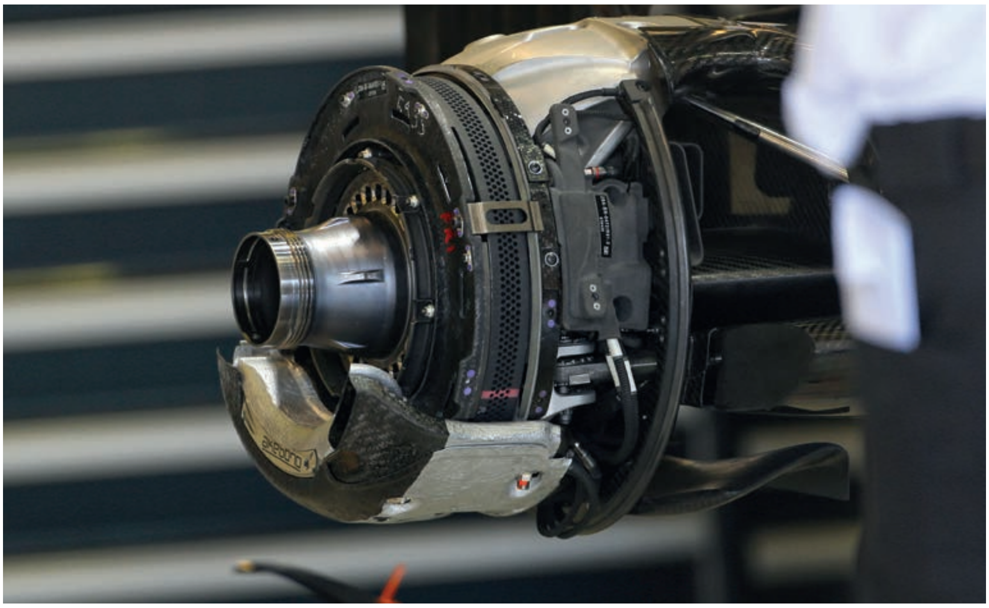
McLaren once came very close to being the constructor with the most wins in the history of Formula 1, but in 2013 it failed to get a single podium finish and trailed home fifth in the Constructors' Championship. It was the worst season the team had experienced since 1980.

With rules stability between 2012 and 2013 things should have been much better. The 2012 car was at times the fastest in the field and a match for the otherwise dominant Red Bull. But the 2013 MP4-28 car represented a major change in car concept, adopting pullrod front suspension and a number of other major changes in design, and was a disaster. But it was a failure that McLaren believes it has learned from and has been trying to repair the damage done with its 2014 design.

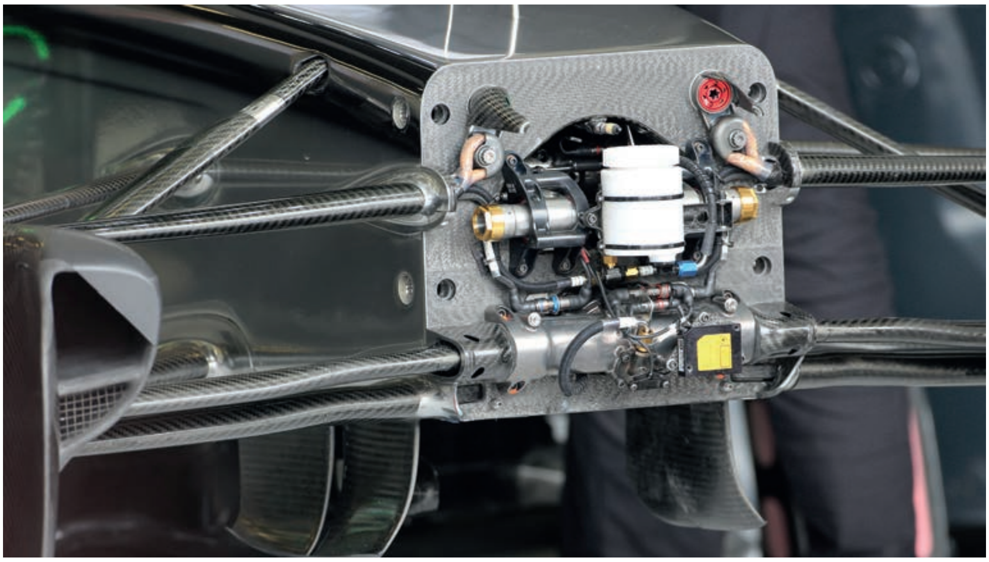
'Looking at car concepts, I would go back to the end of 2012, because what we did in 2013 was a mistake,' Jonathan Neale, chief operations officer and acting CEO of McLaren Racing admits. 'We picked an overly ambitious series of projects to bring together on one car. In trying to optimise those bits and pieces, the car became incredibly peaky in the way it delivered its performance; its sweet spot was very narrow and Formula 1 cars don't really work like that.' The MP4-28 also highlighted another major issue with the team's aerodynamic development, which had a huge impact on its performance.

'Also in 2013 we lost the correlation between track and wind tunnel, and as the body of knowledge moved forward in Formula 1 we fell behind. So we were behind aerodynamically in terms of the way in which the airflows worked around the car and the delivery of downforce,' Neale reveals. 'The 2013 aerodynamic problems were nothing to do with the wind tunnel, they were everything to do with the car. As is the case with CFD, the wind tunnel is a model. It was a case of putting things on the car that worked in the tunnel but they were rushed on and there was not enough attention paid to the sensitivities of some things. A classic case of this was how you manage stall. Most of us want the car to stall as it goes down the straights so, as the diffuser gets closer to the ground, ultimately it stalls and chokes off that flow, losing you drag and making the car quicker. So, stall is helpful in that context but you have to ensure that the downforce comes back when the guy stands on the brakes. If you don't get it right the car can become incredibly hard to drive.'

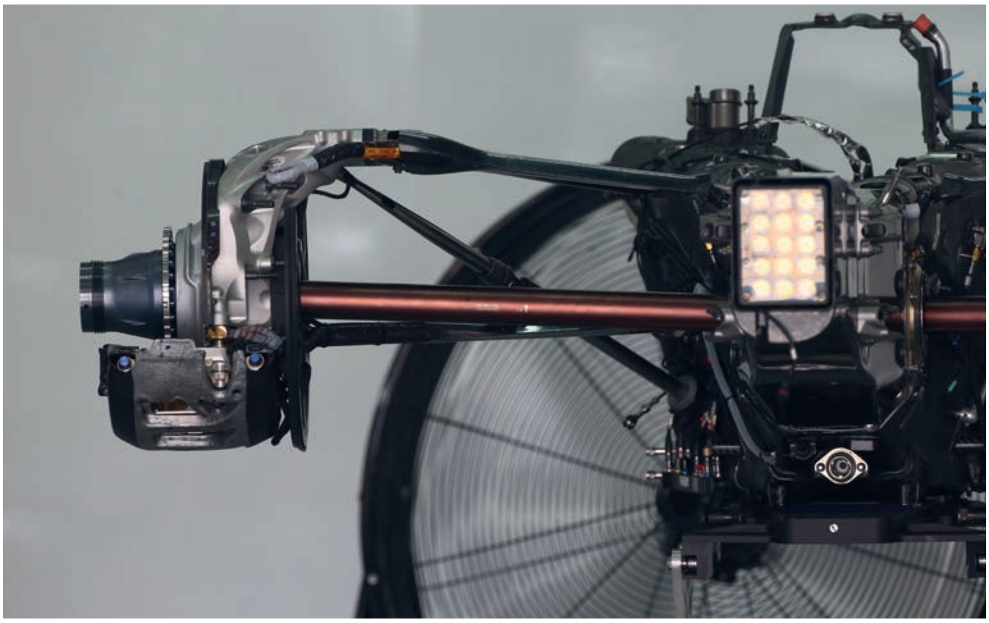
"The car does not have any great flaw in it mechanically, it just does not have enough downforce"



Brakes feature Akebono calipers, but McLaren does not reveal the supplier, or suppliers, of their carbon discs



Bulkhead view shows the front suspension which ditched 2013's pullrod system in favour of a more conventional pushrod arrangement. Front-rear interlinked suspension system, discouraged mid-year, was mounted behind the fluid reservoir



The gearbox and driveline of the McLaren is designed and built in-house and has been one of the most satisfactory parts of the project. This part-assembled view is unobscured by the innovative 'mushroom' wishbones (see box page 12)

The whole McLaren team knew it had to improve and with the introduction of new power units in 2014, it was hoped the MP4-29 would show that improvement. After the first race, where the McLarens came home third and fourth in the race, things looked to have moved in the right direction (the two cars were later elevated to second and third after a Red Bull was disqualified). But the team knew by that point that the issues of 2013 were still disrupting the progress of the new car.

In-house design

'The car concept was basically simple: package the Mercedes engine tightly in the rear of the car, manage the heat and don't set fire to the bodywork with the turbocharger,' says Neale. 'And hope that the tyres that come at you are what you tested with Pirelli at the end of the previous year. Then it was just see what everyone else has got, and we saw that the car does not have any great flaw in it mechanically, it just does not have enough downforce. That is not trivial to fix, but we have done a pretty good job packaging the Mercedes engine – we hit our weight and compliance targets.

'Heat rejection was okay, but with the rapid development of the power unit the heat rejection is constantly changing as Mercedes tweak and changed things.'

Mechanically, one area of the car with which the team is happy is the transmission, which McLaren develops in-house. 'The gearbox casing is something for us that we are not going to give up, because we are quite good at it,' says Neale. 'Having invested in the know-how to do that, it's another one of those areas that continues to yield improved performance. The packaging at the back of these cars is crucial. We manufacture our own carbon case and design our own gears. We don't make the gears but we would if we could. We don't have any customers for our box at the moment like some others do and its not our intention to do so, in part because it does slow down manoeuvrability as a business. If you just have to make five in a particular space of time for yourself, that's quicker than having to do another five for a customer – and another five for a second customer. The manufacturing means that the lead time increases, and that means you have to design things a lot earlier. We don't want to do that as we want to have as much time for design and development as possible and the shortest time for manufacturing possible.'

Downforce wars

Having the best power unit in the field does lead to inevitable comparisons between the McLaren and the other three designs it is fitted to, namely the Force India, Williams and the works Mercedes. In the RE V24N8, Force India F1 technical director Andy Green reveals that he believes that his car has less downforce than the McLaren, something Neale disputes; 'I don't believe that Force India and Williams have less downforce than us and my evidence for that is that, if you look at the Williams end of straight speed, they tend to be about 10km/h faster than the other Mercedes runners. Force India is not bad either, whilst perhaps not a downforce related issue they outperformed us on the super soft tyres.'

It is clear that the McLaren engineers feel that the major performance deficit on the 2014 car is an aerodynamic one, and that the problem is rooted in the problematic MP4-28. 'We have to fight our way back in aerodynamic terms, at a time when everyone from Caterham to Mercedes has exactly the same amount of time in the wind tunnel. It's just 80 runs a week. When you don't have a firm baseline you can end up firefighting,' says Neale, thoughtfully.

The McLaren has a fairly conventional aerodynamic package, using perhaps the most elegant variant of the less than pretty proboscis nose structures seen on many 2014 cars. While distinctive, it's an area of the aero package where Neale thinks that there is little to gain.

'At the start of the 2014 car project there was a lot of work done on noses by teams like Lotus and Mercedes. Everyone is trying to work out how much performance there is in noses, and after an initial scuffle during the opening races not really much has been done as it is not a dominant performance factor. There are two schools of thought out there and both seem to work: the high nose or the low nose. [FIA race director] Charlie [Whiting] was the person most exercised about nose shape as he did not get what he expected, so he has tightened up the rules and we won't have these designs next year.'

Fuelling rumours

The performance deficit experienced by McLaren compared to the other Mercedes runners may not just be down to the aerodynamics. One major difference between the cars is that the Mercedes, Force India and Williams all run on Petronas fuels and lubricants, and the engine was developed using that family of products while McLaren runs on Mobil 1.

Partly disassembled, a pushrod end is visible through the bulkhead opening. This shot shows the front end without the FRICS hydraulics in place

MUSHROOMS: A CUTE INTERPRETATION OF THE RULES?

At the rear of the McLaren there is an aerodynamic part of significant interest and unique to the MP4-29. Nicknamed 'mushrooms', these aerodynamics exploit a loophole in the technical regulations. The rear arms of the rear wishbones are fitted with large carbon fibre shrouds that look like the wings of an insect from the rear. From the front, though, it is clear that they are sculpted to give some kind of aerodynamic influence.

'I would imagine that they are trying to make the diffuser work better,' says Rod Nelson, chief test engineer of Williams when he first saw them in pre-season testing. 'One of the major functions of the lower rear wing (beam wing) was not to generate downforce on its own, but it helped you be more aggressive with the diffuser and stops it stalling at lower ride heights, so I would imagine that they are doing that.' This is something Neale confirms; 'One of the features of last year's regulations was the elimination of the lower element of the rear wing. It was one of a whole stack of elements that made the whole thing work. The rear arm shape is a concept that we chose early on and it works. But looking at other cars, it's quite clear that it's possible to generate the same levels of drag and downforce without them as we are clearly not a second-and-a-half up the road, so they are not a make-or-break feature of the car.'

There was at one point a question mark raised over the legality of these parts as the 2014 F1 technical regulations relating to the suspension components states that non-structural parts of suspension members are considered bodywork. The F1 regulations also state that all bodywork must be rigidly secured to the entirely sprung part of the car (rigidly secured means not having any degree of freedom) and must remain immobile in relation to the sprung part of the car.

The 'mushrooms' being mounted to the wishbones are clearly unsprung and clearly move, but they are considered a structural part of the suspension. They are 'doglegged' to comply with another one of the technical regulations which says that:

'With the exception of minimal local changes of section for the passage of hydraulic brake lines, electrical wiring and wheel tethers or the attachment of flexures, rod ends and spherical bearings, the cross-sections of each member of every suspension component, when taken normal to a straight line between the inner and outer attachment points, must:

a) Intersect the straight line between the inner and outer attachment points

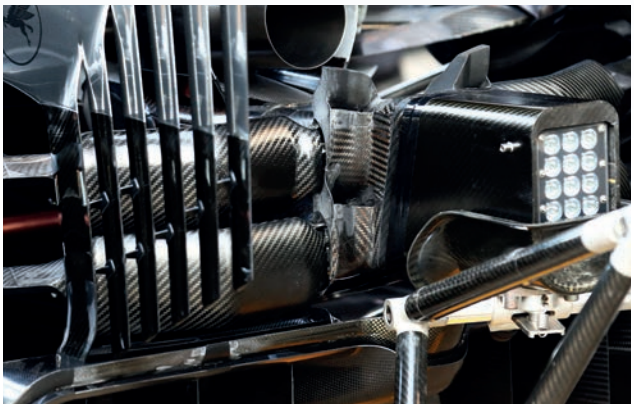
b) Have a major axis no greater than 100mm

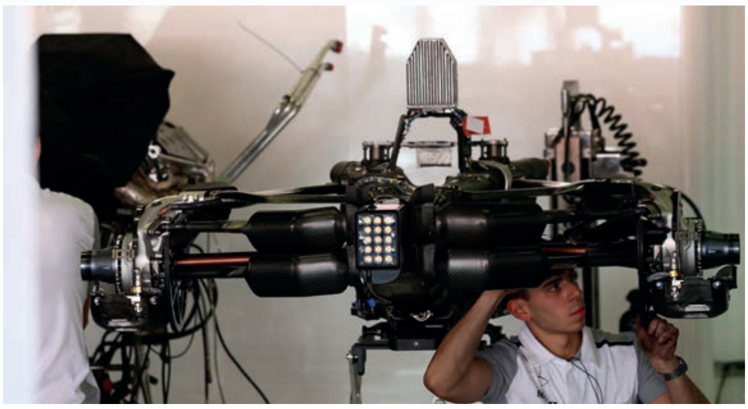
c) Have an aspect ratio no greater than 3.5:1

d) Have no dimension which exceeds 100mm

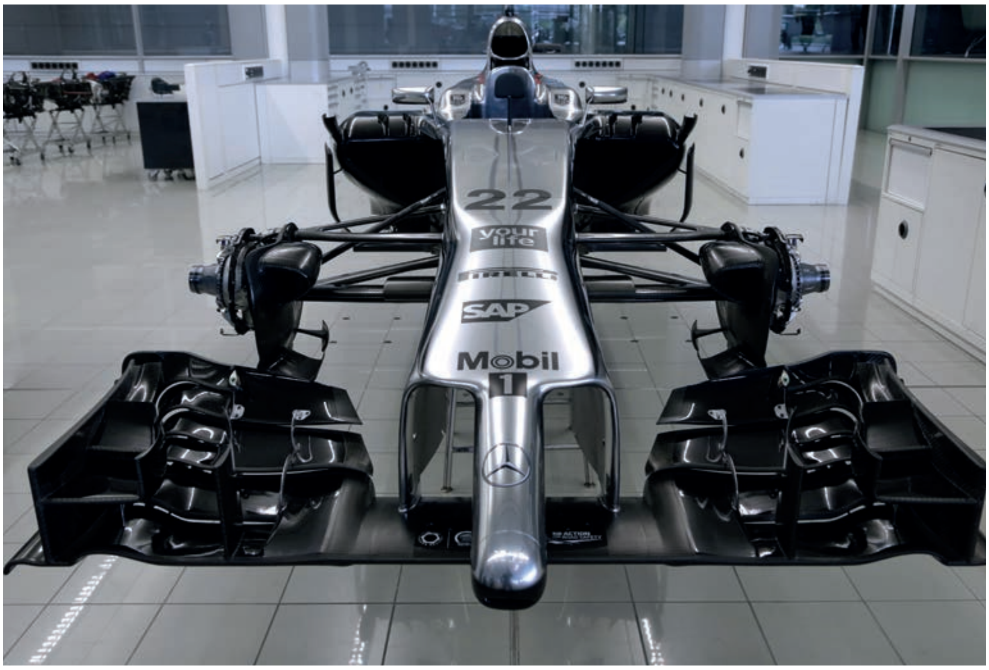
- **The major axis will be defined as the largest axis of symmetry of any such cross-section. The length of the intersection of this axis with the cross-section must not be less than 95 per cent of the maximum dimension of the section**

The doglegs in the mushrooms mean that no dimension exceeds that 100mm limit and that all other parts of the rule are complied with. It is, in the words of a rival team, 'a very cute interpretation of the rules and worth investigating in the wind tunnel'.





Clever interpretation of the rulebook has led to these 'mushroom' shrouds incorporated into the rear wishbones of the McLaren MP4-29. It's thought that they assist in managing airflow around the diffuser and compensate in part for the removal of the lower element of the rear wing mandated by the 2014 technical regulations



The various nose designs of the 2014 cars have been a major talking point, but the team doesn't think any of the configurations has shown a definite aerodynamic advantage on the track

TECH SPEC

Chassis construction
Carbon fibre incorporating driver cockpit controls and fuel cell

Front suspension
Carbon fibre wishbone and pushrod suspension elements operating inboard torsion bar and damper system

Rear suspension
Carbon fibre wishbone and pullrod suspension elements operating inboard torsion bar and damper system

Transmission
Carbon fibre composite case, epicyclic differential with multi plate limited slip clutch

Clutch
Carbon/carbon hand operated

Wheels
Enkei

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
Akebono calipers and cylinders

Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
FIA SECU standard electronic control unit

Cooling system
Aluminium oil, water and gearbox radiators

Engine
Mercedes-Benz PU106A Hybrid , Internal Combustion Engine: Capacity 1.6 litres, Cylinders Six, Bank angle 90, No of valves 24, Max rpm ICE 15,000 rpm, Max fuel flow rate 100 kg/hour (above 10,500 rpm)

Fuel injection
High-pressure direct injection (max 500 bar, one injector/cylinder), Pressure charging Single-stage compressor and exhaust turbine on a common shaft, Max rpm exhaust turbine 125,000 rpm

ERS
MGU-K maximum speed 50,000rpm, max power 120kW, max energy recovery 2MJ/lap, max energy deployment 4MJ/lap
MGU-H Maximum speed 125,000rpm, max power unlimited, max energy recovery unlimited, max energy deployment unlimited. Energy store Lithium-ion battery

Lubricants and fluids
Mobilith SHC

Radio
Kenwood

'When you look at Mercedes, though, broadly we are running the same engine and hardware, yet they are a second and a half up the road. Formula 1 is still simply about power and downforce. Mercedes are good people to do business with, so I'm confident that we have the same hardware, but we run different fuels and lubes so our maps are going to be different. We don't have all the access to the things we would like to tune and play with in the power unit, but that's understandable as we are going to Honda next year and Mercedes for obvious reasons don't want all that knowledge getting out. So would it surprise me if Mercedes has some engine advantage in there? It would not surprise me at all,' Neale accepts. 'Fuel development is key to this generation of engines. The FIA are managing very closely what constitutes a reliability upgrade and what is a performance upgrade on the engine. But there is freedom on fuels and lubes.'

"Mercedes are good people, so I'm confident that we have the same hardware, but we run different fuels and lubes"

That switch to Honda power in 2015 could be the start of a new era for McLaren and it is instigating new working practices for the future which it hopes will allow it to regain its form. 'We are looking at changing the way we pick car concepts,' reveals Neale. 'There's reformation going on in many areas of the business and that's one of them. There is no longer an off season in Formula 1 and I think you will see teams becoming more ambitious in terms of changing suspensions, gearboxes and even whole back ends mid season. We will not always be relying on the new car to carry all of the new concepts but actually picking larger building blocks and having more regard for carry over. For example you could introduce a new back end for the first European race and the new front end for the first late season Asian race (currently Singapore). The restrictions on track testing and wind tunnel time have made the value of a unit of time so great, that the efforts that we go to validate our tools and correlate them has increased our confidence to have a go. So you will see a smearing out of development over a longer period of time rather than stop and go with a new car.'

To this end, McLaren appears to be using the MP4-29 as the clear basis for its 2015 Honda powered design. The engine installation in 2015 is going to be very different to what the team has developed with Mercedes. 'How Honda does things is different, so we are going through a massive repackaging exercise to accommodate the different requirements,' says Neale. 'The implication is that many aspects of the car – including how it works with the tyres – will carry over, and for that reason we will stay in development of this car right the way through until the end of the year. It's our underpinning aerodynamic knowledge going forward that we are developing. So it's really important for us this year to maximise the use of this season to maintain the correlation. But in terms of packaging for next year, there are some fundamental decisions to make with the Honda engineers at the moment about the airflows and where the radiators will be.'

Looking back over the 2014 season so far and the performance of the McLaren MP4-29, Neale is understandably rather pragmatic. It is clear that the car did not deliver the relative performance that the team really wanted, but that the problems have been identified and solutions developed. 'The MP4-29 is a good step forwards in our confidence in mechanical packaging, stability and correlation from last year, but it has revealed some underlying things about our organisation that we need to face up to. We are now making some lasting technical process culture changes and that can be quite painful, but we are going to get the job done,' Neale concludes.

Scalp taker

Force India has punched well above its weight in 2014 and could claim its best ever finishing position in Formula 1

By SAM COLLINS

Force India is often considered the perpetual midfield team, permanently anchored to the battle for 6th position in the constructors' championship. But the new-for-2014 rulebook has tipped things in the favour of the Indian-owned, British based team. At the third race of the 2014 season it scored its second ever podium finish and it has shown great reliability, with only one non finish due to mechanical failure. Every other finish has been in the points with one exception where the car failed to finish due to driver error. Only the dominant Mercedes team has a better finishing record in 2014. Indeed this is the best ever start to a season for the team under any of its previous guises, including that of Jordan. The car Force India is using to achieve these results is called the VJM07 which, as the name suggests, is the seventh design under the team's current ownership. The car uses the best in class Mercedes AMG HPP PU106 Hybrid 'Pegasus' power unit which is certainly a major factor in the team's strong form.

With the power train on the VJM07 all outsourced – engine from Mercedes HPP and transmission from McLaren – the Force India engineers are left with what amounts to a chassis development project with all that it entails: structures, packaging, vehicle dynamics and aerodynamics.

'When you put aside the power unit and simply look at the area of the car that we control then you realise it's mostly an aerodynamic project,' Force India technical director Andy Green explains.

Downforce issues

'What we were trying to achieve was trying to claw back some of the losses from losing the Coanda exhausts. The drop in performance from losing that exhaust system was significant, especially on the exit of the corner when the driver goes back on the throttle; it created a lot of rear downforce.'

The Coanda exhausts served largely the same purpose as "blown diffusers" of previous years, using the plume of exhaust gasses to seal off the outer edges of the diffuser and prevent vorteces from the base of the rotating tyre from entering the region. At the end of 2013 these designs were outlawed and all cars must have a single centrally mounted tailpipe. But with the arrival of the new hybrid power units in 2014 such a concept would be ideal.

'We knew with this car, and the new power units, that there would be very high torque levels, so you would want to throw even more downforce at the rear because that is where the performance lies. So we knew that having it taken away would be a big hit. So this car was simply about regaining some of that, getting more load on the rear and we have got some way towards it but it's nowhere near what we had. We are continuing in that direction, that's our aim, but it's just so hard,' Green continues.

This means that much of the development work being done by the Force India engineers is about making very small gains, iterative developments that on the face of it would not seem to have any significance. 'Even at Monaco, where the cars are travelling relatively slowly, a few hundred grams of additional aero load on

"We increased our target after the opening races to finish fourth in the constructors' championship" the rear is noticeable by the drivers this year. You look at the numbers and you think how on earth will they feel that? But they do. And every time we do a small experiment in that area they pick it up and make the performance. It's a very powerful area,' Green reveals.

As anyone who has set up a competition car will know, not all of a car's traction comes from aerodynamic loads at the rear, and in many classes mechanical grip is dominant, so it is no surprise that this area of the VJM07's design is of particular interest to Green and his engineers, even in a racing class which is dominated by aerodynamics.

Suspension balance

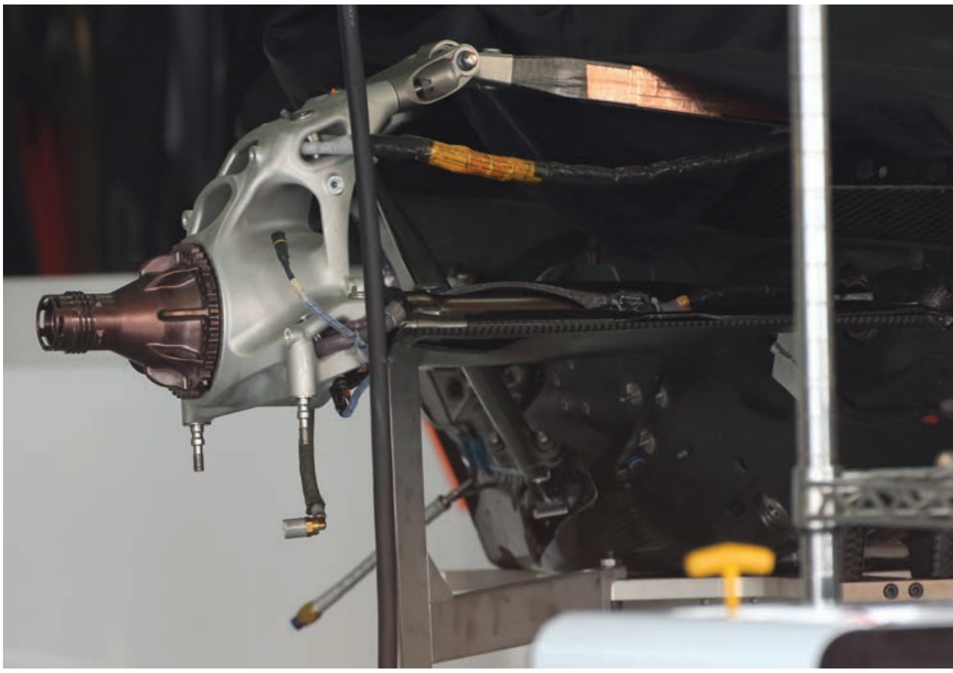
'The mechanical side of it is very important as well to maximise performance in that portion of the corner. It's a bit of a conflict, because you want to soften the car and give it loads of movement at the rear to deal with the kerbs but it inherently brings other things in other areas of the corner. You can't just go softer to get compliance for the corner because the car moves around too much and you don't have an aero platform capable of maintaining its load through that movement. So, it's a balance and we then have to look at suspension systems that change that characteristic as you go from slow speed to high speed,' Green explains.

This is not a unique problem in racing and is common to all aero dominated classes, but with high torque levels in Formula 1, it is more pronounced. However most, if not all teams on the grid, have taken measures to minimise it, including Force India. 'We had an interconnected suspension system at the end of last year and we used the data from that to develop a new system for this car,' Green admits. 'We tested it in Bahrain after the race and we have used it in a couple of races (Shanghai and Barcelona), but it still needed further refinement. We felt we could have raced it at Monaco, but we were not comfortable with the limits it was setting with respect to the tyres, so I didn't want that restriction on us. I wanted to set the car up freely. Doing that allowed us to explore a lot of different avenues. It was the right thing to do, if we had the updated system that we introduced at Canada then we would have raced it in Monaco but it was not ready.

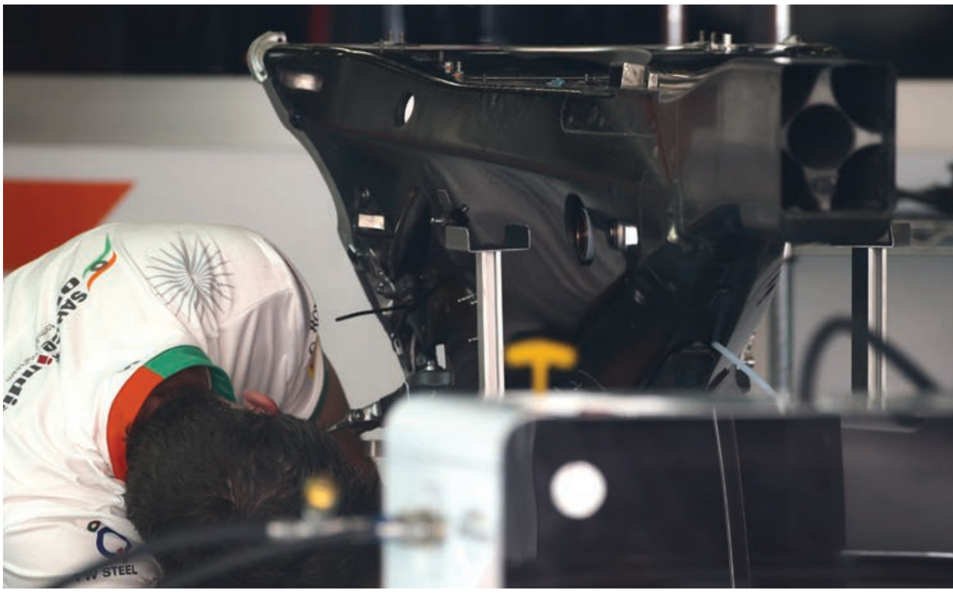
'It's a lot of work and expense, but it's an area where we know we are behind compared to the competition so there was more to come there. Then the FIA "banned" it.'

The interaction between aerodynamic performance and mechanical performance, especially at the rear of the car has forced the team to tackle some fairly challenging compromises. This is especially evident with the rear uprights which have a very intricate and almost organic design.

'They are single piece aluminium parts machined from solid, the design is integrated into the cooling system of the brakes, so a lot



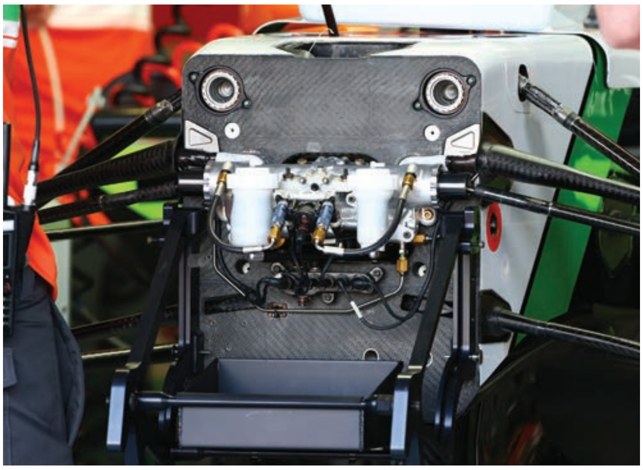
The intricate organic design of the rear suspension uprights has drawn a lot of interest



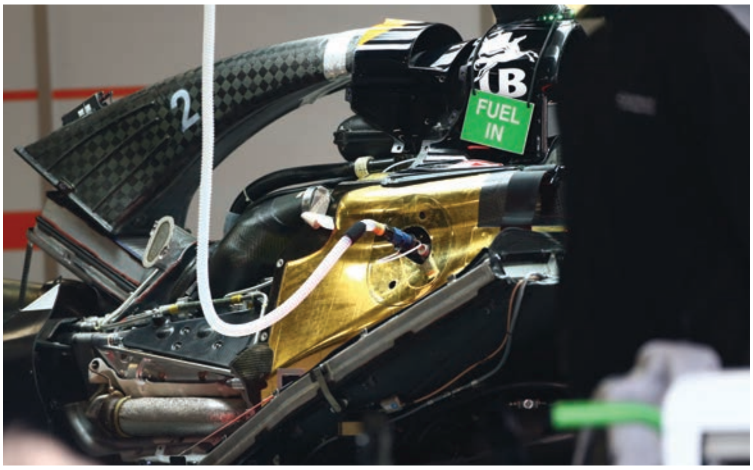
Development continues, but Force India technical director Andy Green had hoped for mid-season upgrades

The aero-assisting Coanda exhaust system is outlawed for 2014, with all cars on the grid now restricted to a single central tailpipe

The team cars look almost identical and meet weight regulations, but one chassis is built on a lighter carbon monocoque



The car displays high levels of mechanical grip, with or without the interconnected suspension setup



Mercedes PU106A power unit was an unknown quantity, but performance has been strong so far

of the intricacy of them is about trying to get the airflow right around the brake disc,' Green reveals. 'There is an aerodynamic aspect to them and of course there is the structural aspect as we want to keep the wheel and wishbones attached, which is significant as there is an aerodynamic desire to get rid of the suspension. If the aerodynamicists had their way they would just pull all the suspension members off of the car, as they just get in the way. So we have a system at the rear where the wishbone is so high that it is in line with the driveshaft, and that brings about problems with structure. Trying to keep the wheel placed where we want it on the road is very difficult as we do not have the space between the upper wishbone and the lower wishbone. The upright has nothing to hold on to, so we have to throw a lot of material at it which is why it looks quite meaty. It is purely to try and keep the tyre pointing where we want it to. So we have a compromise on aerodynamics and it adds a significant weight to the upright to do that.'

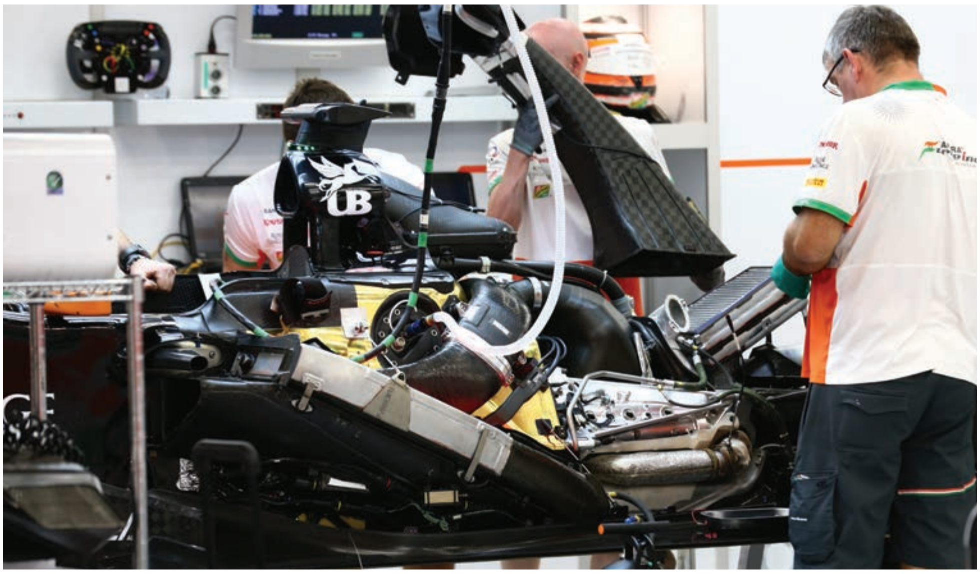
Mercedes power

The uprights themselves have drawn admiring glances from rival teams, partly due to the fact that the relatively small Force India team does not have the capability in-house to manufacture such parts.

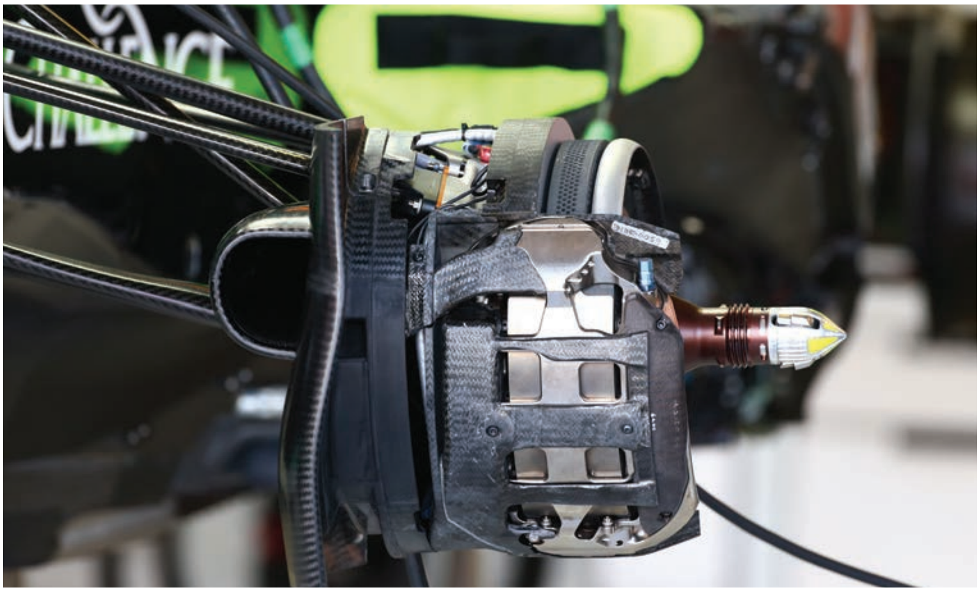
'It was a very iterative process to get to that design shape,' says Green. 'It's very complex machining and they are beautiful to look at. Obviously it's computer controlled and we try to do as little hand finishing as possible. We don't have the capacity to do that in house so it's farmed out. We don't consider them a sacrificial part; that part will last the whole season. They cost so much that we can't afford to replace them unless they are accident damaged.'

Another key area of trade offs for the Force India engineers to deal with was something of an exploration into the unknown, the installation of a highly advanced and unproven power unit, the Mercedes PU106A.

At the start of the season Green claimed that 'it's been a massive job to accommodate all the changes to the power unit – it's the biggest change I've witnessed in the sport since I started in 1990. Cooling has been the biggest challenge – most of last summer was taken up trying to understand the cooling requirements of the power unit, and how best to optimise it in the chassis. There's a lot more to cool and you are



The Mercedes powerplant has kept cool so far, but bodywork changes could result in higher engine temperatures



Front brakes use AP componentry

weighing up the performance of the power unit versus the performance of the chassis and aerodynamics, and trying to hit the optimum on each one of them. We have had to develop a completely new tool set to examine, analyse and optimise it.'

Getting hotter

But once the pre-season testing and the opening races were complete, Force India, as well as some other teams in the pit lane, realised that their cars were overcooled and the power units would be able to survive in an environment that was more hostile than first thought. However Green is not overly concerned by this.

'We had to be conservative at the beginning, so we were overcooled and still are. If we were not then we would not have had the capacity to backtrack if we made a mistake. It turns out that we were well below the limits which allowed us to do what we did pre-season and in the early races.

'Since then, the limits on the cooling have increased as Mercedes has given us even more margin, so we went through a process of revising the bodywork and cooling package which will then remove the headroom we have on cooling, and turn it into performance. We needed it as we were desperately short of downforce on the car. We had a very aggressive programme to get some more load on the car.'

Green feels that the VJM07 did not unlock its full potential and. 'We know we have a deficit to the rival teams because we can see what they have done, and we know where we are and where we could be from the wind tunnel model, it's just that we haven't got it on track yet,' he explained. 'But we know the others around us have a superior load level to us.'

Despite this, the car has qualified and finished well consistently through the year, despite Green's belief that the car has less downforce than the other three Mercedes powered designs (the works car, Williams and McLaren).

It seems that even though it was not running a state of the art interlinked suspension at the start of the year system, the VJM07 still has naturally good mechanical grip.

'The car is bringing results though, and it's pleasing for us to perform the way we did in Monaco. It shows that it's not just a horsepower car. We do not need the big long straights to get performance; we out qualified a McLaren and both Williams on a circuit known for being a downforce track, so we know the car is not bad. It's got reasonable mechanical grip, the aero can't be that bad and we know there is a lot more to come. We are quietly happy with it so far. We thought Monaco would be our weakest track. We have some good races to come. It shows we have a drivable car, we know they both have more downforce than us,' Green adds.

Although the team believe that the car has a deficit in downforce Green is wary of pushing too hard in that direction, and has learnt the lessons of the teams recent past. 'It's part of the remit we set at the start of this project, it's got to be drivable. 'A few years ago we had an issue where the team was just chasing downforce without any consideration of how the driver drives the car,' he says. 'There is a lot more performance to come there, when you talk to the drivers you know there is a long way to go.'

Lighter chassis

One challenge that was not widely discussed at the start of the season, but one faced by all teams, was meeting the weight limit. Initially Green and his engineers were not overly concerned but once the first chassis was built and tested it became clear that perhaps it was more of a headache than first thought.

'At the start of the year we knew we were marginal on weight so we did a lightweight programme,' says Green. 'Everything we did over the winter was performance versus weight.

'When we put the car on the scales Sergio Perez we did not have an issue with the car weight at all – there was enough ballast to move around so that was fine. We were OK we thought, but when Nico Hulkenburg got in the car we realised we needed a bit more, so we knew we had to develop a lightweight chassis for him.'

This was no minor undertaking for the Silverstone based team, which essentially had to go back through the entire car and rework almost everything, after the first test. It also means that the two Force Indias competing in 2014 are different designs.

"It would be criminal to let Nico drive an overweight car"

The Pinocchio effect

'I love these noses,' Andy Green jokes. 'We were constrained by a set of regulations that forced us to come up with unexpected consequences. The problem is the aerodynamic drive is always to lift the nose up. We do everything we can to lift it up and if there is a way, we can do it. The rules allowed us to lift 75 per cent of it up and leave 25 per cent of it down and unfortunately it's aesthetically not the nicest thing. We tried to mitigate it with the paint job but there is not much we can do. It's likely to change next season. I think it will be better next year.

'A few of the teams have put a soft start on the nose, almost sacrificial in some cases. We have seen teams knock it with a jack and it has fallen off. But that's not part of the impact structure, it's just there to meet the regulations, meaning that the impact structure is higher up which is what the FIA was trying to avoid. The structures are still lower than last year, but not at the height the FIA wanted.'

TECH SPEC

Chassis construction
Carbon fibre composite monocoque with Zylon side anti-intrusion panels

Front suspension
Aluminium alloy uprights with carbon fibre composite wishbones, trackrod and pushrod. Inboard-mounted torsion springs, dampers and anti-roll bar assembly

Rear suspension
Aluminium alloy uprights with carbon fibre composite wishbones, trackrod and pushrod. Inboard-mounted torsion springs, dampers and anti-roll bar assembly

Transmission
Mercedes AMG F1 8-speed semi-automatic with seamless shift

Dampers
Penske

Wheels
Motegi Racing forged wheels to team specification

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
AP Racing

Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
FIA SECU standard electronic control unit

Lubricants
Petronas

Engine
Mercedes-Benz PU106A Hybrid , Internal Combustion Engine: Capacity 1.6 litres, six cylinders, 90deg bank angle, 24 valves, Max rpm ICE 15,000 rpm, Max fuel flow rate 100 kg/hour (above 10,500 rpm)

Fuel injection
High-pressure direct injection (max 500 bar, one injector/cylinder), Pressure charging: single-stage compressor and exhaust turbine on a common shaft, Max rpm exhaust turbine 125,000 rpm

ERS
Mercedes AMG HPP

'We realised we had to do something as soon as chassis 1 was completed, chassis 3 is the lightweight car and we pulled a few kilos out of it. The two designs look identical and come out of the same mould, so you can't see any difference, but it's all in the laminate the number of plies and what materials we use. You can't see the difference unless you are on the scales. It required a new homologation, a new crash test, everything. It's a fully homologated car. It was a lot of work and for a team with limited resources it was a bit of a strain.

'It moved the weights around the car too. It was a big thing, but we knew how important it was. We could not let Nico have an overweight car as that would have been criminal,' Green states candidly.

Keeping it legal

Lightening the chassis of VJM07/03 meant that the weight distribution of the car was significantly altered, something that the Formula 1 technical regulations do not allow, so the Force India engineers had to change many other parts of the car to ensure that the lightweight car remained within the parameters set by the FIA. 'From the very early days of the car we are setting up a model of the car making sure the weight is in the legal window, with all the component weights, all the positions and all of the C/Gs. The model then tells us where the overall car C/G and W/D is, and we have a one per cent window to work in,' says Green.

'It's a 5kg mass moving from the front wheel centre line to the rear wheel centre line, so it's very small over 700kg and you have to be right on it. I anticipated some things getting heavier so we made sure our target was slightly forward of the legal limit knowing things at the rear would get heavier.'

Force India gave itself room around the front of the car to adjust the wheelbase, helping to shift the balance where necessary. 'When the car was built and went on the scales it was exactly where we wanted it be,' says Green. 'Both lightweight and heavyweight chassis are identical in that respect.'

With Force India now fourth in the constructors' championship (at the time of writing) the team could be on for its best season in Formula 1, at least with the current name over the door. But the team feels that the car is not all that it could be, only describing its performance as 'solid'.

'It's not the best car we have ever done by a long shot,' Green admits, 'it's got issues that we are trying to solve. In no way are we thinking we have done a great job and that this is a fantastic car. The exact opposite, to be honest. There is a fantastic amount of potential in it we've got to unlock. When we come out of the other end it will be very strong though.'

Despite the disappointment with the car's performance, race results have allowed the Silverstone organisation to reset its ambitions. 'We started as planned and hit our targets, though we would have liked to bring more upgrades.

'We increased our target after the opening races to finish fourth in the constructors' championship and we are going fight tooth and nail to hold on to that. It would be the best ever finish for Force India and we are going to give it everything we have got. It's going to be some good fighting,' Green concludes.

That fight will be a tough one, with former world champion teams Williams and McLaren both using the Mercedes power unit, but those are scalps that Andy Green and his engineers would be happy to take.

Formula 1 in crisis?

Alarm bells have been ringing since 2008, but no one has been listening

The financial troubles that have seen two Formula 1 teams fall into administration and forced to miss races perhaps should not come as a great surprise to those in the paddock. After all there have been many warnings about the financial health of the smaller teams, but little action has been taken to do anything about it.

'There is something terribly flawed in the system,' Sauber team boss Monisha Kaltenborn said of the sport's financial model. 'For me it starts with what the system and the sport is about. It is about different teams, not the big teams and the big budgets. This is a competition and the best win. But if the best are simply defined by the financial resources then something is not right because it not about finance, it is about sport.'

It is worth noting that Caterham, Marussia and the defunct HRT teams all signed up to Formula 1 on the understanding that a cost cap would be in force when they started. However, seemingly endless politics stopped that from happening. They had expected to be racing in a class where engineering and innovation would be the key performance differentiators, but they ended up in an unlimited spending war with only small change in their wallets.

Three musketeers

The three (four if you count the non-starting USF1) new teams were the leading entries of a group of 15 who all wanted to be on the grid, and the level of interest took many, including the FIA, by surprise. It led its then president Max Mosley to claim that 'this exercise has demonstrated that the only reason there have been vacancies on the F1 grid for many years was the excessive cost of participation.'

Even though the problem was recognised in 2008 when the new team entry process started, efforts to cut the costs have foundered, resource restriction agreements have proved ineffectual and every suggestion of a cost cap has got nowhere. At the US Grand Prix, only 18 cars were on the grid, prompting calls for big teams to run third cars or for those teams to make customer cars available for the smaller teams.

In my opinion these are only cures for the symptom of dwindling grid numbers, not cures for the disease (which these 'cures' would actually worsen). Three car teams and customer cars, could do irreparable damage to grand prix racing and the wider motosport industry. The problem, I think, is that F1 sometimes struggles to look outside the security fences of its paddock and has a tendency to follow overly complex routes. The technical and sporting regulations are far too restrictive and as Kaltenborn suggests, the contractual arrangements do not allow small teams to flourish.

Using customer cars would spoil the DNA of Formula 1 which has long been all about designing and developing a car, being a constructor. Formula 1 needs the small constructors. They not only bring on driving talent, but more importantly they develop the skills of young engineers.

The small budgets of teams such as Minardi or Marussia forced engineers to be efficient and innovative, and drivers to give good technical feedback because testing was at a premium. F1 needs to find a way to bring back such teams. One idea is to loosen the sporting and contractual requirements. Ways for new teams, engineers and drivers to get into F1 organically need to be found.

Single car teams should be permitted, while the cost of designing and developing a single car should be the same regardless of how many are built. The costs of staffing, shipping, running and maintaining a single car are much lower. Of course, the opportunity to sell the second seat is

Formula 1 has always been about designing and developing a car

Marussia and Caterham are both in administration, and the solution to F1's growing problem is not customer cars

also gone with a single car, but if the opportunity arises then the single car team should be given the opportunity to expand to two cars.

Two-car teams should not be required to run the same paint job on both cars. I actually struggle to understand why this rule is so strictly enforced in F1. After all, even if it was not in place you would still see two silver Mercedes and two red Ferraris. But further down the grid you would start to see split paint jobs. To my mind this can only be a good thing. There will be more variety on the grid, more colour, and at the same time more opportunity for teams to attract sponsors. Imagine the Lotus team with Maldonado's car painted in a patriotic yellow blue and red livery in deference to his main backers, while Grosjean's car could be heavily backed by Total and Renault.

This is not a new idea - it's universal in NASCAR and common in Indycar. In F1, BAR wanted to do it way back in 1999. Indeed it even launched its cars with two different paint jobs in order to promote two different tobacco brands but it was not allowed to race the cars like that, and ended up running the famous zipper livery.

Customer is not always right

There is a strong financial case for the introduction of customer cars, which is why they are still on the agenda. Customer cars featured in F1 in recent years with Super Aguri and Toro Rosso using other people's designs, despite it not really being allowed. The practice ended in 2010. But strong financial case or not, customer cars are bad for the sport. Formula 1 is about teams engineering and developing cars themselves, and that should be protected.

However a compromise could be found. At the end of the season teams could sell off their old chassis to smaller teams. This would save some costs, but when I say chassis I mean the bare monocoque. If a team were to buy a year old chassis then it could not acquire any data from the vendor, bodywork or any other parts.

The team would still have to develop its own front crash structure, rear crash structure, uprights, suspension geometry and control systems. They would have to do their own aero and power unit installation. This has happened before. The Super Aguri SA05 and SA06 designs were built around the Arrows A23 tub. It is an approach that saves time and money for small teams without removing the engineering aspect from the sport.

But the biggest thing that could make F1 sustainable for junior teams would be a cost cap, as Mosley suggested years ago. To ensure that the cost capped teams are not left behind resulting in a two-class F1, they should be given much more technical freedom.

The cars could have larger wings, a higher peak fuel flow rate, free weight distribution, adjustable gear ratios, active suspension, maybe fully active aerodynamics. Teams could not afford to develop it all so efficient engineering and innovation would be rewarded. The additional technical freedoms would ensure that the cars have strong pace.

F1 has to take a look at where it is, and where it is heading. It needs to decide where it wants to be, but introducing third cars, or pure customer cars, is not the right way forward. It needs to decide what to do soon however as history is repeating itself. Moves to introduce a cost cap have once again been blocked and the grid is being opened up for new teams to join.

Late-night solutions

After a shaky start to the F1 season Renault made the most of a regulatory mini-thaw – and never looked back

By SAM COLLINS

When Red Bull racing won the Belgian Grand Prix, many, not least those at Red Bull, were surprised. The team had not expected to be competitive and admittedly while the Belgian result was something of a fluke (the two Mercedes had rendered each other uncompetitive on the second lap) it was the team's third win of the year. At the start of the season there had been question marks over the ability of any of the Renault-powered cars to even finish a race let alone win one. But the turnaround in form is the result of a breathless development programme from the Renault Sport F1 engineers, still ongoing.

The Renault RS34 'Energy F1 2014' was the first 2014 Formula 1 power unit to be shown off in public, initially in the pages of this magazine in late-2012, then later at a high-profile launch in Paris in the summer of 2013. Everything seemed to be fine. The French manufacturer seemed to be ahead of the game while rumours of problems at Ferrari and unreliability at Mercedes were everywhere. But then came the inaugural pre-season test of 2014 held at the Jerez circuit in southern Spain.

It was not the first time that the RS34 had been run on track. That first test had come a little earlier at a sodden circuit in Italy, mounted to the back of a Toro Rosso, but it was the first time that the cars had been pushed, and it was the first run for Renault's top team, Red Bull. It was a disaster. The Renault powered cars barely completed any laps and those that did were far off the pace.

'The underlying causes were not straightforward,' said Rob White, deputy managing director, Renault Sport F1. 'There wasn't a single component or system that caused particular trouble. A number of related things were troublesome, principally concerning the control and operation of the various sub-systems of the power unit within the car. For example on the first run day, we had problems with a sub-system within the energy store that did not directly concern either the battery or the operation of the battery – it is an electronic part that was in the same housing as the energy store.

'We subsequently had problems with turbocharger and boost control systems with knock-on effects on the associated engine management systems, which went on to provoke mechanical failures.'

Those failures meant that the Renault Sport specialists had to rebuild the battery packs overnight in an attempt to get the cars to run properly the next day, but as White admits, other problems arose. 'Sometimes you make one thing right and three other things pop up that you did not expect, so you can end up chasing a problem.' At Jerez the chase went on through the nights in the Renault trucks and in the garages, while in Paris the chase continued on the dynos at the firm's HQ. 'In parallel to running in Jerez, the team at Viry ran dyno test programmes to investigate the trackside problems and to propose solutions. We identified the probable root cause of our main turbo control issues, implemented some workarounds that were first seen at the end of day three and deployed in the three cars for day four of the test. This established a very minimalist baseline from which we could build,' says White. But chasing the problem was a game that continued right through the pre-season testing period.

For the second pre-season test, held in Bahrain, Renault brought an updated version of the RS34 in an attempt to solve the issues seen in Spain.

White says; 'We made a number of specification changes to the energy store, involving modified hardware, requiring some gymnastics in engineering, procurement, assembly and logistics. We also introduced two levels of power unit control software updates, the first being effectively what would have been a decent starting point for Jerez.

'It eliminated some bugs that allowed us to make mapping and calibration corrections, which subsequently allowed us to operate the cars in a more robust way to gather mileage. The second layer of software changes had more functionality to allow a greater authority to the control systems, giving better performance and driveability, and a larger degree of power unit systems integration. All the cars started on the first route and all cars migrated to the second solution as we gathered mileage.'

The issues were, at least in part, seemingly blamed on an issue with the dyno at Renault Sport F1. 'We now know that the differences between dyno and car are bigger than we expected, with the consequence that our initial impressions were incomplete and imperfect,' White told the press after the first test. 'We are frustrated to face this litany of issues that we should have ironed out on the dyno.'

But White clarified those remarks later in the season: 'It was not a problem with the dyno – instead it was a case of the only way you can really test the environment of putting something in the back of a car on a track and running it on a track is by actually doing it. There are things that you just cannot simulate on a dyno.'

Renault Sport uses a number of dynos for its F1 programme, with identical test cells not only at its base in the outskirts of Paris, but also at its subcontractor Mecachrome. The French aviation specialist has a very long relationship with Renault and in 2014 is responsible for building all of the engines used in Renault-powered cars racing in Formula 1, while the technical support and operation of those engines is conducted directly by Renault Sport engineers, led by head of track operations, Remi Taffin.

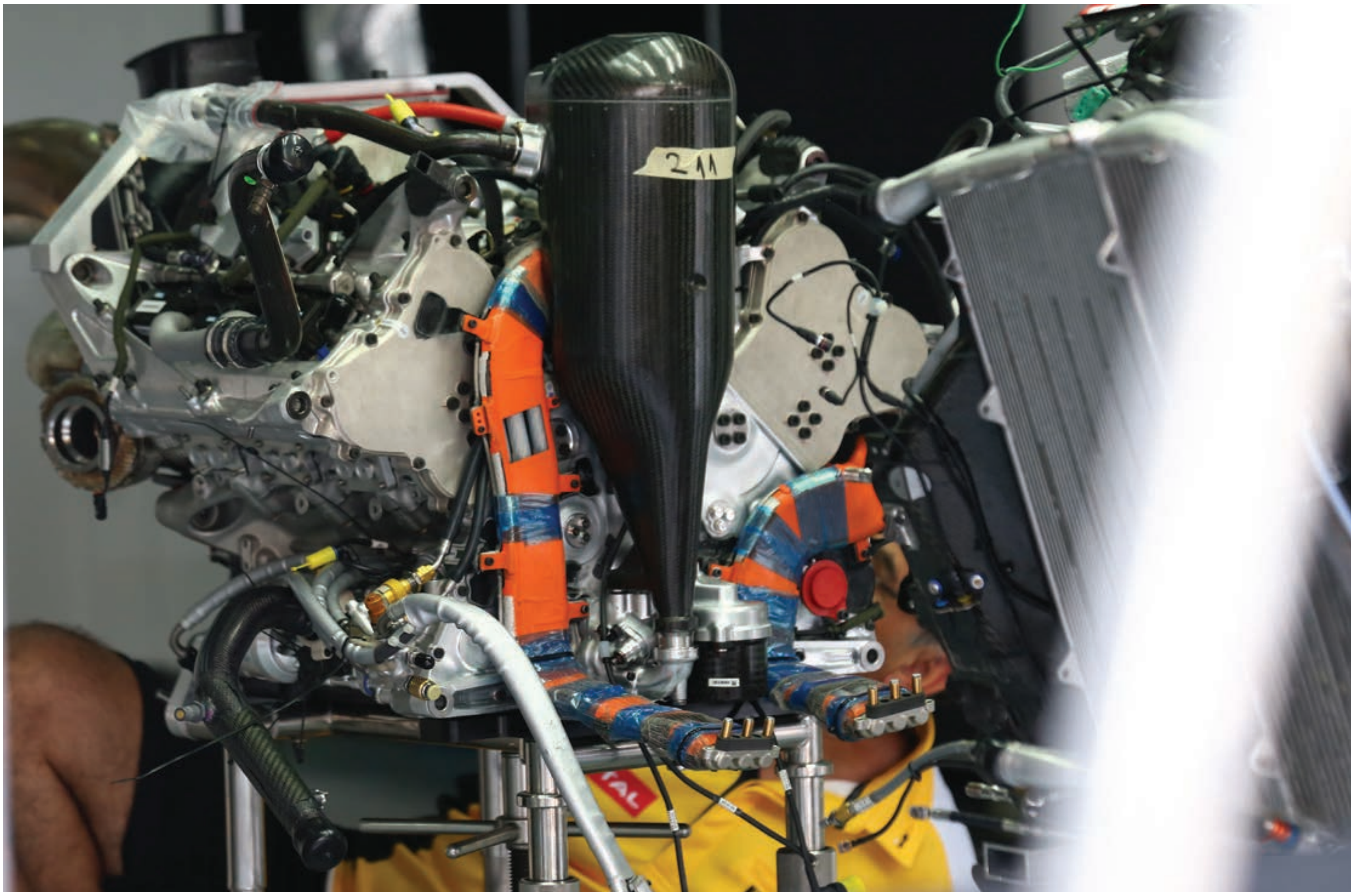
But the reliability problems continued right through both tests in Bahrain, and the deadline for freezing the specification of the whole power unit for the duration of the 2014 season came and went without Red Bull able to complete a race distance. That engine homologation, or 'freeze' as it is more commonly known, would originally have meant that the Renault power unit would have been more or less as it was as the teams left Bahrain for Melbourne and the opening race of the season, but a subtle change in the regulations threw Renault Sport a lifeline.

Appendix 4 of the 2014 F1 sporting regulations was amended to include the wording: 'A power unit delivered to the FIA after 28 February 2014, or modified and re-delivered to the FIA after that date, with which the FIA is satisfied, in its absolute discretion and after consultation with all other suppliers of power units for the Championship, could fairly and equitably be allowed to compete with other homologated power units.

'Such changes will normally only be accepted if they are being proposed for reliability, safety or cost-saving reasons.'

There was no disputing the lack of reliability of the Renault power unit. At the first race of the year only three of the eight Renault powered cars finished the race, but

A subtle change in the regulations before the first race of the season threw Renault Sport a lifeline



From bad to good – Renault's 2014 updated version of the RS34: 'People think that it is just a dumb old engine because we have these advanced machines attached to it, but there is nothing simple about developing an engine like this – it is a highly complex thing and there will be issues', was the opinion of Renault's Rob White

tantalisingly all three were in the points (until one was disqualified due to fuel flow meter irregularities).

In the early races of the season many problems were found with the hybrid elements of the power units. Failures of batteries and MGU's were common on some cars, but many of these issues were fixed without having to resort to using the 'reliability, safety or cost' route.

Software, lubricants and fuel are not 'frozen' like the rest of the power unit and it was the first major area of in-season development according to Taffin. 'At the test in Bahrain in April we tested several new software modes that moved us closer to the limits of the Power Unit than before,' he admits. 'In the opening three races we were some way from the edge of the performance envelope but the new modes allowed us to run more to the extreme. The power unit had improved driveability and greater life from each part. Likewise we worked on the energy management per lap, particularly in the slow corners. We knew we were missing out on the straights but the new software gave us greater traction in the turns.'

The second part of that update came in Monaco where more software changes were made to improve drivability and reliability. Total also introduced a new fuel at the race which again helped improve traction and responsiveness, according to Renault.

But as the electrical gremlins started to be worked out of the system, other issues had started to show their head, mostly based around the internal combustion engine, which surprised many to the mild annoyance of Rob White: 'People think that it is just a dumb old engine because we have these advanced machines attached to it, but there is nothing simple about developing an engine like this – it is a highly complex thing and there will be issues.'

Indeed ahead of the Canadian Grand Prix some hardware changes were introduced under the 'reliability, safety or cost rule.' The new specification parts were introduced as the teams cycled through their allocations of power unit parts, but Renault has been very cagey about exactly what was changed mechanically, despite the fact that for them to have made the changes in the first place both Ferrari and Mercedes would have had to approve. The reason for this caginess may be that Honda, coming in 2015 would not be entitled to see the paperwork.

Renault has been cagey about exactly what was changed mechanically, despite the fact that both Ferrari and Mercedes would have had to approve

The rumour mill in the paddock suggests that the RS34 received a new specification turbocharger, MGU-K and MGU-H shafts as well as a revised lubrication system, though this is not confirmed.

Regardless of what the changes were, they worked – and the performance of the Renault-powered cars, especially the Red Bull, bore this out – but there were still reliability issues, and the world champions started heaping pressure on to its power unit supplier. 'The reliability is unacceptable. The performance is unacceptable. There needs to be change at Renault,' Red Bull Team Boss Christian Horner complained following the Austrian Grand Prix where one of his cars had again broken down. 'It can't continue like this. It's not good for Renault and it's not good for Red Bull.' Renault's other customer teams were hurting, too, including Toro Rosso, Caterham and Lotus.

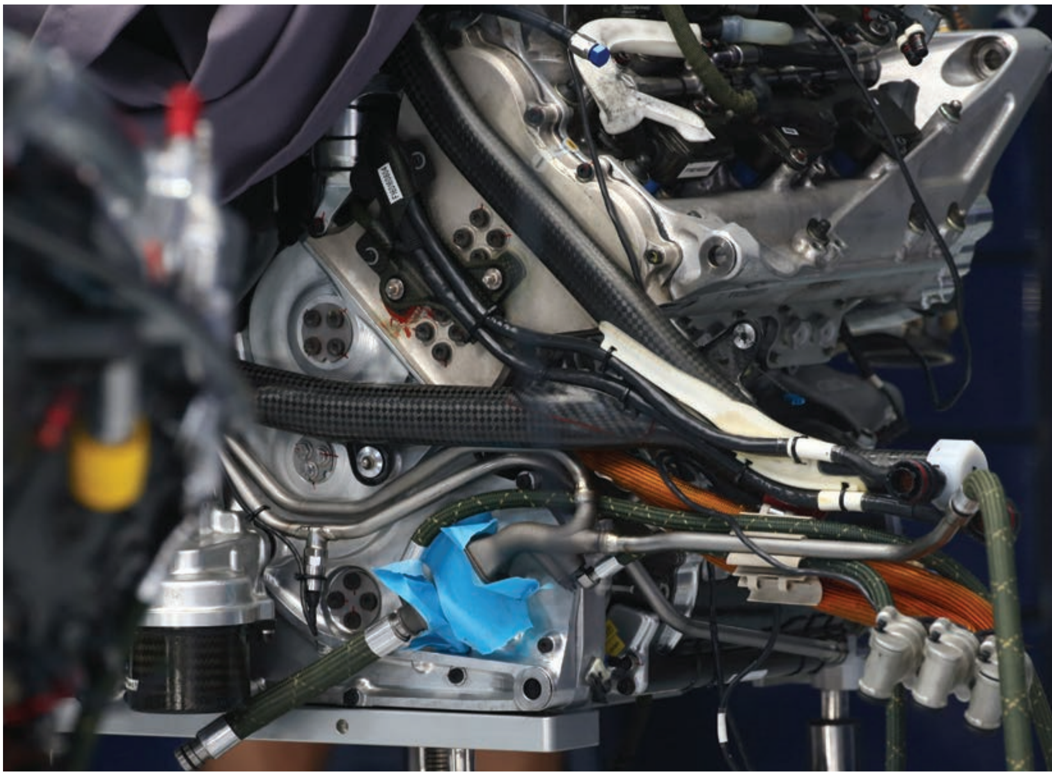
Eventually changes did come, and new management was put in place at Renault Sport F1. Focus was placed on the Red Bull team and although not likely as a direct result, the performance of the cars improved, leading to that win at Spa. 'A victory at an engine circuit where we were expected to struggle shows the never-give-up, never surrender mentality we

"A victory at the circuit we were expected to struggle on shows our never-give-up attitude and how the knocks make us work harder"

have at Renault Sport F1 and how the knocks just make us work harder and smarter,' Taffin enthused following the win. 'In the past few months we have been working even closer with Red Bull, and the race on Sunday was an example of optimising a chassis and engine package. This clear direction and streamlining is paying dividends.'

For much of the mid-season, Daniel Ricciardo was still in contention for the drivers' title, but much of Renault's work became focused on the 2015 power unit, which could have very little in common with the RS34. By regulation the only things that must be carried over are a few dimensions. Everything else can be updated within a set budget of changes (see RE V23N11). 'We are looking at all of the pieces that we are allowed to change and we are working through a process of what parts we want to change. That is not complete yet but it will be a change,' White says cryptically.

Perhaps the troubles of the 2014 season, turning the RS34 into a race-winning engine will have taught the Renault Sport engineers some crucial lessons that perhaps their rivals have yet to encounter. When the RS35-powered Red Bull RB11 is rolled out at Jerez next year it could again be a title contender.



'We are looking at all of the pieces that we are allowed to change and we are working through a process of what parts we want to change. That is not complete yet but it will be a change,' says White of Renault's engine plans going forward to the 2015 Formula 1 season

Backdrop to a world beater

At the end of 2013 the FIA Formula 1 World Championship bade farewell to its normally aspirated V8s and embraced brand new power units that combined a hybrid V6 turbo engine with two energy recovery systems – the MGU-K that works under braking, and MGU-H which harvests energy at the exhaust. Monza's 2014 race offered an ideal opportunity to compare and analyse the performance of modern low downforce-spec F1 cars with their previous counterparts.

The recent grand prix emphasised an important point; the 2014 regulations have greatly enhanced the cars' efficiency while maintaining – and even increasing – their level of performance.

1. A two-second gain in a year

The 2013 season saw F1 cars fitted with normally aspirated V8s delivering around 800bhp (that's 590kW without the extra 60kW provided by the KERS). Monza's speed traps recorded single-seaters clock around 340km/h, with pole-sitter Sebastian Vettel posting a lap of 1:23.755 in qualifying aboard his Infiniti Red Bull Racing-Renault. A year later the fastest Q3 time was 1:24.109, achieved with a car weighing 50kg heavier – a 1.8secs deficit – and using harder tyres. Once these differences have been accounted for and the times corrected, this year's lap represents a two-second gain over the course of 12 months.

2. Fuel consumption down to 1.9kg per lap

The 2014 regulations also brought another revolution, with a 35 per cent reduction in the amount of fuel permitted for each race (100kg against 150kg last year). It's been made possible thanks to the V6 engine's high degree of hybridisation: 20 per cent of the power is now electric and comes from the energy recovered under braking and harvested at the exhaust. The average Monza consumption rate went from 2.5kg per lap in 2013 to under 1.9kg a lap this year. With the same mass, the corrected 2014 time is faster.

3. An F1 car's energy source distribution

In 2013, the vast majority of energy available came from the 160kg of fuel used by the car. Power generated by fossil energy and transferred to the wheels reached 30 per cent, while the remainder escaped in the air. A single KERS unit also ensured the share of electric power remained quite limited. In 2014, with a 100kg restriction in fuel mass, the share of electric power has grown significantly. A greater percentage is now transferred to the wheels, which vastly improves overall energy efficiency. Electric energy is much more important (4MJ) than it was last year. It comes from two sources: braking and the exhaust.

4. Better energy efficiency

In 2013 an F1 car's efficiency was rated at 30 per cent, which has increased to 40 per cent in 2014. This has been made possible by reducing the internal combustion engine's displacement (and amount of friction), the introduction of a turbocompressor, and cutting the number of revs from 18,000 to 13,000. The efficiency of a car fitted with an internal combustion engine cannot exceed 50 per cent. Only a fully electric engine can achieve a much higher efficiency.

Additional stats and facts

- 30 per cent fuel mass reduction between 2013 and 2014.
- 0 points: the aerodynamic efficiency improvement of an F1 car between 2013 and 2014.
- In qualifying, the 25kg battery delivers an extra 10 per cent of energy, which amounts to 200g of fuel per lap.
- While overtaking during the race, Daniel Ricciardo's Infiniti Red Bull Racing-Renault reached 362.1kph, smashing the 2013 top speed by an impressive 20kph.

Information supplied by Renault Sport F1

Linear star-to-be?

Coming from a sound pedigree, Red Bull's RB10 car again represents evolution from a position of strength

By SAM COLLINS and KATE WALKER

"We did have problems with it setting itself on fire, but that was not because it was not cooling, that was because it was burning"

As the 2013 season drew to a close, they were unbeatable. The Red Bull RB9 was simply the best car on the grid and the team cruised to its fourth straight world championship. But 2014 was different. The dominant family line of evolutionary designs that started with the RB5 in 2009 was broken by a new rulebook. The RB10 would, on the face of it, be the first of a new breed of Red Bull, and the last car that Adrian Newey saw through its life.

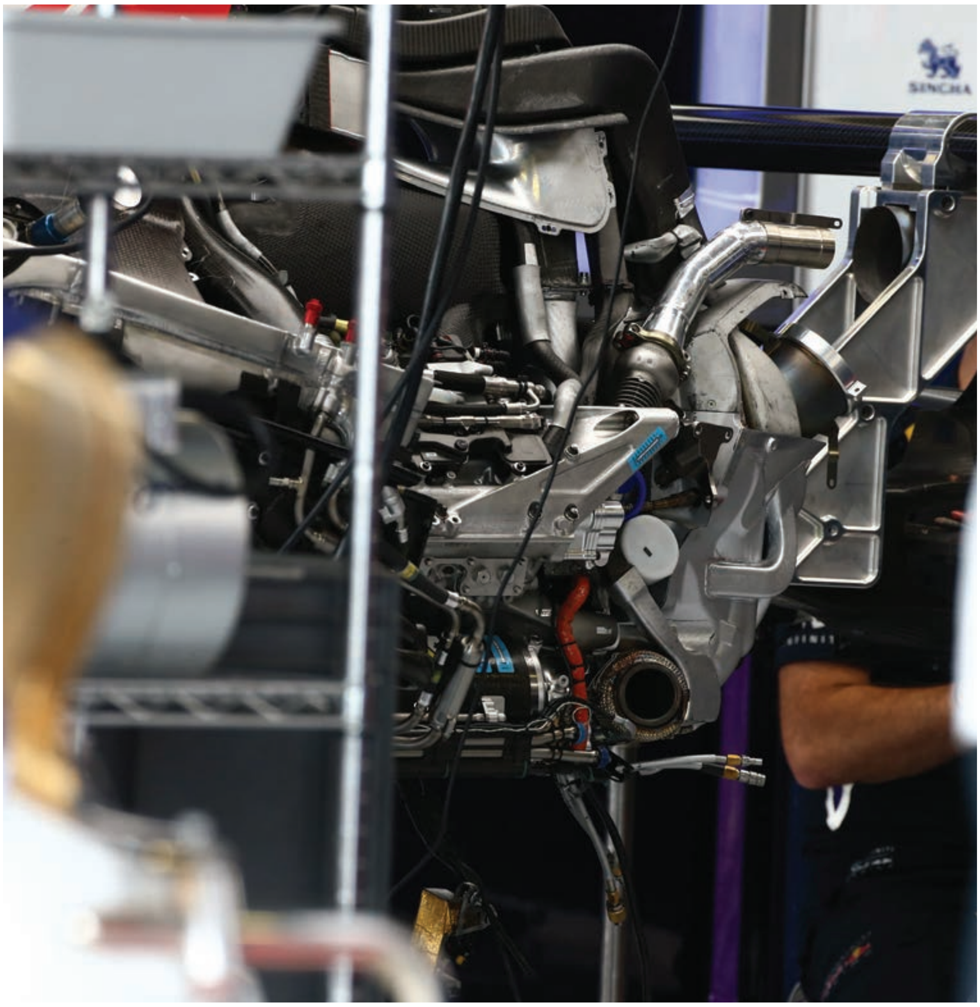
At first glance, however, there are some clear family traits that suggest that in reality the family line has continued, albeit with some new features, it is something that its chief designer, Rob Marshall confirms. 'The RB10 is to an extent an evolution of the RB9 but the cooling layout of the car is very different,' he admits. 'But, in other areas of the car, things are very generic, RB9 to RB10. Despite the big regulation change it is still an evolution in those areas.'

Red Bull has maintained its comfortable position in the standings. The reason for this, according to the team's rivals, is the car's aerodynamic performance, generally felt to give the highest downforce level and the best efficiency, something the team itself believes too, another example of family resemblance perhaps.

'It is difficult to say if we do things differently in terms of aero development,' says Marshall. 'Or if we have a way of iterating concepts faster as we do not know what our rivals do. In aerodynamic terms, basically the aim with RB10 was to recover as much of the loss imposed on us by regulation changes as possible.

'There were some features that were radically different, notably the introduction of a narrow front wing and losing exhaust blowing. They were the focus of much of the work, and I guess it went better for us than the others.'

But the aerodynamic advantages of the RB10 were not evident when the car first appeared in an incomplete state just ahead of the start of pre-season testing. When it did



A look at the left-hand side of the RB10's engine bay with the exhaust system and transmission removed reveals the location of the MGU-K (black cylinder at the engine block base) plus the sheer complexity of a 2014 power unit

take to the track its runs were slow and very short. Whenever it returned to the pits it was accompanied by the acrid smell of burning car, indeed sometimes it did not even manage to get out of the garage before smoke billowed from its rear end. It was clear that the RB10 had serious issues, and many of them were blamed on the Renault power unit, which certainly had its own issues, but not all of the RB10's problems were down to that.

'It was, you could argue, a result of aggressive packaging, but we felt that we needed to take a few risks to try to get a good package that would minimise the aerodynamic damage of this very large cooling requirement,' Adrian Newey explained after the testing issues were discovered. 'The Renault seems to have a particularly large cooling requirement. Everybody of the three engine manufacturers will have a different target for how hot their charge air is going back into the plenum and Renault have given us a fairly challenging target. It has all sorts of advantages if we can get there, but it is not easy to achieve.'

Cooling slots

These comments, allied to additional cooling slots being added to the bodywork of the RB10 in testing, suggested that the car was getting too hot but Marshall explains that this was not the case. 'That is something of a misconception about our car. We have never really had cooling problems. We did have some problems with it setting itself on fire, but that was not because it was not cooling, that was because it was

Vocal critic Newey set to bow out

While the Red Bull RB10 is billed as Adrian Newey's final grand prix car, in fact he will remain with the team until the end of the calendar year, and is therefore involved in the development of the new RB11, although he won't see that through to the start of the season. But he has been a vocal critic of the 2014 regulations, and is stepping back from his role at Red Bull Racing to work on other projects (thought to be the America's Cup) as a result. His thoughts on the current regulations are certainly thought-provoking.

'If you make the cars of an increasingly fixed aerodynamic specification then it becomes GP1 as far as the chassis is concerned. And we're already, in my opinion, in grave danger of getting close to that; that the regulations define a lot of the car. So, increasingly the cars will look more and more similar. I would actually be arguing for an opening of the aerodynamic regulations. As far as the cost is concerned then I think the Resource Restriction Agreement, in terms of restriction in wind tunnel testing and CFD, goes a long way to reducing the aerodynamic cost because aerodynamic cost is two things: it's the research – wind tunnel, CFD – which is hugely expensive, then the manufacture of the parts that comes out of that. This year I think we've seen a slowing of the number of parts that people are introducing because, as I say, the regulations are quite restrictive on the one hand, and on the other we are now heavily into a set of regulations that had their roots in the 2009 change.

So, everybody's becoming quite evolved in where they are. But certainly from what I hear and the people I've spoken to, including journalists, I think the public does have a lot of interest in the changes to the cars and what happens, and that level of interest is what differentiates it from other sports.

In F1 you have got this combination of different factors. You've got the driver, the chassis which is obviously not just aerodynamics but it's heavily aerodynamic-driven, and the powertrain. And it's that blend of features that makes it exciting and interesting. If you look at IndyCar, for instance, which went to one-make chassis some years ago, ever since it's been one-make its viewership has fallen and fallen.

Budgets

Obviously, as engineers, I guess we would ideally like the sort of CanAm-type regulation of maximum length and width or whatever it was and do what you like within that, But, realistically, that's not practical nowadays, so I think it's a very difficult one to strike that balance between something which allows the maximum amount of freedom while not having the budgets going completely out of control, where it becomes a complete spending war and without having a huge difference in the performance of the vehicles, because if we had too much freedom, the chances are that one team would strike it right each year and everybody would complain that the racing's a bit dull.

Unfortunately, that has happened a bit this year but that's another matter. I think as far as the power train is concerned, it is absolutely correct to emphasise that these power units are an incredible piece of technology and something of which we should be very proud of as an industry.

What's not clear is that as the freeze becomes more and more solid, if one power unit then has an advantage over another, or one is clearly behind, then how do you address that state of affairs? If you are in that position, you have no way of upgrading your power unit because you are frozen, and you are doomed to forever be behind, but I think that's something which hopefully can be discussed and should be resolvable, particularly because the engines do all now carry – or all cars carry - torque sensors. Those torque sensors do seem to be a little bit noisy but basically burning, and that was a different problem. In fact, the cooling has always been good on the car. Cooling has been a significant area of development over the years, but the years where you have to do a lot are the years where the car doesn't cool well. This year it does, so we have not done perhaps as much as others.'

The Red Bull cooling system does differ to that of the other Renault-engined cars. Indeed, each has a distinct and different solution. On the RB10, the PWR heat exchangers are narrow and fairly flat and run right along the flank of the car, with an intercooler at the base. It is a solution that has drawn admiring glances from rival teams.

Tight packaging

Much of pre-season trouble has since been put down to the Red Bull design trend of very tight packaging of its cars, especially around the rear, and Marshall accepts that the team pushed this area a bit too hard on the RB10.

'We took some big bold steps on how small we could make everything and it took us longer than it should have done to get to the point where we had stopped those things burning. It was a side effect of pushing the envelope and seeing how far we can take things. We pushed too far and didn't give ourselves enough time as we were fighting for the 2013 championship,' he admits candidly. 'The truth is if we had a month longer pre-season testing would have been a lot less trouble but as it was, the first time the car had run was the first test, and the first time a lot of systems on the car had run was also the first

Red Bull developed two transmissions for the 2014 season, one for the RB10 (top) and the other for the Caterham CT05 (above). The forward section of the first iteration of the former is believed to have had to be reworked due to its unfortunate tendency to catch fire, while the latter features a metal forward section which did not suffer from similar issues.

they are very reliable and give a good signal. So, it's entirely possible for the FIA to look at the outputs from those torque sensors and see where everybody is, not only across engine-matched factories, but also of course the variable of fuel. So, if a particular engine and petroleum company has the benefit over another, then it's able to do so and within that, it has the means, if it wishes to, to allow some equalisation for anybody that finds themselves behind in a frozen area.

My opinion of it is that, from a technical aspect first of all, you have to question the whole thing behind the new power units. When you get into things like batteries, then an electric car is only green if it gets its power from a green source. If it gets its power from a coal-fired power station then clearly it's not green at all.

In the case of a hybrid car, which is effectively what the F1 cars are, then a lot of energy goes into manufacturing those batteries and into the cars, which is why they're so expensive. And whether that then gives a negative or a positive carbon footprint depends on the duty cycle of the car – how many miles does it do? Is it cruising on the motorway at constant speed or stop-starting in a city?

So this concept that a hybrid car is automatically green is a gross simplification. On top of that there are other ways to make it fuel efficient. You can make it lighter, you can make it more aerodynamic, both of which are things that Formula 1 is good at.

For instance the cars are 10 per cent heavier this year, a result, directly, of the hybrid content. So I think technically, to be perfectly honest, it's slightly questionable.

From a sporting point of view, to me, efficiency, strategy and so on, economy of driving – this concept is very well placed for sportscars, which is a slightly different way of going racing. Formula 1 should be about excitement. It should be about man and machine performing at its maximum every single lap.

Compromises

Don't get me wrong, I'm not suggesting we should go back to gas-guzzlers, although actually the V8s were extraordinarily efficient. But it seems to me that what we have done is create a set of regulations which are technically interesting, but I still question whether they get all the compromises right.

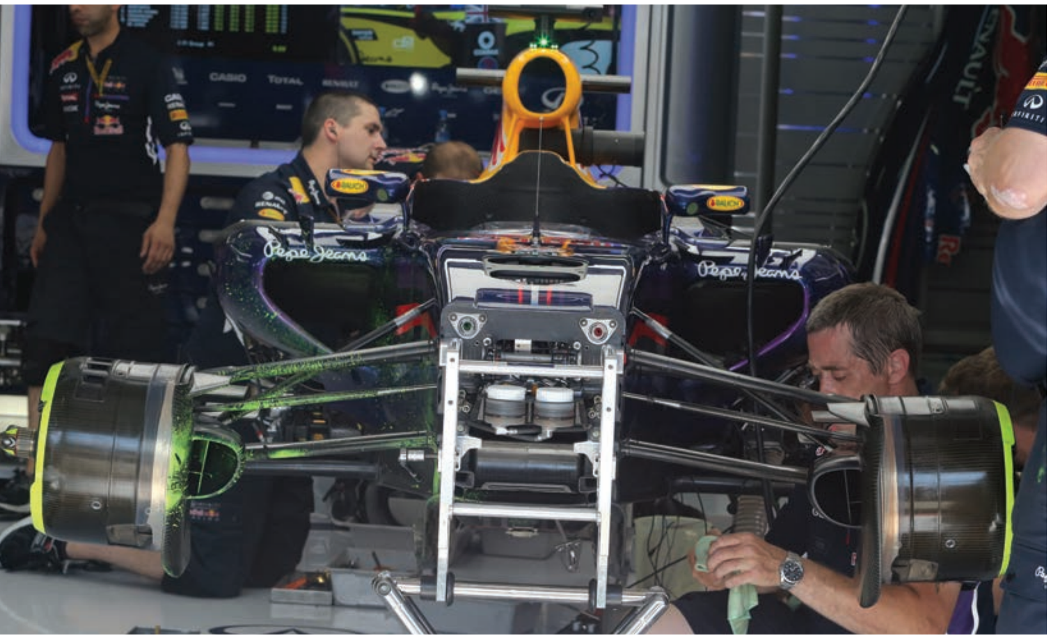
On the aero side, yes of course we have lost some downforce, but the aerodynamic efficiency of the cars hasn't dropped a lot. What has dropped is the load they can give at maximum downforce, maximum wing level and of course the cars are going a lot slower and that should be factored in when we talk about the whole fuel efficiency thing. OK, they're using 50 kilos less fuel but they're going a lot slower to achieve that.

Ultimately, then there is a relationship between cost, weight, aerodynamics…all sorts of factors if you're going to go into road relevance.

How you weigh that, how you proportion it is impossible to pin down for an open-wheeled single-seater. It's a very different beast. So, no easy answer there.

The cost of the power unit has at least doubled compared to last year, which is difficult for some of the smaller teams, so it's a very complicated balance, and that I think is the honest truth.

"Don't get me wrong, I am not suggesting we should go back to gas-guzzlers, although actually the V8s were extraordinarily efficient"



The RB10 retains the long-established Red Bull suspension layout of pull rod-actuated dampers and torsion bars at the rear and pushrod at the front. At the start of the season it featured a front-to-rear interconnection but this was dropped when the legality of such systems was questioned mid-season

TECH SPEC

Chassis construction
Composite monocoque structural designed and built in-house

Front suspension
Aluminium alloy uprights, carbon-composite double wishbone with springs and anti-roll bar

Rear suspension
Aluminium alloy uprights, carbon-composite double wishbone with springs and anti-roll bar

Transmission
Eight speed longitudinal gearbox mounted with hydraulic system for power shift and clutch operation

Dampers
Multimatic

Wheels
OZ Racing

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
Brembo calipers, frictional material; carbon/carbon composite discs and pads

Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
MESL Standard Electronic Control Unit

Engine
Renault Energy F1-2014, 1.6 litre 90 degree 6-cylinder. Max rpm 15,000, 24 valves. Cylinder block in aluminium

Fuel
Total

test. If we had been able to rig-test some of the systems ahead of that, we would probably have had fixes in place ahead of the first test.'

It has been suggested that had Red Bull used one of its allowed pre-season filming days to shake down the car then it would have been able to solve the problems earlier, but Marshall dismisses this. 'If we had a filming day before the first test we would have still set the car on fire and would not have fixed the issue before the first test or the second. We needed to fix long lead time items, but there was not time to do so. Every time we sent the car out we knew it would come back on fire.

'The alternative was not send it out, and not learn about the rest of the car. We accepted that there would be a lot of work to do between runs but still learn about the rest of the car.

'We knew what we needed to do to fix it. We had made something too weak and had to make it bigger. It was not one of those things that was a quick fix, it took multiple weeks, and the new spec did not arrive until the Australian Grand Prix, and we have used it ever since.'

Bell housing

This suggests that the issue related to the transmission casing, specifically the bell housing. The Renault RS34 has its turbocharger and wastegate located at the rear of the V6 engine, essentially in the bell housing. Red Bull uses a full composite structure in this area and its is clear to see that it essentially has holes in it to accommodate the turbo and associated pipework. As the casing is a fully stressed member holding all of the inboard suspension pick-ups it could be assumed that having large holes the bell housing would reduce rigidity but, according to Marshall, that is not the case. 'Dealing with the heat in the bell housing area on our transmission was a challenge, but stiffness wise it just means a bit more weight on it and we don't think the car is compromised by cutting a hole in the gearbox,' he adds.

Red Bull Technology, the organisation which is basically responsible for the design of the car also supplies the complete transmission to the Caterham CT05, and the internals to the Toro Rosso STR9. However, in the case of the Caterham the gearbox is notably different to that of the RB10, possibly explaining why the green cars did not burn quite as often as the RB10 during its early running.

'The case used by Caterham is half carbon, half metallic,' Marshall explains. 'The front half is the metallic bit, the regulations do not allow us to hand over suspension components to another team, so they have to design their own suspension to design their car. Many of the suspension pickups are on the bell housing, so doing a metal case for them meant that it helped them in terms of lead time. The rear of the gearbox is the same as ours, but the front bit, the bell housing which is not really gearbox but a spacer, is different. The lead times gives them a bit more freedom as a carbon case like ours takes much longer. We also have different exhaust systems so you could not fit the Caterham gearbox on our car.'

Having to add weight to get the troublesome component to be able to withstand the demands of 2014 Formula 1 would have been an added headache for the engineers at Milton Keynes, who like all of the others developing cars for this season struggled to get the design under 690kg and maintaing the mandatory 314kg/370kg weight distribution. 'Getting the car to a reasonable weight was very challenging; it was one of the things we were most concerned about as we designed the car,' Marshall continues. 'You don't have to get it very wrong to be a long way out. If you are one per cent out, it is big. Estimating the weight of components is very difficult, especially carbon work. If you are working with metal components, its reasonably easy to calculate the weight of them as long as you do not forget all the washers nuts and bolts. In carbon you can't do that so easily. That was our biggest target from a mechanical point of view, making sure the car was not overweight – we achieved that and we have got some freedom within the weight distribution window.'

It has been suggested that the weight limit in 2014 was too tough for the teams to meet, and not every team was able to do it. According to Newey, that not only puts a pressure on drivers to lose weight but also on the financial resources of the teams. 'We're certainly right on the edge of the weight limit with both drivers, and our drivers are on the lighter end,' he reveals. 'I think the power units have come out heavier than expected and that's putting a lot of pressure on the teams. It's another hidden factor that drives the cost up because saving weight tends to be a very expensive business.'

The Red Bull RB10 finished second in Australia, the first time the car had been able to complete a race distance. However, its reliability issues during the season cost many points. But if the problems that troubled Red Bull and Renault in 2014 can be resolved, then the RB11 should be a title contender.

Stuck in the middle?

Red Bull's bashful sister team has managed to take a little of the limelight in 2014, but reliability issues are still holding it back

By SAM COLLINS

It had all started so well for the Austrian owned Italian team, Scuderia Toro Rosso. It had managed to get its car, the Renault-powered STR9, built before all of its rivals and was one of the first to run a 2014 car on track, when its new driver took the car to a soaking wet circuit not far from the factory, and ran trouble free.

But by having one of the first new cars to appear Toro Rosso, Red Bull's second F1 team was also in line to take the brunt of the unintended consequences of the new-for-2014 rules. During the launch, held at the Jerez circuit pictures of the front impact structure on the car went viral and even prompted a chain of English sex shops to suggest on twitter that the design was inspired by one of its most popular 'toys'.

Despite being ridiculed from the moment the car left the garage at Jerez, the team knew that the joke was on the rule makers who had forced the teams to adopt the strange looking noses prevalent on the 2014 Formula 1 grid. With the coverage the noses received it could not get much worse. Toro Rosso felt that it was fully prepared for the first test.

'We felt that the pre-season testing was really important,' Toro Rosso technical director James Key admits, 'not just for our younger driver but also for our established driver, because the cars are fundamentally different and the driver workload with the new systems has increased. They had to get used to it. So at the start of the year we focused on being ready, we were the first Renault powered team to fire up the car, and the first one to run. I also think we were the second team to run a car at the first test.'

"We are not where we should be in terms of reliability. We had eight non-finishes out of the first 18 car starts. That is not good enough"

The Toro Rosso STR9 is pretty conventional in 2014 F1 terms, with the exception of the extra central airduct behind the driver's head routed to twin oil coolers

Everything looked good, even after the first shakedown run but there were serious problems brewing. Renault had made something of a miscalculation with its power unit, something that was not seen on the dyno or during Toro Rosso's shakedown run. 'The winter testing situation has been well documented now, and it's no secret that we had a lot of issues,' admits Key. 'For us it started off well, but we were not running in a fully optimised condition at the start and as we started to introduce new elements on the power unit in that first test, the issues started to appear. Unfortunately, there were some relatively complex ones for us to deal with.'

Those issues surrounded the Renault RS34 power unit, and ultimately ruined the first test for not only Toro Rosso, but also sister team Red Bull, with both teams struggling to complete many laps at all at full power. Many of the issues went on to be resolved but development that would normally have been conducted in pre season testing went on into the season, indeed even during the summer months there were reliability related upgrades being introduced with the RS34.

'Obviously winter testing was not what we wanted, and the first time we managed to get a car to run for a race distance was the Australian Grand Prix. It was the first durability test for everything,' Key continues. 'Just being able to do that was the result of a massive amount of work for us. There were three strands where you would normally have one, namely car developments for Melbourne. While we did that as normal and brought a major aerodynamic update for the first race, with a few mechanical bits, we additionally had a lot of chassis-based work to do as a result of

"We went through 17 different cooling schemes before we came up with the one we put on the car. Since then we have changed it twice"

some things we discovered in winter testing and some others we knew before the car ran. Finally, we were fighting all of the reliability issues with the power unit and its installation. It tripled the workload.' Despite this, Toro Rosso made it to the first race, and came home in the points.

During the preseason tests and the opening races, much of the design of the Toro Rosso STR9 was revealed, and in general it is clearly a fairly conventional 2014 specification grand prix car. It has wishbone suspension all round with pushrod actuated dampers, allied to torsion bars at the front and a pullrod arrangement at the rear. But one detail stood out, a large duct underneath the conventional roll hoop inlet for the charge air – something seen in a smaller form on the 2012 Toro Rosso STR7.

It was a clue that the Toro Rosso cooling system was rather different to that of the other Renault-powered designs. 'It was very difficult to second guess what to do with cooling, we had no reference point at all,' says Key.

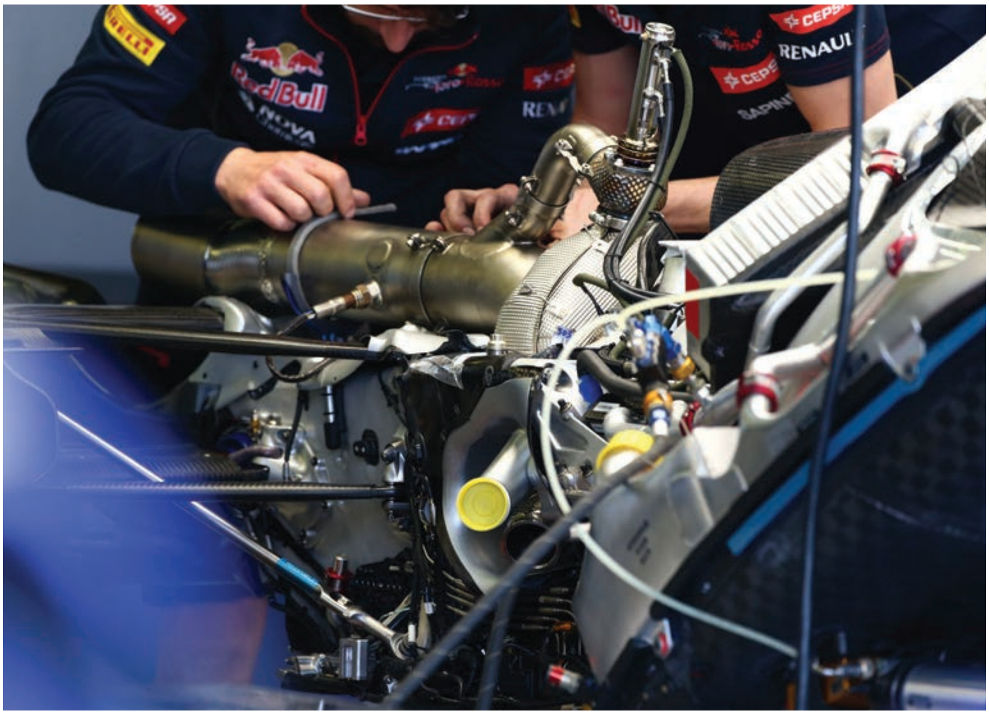
'We looked at a lot of things, but it was hard to tell how much effort competitors were putting into new technologies for cooling, particularly charge air cooling. If you looked at using a more traditional solution you would immediately start worrying that you may be two years behind everyone. In the end, we built it around where we thought that the heat rejection numbers would end up based on what Renault told us.'

The unique layout saw the extra duct behind the driver's head feeding twin oil coolers, one mounted above each side pod under the engine cover, while in the side pods themselves are the water coolers and twin intercoolers under them.

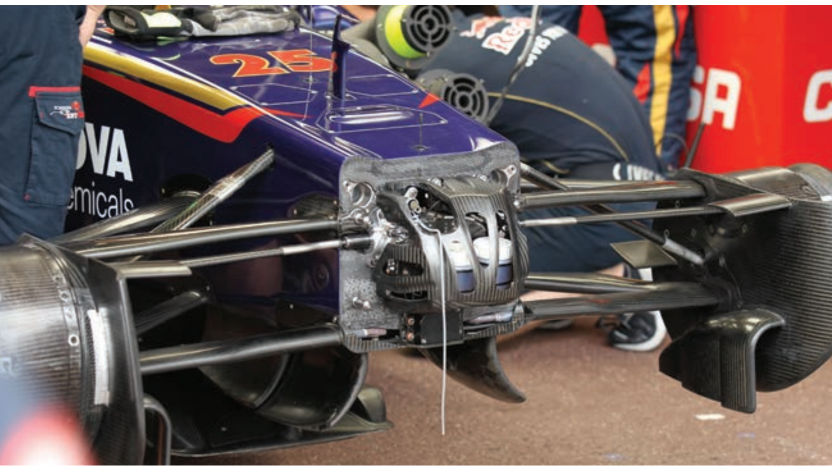
'The central duct is something we discussed for a long while. Originally the car did not have it, but we recognised that if we were to have everything covered we would have to do it. Once everything in the design was together we realised that there were compromises in what we had and putting the coolers fed by the central duct where we have is our solution,' Key explains. 'Looking at the others, you see how they have dealt with the same compromises. Red Bull has ended up with very long narrow coolers which is a very clever idea. Looking at the packaging, it's incredible, and would have meant an enormous amount of work. It wouldn't be easy for us to do, especially as they have gone for a completely different technology in terms of charge cooling. That has a knock-on effect on everything else. As soon as you move something fundamental, like a cooler or the big electronic boxes, every else is impacted.

'We went through 17 different cooling schemes before we came up with the one we put on the car. Since then we have changed it twice, so that's at least 19 layouts. The package we introduced at Monaco is based on the original geometry but is completely different in the way it works. Cooling has become a big development item that it never was before.'

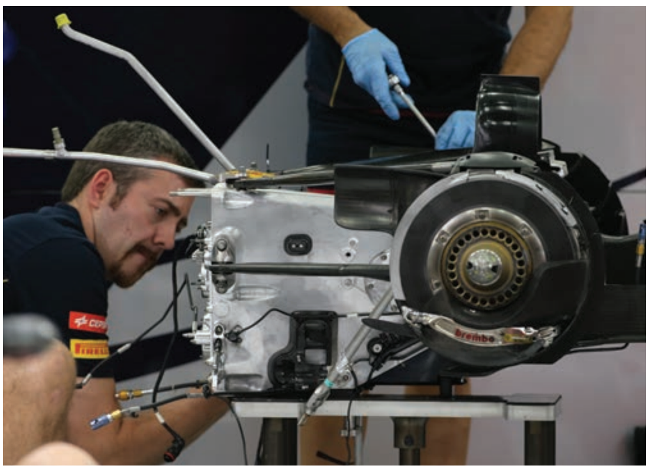
While it has been speculated that the STR9 layout raises the centre of gravity of the car Key denies this and states that the main water coolers are no higher than those of the Red Bull, they are just a bit wider. 'Our coolers are mounted quite high up in the car



Tight packaging of the rectangular oil cooler with the integrated radiator and intercooler is evident from this view. Turbo, exhaust and wastegate assembly is close behind



Bulkhead arrangement of the STR9 features a fairly conventional pushrod front suspension. Turning vanes and brake shroud assemblies are also visible in this shot



Toro Rosso gearbox shares internals with other Renault F1 cars, but features a unique aluminium casing. Other teams have opted for all carbon designs

at first glance, but it does not have an impact on centre of gravity, it's an optical illusion – the top of the radiators is still at the same location as you would expect. But overall, the cooler layout we have got has some good little efficiencies about it. We may apply a similar philosophy next year as well.'

The fact that Red Bull and Toro Rosso have adopted such different cooling layouts on their cars is a hint at one of the major differences between the approaches of power unit suppliers. Notably, the Lotus cooling layout (See RE V24N9) and the Caterham layout (RE V24 N6) are also drastically different.

According to Key, this also could be the root of some of the problems experienced by the Renault runners at Jerez. 'I don't think some of the issues that Renault had were down to engineering errors, I think to an extent it is down to the business model. If you look at the other two power unit suppliers they both have factory teams, so the ability for them to have very close working between power unit development and chassis development is very strong. That's their business model, and you see the effect on some chassis related items, the Mercedes 'log' exhaust is a classic example of that,' Key says.

'Renault is not in that position. It is a power unit expert, so we (the Renault teams) have a very different way of working to the others. We have been very open with Renault. It is something I don't think you would get with another supplier as they would be focused on what's best for the factory team, and sell that to everyone else. With Renault we get a bit of freedom and that's why the four Renault cars are so diverse. We are more able to play with things.'

One area where there is some more fundamental similarity between the Renault-powered cars is the transmission. Caterham, Red Bull and Toro Rosso all use identical gearbox internals (although Lotus has taken a different approach). However, it is immediately apparent that the Toro Rosso has a substantially different casing around those internals; it's made of aluminium, whereas Red Bull and Caterham have carbon fibre cases.

Transmission casing

'It made a huge amount of sense to work closely with Red Bull Racing on the transmission, they had already done a fair amount of work with Renault on the type of gearbox that you would need to cope with the demands of the power units and the new regulations,' says Key. 'They had been in the loop with Renault for a lot longer than we had so it made no sense to do a separate thing.' But this did not mean the end of Toro Rosso (and Minardi's) long history of manufacturing gearboxes.

'We share the internals, but we couldn't share the same gearbox case because Red Bull was working to a different timetable to us. They would define their gearbox case at the last possible minute, so they get something

Stopping power

Braking systems have been a key area of performance for all teams in the 2014 F1 season, and Toro Rosso is no different. According to James Key, Toro Rosso's technical director, the team hopes for further improvements in this area.

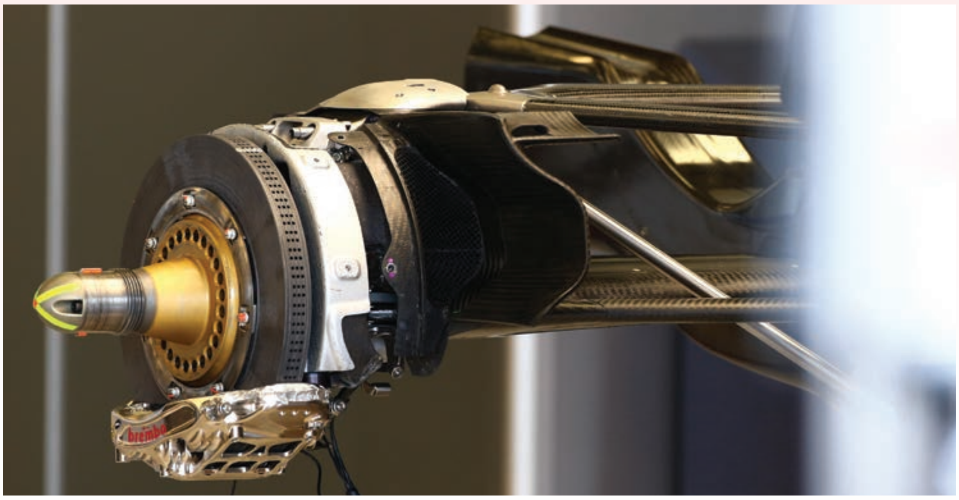
'There is still scope for optimisation in the brakes, it's a completely different scenario to what we are used to because the control system does everything on the rear axle now. In theory that means that what the driver demands he should get, but in practice you don't see that. Its been one of our issues on the STR9, we have noticed that our braking system is a little bit too weak compared to others.

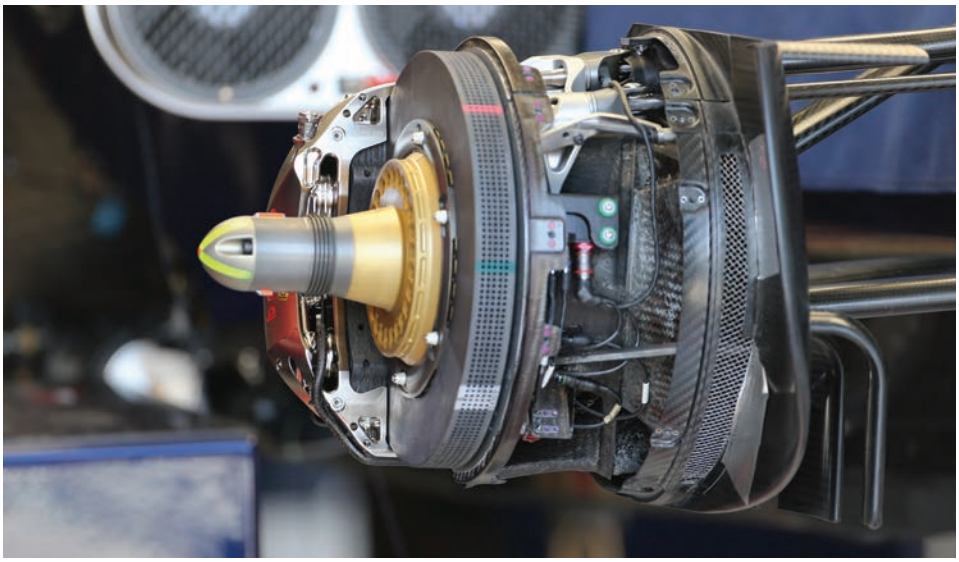
'Going forward, I think there is also scope to start looking at materials again, going for a much lighter rear brake and a standard front. With that in mind, there are so many knock-ons to consider. The brakes pump heat into the tyres, but if you suddenly lose a load of that heat from the disc you can end up in the bizarre situation of rear tyre warm up problems. In winter testing sometimes we actually saw that,' he says.

'The problem is that, in theory, you should be getting particular braking torque at the wheel, but there is no way of actually knowing that without looking at the contact patch. Even when you look at all the related systems it is still highly complex. Its very difficult to monitor what is actually happening at the wheel and it is not that obvious, it can be very transient. You can measure at one point and it may not be accurate as things change with lots of little factors like compliances and things like that. You can only estimate the torque, you don't know for sure.

'Anti-effects are also a factor. If you have lots of different hydraulic pressures going on through a braking phase as a result of the MGU-K interaction, it can also change your anti-effects a bit too.

'It's pages and ages of maths, but eventually you want to get to the point where the driver has no idea if its the MGU or the hydraulic brakes doing the work. As a team, we are getting pretty close to that. We were were nowhere near that at the start of the year. The drivers feel the tiniest little subtlety and it can make them feel uncomfortable as they try to modulate the brakes, and if they do feel that, they can back off disproportionately. They just want a consistent feel.'





Top: Brembo componentry features in the STR9's brake by wire system. Three-row ventilation drilling visible on rears
Bottom: Front brakes show five-row drilling and electrical connections

That nose

Toro Rosso's original 'Ann Summers' nose has been adjusted significantly since the car first appeared requiring a new frontal crash test for the car. 'It is a bit of a performance area, its hard to say how many iterations of nose we will go through but perhaps three or four,' explains James Key. 'It's become an area because the aero has been developed for ages around high noses, so all of that knowledge has been carried over. If you try to recreate a high nose aerodynamically with a low nose, you end up with the shapes we have now.'

TECH SPEC

Chassis construction
Carbon monocoque structure

Front suspension
Upper and lower carbon wishbones, pushrod, torsion bar springs, central damper and anti-roll bars

Rear suspension
Upper and lower carbon wishbones, pullrod, torsion bar springs, central damper and anti-roll bars

Transmission
Scuderia Toro Rosso aluminium alloy 8-speed sequential hydraulically actuated, supplied by Red Bull Technology

Clutch
AP Racing, pull-type

Dampers
Penske/Multimatic

Wheels
Apptech, Magnesium alloy

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
Brembo pads and discs, brake by wire

Steering
Scuderia Toro Rosso

Fuel system
ATL Kevlar-reinforced rubber bladder with Scuderia Toro Rosso internals

Electronic systems
FIA SECU standard electronic control unit

Cooling system
Scuderia Toro Rosso for radiators, heat exchangers, intercoolers

Cockpit
Seatbelts: OMP/Sabelt

Engine
Renault Energy F1-2014, 1.6-litre 90 degree 6-cylinder. Max rpm 15000, 24 valves. Cylinder block in aluminium

Barbecued beef: The Toro Rosso team endure yet another technical failure, as Daniil Kvyat's STR9 catches fire and is retired from the German Grand Prix at Hockenheim in July, after qualifying ahead of both Force Indias

that is fully optimised. We wanted to define our box quite late as well, and it's too tricky for both teams to define at the same late point with perhaps some different requirements,' Key continues. 'So we just went for the important bit in terms of reliability which is the internals, and it's worked out really well. Doing our own casing means that we have complete freedom over our rear suspension and wheelbase.'

The tradition looks set to continue for the same reason but Toro Rosso may eventually move away from metal transmission cases according to Key. 'I think it takes a while to satisfactorily develop a composite case these days, probably a couple of years,' he says. There are definite advantages to doing it both structurally and weight-wise, but aluminium is a really well known technology and that's where we are at the moment. For 2014, we need something that worked but we are looking at other options for later seasons. I think there are different ways of using the materials to explore, and we are keeping an eye on a lot of things.'

Key, and the rest of the Toro Rosso management, are keen to move the team forwards, and recent improvements to the team's facility in Faenza in Italy show that. Indeed, the investment in design capability has opened up some new avenues for the organisation.

'Optimising the car has taken a new direction, we have a new CFD cluster and it has spare capacity because of the limits placed on us by the regulations, so we are now using that for some other vehicle dynamics work, and the cluster is developing into more of a super computer rather than a pure CFD tool. Actually because we have gone so far with the hardware for CFD the software needs to catch up,' Key says.

Toro Rosso did enough to secure seventh place in the constructors' championship going into the mid-season break, and stayed there for the rest of the season. While the team had hoped for better performance reliability, team errors have prevented a higher score. 'We are in a tricky situation. Williams and Force India are strong this year and they are typically our competition, but they are benefiting from the great job Mercedes has done with its power unit. We are compensating for that. Perhaps we are a bit behind but the playing field is not quite level.'

Franz Tost, the team principal, adds to that sentiment. 'We are not where we should be in terms of reliability as we had eight non-finishes out of the first 18 car starts, or nine races. That is not good enough. In addition, the team has not been perfect, making mistakes that led to faults like suspension failure. The solution is straightforward, we simply need to be more disciplined in order to avoid making further mistakes,' he admits.

E-numbers

The Lotus E22 had a lot of original design features, but cooling the Renault power unit was a particular challenge for 2014

By SAM COLLINS

"I'm not sure what Red Bull are doing, but I think they know what we are doing"

The Lotus E22 shows off its unusual, but effective, asymmetrical twin-tusk nose design. It complies with FIA regs for 2014, but won't for next season

The winter of 2013 and 2014 was a tough time for the Lotus F1 Team. It had lost its star driver before the season had ended due to late payments, and the new car was falling behind schedule. The team boss Eric Boullier had left to join McLaren and Technical Director James Allison had returned to Ferrari. There were even rumours in the press that the team would not make it to the 2014 season, but it did. And although it was the last team to actually reveal its 2014 F1 car design, it was clear that the new Lotus E22 was not there just to make up the numbers.

The team's name, Lotus, is the hangover of a sponsorship deal that has largely come to an end, and is rooted in the legal dispute that saw two teams named Lotus on the grid at one point. Today, the team owns the rights to the Team Lotus name, after an expensive settlement with Tony Fernandes but has, to date, chosen not to use it. The name of the car though reveals the team's real roots, E22, the twenty-second grand prix car built in Enstone. This is the team that started life as Toleman, became Benetton, then Renault and eventually Lotus. But, despite having no historic link to Colin Chapman's marque, its own innovative reputation has clearly had an impact.

Twin nose arrangement

When the E22 was first shown off it was clearly an intriguing and highly distinctive design all round, but the thing that really stood out was its twin nose arrangement. In 2014 a new rule governing the height and side of the front impact structures on F1 cars was introduced and Lotus took advantage of a loophole in the rules, which has been closed for 2015.

The rules regarding the nose size state that an impact-absorbing structure must be fitted in front of the survival cell. This structure need not be an integral part of the survival cell but must be solidly attached to it. It must have a single external cross section, in horizontal projection, of more than 9000mm^2 at a point 50mm behind its forward-most point.

But what it does not say is that a 'single' impact absorbing structure must be fitted in front of the survival cell. In other words multiple structures could be used, it is an approach first seen on the Audi R15+ LMP1 car, but to ensure that the design stayed legal, the two 'tusks' at the front of the E22 are slightly different sizes.

'We looked at a lot of different solutions when the regulations came out for noses,' reveals Nick Chester, the new technical director at the Lotus F1 team. 'We looked at traditional low noses like those used by Mercedes, ones with a central prong like Toro Rosso, and we looked at the twin tusk and found that it was a reasonable degree better.

'So we did a lot of work at that point on getting it through the crash test. It's not an easy thing to test but we got it to work. One of the tusks is shorter, as the rules state that there must be a single section 50mm back from the tip, but in the frontal crash tests both tusks are absorbing a good chunk of energy. We could not pass the test with one or other of the two tusks alone.'

A bold new look

A significant project to improve aesthetics of Formula 1 took its first major step when Lotus ran in the post British Grand Prix test at Silverstone using 18in wheels fitted with special low profile Pirelli tyres. The Italian tyre maker has stressed that the test is not about the performance of the tyres at this stage, rather the way they look.

'These are just a prototype concept, but if the teams decided that they wanted us to proceed in this direction, we have the capability to carry on development in this area and come up with a production-ready version in a comparatively short space of time,' Pirelli's motorsport director Paul Hembery explained at the test. 'We've heard a lot of opinions already and we look forward to canvassing more views in the coming weeks and months. Even though performance wasn't by any means priority here, the new tyres still behaved exactly in line with expectations, so we're potentially at the beginning of a huge development curve, with the wheel and tyre rules having remained unaltered for many years.'

The test is the first step in a project to improve the look of Formula 1 cars which for the last two seasons have been widely criticised for being very ugly. As a result a project has been instigated which could fundamentally change the look of F1 cars. 'Its pretty far-reaching and we expect to see the manufacturers working with their concept car designers on what the cars should be in future, these wheels are just the first step,' explained one insider.

Wheel and tyre sizes have been fixed for a long time in Formula 1, while fans have become used to the aesthetics of low profile rubber elsewhere. Changes – as flagged by Lotus here – will mean a major rethink in chassis and aero design

It is thought the project, which has not been officially announced by the F1 Strategy Group, is in its early stages but could be a result of manufacturers wanting more brand identity in the cars similar to the NASCAR Generation 6 cars.

The test of the larger rims and low profile tyres went smoothly, although the car fitted with them was notably off the pace compared to the traditional 13-inchers. 'They seemed more reactive and more nervous,' said Lotus Test driver Charles Pic after running on the new tyres. 'But, we ran them in a very conservative manner as regards to speed, tyre pressures and avoiding the kerbs. I think that it is a tyre that will react quickly; the reaction you get in the steering wheel feels like it's more nervous and you get a snap, it's quicker.'

Fitting the new designs to the E22 required some changes to the car according to Chester. 'We viewed it as a shakedown run; simply a case of "let's see" for Pirelli, rather than a performance run. We had to trim the floor and change the ride height to adapt to the different loaded radius of the tyres. Some of the suspension set up also had to be modified, such as the cambers. These were very basic revisions to enable Pirelli to evaluate the concept and see what the bigger wheels look like on the car,' he explains. 'Having 18-inch tyres would have a big impact on design. We would want to be testing in the wind tunnel for at least a year ahead of their introduction. The ride height and suspension packages would have to be changed and the tyre profile itself would be very different. It would be an interesting challenge.'

Lotus has two versions of the nose in use on the E22, a standard version and a high downforce version which features a turning vane, or winglet, between the two tusks. It is a concept that other teams including Caterham and Toro Rosso have evaluated in the wind tunnel but have chosen not to use. 'We have heard people saying that this layout makes the car more sensitive, but we don't think that,' says Chester. 'We spent a lot of time looking at it when it is yawed and steered and we don't see an increase in sensitivity over previous years. Overall the layout gives us a bit more downforce.'

However the Lotus engineers did test a rudimentary Mercedes style nose at the Brazilian Grand Prix.

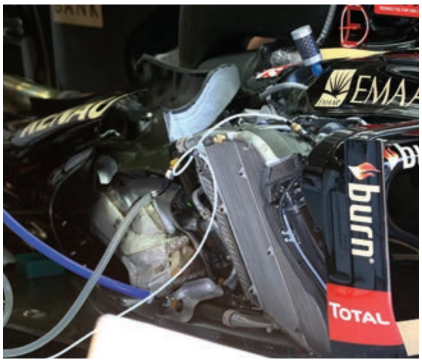
Weight issues

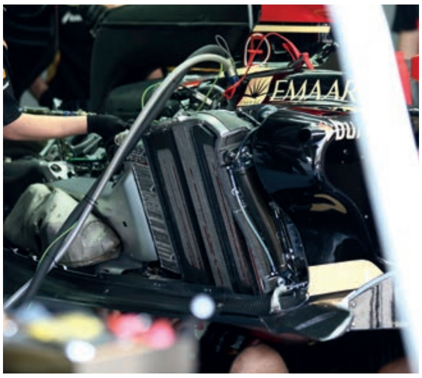
The chassis of the E22 is, at first glance, relatively conventional, with pushrod-actuated torsion bar front suspension and a pullrod-actuated layout at the rear. For the first half of 2014 the front and rear suspension was interconnected using a neat hydraulic system but that was removed ahead of the German Grand Prix.

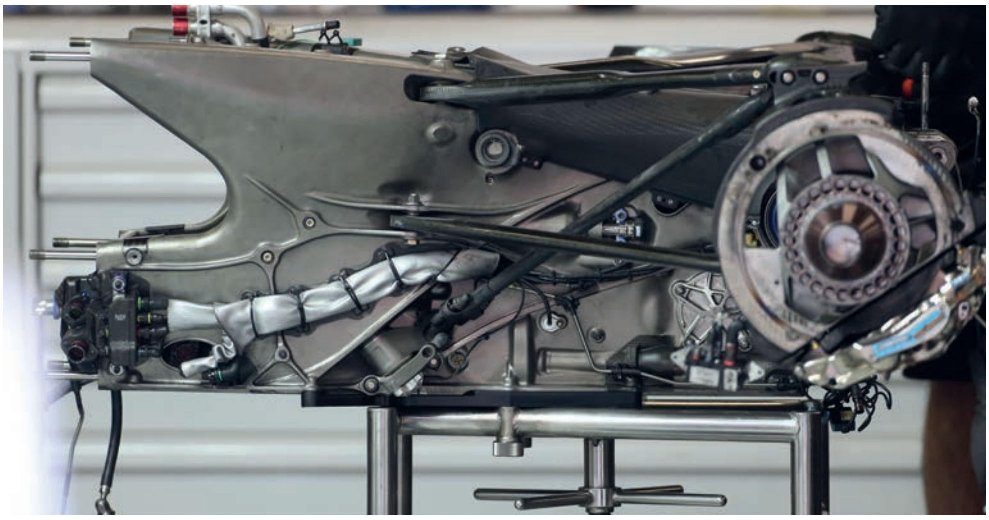
One of the major design challenges that all Formula 1 teams faced at the start of 2014 was getting the car down to the weight limit of 691kg while at the same time getting it within the mandated weight distribution of 314kg front and 370kg rear. 'There is some ballast on the car,' says Chester. 'We had a very strict programme in terms of developing the individual component weights because we have to hit that weight distribution limit. We knew we were going to be close on the overall weight limit; we did not have much of a range to play with. So, we had to make sure that we did not have to make the car overweight in order to meet the weight distribution limit. Even now we don't have the ability to move right across the 7kg range we are allowed but at the end we are where we want to be. As a result the wheelbase is a tiny bit longer, the extra length can be put down to getting the CG where we want and a bit of packaging too.'

At the rear of the car there was an interesting design feature at the start of the season that again showed a lack of symmetry. The rear wing had a single support structure but this was offset to one side with the exhaust tailpipe kinking around it. 'The layout was just quite efficient structurally,' says Chester. 'There's a lot of other things out there with Y-lons and the cascades that go with that. We are looking at that as some cars have really nice details there, so we may try that.'

Overall, the aerodynamics of the car seems to be an area that Chester and his team are relatively satisfied with and despite the trimmed down front wing mandated in 2014, he believes the car could be better than the race-winning E21. 'If we had the exhaust blowing on this car as we did with the E21 then I think this car would be equal or better to that one. A lot of drivers are complaining about traction this year, I think







Above: A titanium-cased gearbox is used on the E22 – the only Renault-powered car not to use a Red Bull gearbox
Left: Experimentation with radiator and charge air cooler placement and ducting is ongoing

some of it is that on the one hand the cars have got a lot more torque, and on the other the exhaust blowing has gone, so on corner exit it makes the car harder to drive.'

One aerodynamic concept that was used on the E21 but dropped for the E22 was known as The Device. This was a way of stalling the rear wing and reducing drag on high speed sections of the circuit. Sometimes called passive double DRS, both Lotus and Mercedes attempted to use it in 2013.

'It was just too hard to make reliable, it was impacted by the wake of other cars and also if it did start to misbehave it would cost us downforce on the rear wing throughout the lap,' admits Chester. 'We raced it at Silverstone last year and it was neutral in terms of loss or gain, but when we ran it at Spa it was a loss, not a gain. We felt it was a really interesting system but required too much development for the returns it was giving. We are no longer pursuing it, and I imagine that most teams think its too difficult – maybe someone will do it some day.'

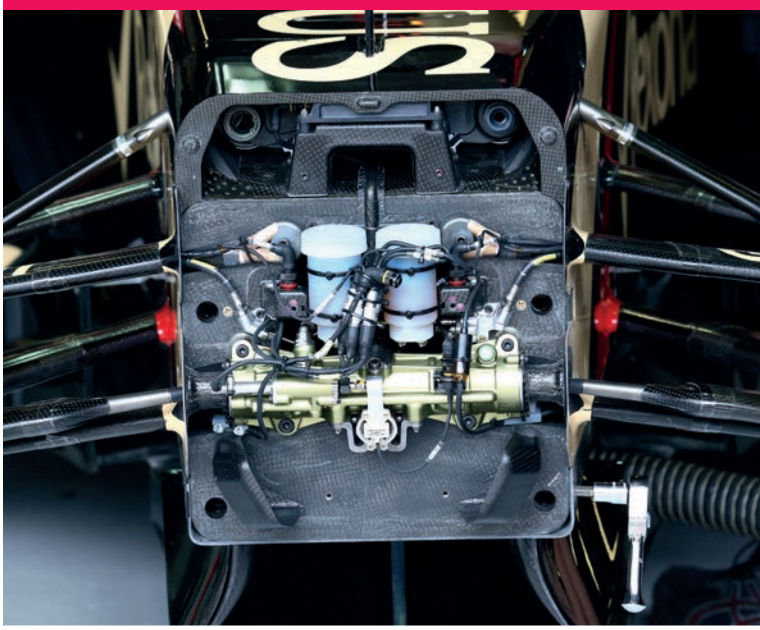
One of the less discussed rule changes for the 2014 season relates to the transmission of the cars, which now must have eight fixed ratios and last much longer, resulting in much larger gearboxes, but it has less of an impact on the car's aerodynamics than may be expected according to Chester. 'The increased size of the transmission has not really made it any harder in terms of aerodynamic packaging at the rear end. In fact the back of our gearbox is pretty thin. We are more driven in that area by cooling exits.'

Lotus is unique among the Renault-powered teams in 2014 in that is uses its own bespoke transmission with a titanium case. The other three – Caterham, Toro Rosso and Red Bull – all use internals supplied by the latter, although Toro Rosso also manufactures its own casing.

'Doing our own casing gives us freedom on the suspension geometry, but for us it is also just a good way of developing a gearbox with the resources that we have got,' Chester explains. 'To do a full carbon fibre gearbox is a massive job, and while we are not ruling out doing one in future, we are quite used to the titanium casting method now. I think going to a carbon case may see a bit of a weight saving and we have run them in the past, but in terms of a design task it is pretty huge and we thought it was not worth it. One of the main reasons we did not pursue it for 2014 is because of the heat from the turbocharger. We thought it would be a risk to move to a carbon box when you are dealing with all of that.'

One of the advantages that Lotus feels it has with the E22 relates to the way torque is transferred from the crankshaft to the clutch, something many struggled with initially with

Bulkhead form and function

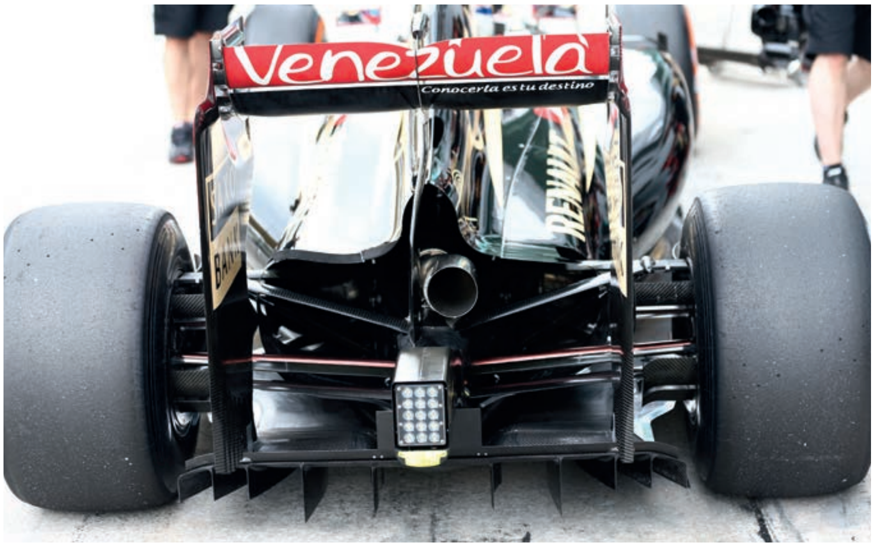


The front of the Lotus E22 reveals a fair bit about the car's overall design. Looking at the bulkhead you can immediately see that the torsion bars sit on top of the chassis underneath the vanity panel. The bars are mechanically linked to one another and, somewhat curiously, the one on the left of the car regularly features a bolt in its centre while the right hand side bar does not. Nick Chester, Lotus F1 Team technical director is very cagey about this arrangement. 'The torsion bars are different to look at. It depends on what people think we are using the two bars for; they don't necessarily do the same thing,' he states when asked to comment on the 2014 design.

Also visible at the front of the car, sometimes hidden behind a Kistler control box, is the steering rack, mounted near the base of the chassis. 'The steering rack position is defined mainly by aerodynamic demands,' Chester explains, 'especially regarding where you want to put the track rod.

'We do a lot of suspension layout tests when designing the car and they pretty much define where the track rod goes in terms of height, so that fixes your rack, then you have to play a little bit with the geometry to ensure that the steer characteristics are right.'

An experimental 2015 nose signals next season's replacement for the Lotus twin-tusk nose design



The slight asymmetry of the wing strut and tailpipe arrangement is just as effective and lighter than other teams' more complex structures

the high torque figures of the new power units. Chester will not be drawn on the exact details but is willing to admit that there is a system in existence. 'We have something different in the transmission, it is not a trick really it is just something we did because we thought that it would give us more reliability in the clutch area.

'It is a purely mechanical solution between the crank and the basket that gets the torque into the clutch. I'm not sure what Red Bull are doing, but I think they know what we are doing. I'm not sure if they stuck with their original solution, or have switched to our concept.'

Installing the Renault power unit in the E22 has proven to be a major challenge for the team. Initially there were well-documented reliability

"The mapping got better and we got a lot more power by Barcelona, where the car was performing pretty well"

issues, then there were some performance related setbacks, but overall the biggest issue with the RS34 power unit is its cooling demand. Here, too, Lotus has taken a different approach to the other Renault-powered designs.

'There are a lot of different ways of cooling these turbo engines and on the grid there is a bit of a split between people who are using air to air cooling for the charge air and water to air cooling. We have gone for the latter solution,' says Chester.

'It's similar in concept to both Ferrari and Mercedes, though not in the installation. The reason we have gone down this route is for packaging. Red Bull has used an air to air solution which is quite big and has horizontal radiators. How you do it depends very much on how you are developing the bodywork on the back of the car. Red Bull differ to us there, but from our research both solutions work. We may change what we do in this area next year as we try to find the most efficient way to cool the car as it defines a lot of other parts.'

The radiators in the E22 are mounted longitudinally along the outer edge of the side pods, something that Lotus feel could give better flows under the bodywork. Additionally, the 1.6-litre Renault engine has not proven a major challenge to keep cool according to Chester. 'In terms of cooling we saved a little bit in terms of the combustion engine, so that saving is all on the right hand side of the car where all of the ICE coolers are housed. We achieved our cooling targets there quite easily but the charge air cooling has been more tricky. We have improved it through the season and have redesigned the radiators twice now to bring the charge air temperature down.'

This has at times resulted in additional ducting appearing on the E22 throughout the season, notably with a side cooling exit and some smaller openings in other areas of the car. 'Its such a different system to cool,' continues Chester.

'You can no longer just arrive at the track and have your temperatures perfect, so we did play with some additional exits to reduce our charge air temperatures a bit and we ran them in some races.'

Overall the E22 has not been as strong in races as many expected, which many put down to ongoing issues with the RS34 power unit, but Chester admits things are not quite as he would like in other areas too. 'Lots of things have improved; we were hurt at the start of the year as the car was late, and we had pretty poor reliability. At Melbourne we were in pretty bad shape, but through the following races leading up to Barcelona we improved in a lot of areas. Not just on the chassis side but on the power unit side too. The mapping got better and we got a lot more power by Barcelona, where the car was performing pretty well.

'We were not happy with the races that followed, as the car struggled with low speed corners and the way the power is delivered, but tracks with high speed corners were better,' he concludes.

However, his colleague Alan Permane, Head of Track Operations at the team is rather more blunt in his assessment. 'The suspension changes we had to make at the German Grand Prix complicated things for us,' he said.

'However it is clear that we lack pace relative to our opposition.'

TECH SPEC

Chassis construction
Carbon fibre with aluminium honeycomb monocoque

Front suspension
Double wishbone, push-rod actuated torsion bar springs and dampers, anti-roll bar

Rear suspension
Double wishbone, pull-rod actuated torsion bar springs and dampers, anti-roll bar

Transmission
Paddle operated 8-speed semi-automatic

Clutch
Carbon multi-plate

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
carbon carbon discs all round

Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
FIA SECU standard electronic control unit

Engine
Renault Energy F1-2014, 1.6-litre 90 degree 6-cylinder. Max rpm 15,000, 24 valves. Cylinder block in aluminium

Dimensions and weight
Overall length: 5088mm Overall height: 950mm, Overall width: 1800mm

The ugly duckling

The product of an all-or-nothing strategy, the CT05 came in low on looks, but also performance and 2014 only got worse for Caterham

By SAM COLLINS

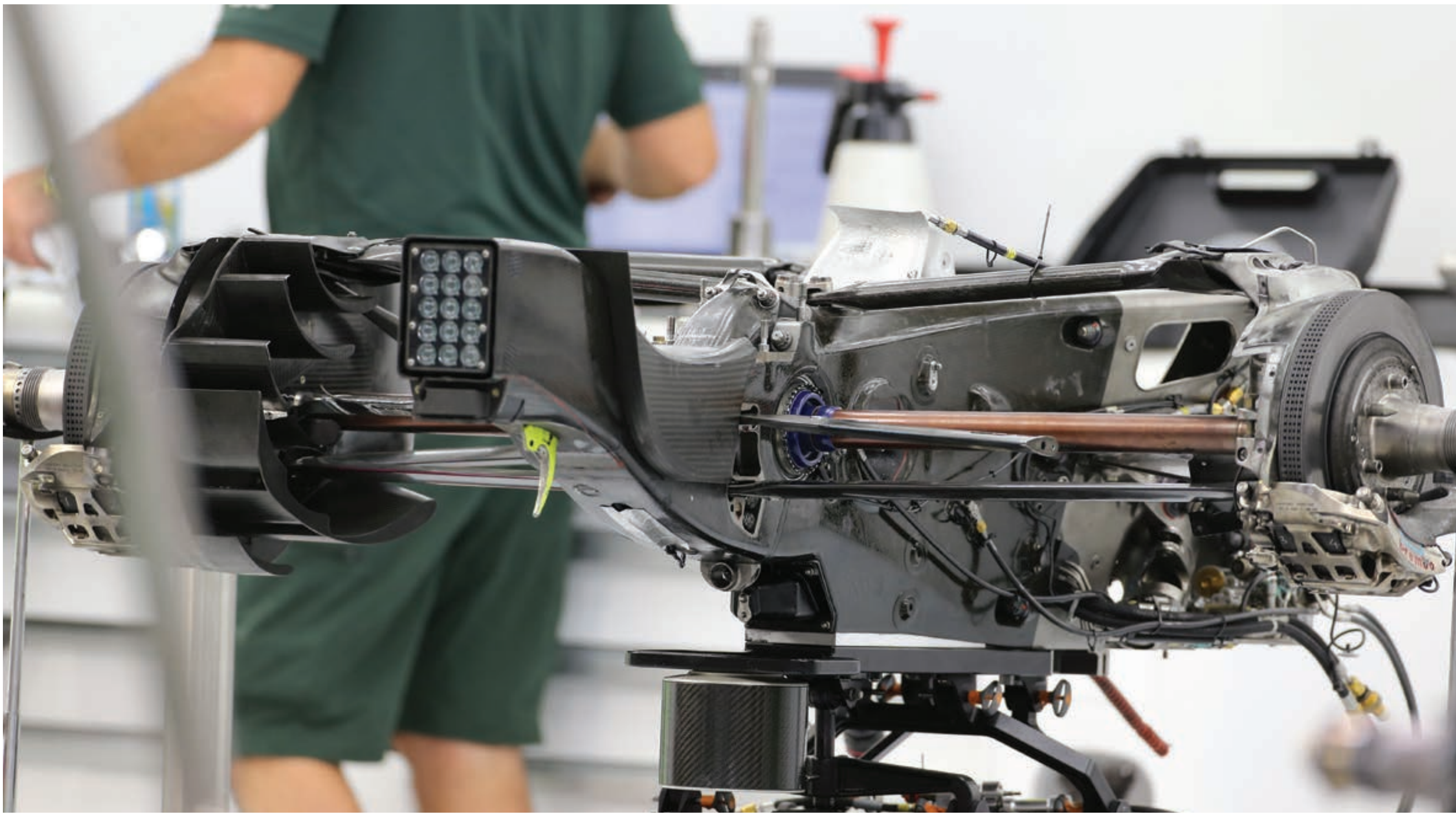
Images: JAMES MOY

The Caterham Formula 1 Team gathered many column inches at the end of the 2014 F1 season, not because of the team's on track performances, but rather the lack of them. A complex and messy financial crisis saw the outfit go into administration following the Russian Grand Prix, skip the following two races and resort to crowd funding to make it to the final race in Abu Dhabi.

Caterham's struggles started at the beginning of the year, just before the team headed off for the first winter test of the year at Jerez, Spain, its owner Tony Fernandes issued an ultimatum: 'If we are at the back, I don't think we're going to carry on. After five years and to get no points, there's a limit to everyone's patience and money. If we are not competing then we have got to seriously examine ourselves as to whether this makes sense.' By mid season the team had failed to score a single point, and its arch rivals Marussia, had scored two.

Caterham started developing its 2014 design – dubbed the CT05 – in 2012, and largely overlooked the 2013 season to focus on the new rules. It was something of an all or nothing approach. As a result, the CT03 of 2013 was a lightly upgraded 2012 spec CT01. The CT05 only just made it to the first test, and when it was first rolled out of the garage it was widely agreed to be one of the ugliest F1 cars of all time, which is especially galling in a season defined by the poor aesthetics of most of the designs.

One of the most striking features of the car's look was its nose design. The main impact



Caterham buys its transmission casing from Red Bull Technology. The composite design is shared with the Red Bull RB10 along with the internals which are also shared with the Toro Rosso STR9. Using the Red Bull casing means that the inboard suspension layout is essentially identical on the RB10 and CT05

structure is forced by regulation to be narrow and low, but teams are still allowed to use a 'vanity panel' to avoid having ugly steps in the bodywork. Caterham used this to find some aerodynamic gains.

'What you see on the car is not actually our first nose configuration – we looked at something different that is actually on another car,' Mark Smith, then Caterham F1's technical director claimed at the start of the year. 'But we wanted to try to achieve something that did not become a protracted impact test problem for the start of the season. So the impact structure we have is very straightforward. It's kind of a banker, and it's been easy to make it work in terms of the crash test. The reason it looks the way it does is that we wanted to retain some of the benefits of a high nose, like feeding airflow to the rear of the car.'

But that distinctive nose was not meant to last as long as it did. Caterham had tested other solutions in the wind tunnel including one similar to the twin tusk design used on the Lotus E22 – and hoped introduce the upgrade during the European season, but other circumstances saw it delayed to the late season flyway races. 'For quite some time now we have been exploring other solutions in CFD, and we have got something different,' said Smith.

"We wanted to try to achieve something that did not become a protracted impact test problem"

The space under the car's nose is crucial in aerodynamic terms, and it was a major area of focus for the Caterham F1 engineers based at the Leafield Technical Centre, near Oxford. That focus saw the adoption of pullrod actuated front suspension, something that only features on one other car in 2014 – the Ferrari. 'We did not just do it for aero reasons – it is something we looked at both mechanically and aerodynamically,' Smith explains.

'Because the front of the chassis had to be lower by regulation, we thought it was worth having a look – and then found it was slightly better. The CFD and wind tunnel work we did showed that in aero terms it is not significantly better one way or the other, though it did show that it is marginally favourable, particularly with respect to the way you treat the air around the front brakes.

'Bizarrely enough, we also found that it is slightly better in terms of motion ratio too. Also, we can put more of the inboard components lower in the chassis so there is a small centre of gravity gain too. Overall, however, we did not have a strong feeling one way or the other in terms of which way to go, but when we looked at the subtle benefits it brings we went with it.'

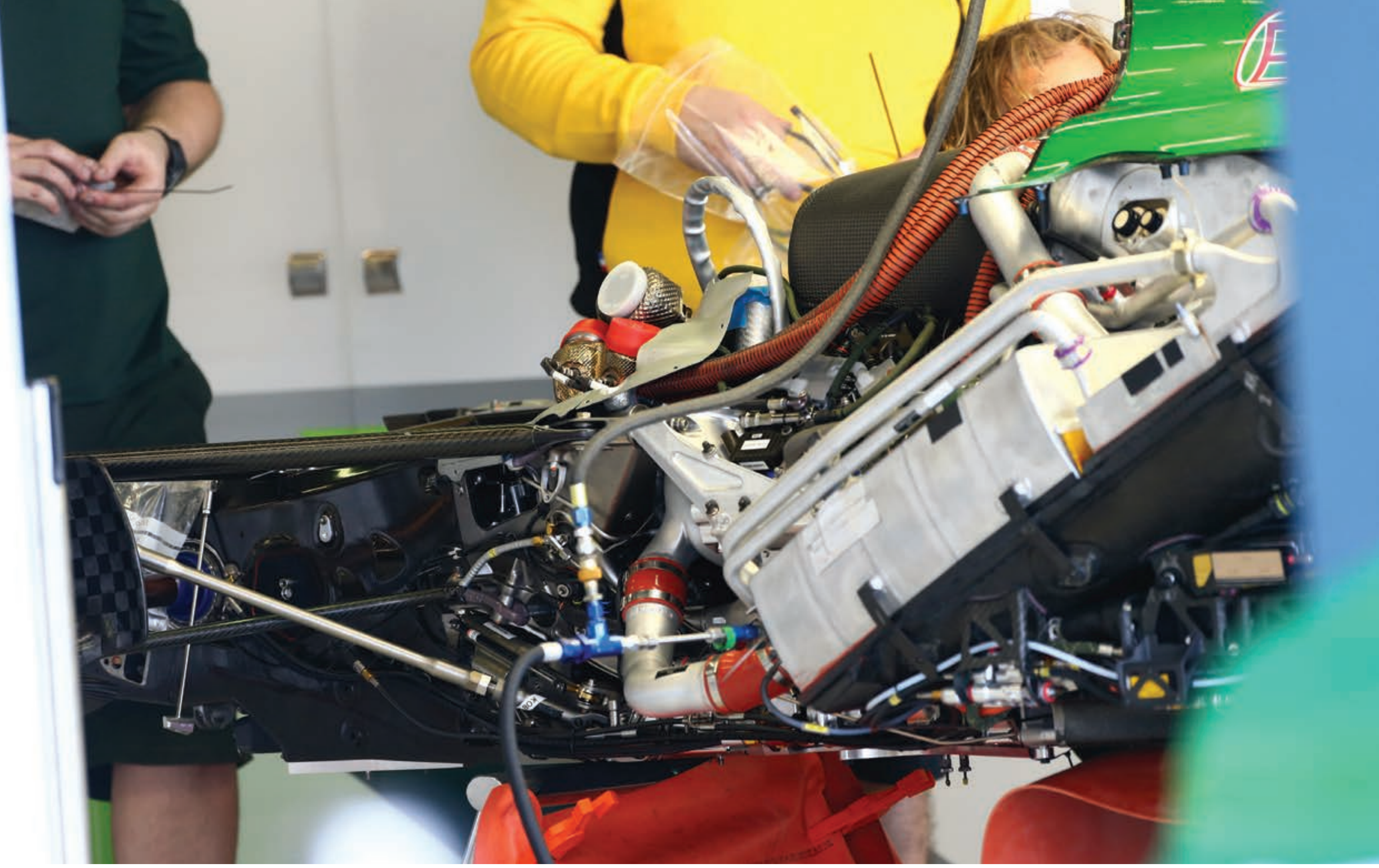
Ever since Caterham arrived in Formula 1 back in 2010 – originally as Lotus Racing – the team lacked access to its own wind tunnel. At one point it considered constructing its own at Hingham in Norfolk, but opted instead to utilise commercially available facilities – initially at Aerolab in Italy, then later one of the wind tunnels belonging to Williams F1. But a small rule change for 2014 forced Smith to consider a change, not only to the facility it used, but also the scale of its model.

'One of the main reasons we switched tunnels was the new aero restrictions. We ran 24/7 in the Williams tunnel with a 50 per cent scale model. One of the problems with the new restrictions on wind tunnel testing is that we need to get more return on our time. We had also wanted to go to 60 per cent for a long time, but the additional costs of not only doing a new model, but also developing it, were too high. There are more parts, and the majority of the parts are rapid prototypes, so the cost is really proportional to the volume, making 60 per cent more expensive.

'When the aero restrictions came in, the number of hours you could run came down, so there was a cost saving there which allowed us to increase the scale.'

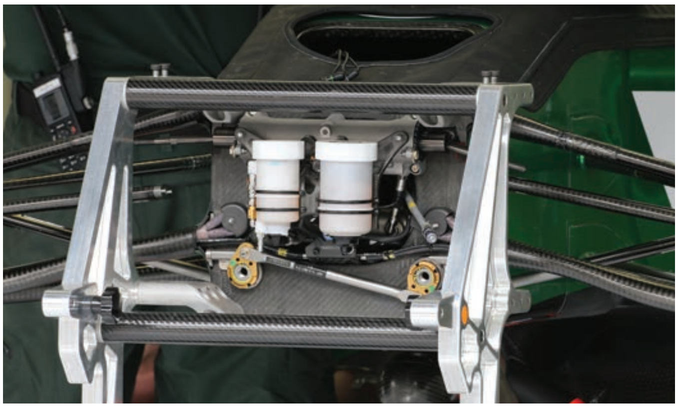
That left the team with something of a dilemma. 'We looked around at available wind tunnel options,' says Smith, 'and there were not many available, to be honest. But we knew about TMG, and they are state-of-the-art.'

But switching scale and facility halfway through a car's development was a brave step. The CT05 was initially developed using a 50 per cent model at Williams, but just before the car



Installation of the RS34 power unit, and some of the substantial cooling required. Caterham has deliberately given itself a larger cooling margin

Front brake setup, with some of the aerodynamic elements visible



Pull rod front allows components to be mounted at the base of the chassis

was launched, Caterham started running a 60 per cent model at TMG in Cologne, Germany.

'We have a reference that we use to correlate between the two models, and the track. It's early days, and we anticipate that there will be some differences, but we get increased resolution from the scale increase. We do have some aero guys who have used the tunnel at TMG, however, so that should help too,' Smith claimed at the car's launch.

The TMG tunnels are widely considered to be the best that are commercially available, and gave the Caterham engineers some new tools to work with. 'It is very much a bespoke session. Closing the loop with CFD using PIV [particle image velocimetry] is a good step forward for us. We have invested heavily in CFD with both new people and a hardware update that should be running any time now. We have the capacity to do more, but we have to ensure that the quality is there too, and the PIV is essential in that respect.'

Caterham was one of four teams using the Renault RS34 'Energy F1' power unit, and like the others was hit with a number of issues – not least the fact that is seemed to have a larger cooling demand than the two other power units used in 2014. This caused major issues for Red Bull and Toro Rosso, but Caterham did not suffer as badly due to the way that the car was designed. 'My brief was that we should not be in a position where the cooling was marginal at these first four races,' says Smith. 'Obviously there are different demands at different circuits, but we did not want to be cutting holes in the bodywork when we got to Bahrain. We are conservative by intent, and with the data we have in terms of heat rejection from Renault, plus analysis in CFD and wind tunnel in terms of mass flow rate through the ducts, we knew we would be able to cool things and have a little bit of a margin.'

In the run-up to the power unit homologation deadline, Renault is thought to have reworked the energy store, turbocharger and a number of other key elements and will bring further updates to the power unit ahead of the European races. But there were still issues with the power unit, as Cedrik Staudohar – the Renault track support engineer embedded with Caterham – admitted mid season.

'The chassis-engine package is improving with each session as we understand more about its strengths, and the aim is clearly to keep this upward trend going,' he says.

With issues simply getting the power unit to work properly interrupting the car's early development, some areas appear to be somewhat behind. One of these was brake-by-wire, which has failed on the car on more than

The crash at the Australian Grand Prix damaged the CT05's vanity panel, exposing the true shape of its nose structure

TECH SPEC

Chassis construction
Carbon fibre, mostly epoxy resin

Front suspension
Twin non-parallel wishbone, pullrod actuated

Rear suspension
Twin non-parallel wishbone, pullrod actuated

Transmission
Red Bull technology

Clutch
AP Racing

Dampers
Caterham, Penske Racing Shocks

Wheels
OZ Magnesium alloy

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
Brembo carbon/carbon

Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
FIA SECU standard electronic control unit

Cooling system
Caterham – Aluminium alloy fabrication

Cockpit
Seat belts: Schroth Racing
Driver's seat: Caterham carbon fibre shell

Engine
Renault Energy F1-2014, 1.6 litre 90 degree 6-cylinder. Max rpm 15,000, 24 valves. Cylinder block in aluminium

Dimensions and weight
Front track: 1800mm (max)
Rear track: 1800mm (max)
Wheelbase: More than 3000mm
Length: More than 5000mm
Height: 950mm

Radio
Riedel

Fuel provider
Total

Lubricants provider
Elf

one occasion. There were issues with it at the opening test in Jerez, which saw driver Kamui Kobayashi running without any rear brakes at one point. ('It was quite exciting,' he told the Japanese press.) More obvious was a similar failure at the Australian Grand Prix which saw the same driver lose the brakes on the first corner of the first lap, leading to a race-ending collision. The team's troubles were only just beginning.

Even after revealing the 'don't fancy yours much' CT05, Fernandes was still supportive of the team, especially after it achieved the highest mileage of any Renault powered car at the opening test. 'More laps than Red Bull, Toro Rosso and Lotus didn't show up. Shows what spirit and right people can do. Not just money,' he tweeted enthusiastically. But then ahead of the first race he tweeted: 'Caterham doesn't look like it has promise. Let's see.'

Its performance on track was poor and Fernandes, also the owner of a major English football club, was unimpressed and wanted out. Aside from the odd strong performance, the team remained firmly anchored to the back of the grid, roughly a second off the pace of the slowest midfield teams. Ferndandes was getting fed up and at the start of the 2014 season he demanded that the team improve, but if anything the team took a backward step. The ugly CT05 was rolled out at Jerez and

> "We are conservative by intent. We knew we would be able to cool things and have a bit of a margin"

struggled for pace from the off, when rival team Marussia scored points at the Monaco Grand Prix the situation worsened and Fernandes, now more interested in his Premier League football club, put Caterham F1 on the market.

In late June a sale was announced, a consortium of Swiss and Middle Eastern investors 'advised' by Colin Kolles and trading under the name of Engavest SA were reported to be the buyers. New management took charge immediately and, by the British Grand Prix, former Dutch F1 driver, Christijan Albers, assisted by Manfredi Ravetto, took over the day-to-day running of the team, reporting directly to the board and replacing Cyril Abiteboul who left the team to join Renaultsport F1.

Albers said following the sale that 'we are aware of the huge challenge ahead of us given the fight at the bottom end of the Championship and our target now is to aim for tenth place in the 2014 Championship. We are very committed to the future of the team and we will ensure that the team has the necessary resources to develop and grow and achieve everything it is capable of.'

Around this time the team fired around 40 employees on the spot, sparking an as yet unresolved legal challenge for unfair dismissal. Updates finally started to appear on the car and things gradually started to improve but just a few weeks after his appointment Albers quit the team, leaving Ravetto as team boss. He admitted that the team was in difficulty from the outset, and suggested that had his employers not stepped in the team would possibly not have been able to race at Silverstone.

'The new front wing and car updates are delivering more aero performance, we delivered that,' Ravetto told *Racecar Engineering* some weeks later. 'Technically talking we have delivered an almost new car since Spa. It does not even look like the shit box they started the year with. But I'm not saying that the patient we are trying to treat is out of danger. We took over a patient that was almost dead, we have tried with some success to keep him alive. The next step is to try to stabilise things but that is not completed yet and the patient remains critical.'

So it was until the build up Japanese Grand Prix at Suzuka, when a group called the 'The Sheriffs Office' arrived at the team headquarters in Leafield, England and seized a large amount of the team's property and equipment including spare parts for the cars running in the Japanese and Russian Grands Prix.

It later transpired that Caterham Sports Ltd has over 50 judgements against it totalling almost £1,000,000. It was just the tip of the iceberg. The Cromwell tools hearing was due to be heard on 11 November and the items seized could not be auctioned off until then. The team raced at Suzuka and again in Sochi without

Front of house – the nose designs for the Caterham CT05 cannot change the mood of the camp which lurched through the 2014 season without picking up points

Looks are not everything but when the car's performance continues to struggle something has to give – and the result pitched Caterham into terminal decline


Suspension issues forced a crisis in Caterham's relationship with driver Kamui Kobayashi


Undertakings to pay existing and future creditors that were not complied with compounded the Caterham's predicament

great incident or result. Though in the latter race one of its cars driven by Kamui Kobayashi was apparently retired to save mileage and a failed element in the suspension had to be repaired rather than replaced as the required spare parts were languishing in a debt collectors warehouse.

Kobayshi was understandably unhappy with the situation; 'Scary!' the Japanese driver wrote on his Facebook page. 'Last night a suspension defect was found. There's no spare so it was repaired by wrapping it in carbon.

'It's checked all the time but, even so, being asked to race like this is too scary! I want to go home already. From here on there are still practices and the race to go. I am seriously troubled. As a racing driver, should I drive? Should I safely decline? I drive again in 15 minutes…'

The post was later pulled and the team countered that the car had been run in a safe condition. 'After Friday's practice at the Russian Grand Prix, the team performed the standard checks on the cars and we noticed a small inconsistency on the left rear suspension of Kamui Kobayashi's car,' read a team statement. 'It was extensively evaluated at Sochi and Leafield and ultimately a carbon fibre wrap was applied to provide additional reinforcement – a normal procedure. The component was signed off as safe and re-checked between each subsequent session, to be absolutely sure there was no issue.'

Kobayashi retired from the race and has been quoted as saying that it was as result of the team wanting to save mileage on the car. 'The fact of Kamui having to retire from the race has nothing to do with the above,' concluded the team statement.

'We saw an issue on the brakes – a problem that Kamui had already reported on Saturday during FP3 – so we decided to change them, but the problem persisted so we decided to stop.'

After the Russian Grand Prix the team was put into administration and was forced to skip the US and Brazilian Grands Prix. A dispute had arisen over who actually owned the team, Engavest or Tony Fernandes, and it eventually transpired that it was still the latter. 'We agreed in good faith to sell the shares to a Swiss company named Engavest on the basis that Engavest undertook to pay all of the existing and future creditors, including the staff,' Fernandes told the media.

'The continued payment of staff and creditors was so important to me that I ensured that the shares would not be transferred to the new buyers unless they complied with this condition. Sadly, Engavest has failed to comply with any of the conditions in the agreement and Caterham Sports Ltd (the UK operating company of the F1 team) has had to be put into administration by the bank, with large sums owing to numerous creditors.'

As the administrators investigated ways to save the team, Caterham turned to crowd funding to raise the budget to contest the Abu Dhabi Grand Prix.

It launched a crowd funding project called 'Refuel Caterham' via the Crowd Cube website, hoping to generate the £2.35million required to run in the final round, and in the post event test. It managed to raise an impressive £1.1million in the first 48 hours.

While most of the team staff remained locked out of the team's factory in Leafield, England, a few key personnel have been allowed back in to work on a rescue package to allow the team to be ready for Abu Dhabi and true 2015 season.

'It was all we could do, we are not allowed to use the existing assets or finances, because by law that all has to go to the creditors via the administrators,' explained a senior team member working on the project. 'So we have to go out with the begging bowl to fans, its not ideal but if it keeps us going then that's all that matters.'

It has been a tough year for the Caterham Formula 1 team and as this goes to press its future is unclear and there are no guarantees that the team will race in 2015.

The new sound of F1

Why the fuss? Quieter, cleaner engines mean engineers are hitting the right note

I propose, albeit slightly reluctantly, to throw my hat into the ring concerning F1 engine – sorry, power unit – noise. As F1 is ultimately financed by TV audiences and there has been a largely negative response to the soundtrack accompanying the cameras over the course of the 2014 season, it's clear that the lack of exciting noise has proved a significant issue.

Perhaps this has been exaggerated by two factors, one being the dire warnings of the engine sound over the recent past that may have pre-conditioned attitudes, the other the high-pitched scream of the various multi-cylinder engines we've all become used to over the past couple of decades. Before that we had turbo engines in F1 (and just 4 cylinders – not even 6 – in the case of the formidable 1980s BMW units) but while nothing like normally-aspirated motors, they were not as muted as the new PUs.

I'm not quite sure why. Perhaps it's because – in qualifying trim at least – they always sounded on the verge of self-destruction!

Before that, the widely-used Ford/Cosworth DVF had a V8 bark, but not to the extent of recent 'screamers' – although the 12 cylinders of Ferrari and occasional others always added a nice crescendo.

Adapting to the different volume and pitch is inevitable, and I'm not a believer in creating artificial noise, as has been suggested by some. Let's face it, F1 is artificial enough as it is. The problem must be tackled practically, and steps are being considered to rethink the transmitting of the sound from the racetracks, which I suspect has not changed in essence for a good many years. This will help, as will a general aural accommodation by viewers as time goes by. Hopefully, the primary engine (ICE) rpm will increase closer to the 15,000 permitted by the regulations, whereas it appears that currently 12,000 – less when short-shifting due to the torque – is the norm. Some of this might come from development and further-reduced friction in the ICE, but I think perhaps some tweaking of the fuel flow allowance will be necessary to make that happen. My brother favours a megaphone exhaust…

Although I join those who don't like the TV sound, it fits in with the twin desires of the FIA to reduce noise to comply with ever-encroaching environmental legislation, and to be seen as leading the drive for greater efficiency. It is a fact that noise equates to wasted energy going down the exhaust pipes, so the more efficient the motors, the quieter they will become. I don't doubt that most of the mechanics and pit-crew actually love them – like me, many who've been close to noisy racing engines over a long period of time have eventually suffered hearing difficulties, although the onset of ear defenders/headsets has mitigated the worst effects.

Drivers are affected too. German racer Volker Weidler had to unfortunately retire prematurely from the sport in the 1980s shortly after winning Le Mans 24 Hours, due to serious hearing problems. Mind you, he won in the unique Mazda Wankel car, which hurt everyone's ears that year and which most of us on the pitwall prat-perches earnestly prayed would quickly blow up. There can be no doubt that other drivers have been similarly affected, however.

Hello? Hello? Can you hear me? Ah, I see – you must work in motorsport…

I never really was a total fan of the 18,000-plus rpm F1 engine note. While never failing to be amazed by the ear-splitting shriek – and the fact that they could all hang together so reliably – there was something too controlled and uniform about them. When visiting historic events I am struck by the harsher and more elemental exhaust sound that emanates from early supercharged engines. Along with the scream of the blowers, the exhaust notes somehow convey the almost uncontrolled energy being unleashed – and there is much more variety, as I have mentioned previously. My particular favourite must be the pre and post-war blown straight 8 Grand Prix Alfetta. The urgent, almost primitive and ungoverned sound – simple carburation plus imperfect ignition timing and combustion, all limited by the technology of the time – complete with throttle-off crackle makes my hairs stand on end, cliché or not. And then there's the smell of course – as my RCE colleague Ricardo Divila recently reminded us, exotic fuel mixtures and vegetable-based lubricating oils excite the olfactory senses to add greatly to the visual and aural feast.

If technology now was capable of transmitting smells to accompany the TV picture and soundtrack, it would be rather wasted where modern F1 is concerned. You'd be more likely to have the scent of frying hamburgers or boiled bratwurst wafting into your living-room than anything to do with the racecars, given that it's all so clinical.

So we have to face facts – the drone is here to stay. Hopefully, however, so also will be the oversteering and occasional power-on spins largely lost to us since serious downforce, excessive electronic engine control and radial racing tyres stifled what should be one of the arts of race driving. Balancing a car on the limit of adhesion with both steering and throttle – an excess of torque over grip – and scrabbling for traction out of corners still remains a thrill for drivers (surely?) and spectators alike. Let's wish fervently that ongoing refinement and development of power units, software and tyres doesn't take this feature away from us again, as it certainly helps to compensate for the dull exhaust note.

If F1 is going to produce more races of the intensity of the Bahrain Grand Prix and the season long Hamilton/Rosberg fight then perhaps visual stimulation is enough. As for me, however, I'll continue my fascination with F1 and other forms of contemporary motor racing, but will settle for getting my essential sensual kicks from the likes of Goodwood and Shelsley Walsh.

The more efficient the motors, the quieter they become. Mechanics and pit crews must love them

Catching up

After defining the new regulations and starting the season with high hopes, Ferrari, and its customer teams, have struggled all year

By SAM COLLINS

Ferrari came into the 2014 season full of ambition. It had directly influenced the new power unit regulations and the switch from the planned four-cylinder engine to the six-cylinder version that came to be used. At the car's launch there was much optimism – James Allison the team's technical director highlighted how neat and compact he thought the new 059/3 power unit was.

'Our engine department have been aggressive and bent over backwards for us on the chassis side to produce an engine that can be packaged tightly and can be cooled with radiators that are not too big,' he explained. He had also seen the Renault RS34 data, but crucially not that of the Mercedes PU106A,

> "The engines are incredibly busy compared to the V8s, and the Ferrari has been rather exquisitely packaged"

so could make a direct comparison. 'Our car has quite a neat bodywork package and the radiators are quite small and that is a result of what the engine guys have done. The engines are incredibly busy compared to the V8s, and the Ferrari has been rather exquisitely packaged, and it's very neat and small.'

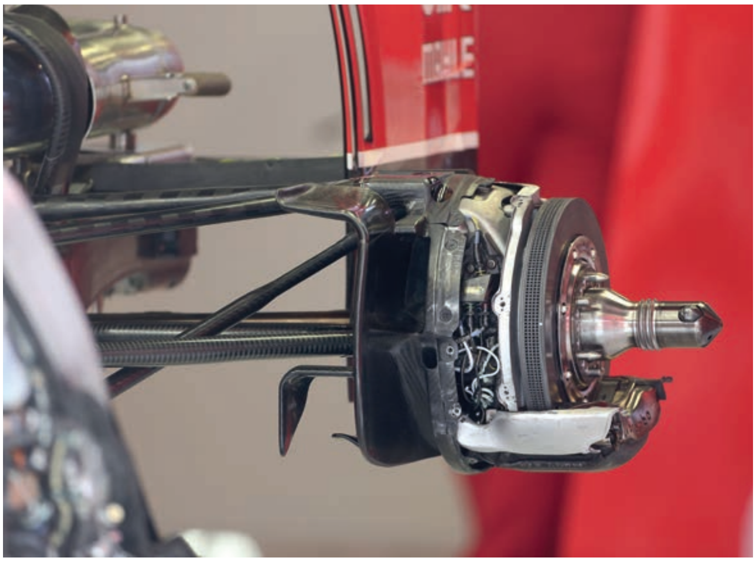
Ferrari had attempted with the F14 T (665) what Mercedes executed to near perfection with its W05 Hybrid, namely a fully integrated car design. Compromises were made by the engine department then headed by Luca Marmorini in order to make the best overall car, but the compromises possibly went too far and the engine reportedly ended up overweight and down on power.

The car retained the pull rod front suspension layout that Ferrari first introduced in 2012 largely for aerodynamic reasons, and it also utilised a pull-rod layout at the rear as is universal among 2014 designs.

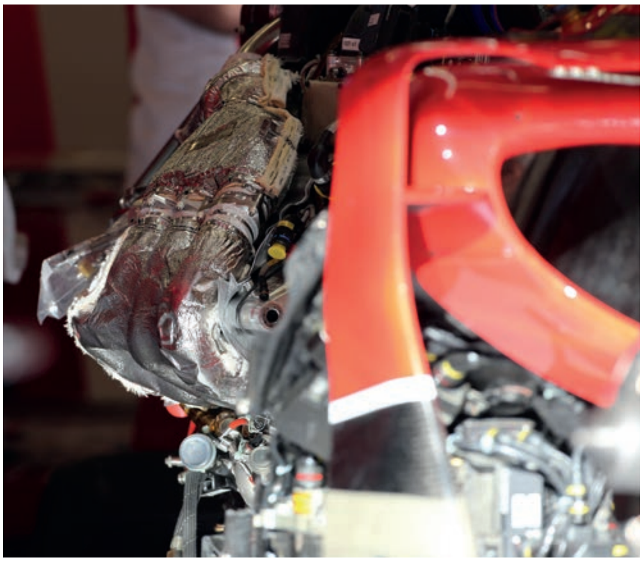
In overall terms the F14 T is significantly longer than the 2013 design, and notably features quite a long transmission (also used by Sauber). This gearbox features its oil tank inside the casing while most other teams mount it externally, allowing for a shorter transmission. The turbocharger on the 059/3 is wholly mounted at the rear of the engine and is thought to be split with the MGU-H between the compressor and turbine. The intercooler is located at the front of the engine inside the V angle. Ferrari has also mounted the oil tank for the V6 engine at the rear rather than the more traditional front layout used by Renault and Mercedes. The MGU-K is also at the rear of the engine, further complicating this region of the car. It is thought that this layout could give some aerodynamic benefit but the cars on-track performances do not obviously reflect that. It also moves the weight of the engine slightly further forward in the car. Curiously, for most of the season Ferrari opted not to coat or wrap the exhaust manifolds, something that some suggest may cost them performance at the turbocharger and MGU-H.

The problems with the F14 T became clear at the Australian Grand Prix, where the car was clearly off the pace. In addition to the issues with the power unit the chassis too

Ferrari is one of only two teams on the grid to adopt a low, wide nose



The rear brake setup – note the caliper mounted at the base of the disc



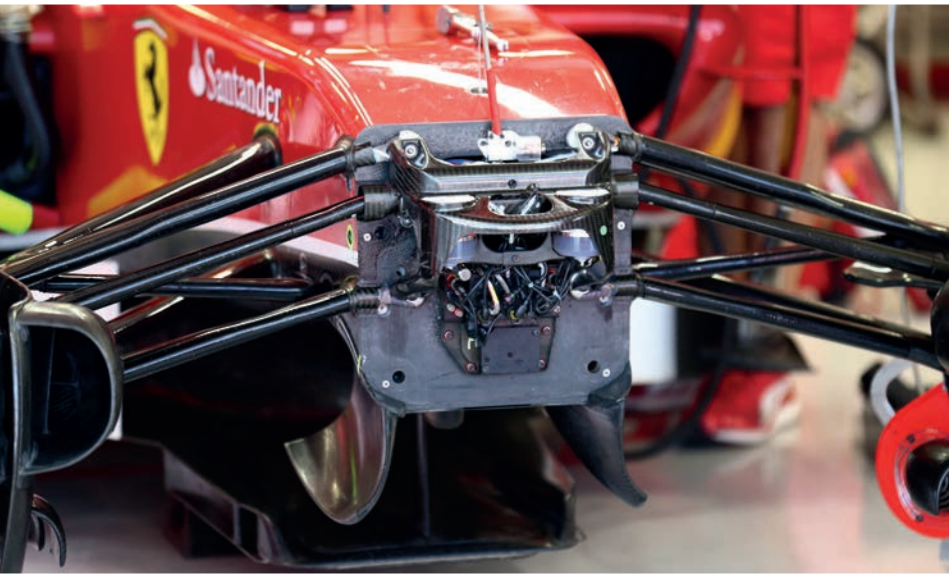
Later in the season Ferrari started to experiment with heat shields on its exhaust

seemed to have an imbalance and one of its drivers Kimi Raikkonen, struggled to get the best out of it. 'Our competitiveness was not acceptable in Melbourne. While we can take some satisfaction from the reliability shown by the F14T, it is clear that we have our work cut out to improve our car in order to compete on equal terms with the Mercedes team,' Allison admitted after the open race. 'There is plenty about the F14 T that is working very well: the starts and the pace in the corners – especially the high-speed ones – are particular strong points, but we need to work further on the stability under braking and the speed on the straights.'

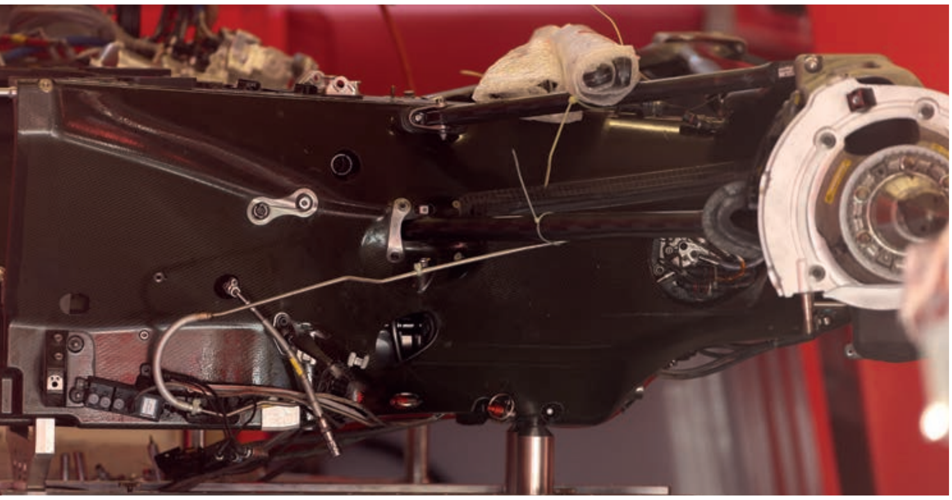
A heavy development programme was begun at Maranello, but it did not deliver the expected results as quickly as expected and soon a number of key figures in the car's creation left the team – Stefano Domenicali the Team Principal resigned in April, and by the summer Luca Marmorini who headed up the development of the power unit had announced that he too was leaving the team.

'I don't think Ferrari has ever lacked for resource or quality of people or quality of drivers. We have many of the key parts for being a successful team,' Allison said after the departures. 'What all of us are trying to do, with the new team principal spearheading that, is to identify the areas where we are not yet championship-leading material to put those right. Most of those weaknesses are organisation and a tendency to work a little short-term in the past. Any driver responds to more downforce, any driver responds to more horsepower, any driver responds to more mechanical grip – and we are putting all of those things into next year's car. My hope is that both of the drivers will be satisfied with the outcome.'

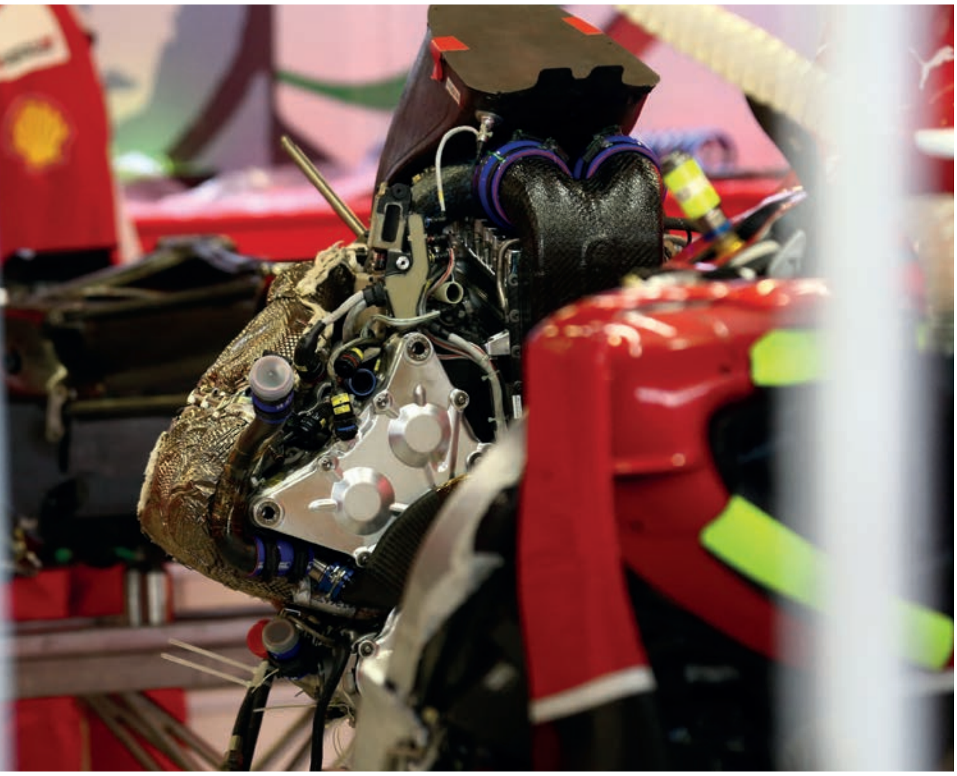
He later admitted that the F14 T not only lacked power but also downforce in comparison to rivals Red Bull and Mercedes. 'It's difficult to split the blame in percentage terms, as it's the car as a whole which is not competitive enough. We need to work on every aspect, it's not just a question of the engine or just the aerodynamics, but also the suspension and the systems. Every



The bulkhead showing inboard wishbone mounting and controversial pullrod front suspension layout



F14 T's gearbox, probably the longest currently on the grid because of its integral oil tank



The Ferrari 059/3 power unit went overweight and disappointed with output figures

TECH SPEC

Chassis construction
Carbon fibre and honeycomb composite structure

Suspension
Independent suspension pull rod activated torsion bar springs front and rear

Transmission
Semi-automatic sequential and electronically controlled gearbox with quick shift

Wheels
OZ

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
Brembo ventilated carbon-fibre disc brakes front and rear, and brake by wire rear brakes

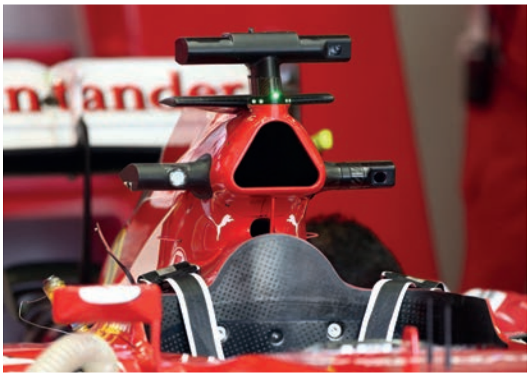
Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
FIA SECU standard electronic control unit

Cooling system
Aluminium oil, water and gearbox radiators

Engine
Ferrari 059/3 1.6 litre six cylinder single turbo. V6 90 degree. Bore 80mm, stroke 53mm, 4 valves per cylinder, 500 bar-direct injection

ERS
Battery energy per lap 4MJ, MGU-K power 120kW, MGU-K max revs 50,000rpm, MGU-H max revs 125,000rpm



The roll hoop and engine intake, coupled with the mandatory camera mountings

part of the car has to be improved so that it can become more competitive next year,' he added.

The 2015 Ferrari may not make up all of the deficit to its rivals but it hopes that it can at least make up some of it. 'It's not just the engine which has to improve; the chassis needs to improve, also, as does the suspension and every part of the car,' says Allison. 'I don't know if we can close the gap in just one year. We are trying but we are also looking at the medium- to long-term future, not just the short term. We want to get this team back to being ahead of all the rest and to have it stay there for many years. Having said that, we are working as hard as possible for next year, to have a much more competitive car. At the same time however, we are establishing the basis to make Ferrari the benchmark team in Formula 1,' Allison adds, with a degree of hope, one feels.

From hero to zero

Usually competing at the front of the F1 midfield, it's hard to see why Sauber has failed to impress

By SAM COLLINS

The 2014 season has turned out to be Sauber's worst ever. For a team that has won races and scored many podium finishes in previous seasons the year was a catastrophe, and it seemed incapable of finishing in the top ten anywhere. Going into the final race of the season the team sat behind Marussia in the Constructors' Championship, a team that no longer existed.

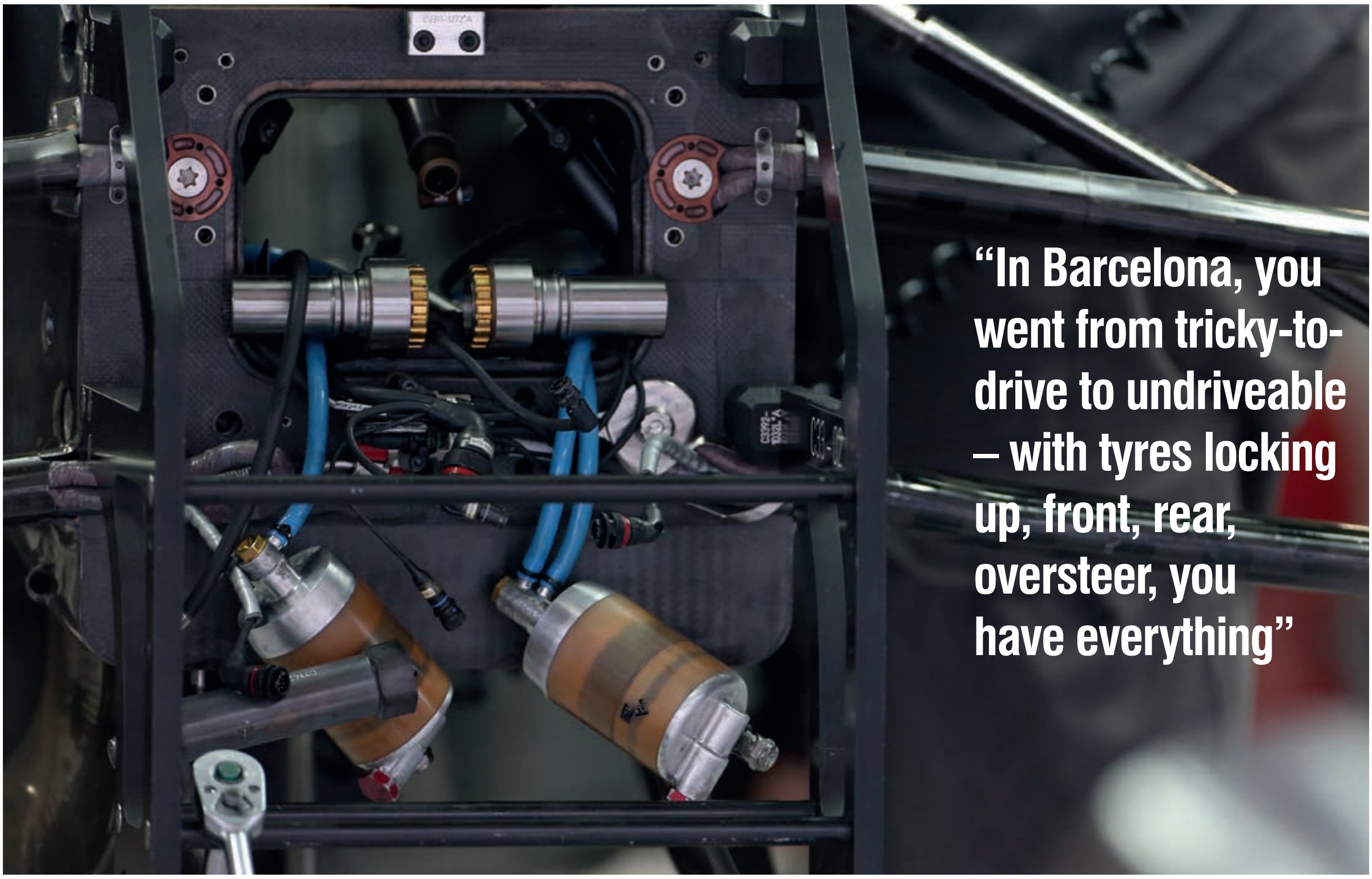
So where did it all go wrong? Sauber has always prepared cars that are capable of fighting at the front of the midfield, but the C33 was seemingly strangely off the pace of its usual competition, the likes of Force India and Williams. It has been suggested that this is something to do with the use of the Ferrari 059/3 power unit and transmission, but Eric Gandelin, Sauber F1 team chief designer, hinted at one of the reasons that the car was behind at its launch.

'We have had to make various decisions on the chassis before all the necessary data and information was available to us,' he admitted. 'That is understandable, given that engine development continues alongside that of the rest of the car up to the last possible moment. And ultimately, of course, that is in our interests as well.'

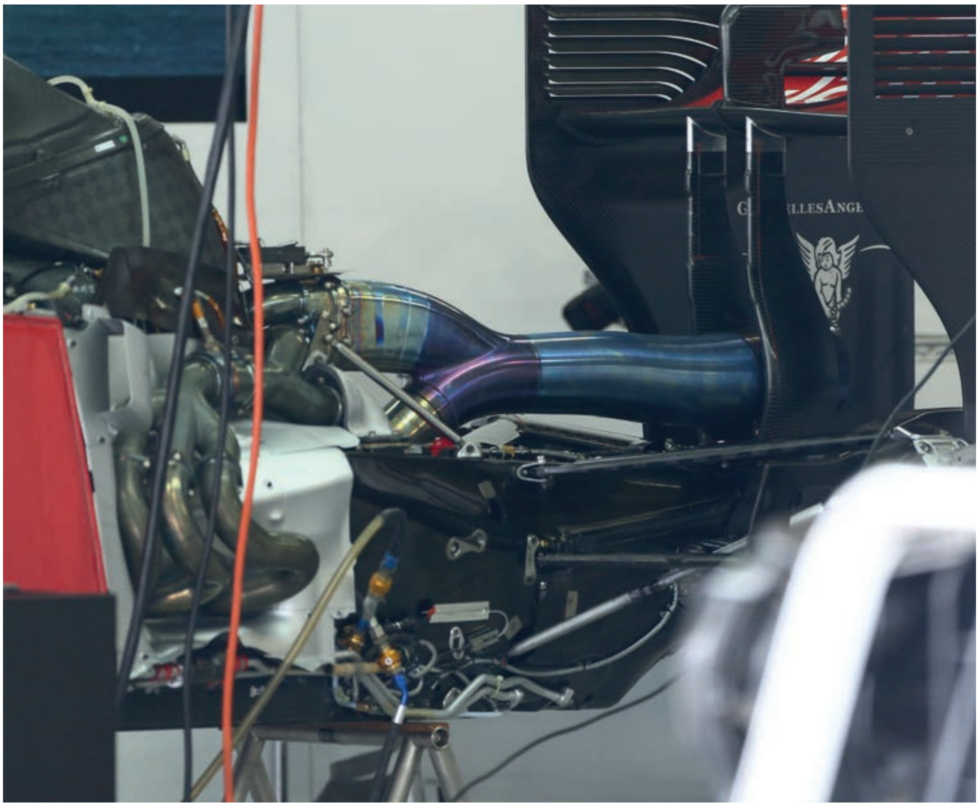
Compromised

This lead to the C33 being somewhat compromised before the car even left the garage for the first time. As Gandelin and his team lacked some key information about the power unit they had to deliberately make some parts of the car quite conservative. 'We followed the path offering the greatest possible flexibility, so we would be able to respond to unexpected factors or developments,' Gandelin explained.' This new power unit has presented

"We had to make various decisions on the chassis before all the necessary data and information was available to us"



"In Barcelona, you went from tricky-to-drive to undriveable – with tyres locking up, front, rear, oversteer, you have everything"



Top: 'Formula 1 is not just about different engines, engines do play a role there but the gap should not be that big,' says Sauber team principal Monisha Kaltenborn

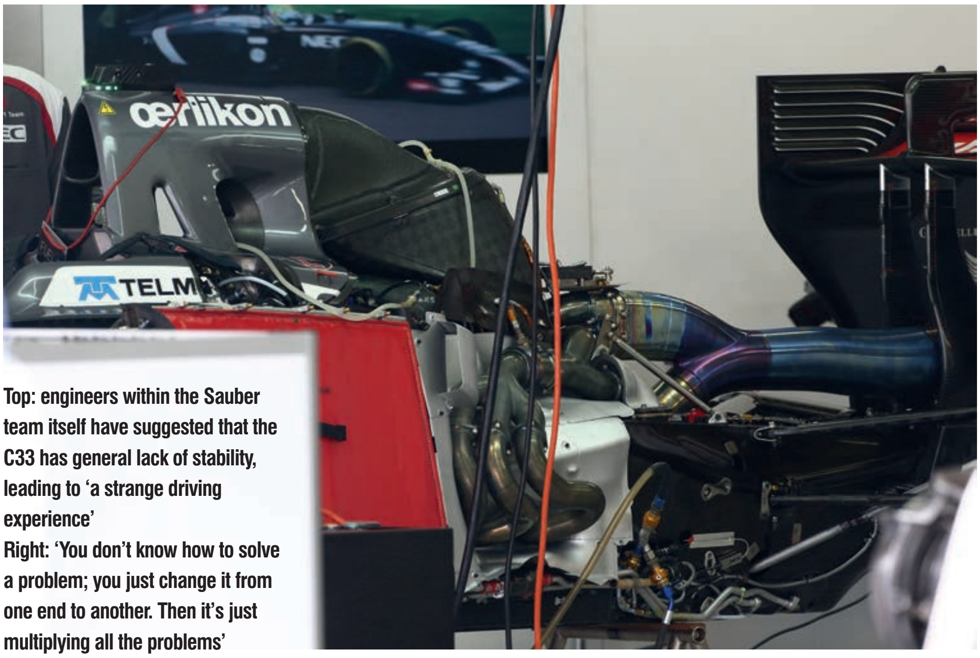
Above: There are more electronics to package within the bodywork, and while the minimum legal car weight has risen from 642kg to 690kg, this only partially compensates for the addition of all the new systems

us with big challenges in terms of packaging as well. The size of the radiators has increased significantly and we have a lot more electronic boxes to package within the bodywork as well. In addition, the minimum legal car weight has been increased from 642kg to 690kg, which only partially compensates for the addition of all the new systems. So, weight saving has been one of our priorities in the car's design. Overall, this has presented our team with a huge challenge.'

That huge challenge was never fully met according to Sauber engineers and the car remains slightly overweight in order for it to work within the limited weight distribution window.

The problem was worse at the start of the season, leading to one of its drivers, Adrian Sutil having to race without a drinks bottle at one of the hottest races of the year; 'Bahrain was one and a half hours with no drink,' he complained later. 'In Malaysia I had a little bit for tea – it was enough for teatime at 16:00, not more. Normally you have one litre or one and a half in Malaysia so you can drink during the whole race. But in this situation now we are talking about 300g or 400g and you also have to count the bottle that has an empty weight of 0.5kg.'

In an attempt to counter its weight problems Sauber introduced a lighter version of the C33 in Barcelona, but Sutil admitted that it still was not enough: 'The lighter the better because then you can place some of the weight where you need it. We are talking about a few more kilos, but I don't want to say a straight number. It's



Top: engineers within the Sauber team itself have suggested that the C33 has general lack of stability, leading to 'a strange driving experience'
Right: 'You don't know how to solve a problem; you just change it from one end to another. Then it's just multiplying all the problems'

TECH SPEC

Chassis construction
Carbon fibre monocoque

Front suspension
Upper and lower wishbones, inboard springs and dampers activated by pushrods (Sachs Race Engineering)

Rear suspension
Upper and lower wishbones, inboard springs and dampers activated by pullrods (Sachs Race Engineering)

Transmission
Ferrari 8-speed quick shift carbon gearbox, longitudinally mounted, carbon-fibre clutch

Wheels
OZ

Tyres
Pirelli
Fronts: 245/660-13
Rears: 325/660-13

Brake system
Six-piston brake calipers (Brembo), carbon fibre pads and discs (Brembo)

Steering
Sauber F1 Team

Fuel system
ATL Kevlar-reinforced rubber bladder

Electronic systems
FIA SECU standard electronic control unit

Engine
Ferrari 059/3 1.6 litre six cylinder single turbo. V6 90 degree. Bore 80mm, stroke 53mm, 4 valves per cylinder, 500 bar-direct injection

ERS
Battery energy per lap 4MJ, MGU-K power 120kW, MGU-K max revs 50,000rpm, MGU-H max revs 125,000rpm

Dimensions
Overall length: 5300mm
Overall height: 950mm
Overall width: 1800mm

Track
Front 1460mm
Rear 1416mm

"The best situation is when you have five to ten kilos to play with and then you can really place it where you need it..."

still quite a bit what we have to find and I think the best situation is when you have five to ten kilos to play with and then you can really place it where you need it. Then you are in a good area and therefore we still need to wait a little bit longer and reduce the weight quite a lot.'

During the season this, and a lack of straight line speed has seen the grey cars from Switzerland struggle to hang on to the back of the mid field pack, and the general feeling in Hinwil seems to suggest that it is largely due to the power unit.

'If we look at this year's season we're seeing that there's such a big disparity between the different engines. And Formula 1 is not just about different engines, engines do play a role, there but the gap should not be that big,' team principal Monisha Kalternborn complains. 'I'm not happy with the entire performance of the team. That has many different reasons; it's been definitely the chassis, it's been on the powertrain side, that whole package working together, and then of course I will say that members in the team have made mistakes as well,' she admits.

Too heavy

Indeed while the power unit has cost the team a number of race finishes through unreliability, engineers within the team also suggest that the C33 has general lack of stability. This is something Sutil alluded to in interviews in the summer: 'The biggest problem, and why we are not performing well, is the drivability of the car and the strange driving you experience with it. You can't control it in certain races. In Barcelona, you went from tricky-to-drive to undriveable with tyres locking up – front, rear, oversteer, understeer, you have everything. And this is the worst thing you can have, you don't know how to solve a problem; you just change it from one end to another. Then it's just multiplying all the problems.' Tweaks were made to the car's aerodynamic package through the season as well as the various maps on the power unit, but nothing seems to have fully solved the issues with the car. 'It's basic stuff as a headline,' one Sauber engineer told RE. 'We don't have enough power, we are too heavy and we don't have enough downforce, because we already lose so much on the straights.'

Sauber is hoping that while its engineers can solve the shortfalls of its chassis with its 2015 car, Ferrari can improve its power unit and the team can return to the performance level that it is more familiar with.

Innovation on a budget

Finances and an unfortunate accident marred the season for Marussia, but throughout the car had performed well

By SAM COLLINS

“We always strive to give our people freedom for creativity – and they come up with some very nice solutions”

The Marussia Formula 1 team started life in 2009 as Manor Grand Prix, an offshoot of the well-known Manor Motorsport junior formula team. Before it had ever taken to the track, investment from English entrepreneur Richard Branson saw it rebranded as Virgin Racing. Then, in 2011, the organisation became part of the nascent Russian supercar constructor Marussia Motors. That company shut down without producing a significant number of cars, and in late 2014 the Marussia F1 team ceased trading.

The MR03 is what will probably be the last car built by the organisation, and it took to the track for the first time at the Jerez circuit during the official 2014 F1 pre-season test.

At first glance the red and black machine was a fairly conservative design, at least externally. But the bodywork masked what is one of the more interesting cars on the 2014 Formula 1 grid. 'This car is the biggest step we have ever had from the perspective of innovation,' said Dave Greenwood, Marussia F1's chief engineer before the team entered administration. 'I think the scope of innovation on the car is testament to the people we have on the team. We work them incredibly hard, but strive to give them the freedom for creativity and they come up with some very nice solutions.'

Much of that innovation was focused on integrating the Ferrari 059/3 power unit into the back of the car, a big task for a team that only utilised a 'KERS' hybrid system for the first time in 2013.

'Obviously there was help from Ferrari with the whole power unit but there was also a change in skills from our side in order to integrate that,' Greenwood continued. 'All of the systems that link up to the power unit we have to do ourselves by regulation – that means all of the cooling, the pipework, plumbing and pumps. That's all got to integrate with the Ferrari bits, which is not easy. It has placed a huge emphasis on our electronics guys.'

The only significant external sign of the work that the Marussia engineers have done on that integration is around the roll hoop and air box inlet of the car, which does not feature exposed supports like every other car on the grid, but instead has an additional pair of cooling ducts routed around the roll structure. 'We have done something there – a bit of innovation – and that's what you have to do to move forwards. We are really happy with what

"We were conservative, but we're now trying to get more downforce at the expense of cooling"

we have done there,' Greenwood said. 'You can see the trend of what's behind the roll hoops, and ours is about providing ducting for some coolers. We determined that it was the best way to minimise the cooler volume within the sidepods of the car. It works really well, and we will use the same concept in 2015. We are not the only ones to do it, but ours is the biggest and we are using it to cool two really key systems.'

Keeping cool

Cooling the new-for-2014 power units is no easy task, as demonstrated by some of the very public difficulties experienced by other, bigger teams. But the Marussia was, according to Greenwood, fairly strong in this department. 'The car cools well and the data we got from Ferrari was fine – no holes needed to be cut once the car started running,' he says. 'We worked massively hard on it, and everything has been evaluated in terms of downforce vs cooling. But we were slightly conservative at the start of the year so had to work on things to bring back downforce at the expense of cooling.'

While it could be expected that the turbocharger itself would be the most taxing part of the power unit to cool – especially as it is buried deep in the bell housing region between the V6 engine and the transmission – Greenwood claims that other areas were a headache for Marussia. 'One of the biggest challenges was the amount of electrical boxes – there's a huge number of them with these power units, and cooling them is a big deal. The turbo is a factor too, but we have not really been involved with that as it is very integrated with the engine and gearbox.'

All of the different subsystems of the power unit have meant that the car needs a large number of heat exchangers, many with differing demands and locations. For efficiency reasons, the MR03 has not placed them all in the sidepods of the car, unlike some of its rivals. Nonetheless, the sides of the car are still exceptionally crowded. 'The sidepods are clearly different from side to side – there's a lot to package in there like intercoolers, watercoolers, oil coolers and gearbox coolers,' adds Greenwood. 'There are coolers for the hybrid system, including the energy store and both MGUs, and all of them require different types of cooling. Aerodynamically the sidepods have very similar performance, then it's just differences on how it's laid out.'

With the cooling issue largely solved, Greenwood, chief designer John McQuillam and the rest of the Marussia team looked at ways of improving performance, especially with the power unit, and in some areas that actually means reducing some cooling.

'Some of the electronic boxes were over-cooled, so we tried to find ways of reducing that and getting some performance back. But the big task in the season was the mapping,' Greenwood claimed. 'When I say that, I do not mean the engine mapping specifically, but rather the way that the ERS is working, the diff and the general torque mapping for driver demand. We collaborated with Ferrari on that and it's a big area of performance to unlock. That's what we concentrated on mid season.'

As the MR03 uses the Ferrari carbon fibre transmission, it shares its inboard suspension pickup points and turbo housing with the Ferrari F14-T as well as the Sauber C33. It is the first time a Marussia – or Virgin – has used a composite main case, but it has not provided many challenges for the team. 'It is identical to the casing used by Ferrari,' says Greenwood. 'We bought it from them and then from that point we add our external and internal suspension. But it's not something where we have had to do anything different due to the change of material – all of that work is done by Ferrari.'

Single 'Y-lon'

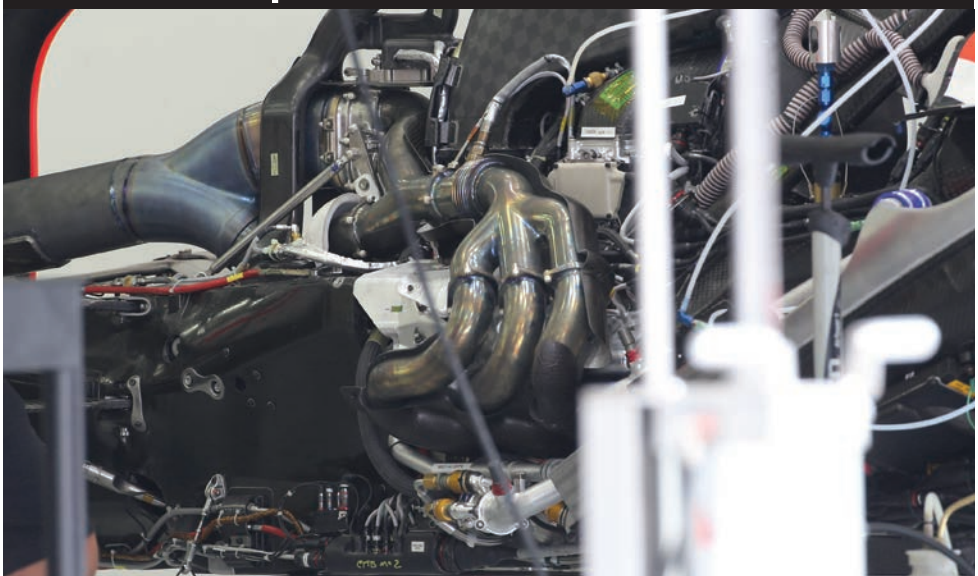
One area where the Marussia differs to the other two Ferrari-powered cars in 2014 is the rear wing support. At the opening races of the year, both the Sauber and the Ferrari used near-identical twin pylons, but the Marussia had a single pylon which split at the base to allow the exhaust to pass through it, then attached to the same mountings on the top of the transmission casing that the other two cars use.

'We term the rear wing support a Y-lon, as it is an inverted Y in shape,' says Greenwood. 'We evaluated all of the different options – both single and twin pylons – and found that this was the best compromise in terms of structural support for the rear wing and minimum impact un the underside of the rear wing.' Interestingly, McLaren independently developed a near-identical concept, and at the Spanish Grand Prix – doubtless inspired by its customer – adopted a layout very similar to that of the MR03, other teams have adopted similar designs too.

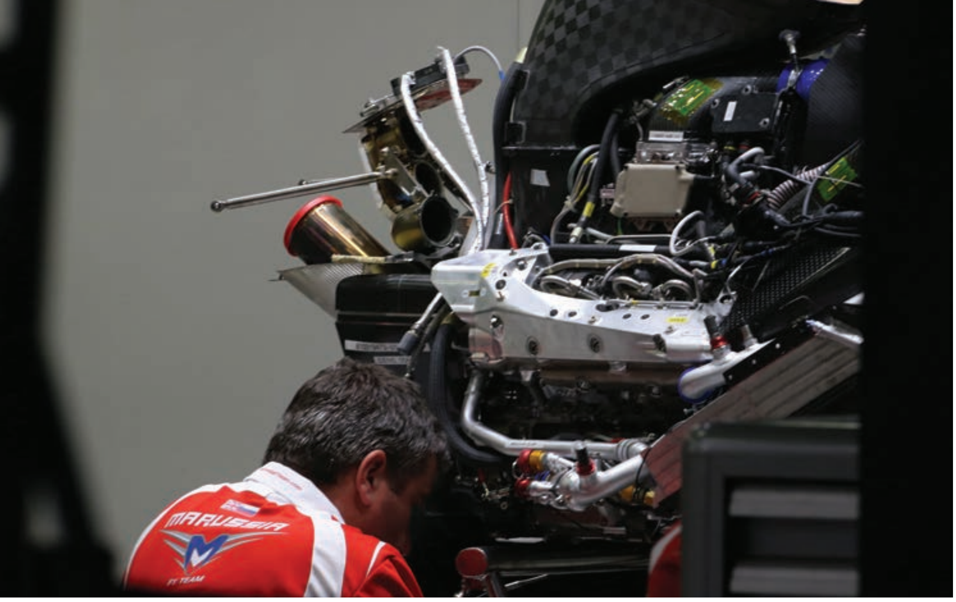
But while the inboard rear suspension is largely defined by the transmission supplied by the Italians, things are different at the front. The MR03 is unique in modern top level car construction in that it features a metal front bulkhead – everything else in F1 and LMP racing has a carbon fibre front. It houses the inboard suspension pickup points, steering racks and master cylinders as you might expect.

'We realised that we could get a much better designed car, which was lighter, stiffer and had better tolerances with a machined bulkhead,'

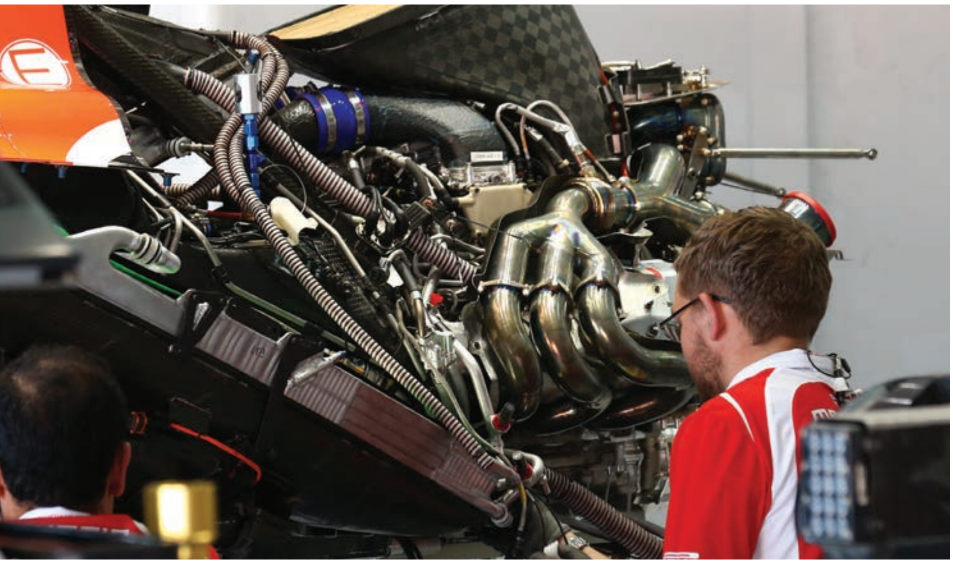
Downstream split



Pictured above is the rear end of the MR03 with bodywork and heat shields removed. The exhaust layout is of particular interest – the headers curve around the cylinder head, and then join together in a collector (one on each side linking three pipes). Downstream of the collectors, the pipes then split in two. The Ferrari turbocharger is reportedly split in a similar – though less extreme – way to the Mercedes design, with the MGU-H sat between the two sides of the turbo. The pipes heading down to the turbo can be seen here. The other pipe heads upwards to a unit thought to be the wastegate. The left bank pipes enters this housing at its base, while the right bank enters it above. A single exit pipe joins with the pipe leaving the turbocharger.



The Ferrari 059/3, 1.6-litre V6 engine, which has a single turbo



The rear end of the MR03 with heat shielding and transmission removed – many interesting things to see here

says Greenwood. 'It's machined from billet, then bonded to the chassis. It's not that complex and it's a nice solution. It's not something we will move away from any time soon either. Doing the bulkhead this way has solved a lot of little issues. When you have carbon parts with inserts, you can always have annoying issues as time goes on, but when you do this it all goes away. We did not found any weight penalty either.'

The joys of spring

At the top of the bulkhead between the torsion bars, a spring damper unit can be seen mounted across the car. This unit plays a key role in the car's suspension layout. 'It is no secret that everyone on the grid has an interlinked suspension system that incorporates Cambridge inerters front and rear,' says Greenwood. 'The way you get all of those elements working together is a way you can get performance. It's not just ride-driven either – it's about securing the best aero platform too, the way you can move the car through the aero maps.

'You find a spot where the car has the most downforce and that's where you want to run it as much as possible. Then you have the way that the car shifts going through a corner, and the way you make the suspension work is to optimise where the car is in terms of ride height. That unit combines lots of elements you would normally separate, and it allows us to have something that gives us gains in ride and aero performance with as little weight as possible.'

One of the few things carried over from the 2013 MR02 is its reliability, which saw rookie driver Max Chilton finish every race of the season, a trend he continued into 2014, though the run was eventually broken.

'Reliability has been the strong part of the car,' says Greenwood. 'I think we are pleased with the design from the car weight point of view. We hit our targets, we have had a few non-finishes in races, but they tend to be for accident damage rather than unreliability. Reliability has been strong with both the power unit and the chassis.'

Lighter weight

Weight has been a major problem for some cars on the grid in 2014, notably the Sauber C33, which although mechanically is very similar to the MR03, was overweight at the first races of the year. Greenwood, however, reveals that this has not been a problem for Marussia, or rather it was one that the team solved before the season.

Stopping the MR03

In Formula 1, most teams use friction material from either Carbon Industrie or Hitco, with a few – including Marussia – also using Brembo when the situation demands. In theory this means that the braking of the car should not really be a factor, but the introduction of the new hybrid power units in 2014 has raised a number of issues with a car's braking system.

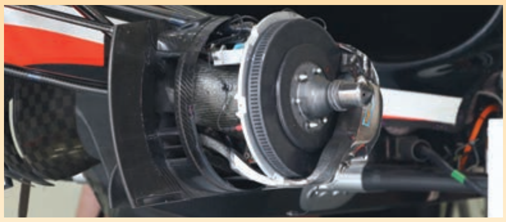
'There are big elements to what is going on in braking with us,' says chief engineer Dave Greenwood. 'There is the pure generation of braking torque, by which I mean the front axle that is totally driven by the brake disc and caliper. The material is something we look at and experiment with different suppliers. We work a lot with one supplier in particular and develop some of their products so we are totally happy with that element.

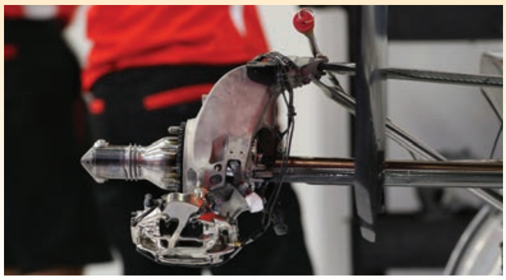
'On the rear axle, however, the brake torque is generated by the engine, the brakes and the MGU-K. That's much more complicated, and the control of the rear caliper is determined by the brake-by-wire system. There are a lot more elements to getting the braking right this year compared to 2013, and the control systems related to it are very complicated. In the early part of the season we struggled a lot with it, but so did many other teams.

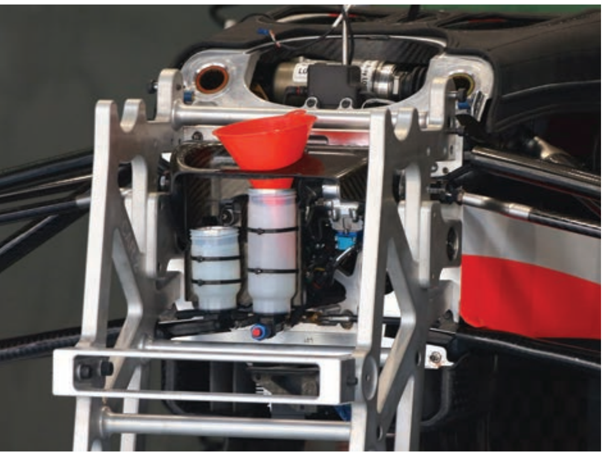
'We improved it a lot at the Bahrain test, but it remains a major area of focus.'

One of very few areas of modern racecar design that there is not a particular trend on is brake caliper position. On the rear of the MR03, the caliper sits at almost the lowest possible point, but at the front it is mounted at the rear of the caliper rather than at its base. 'I don't think you will find a consensus on where they should be positioned,' says Greenwood. 'It's something of designer preference. Mounting at the base of the disc gives you a lower cg, and they are striving to always go in that direction. But there is the factor of ease of use to consider too. You need to be able to bleed your brakes, your bleed nipple needs to be a high point and a very low slung caliper is harder to bleed.

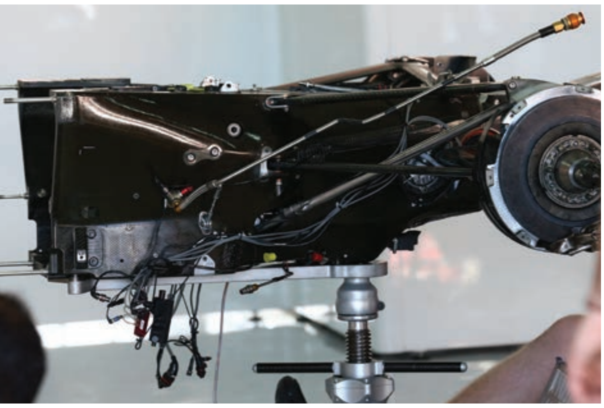
'But the bottom line is that it is something that the designers do when they are creating the upright and working with the caliper supplier. Aerodynamically, the way you do the internal ducting inside the drums is also something that is looked at, and these things are getting more and more complex, but that development has a lot of effect. We do a lot of work on the brake dyno, and it's a much more repeatable process than using the car at a test.'





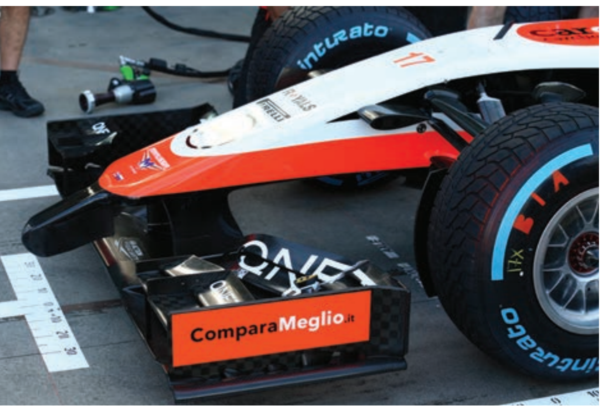


The front bulkhead is machined from billet, unique in current top level racecar construction. Note the spring damper unit between the torsion bar holes



The Marussia shares its transmission with the Ferrari F14-T and the Sauber C33. The MR03 is the first car with which Marussia has used a composite main casing

Close-up view of the Y-lon rear wing support



The nose is defined jointly by regulations and aerodynamic demands

'Normally when you talk about reliability, you talk about weight as well,' says Greenwood. 'Generally speaking, lighter components are less reliable, so we have achieved reliability with the car on the weight limit. We are where we want to be, and that's testament to John McQuillam, [deputy chief designer] Rob Taylor and the gang of designers have done a great job from that point of view.'

In 2014, as in previous years, the weight distribution of the cars is tightly restricted, something that was originally introduced in 2011 to ease Pirelli into F1 as the sole tyre supplier, but the regulation has remained even though the car weights have changed. This means that this season every car must have a weight distribution resulting in no less than 319kg on the front axle and 375kg at the rear. With a minimum weight of 691kg, this gives teams just a 7kg window to work with. Meanwhile, with the number of coolers fitted to the cars, it is inevitable that they will be unequal in weight side to side.

At the weight limit

'At the moment we don't look at side to side weight distribution at all,' says Greenwood. 'Generally weight is such a challenge with these cars, you would balance the car left or right for each track if you could. But this year it has just been about getting things to the weight limit. With this year's car it's been hard to get there because there was no data to go on, and as a result it was something we were very worried about during the build.

'Ultimately we have been fairly successful. The weight distribution is roughly where we wanted it to be, though there is always some room for improvement. One thing you don't want to do is add weight to get to the distribution window and we have not had to do that, so that's good.

'We are at the minimum weight at the end of the race. Next year's car design was much easier because we knew what we had in reality and not in the virtual world as was the case with this one.' It remains to be seen if that design will ever be constructed.

But the MR03 dropped out of the 2014 championship not only ahead of rivals Caterham but also ahead of the Sauber team. 'The aero performance of the MR03 is not bad, and we are strong in certain places – especially high speed corners,' says Greenwood. 'But we were not getting the benefit of the aero in low speed corners. It is a problem that is exaggerated by a related issue with the car's stopping power. We felt that braking is one of the big areas that we needed to concentrate on – all the team in F1 now have GPS allowing them to look at all of the other cars. That is an area where we were poor. We looked to find gains – there is significant lap time to be had there, and if we had found those gains than we should have been be regularly in Q2.'

TECH SPEC

Chassis construction	Carbon fibre composite
Front suspension	Carbon-fibre wishbone and pushrod suspension elements operating inboard torsion bar and damper system
Rear suspension	Carbon-fibre wishbone and pushrod suspension elements operating inboard torsion bar and damper system
Wheels	BBS
Tyres	Pirelli Fronts: 245/660-13 Rears: 325/660-13
Brake system	Carbon/carbon discs and pads with rear brake-by-wire system, AP Racing
Steering	Marussia F1 Team-desiged hydraulic PAS
Fuel system	ATL Kevlar-reinforced rubber bladder
Electronic systems	MAT SECU TAG 320/Scuderia Ferrari
Seatbelts	Sabelt
Engine	Ferrari 059/3 1.6 litre six cylinder single turbo. V6 90 degree. Bore 80mm, stroke 53mm, 4 valves per cylinder, 500 bar-direct injection
ERS	Battery energy per lap 4MJ, MGU-K power 120kW, MGU-K max revs 50,000rpm, MGU-H max revs 125,000rpm
Dimensions and weight	Overall width: 1800mm Wheelbase: 3700mm
Radio	Riedel

The car's aerodynamic deficit in low speed scenarios also has a factor in the braking performance. 'These cars are different to what we are used to aerodynamically and while we are happy with downforce in high speed corners, we had a lot to do in terms of generating downforce in the braking zone.

'We lost the effect of exhaust blowing, so we are working to get more downforce in that area – it has an impact on how we perform on track too. Monza, for example, was not a great venue for us, but Barcelona with lots of medium and high speed corners was better – it's the aero dominated circuits.'

The Marussia MR03 was perhaps the strongest car yet produced by Formula 1's failed new teams experiment. The obvious deficit in resources has led to a equally obvious deficit in on-track performance, which is why the team's management were keen on the introduction of a cost cap.

While there are still discussions ongoing about saving the Marussia team (renamed to Manor Grand Prix) the reality is that the Marussia MR03 will only be seen on the grid in 2015 as the basis for another team's design, perhaps that of the new Romanian Forza Rossa team.

Back in the mix

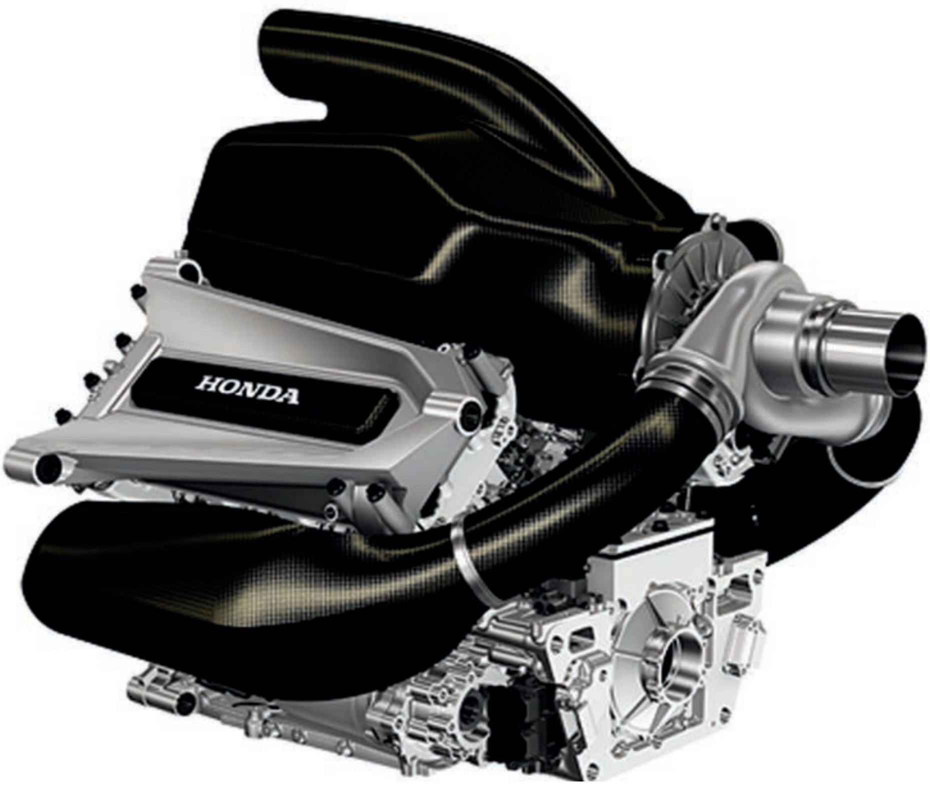
Honda is on the brink of its F1 2015 return and the firm has a clear eye on a long-term future this time around

By SAM COLLINS

Honda's return to Formula 1 in 2015 is a project that has a long-term future, with the company's chief officer of motorsports promising that there is no exit strategy under consideration.

The engine, currently under design, will be tested for the first time over the winter, in the back of a McLaren MP4-30 as the company chases track time compared to its rivals. While Mercedes, Ferrari and Renault all have a season of data under their belts, Honda is starting from scratch. Some may say that puts them at an advantage, with performance targets already established, particularly in the tricky area of cooling, but the company itself says that the 2015 season will be one of catching up.

'I don't think coming late gives us an advantage having seen the others, in fact I think it's a disadvantage,' says Yasuhisa Arai, Honda's chief officer of motorsports. 'We don't have any kind of track test data. Just imagine the difference between track and dyno, all those tiny things. We need that race track data. It is a big disadvantage for us.'



Honda's new power unit. Like all of the current F1 generation it is a turbocharged 1.6-litre V6 engine with direct injection, with a pair of motor generator units and an electrical energy store

> "It is a new F1 era for Honda, but we never refer to it as a Fourth Era... this suggests that it will end at some point but we will never stop"

For Honda, its return to Formula 1 means much more that perhaps it did in the past where it was primarily a technical exercise to improve the understanding of the firm's engineers. This time round it is a key part in attempting to restore faith in a brand that has lost its sporting reputation. 'In Europe fans believe that Honda is a sporting brand and with the launch in 2015 of some very sporting road cars they will tie in perfectly with Honda's engagement with Formula One. We will use Formula 1 as a catalyst to deliver the message that Honda is building very sporting cars again,' Arai concludes.

Fourth era?

Honda's return to Formula 1 was first revealed on the *Racecar Engineering* website in late 2012, and, when the project was formally announced the following spring, the provisional projects started some time earlier took on new impetus. 'We announced the project in May 2013, and the real work started just before that,' explains Arai. 'We have only had one year and a half of work on the project, we have really been pushing, pushing, pushing. It is always the Honda way.'

The 'Honda way' has been a part of Formula 1 since 1964, when the Japanese marque entered its first grand prix. When that project started the engineer appointed to head it did not even know what F1 was. Over the next five seasons the Japanese engineers learnt a lot and the brand took two grand prix victories before withdrawing following the 1968 season.

That period became known internally as the 'First Era Formula 1 activity'. It was followed in 1983 by the 'Second Era' where Honda returned to the sport as an engine supplier, eventually leading to that famed partnership with McLaren and four back-to-back world titles, to add to the two it already had with Williams. During this era, Honda built a number of its own Formula 1 cars in secret but never raced them and has only shown them off in public in recent years. Honda again left the sport at the end of the 1992 season, drawing the era to a close.

Honda kept its toes in the water via its founder's son's concern Mugen, which supplied engines to a variety of teams, notably Ligier and Jordan in the 1990s, but its return proper came in 2000. It should have come in 1999 with a Harvey Postlethwaite penned Dallara chassis but that project collapsed following the designer's death. Honda then partnered with, and later acquired, the BAR team but after years Honda only had a single win to show for its substantial investment, and in the economic downturn of 2008 it decided to quit Formula 1. This period is known as the 'Third era', and the development of the engine is covered in RE V24N10.

The firm's return to Formula 1 in 2015 could then be considered as the 'Fourth Era' but Arai strongly rejects that title for his group's new activities. 'It is a new era for Honda, but we never refer to it as the Fourth Era,' he says forcefully. 'After 2015 we are continuing our Formula 1 race activity forever. To call it fourth era suggests that it will end at some point, but we will never stop.'

Honda revealed the first renderings of its new power unit shortly before the 2014 Japanese Grand Prix. Like all of the current generation it comprises a turbocharged 1.6 -litre V6 internal combustion engine with direct injection, along with a pair of motor generator units and an electrical energy store. Arai admits that some of the technology featured on the new power unit has been developed over a number of years. 'After 2008 we did not focus directly on Formula 1 technology but we did work on developing the high pressure direct injection technology for racing and worked hard on turbochargers. We also looked at building small-displacement, high-output engines. So yes we continued after we stopped Formula 1 activity in 2008 but the work was not specifically focused on Formula 1.'

Using some of that learning, Honda rolled out a World Touring Car Championship engine (which was never meant to be used in competition) and its new GT500 power unit. Both feature elements of the current grand prix power unit concept, the latter of course, being a hybrid.

Hybrid secrets

The unit bolted to the back of the McLaren MP4-30 (the power unit actually debuted at Silverstone in November in an MP4-29) will not be Honda's first hybrid Formula 1 design. Right at the end of its so- called third era activities Honda designed and built its first hybrid Grand Prix car. Based on the 2006 Honda RA106 chassis the first test mule took to the track in an open test at Jerez in 2008, data from that was used to improve the hybrid system both in terms of the energy storage and MGU-K.

A near complete hybrid system was fitted to a 2008 spec RA108 chassis and was on the way to its first full test session (after limited shakedown runs) when Honda announced its withdrawal from Formula 1. At this point the Honda RA109 had been subjected to its mandatory crash tests, something that was a major undertaking as the car had an unusual energy storage layout with the batteries mounted at the front of and underneath the front of the monocoque. The RA109, which had been designed to be a hybrid from the outset, was never officially completed or tested on track, though some of the design and aerodynamic data was used to create the Brawn

"Some of today's staff don't have that racing experience. It's sort of half and half between those who have F1 experience and those who do not"

Some say that in starting again from scratch in F1 Honda – with performance targets already established, particularly in the difficult area of cooling – has the advantage over other teams but the company denies this

In Honda's second F1 era it had no major involvement in chassis development. This is something it hopes to repeat in the current era, leaving chassis work to its partners and focusing on integration

BGP001, which dominated the opening races of the 2009 world championship, and took both titles at the end of the year.

Since then, Honda has not attempted to race a hybrid of its own design at international level, despite the substantial investment that it made in 2008. The GT300 and GT500 specification cars racing in Super GT as well as the Super Formula hybrid prototype all use systems supplied by Gibson (nee Zytek) rather than technology developed in-house.

But the skills gained during the Honda F1 hybrid research project of 2008 have not been forgotten according to Arai, and they have been employed in the development of the new power unit. 'Some of the people from the old Formula 1 activity came back but the new regulations required very different skills. It was not just about internal combustion engines but also hybrid technology too. Some of the staff today don't have that racing experience. Its sort of half and half between those who have Formula 1 experience and those who do not,' he admits. 'I think there is a big difference between the 2009 car and its hybrid system and today, the technology has moved on but we do have some staff that worked on that so they have some idea of how the integration works. But the technology now is quite different and the new system is far more sophisticated.'

Return reasoning

The new regulations, which are focused on efficiency, are one of the major reasons that Honda returned to Formula 1, along with the fact that a brand built on its racing heritage needs a major international racing programme. But it also hopes that some of the lessons learnt in its F1 activity will feed back to the cars in the showroom. 'The power unit technology is not something we can immediately transfer to production,' Arai admits candidly, 'but maybe the experience we gain with things like the MGU-H can feed back to production cars in the future. However, looking at it the other way round we have good experience in the production car hybrid technology area and we are feeding that into the racing programme. That is a big advantage for our F1 programme.'

To facilitate its new operations Honda has constructed two new facilities specifically for the development of its new Formula 1 power unit. The design and manufacture will be moved from Honda R&D's well-established headquarters at Tochigi, Japan to a new base nearby at Sakura City. A second, smaller facility has been constructed in Milton Keynes, England, which is shared with Mugen Euro.

'We have not moved yet, we are just starting to move now. We have had to build up new techniques, and new tools for development at Sakura City, but its something of a secret exactly what,' Arai continues. 'We do have engine dynos as you would expect, there is a wind tunnel there but its not for racing, more for mass production work. We also have a design room there and machine shops but it is not that big.

'Everything on the power unit will be made at or near Sakura City, all the design work and testing will be done there. The Milton Keynes facility is small, it's just some dynos and offices, its for the people who go to the track to support the power units really, just to do document work. The complete power units will generally be shipped from Sakura City direct to McLaren, only if something happens at the track, something goes wrong, will the power units go to Milton Keynes to be checked over.'

Honda's most successful era in Formula 1 was its second, in partnership with Williams and McLaren, when it had no major involvement in chassis development. This is something it hopes to repeat in this new era, leaving all the chassis work to its partners. 'We have no plan to do chassis things again, but we work closely with McLaren, and there's a lot of discussion going on. The integration of the chassis and power unit is the most important thing, because you need good aerodynamics,' Arai says. However with the futures of a number of grand prix teams far from certain, rumours of a second Honda-backed team refuse to go away.

'It is a good question whether or not we will have a second team in Formula 1, but unfortunately it seems that nobody is interested in our power unit,' Arai reveals. 'The reason for that I guess is that its an unknown, they don't know the performance it has, so they are cautious. I don't have any kind of offers at the moment, we are open to a second team. Our contract with McLaren means that the power unit is exclusive to them in the first year but in 2016 we are open.'

A lot of attention is focused on the potential performance of the new Honda power unit. Arai and his engineers are playing their cards fairly close to their chests, but there is no sign of any panic, rather a perhaps not so quiet confidence. 'Maybe after Melbourne many teams will want our power unit, that's what I expect,' smiles Arai. 'Overall the development is on schedule, the numbers we have achieved are what we expected and there is much more to come before the homologation deadline.

'We are really pushing hard and I hope next season the performance we have is much more than the other top teams and at Melbourne I hope we are sitting at the front of the grid. We are confident.'

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