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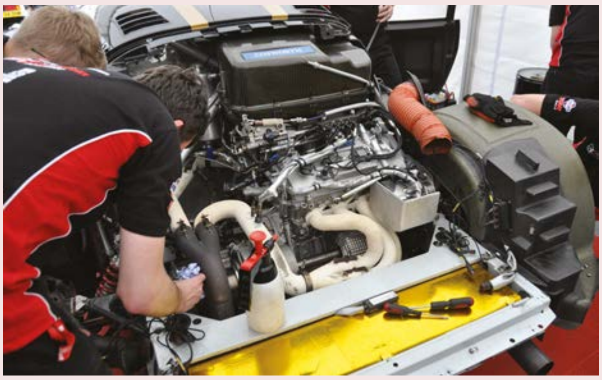

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# From belly flops to pit stops

Having to work through February, I was unable to join the family on the school half-term holiday and so contented myself with sitting at the computer during the day, and watching the television in the evening. I ended up at two favourites; *Impractical Jokers* on Comedy Central, and *The Jump* on Channel 4. The first involves four friends setting each other embarrassing tasks and getting filmed doing them. It's funny in a very schoolboy-humour way. One of the tasks was to get Joe to interrupt a diving competition, and belly flop his way through it. The dramatic change in skin colour front compared to back was noted after about five dives. 'We should probably only make him do one more,' one of his friends said.

*The Jump* involves a group of celebrities taking part in winter sports. The elimination round at the end of each programme, a ski jump onto an air-filled cushion, is almost redundant as the celebrities withdraw due to various injuries. A British Olympic gymnast had to have vertebrae fused after one accident, an Olympic swimmer dislocated her shoulder. An actress dislocated her elbow. I started out wondering how they got the idea past the lawyers, and finished up applauding them for being able to do so.

Why this as a topic this month? Well, it all links to the latest measures suggested to improve the F1 'show'. Television is presenting an open goal, and racing is reacting by discussing the optimum shape of the ball. The proposals laid out are, I am sure, based in logic, but from the outside I can't fathom it. A 'Driver of the Day' may get people voting, but how? Will the audience telephone a premium hotline and pay for the right to take part (*ker-ching!*), or will it be a free vote? Will there be the obligatory 15-second delay between 'and the winner is…' and announcing the recipient of the award? On a more important note; why do this in the first place? If you want the drivers to be heroes, unleash them to speak …

And now, in a bid to spice up Saturday, the most sensible qualifying system introduced to racing is about to be made vastly more complicated. There will be a careful eye on the clock; after seven minutes the slowest driver is eliminated. And, thereafter, every 90 seconds the same until the chequered flag. The commentators will have their work cut out as some drivers will be out on track with a shout of making the 90-second cut to start the lap, and others won't.

**The pits have become a place where Gucci is commonplace, rather than oil and grease**

Somewhere along the line, F1 has seemed to have lost sight of what sport actually is. In these pages Peter Wright explains how F1 could rescue itself aerodynamically, and we will in the coming months *Racecar* will look at Formula 1's proposals for its next generation cars in greater detail. But I think F1 has some far more serious problems.

The decision-making processes are taking F1 so far away from what it should be that I do start to wonder; what is the ultimate goal? VW has once again delivered its verdict on the category – that F1 is not stable enough to warrant the investment needed to succeed. Alfa Romeo on the other hand is looking to go in, although it could develop Ferrari's F1 technology to compete in the WEC.

We are also a world away from the days where every penny earned was spent on the car. The pits have become a place where Gucci is commonplace, rather than oil and grease. When a racing car is fired up the guests are forced out, their eyes streaming from the fumes, this is an unwelcome surprise for them. It shouldn't be.

There are huge technical advances that are being proven in motor racing, yet Formula 1 is not celebrating its successes. Instead, it appears to be focussing on the negatives. Actually, it seems to be focussing on the populist vote, rather than the sporting one. Its solution to dropping audience figures is to change the product, not to adapt to the way it is watched and embrace the internet, following NASCAR's model.

And, I believe that racing is missing the key factor; this could all be irrelevant in our lifetimes anyway. Driverless cars are going to go on trial in the UK, sooner rather than later. The rise of the machines won't stop at the UK borders. How manufacturers will market and sell cars will change dramatically as the Uber-style system takes over and our purchasing habits change from buying cars to buying time in cars. At that point, what happens to the marketing element of racing? I reckon it will need to go back to the pure element of sport to survive.

We need to remember why motor racing started in the first place. One fella says to another; 'mine's faster than yours', and the race is on. It is simple, and we don't need to over-complicate the process. Appealing to the television audience, and then reaching that audience, is important to finance the technology, but I would argue that it is a secondary requirement, not a primary one.

**ANDREW COTTON**
Editor, Racecar Engineering

## CONTENTS




The revived Manor F1 team has produced its first new car for two years, the MRT05

# Regulation issues

## Some of the sporting regulation changes for 2016 are likely to have a big impact on the F1 teams

**By SAM COLLINS**

Formula 1's rulebook is a major topic of speculation, negotiation and uncertainty at the moment. But shortly before Christmas the FIA did release the latest set of sporting regulations, which contained a number of areas which impact the design and operation of the cars.

One major area which has changed substantially for some teams is aerodynamic development operations. While the restrictions on tunnel occupancy remain much as they were in 2015, with a maximum model size of 60 per cent and a max wind speed of 50m/s, there have been clarifications on what counts toward the CFD. In 2015, restricted flow only counted if it was used on a full size F1 car, but in 2016 the wording has been tightened to count any 'representation of a F1 car or sub components' though engine simulation remains unrestricted.

In the wind tunnel, operations has changed slightly too, with teams now required to take two digital photographs of the working section (including the model) before each run. The pictures have to have a date stamp and show the complete model clearly (hence two pictures, front and rear quarter views). These pictures must then be supplied along with the various other data to the FIA technical department.

Wind tunnel operations have also changed for teams in 2016 by a rules clarification issued at the 2015 Abu Dhabi Grand Prix. During the season Mercedes had become rather concerned about the relationship between Haas and Ferrari. In the end Paddy Lowe wrote a long and detailed letter to Charlie Whiting about the legality of the situation. Whiting passed the responsibility of making a decision on the issue to the stewards at the Abu Dhabi race. The main points of Lowe's queries were as follows: could Haas F1, as a non-competitor, share data with Ferrari, and could it share design and development staff with Ferrari?

The answers from the Abu Dhabi stewards were clear. Under the rules as they are written, Haas could indeed share data with Ferrari, as at the time Haas was not a Formula 1 competitor and, as the testing could be deemed to be of benefit to both Haas and Ferrari, and not exclusively for Ferrari, then that too was permissible. Sharing staff was also permissible, though Haas could not simply use Ferrari's designs for its cars in 2016.

**It will now be possible for older power units to be re-homologated and used by customer teams**

## Prancing Haas

For 2016 only, the rules have been clarified and Haas can no longer share data with Ferrari, but at this point in the development of both the Haas and the Ferrari the work is all finished and the cars have now run. It also means that Haas and Ferrari can no longer share staff and this may include the head of the Haas aero programme Ben Agethangelou who still lists himself as a Ferrari employee on his Linkedin profile (though the team insist that he is a full time Haas staff member). Staff will now have to pick which team they are working for and if they want to switch from one team to another they must take a minimum of six months gardening leave. How this, a race stewards' decision, sits with employment law in the European Union is not clear.

Power units is another area that was in the spotlight at the end of the 2015 season, not least due to the somewhat self inflicted situation that the Red Bull teams found themselves in. In the past, manufacturers could only homologate a single specification of power unit a year (Manor was allowed to use the 2014 Ferrari unit under a waiver agreed by all teams). That has

While tunnel time limits remain much the same as in 2015 the F1 teams will be required to provide the FIA with date-stamped digital photography of wind tunnel testing this year

now been formalised and it will now be possible for older power units to be re-homologated and used by customer teams. Toro Rosso is the first team to do this and will use a 2015 Ferrari unit while Haas, Sauber and the Scuderia will use the 2016 version of the PU.

As we closed for press discussions about using only three units per season from 2017 were very much ongoing, but in 2016 teams will be allowed five units per driver due to there being 21 races on the calendar. This is an increase from the four allowed in 2015 when there were only 19 grands prix, and it is also a notable decrease in the required life expectancy of each power unit – something which might well come as a relief to some. However, to other engine builders it might well mean the return of one-race performance specials.

Homologation deadlines will also create something of a voyage into the unknown for the power unit manufacturers, the confusion caused by the omission of a power unit deadline in the 2015 rules, which led to in-season development being allowed, will not be repeated.

Modifications for safety, cost and reliability can still be made and in-season development

**One area which has changed is aerodynamic development operations**

## Tyre rules

For 2016 new tyre usage regulations will be in force in Formula 1, along with a new 'ultrasoft' compound. The new rules are intended to give teams more freedom in strategy and allow for less predictable racing, at least in theory.

Before each race Pirelli will select which three tyre compounds to take to the track and let the teams know what is on offer. The Italian firm will then nominate two mandatory sets of tyres for each car for the race itself, obviously being the same for all, though only one set of the two has to be used in the race. One set of the softer compound tyres will be reserved for use in the final segment of qualifying.

Beyond that the tyre usage becomes free with teams able to select whatever compound they want within the three nominated by Pirelli for each weekend. However, the teams have to make this tyre selection eight weeks in advance for European races, so that they can be produced in time. If a team misses the deadline the FIA will make the tyre selection for it. That selection deadline is extended to 14 weeks in advance of a flyaway race, so teams needed to select tyres for the opening races before Christmas for Australia, something which might have proved tricky considering none had actually run a 2016 car, and one team, Haas, had never run an F1 car! Total amount of tyres used per weekend (13 sets per car) remains unchanged.

**F1 winter testing began on 22 February, yet design dossiers for the power units had to be submitted to the FIA by 14 February, which meant the PU designs had to be signed off before the engines had run on a circuit**

within the token system will continue and is now officially part of the rules.

For 2016 the homologation deadline for power units came on 28 February (one suspects here that the FIA perhaps did not remember that 2016 is a leap year), and design dossiers had to be submitted two weeks prior to that (yep, on St Valentine's day).

The trouble with this was, winter testing did not begin until 22 February, meaning that the power units had to be signed off before they had ever been run on track.

The loophole which in the past would have allowed a power unit supplier which was not also an entrant, Renaultsport, Honda or arguably even Mercedes HPP, to have used an old car to run on track outside of the usual restrictions had been closed. Now the testing ban applied to not only teams but also power unit suppliers and 'third parties'.


**The tyre usage regulations have been changed for 2016 with the hope of spicing up the show with less predictable race strategies**

# Born in the USA

**Bringing a new team into Formula 1 is the toughest job in the sport, but Haas F1 believes its unique approach can help it succeed where others have failed**

**By SAM COLLINS**

Gene Haas has always done things a little differently, rarely following a path just because it is the one most trodden. He built up his eponymous machine tool business exactly this way, looking at his competition and working out what not to do, and as a result created a range of lower cost, easy to use designs.

Now Haas has decided to bring this ethos to grand prix racing, gaining an entry into the Formula 1 World Championship with an all new American based team. It is of course not the Californian's first foray into motor racing, his NASCAR team (co-owned with Tony Stewart) has won the Sprint Cup twice and is one of only four teams to have won all of the three major NASCAR championships.

But in 2010 F1 discussions started between Haas, Joe Custer (then the VP of Stewart Haas), and Gunther Steiner, the Italian former Red Bull Racing technical director who in recent years has run a composites business in North Carolina. The strategy they came up with was that Haas would launch his own Formula 1 team, but not in the same way as the likes of Caterham, Marussia and HRT.

'When we first started discussing this project four or five years ago I told Gene that you cannot do everything from scratch,' Steiner reveals. 'At the time the new teams were racing and all struggling and I told Gene "they will never catch up". F1 is such a high technological level it was always going to be impossible for them. Just to get where the others are will cost you billions and takes five to ten years, not one or two. An OEM maybe could do it but if an OEM came in they would buy a team and not start from scratch, perhaps Porsche is the exception with its WEC programme, but even they would struggle as it's such a big step from LMP1 to F1. I don't think Audi could do it because it's not all in house, they use a lot of contractors.'

By 2014 the trio soon felt that they had a workable business model and lodged an official application for entry into the 2015 World

Haas quickly deferred the entry to 2016 as the team, and indeed the regulations, were not quite ready for what was planned

Championship season. This was accepted but Haas quickly deferred the entry to 2016 as the team, and indeed the regulations, were not quite ready for what was planned. Steiner by this point had been appointed team principal and Custer chief operating officer.

## Regulation changes

But it was some quiet changes to the F1 regulations that really got the ball rolling. 'We are not starting from nothing, our mechanical parts will come from Ferrari, our approach is completely different to everyone else,' Steiner says. This is because F1 teams had had to be full constructors and this meant that they had to use a bespoke chassis, front impact structure, suspension, suspension geometry, radiators, bodywork, steering system, brakes, floor and fuel tank. But a very quiet change to the F1 Sporting regulations at the start of the 2014 season changed what it meant to be a F1 constructor. The 2014 definition allowed teams to buy everything but the chassis, front impact structure, suspension, suspension geometry, brake ducts and bodywork. In 2015 the rule changed again to remove the requirement for teams to design their own suspension, suspension geometry and brake ducts.

Haas is so far the only team which plans to fully exploit these stealthy rule changes via a partnership with Ferrari, which sees the Italian company supply the newcomers with not only power unit and gearbox, but much more.

'We have the front suspension, rear suspension, hydraulics, steering, electronics all from Ferrari. Radiators we have to do as that is classified as bodywork apparently,' Steiner admits. 'We are using these things to focus on the overall car design, why make an effort to do our own damper or something when we can just get them from Ferrari? They [were] second in the championship and have won races, so we know that they are fine. We will have everything the same as Ferrari in 2016.'

All this means that the Haas team has

Haas has succeeded in business by doing things his own way – now he's hoping that approach will pay dividends in Formula 1


Gene Haas has already tasted success on the race track with the crack NASCAR operation that he co-owns with Tony Stewart

The Haas factory is in the very heart of NASCAR country in North Carolina, next door to the Stewart-Haas team. It's located very close to the Charlotte Motor Speedway and the Haas-owned Windshear wind tunnel


As befits a Formula 1 race team owned by a successful businessman, the Kannapolis premises are plush. Haas also has an in-season European race team base at the old Marussia factory at Banbury in the UK

focussed all its design efforts entirely on the bodywork and chassis, hugely streamlining the process of designing and constructing a modern grand prix car. Steiner continued 'We were focussed on the wetted surfaces, cooling system and the chassis.'

The design and construction of the chassis would become a joint project between the Haas engineers and the staff of Dallara in Italy. 'Dallara was a good choice for us because we massively reduced the ramp up time, they were already 80 per cent there,' Steiner says. 'They have very good people there like Andrea Vecchi who are not only engineers but very good project managers.'

## Italian connection

But to say the 2016 Haas VF-16 is a Dallara would not be correct, this project is very definitely being run by the Haas engineers. 'We have blended our people with Dallara's because you cannot do everything from scratch, it takes time to build things up, to do it from scratch you would have to put in IT infrastructure, HR, hire the right staff, but Dallara already has all of that,' Steiner says. 'I have known Dallara for years and I know the strong points of the company as well as the weak points. Dallara's engineers have not been exposed to proper F1 for some time and they accept that. So we use their, infrastructure, engineers and designers as well as putting our own highly experienced people in there like Rob Taylor [who worked with Steiner at Red Bull in 2006]. Rob is the best lead designer you could ask for, he is calm, very intelligent and listens to everyone. He is sitting at Dallara directing the guys there and managing the car design.'

The aerodynamic design has a similar set-up but the choice of wind tunnel was not a straightforward one for the new team, Haas already owns the vast 180mph full scale moving belt Windshear facility in Concord, North Carolina, once often utilised by F1 teams but deemed illegal some years ago. Now no team may conduct wind tunnel testing at more than 60 per cent scale. Steiner and his newly appointed chief aerodynamicist, Ben Agathangelou, had to find a suitable facility. One early idea was to adapt Windshear in order to accept 60 per cent models, but converting the huge working section designed primarily for NASCAR racing to something that would meet the demands of F1 would be difficult.

'Adapting it, we knew you could do it, you could put a sting in like a normal tunnel, but it would be very big, or change the scales under the belt, it was all doable, but would have to still be adaptable to NASCAR as that is the main business there. That switching was one of the concerns, it was possible but at what price, and what risk? We felt it was just easier to do a 60 per cent model and go somewhere designed for model testing. We are developing a racing car, not a wind tunnel, so we decided not to adapt Windshear for the time being. Maybe in a few years we will look at it again.' So the hunt was on for a suitable tunnel, and that meant looking beyond the USA.

'We could have rented Dallara's tunnel but it

Pristine race bays awaiting the first 2016 chassis back in 2015. These have a heavy Italian influence, with Dallara design input and plenty of parts supplied by the Ferrari F1 operation

Haas made a fortune in CNC so it's no surprise there's a well-equipped machine shop. A big 5-axis machine specially designed for the team has been installed

While there is plenty of meeting space at the US headquarters Haas F1 has invested heavily in state of the art video conferencing kit so that it is able to keep in touch with its team in the UK

There were just eight people working in the Kannapolis machine shop when we visited the site in the summer of 2015. Stewart-Haas shop next door is also used

is only 50 per cent and we wanted to test at 60 per cent. Ferrari had capacity so we decided to use it. We plan to continue like this for the next two three years.' One major factor in choosing to use the facility at Ferrari was that Agathangelou had recently overseen its modernisation. A few of the Italian based Haas staff are based at Ferrari but the main bulk are to be found at Dallara.

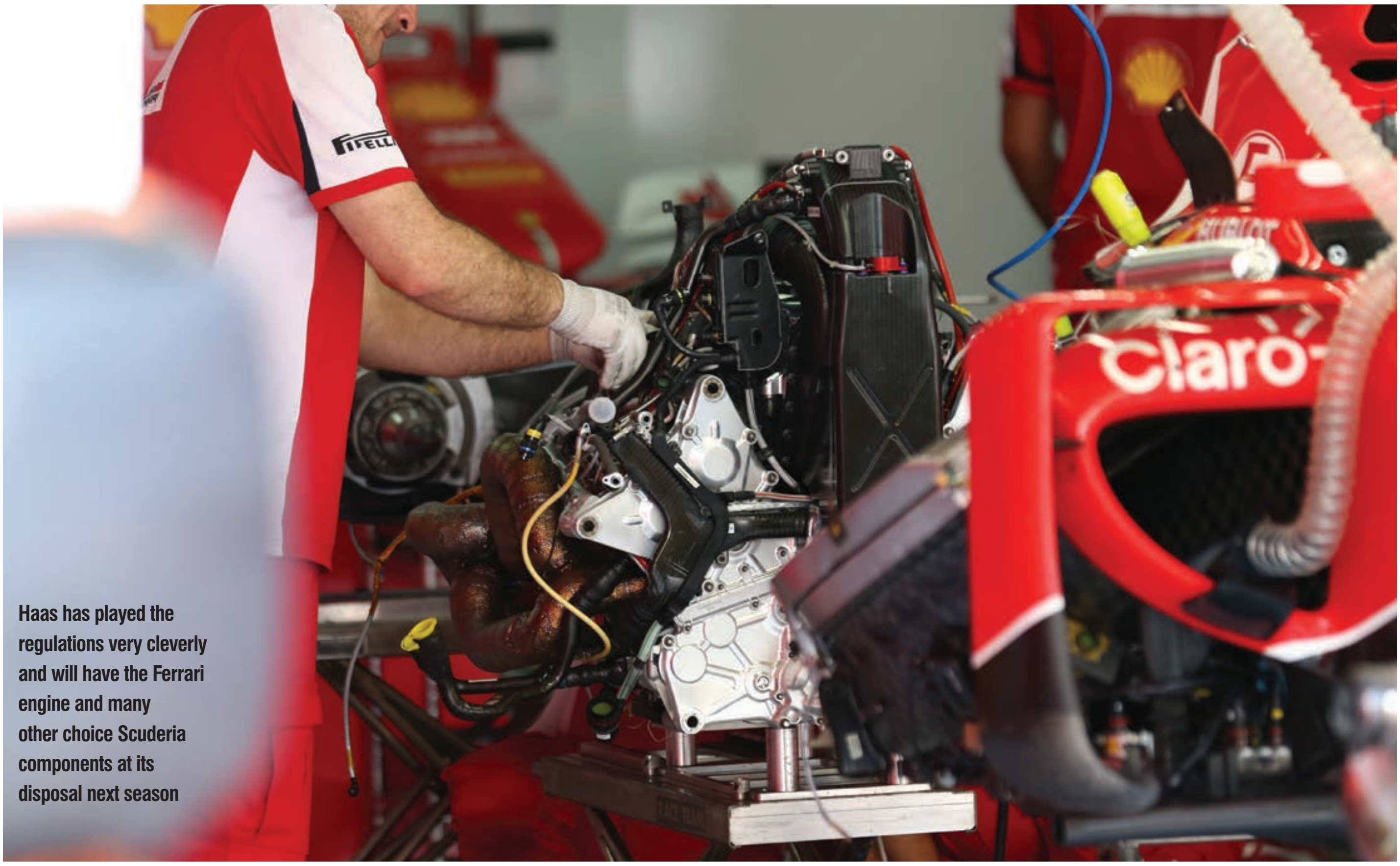
## Home base

However, the entire team was not to be based in Italy, the organisation's main base would be in a large purpose-built facility next door to the existing Stewart-Haas NASCAR team in Kannapolis, NC, and it is clear that the plan is for the entire design and manufacturing operation to move into the new factory. It has been deliberately designed with redundancy so that as the team expands its US staffing level and manufacturing capacity it already has the space waiting. This includes a space for a full composites facility including mountings for the autoclaves and a clean room. However, for at least 2016 and probably 2017 the composites work will be done in Europe. 'We are prepared to do all the composites in house, but it's difficult and you have to only take on what you can manage at first.' Steiner says. 'We already have the rooms set aside and laid out and we could put the machines in but you still need the people. It's very difficult to find good composites people in the USA, it took me years to build up my company Fibreworks, and the last thing I want to do when setting up a new F1 team is set up another composites shop from scratch. Dallara are very good at things like wings and deflection because they have to do it on other projects all of the time. They own a composite manufacturer so they can produce what we need and they are very good at that. So we will have most of the composites done in Europe and focus on the bits we are good at like machining and fabrication.'

Indeed, for Haas the machining and fabrication is an obvious point of focus, when

Gunther Steiner, pictured left in discussion with team owner Gene Haas, is the technical director at the Haas Formula 1 operation

**Haas is so far the only team which plans to fully exploit these stealthy rule changes, via a partnership with Ferrari**




Haas has played the regulations very cleverly and will have the Ferrari engine and many other choice Scuderia components at its disposal next season

*Racecar* visited the facility a large new 5-axis machine was being installed, a prototype specifically designed for the team. In another area a large machine shop kitted out with the latest Haas CNC equipment was working on car parts and pit equipment. It is complemented by the equally well-equipped machine shop next door at Stewart-Haas Racing.

'The guys in the machine shop are primarily working on parts for the wind tunnel model' Steiner says. 'I think about 50 per cent of the parts on the model are made here, all the metal components, while all the SLA [3D printing] parts are done at Dallara. [In 2016] we will make 100 per cent of the scale model parts here, but right now Dallara has eight SLA machines and we are waiting to install our first. We made the pit equipment here and filled a shipping container with it all. We make all that kind of stuff here, USA is the home of fabrication. Making this stuff in the USA is much cheaper than in Europe. It takes about two days to ship the parts from here to Dallara so we know that something that if you were doing in Europe would take four days, we would take five instead as it takes two days rather than one to ship. But we know that and factor that into the production schedules.'

In the plush design offices on the first floor of the new factory much of the space is unoccupied, but will rapidly fill as the team grows. 'We have about 20 people in the CFD group at the moment by [2016] that will be about 20, right now the main engineering work we are doing here in Kannapolis is the CFD. I think we have about four Phds in the CFD group at the moment' Steiner claims. The group of CFD engineers are disarmingly young, many of them relatively recent graduates, but this is something Steiner sees as an advantage. 'We do have a lot of young guys in the team, but for CFD especially there are no old guys who know the cutting edge technology. These guys are scientists really and therefore it's a good thing to have the CFD here, they don't need the big Formula 1 experience they just need to be clever people that know how to use computers and understand physics.

## Young talent

'We have bright people here from good universities, we think actually it's better to have them here so we keep them out of the mainstream of CFD in F1, and we are doing some very interesting and different things in that area. I expect we will reach the maximum allowed next season, we are doing some heavy stuff already. At the moment we can do what we like, the usage restrictions do not apply until next year so we are doing a lot of stuff.'

Here the links with the NASCAR team start to become apparent, while the engineers do not work on both, an experienced engineer from Stewart Haas is playing a key role. 'That CFD group is run by Matt Borland, who was the technical director at the Stewart Haas NASCAR team for a long time, he is responsible for managing the knowledge transfer between the two. Technical approaches and methodologies things like that,' Steiner explains.

The CFD cluster used by Haas F1 is not located in the USA and this highlights how misfortune for some can be good fortune for others. The collapse of the Marussia team in late 2014 came just at the right time for Haas F1 which was not only looking for a cluster but a European base of operations for the racing team, the near demise of the then Russian-branded Manor operation gave Haas both of the things he was looking for. He acquired the former Marussia HQ in Banbury and some of the equipment within.

'The designers and the wind tunnel programme are in Italy and the race team is in England. We have the CFD engineers here in the USA but the cluster is at Banbury. Marussia had quite a good cluster, quite new as they had to replace it about nine months before the team collapsed. It was very difficult to take out the cluster and re-install it somewhere so

**To say the 2016 Haas is a Dallara would not be correct. This project is very definitely being run by the Haas engineers**

# Complete vehicle system simulation

**Using physical modelling tools to simulate the complete vehicle leads to a better understanding of the system behaviour and interactions enabling system level optimisation.**

As the complexity of today's vehicles increases due to hybridisation, more advanced driver assistance systems and many other active systems it becomes increasingly important to be able to simulate how the complete vehicle system behaves and interacts. Using simulation from the start of the project enables design decisions to be influenced and optimal system solutions to be found.

As the complete vehicle system covers many different domains including mechanics, electrical, thermal, fluid and control we need to use system level modelling and simulation tools that can create predictive models covering all of these domains.

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Using Dymola, Claytex has produced complete vehicle system models for studying engines, drivelines, vehicle dynamics, thermal management, hybrid technologies and body systems. These have been applied extensively in Formula 1, NASCAR and IndyCar enabling the teams to evaluate and optimise new technologies and ideas before arriving at the track. In motorsport these models are deployed in the design office, integrated into the trackside tools and telemetry systems and used for HiL and DiL testing.

**Right:** The show car is actually a 2013 Marussia bought at the auction at which Haas also acquired its UK team base
**Below:** The VF-16's testing programme was hit with technical issues but the team managed to turn a respectable 474 laps, while its speed seemed to suggest it might run in the midfield



we decided to leave it where it was. We have since put in MPLS lines between the sites we are using, and while it costs quite a bit it means we have very fast data transfer. We have also invested quite a lot in video conferencing between the facilities, it's much better to see people than just on the phone. Especially when its all new and you need to get to know the people you work with' Steiner says.

Beyond housing the cluster the Banbury facility is to be used primarily as a base for the new racing team and it does not have any kind of manufacturing capabilities, though it does have some inspection areas and non-destructive testing equipment.

Some may believe that the new definition of a F1 constructor being used by Haas is some way down the slope towards full customer cars, but Steiner argues that it is still a major piece of engineering and it is an efficient way of going racing, right in line with the philosophy of Gene Haas: 'Our approach is different but could be copied and that could be good for F1,' Steiner says. 'We don't want to buy our way to success, we have a fair budget but we are trying to do things the most efficient way, not cheap, not low budget but efficient.

'Sometimes that means doing things outside of the box. Gene Haas has based his whole business on being efficient. It's not just about throwing money at it and if it does not work then we are bankrupt in three years as others have done before it is about spending the money wisely.'

With Ferrari supplying much of the 2016 Haas car it perhaps could be expected that it could be rather more competitive than the cars of other new teams in recent years, and Steiner makes it clear just what the team's own performance expectations are. 'I don't want to make big claims because we will be judged on the race track not before. In the first year we are not out there to beat Ferrari or Mercedes, that's not our target. But it's important to say we do not want to be last. I'm not going racing just to be there, just to be in Formula 1, and nor is Gene. Our aim is not just to participate, for us our aim is to get points, to be competitive. To win is difficult and will take time but to get points that is what we must do.'

Testing was mixed for Haas, and while it looked good at the start the usual teething problems soon caught up with it. Even so, it managed 474 laps, which isn't bad, and looked quite fast, too. Indeed, going into the Australian GP many expected that Haas could get those targeted points at the first attempt.

**'Testing was mixed for Haas, and while it looked good at the start the usual teething problems soon caught up with the new team'**

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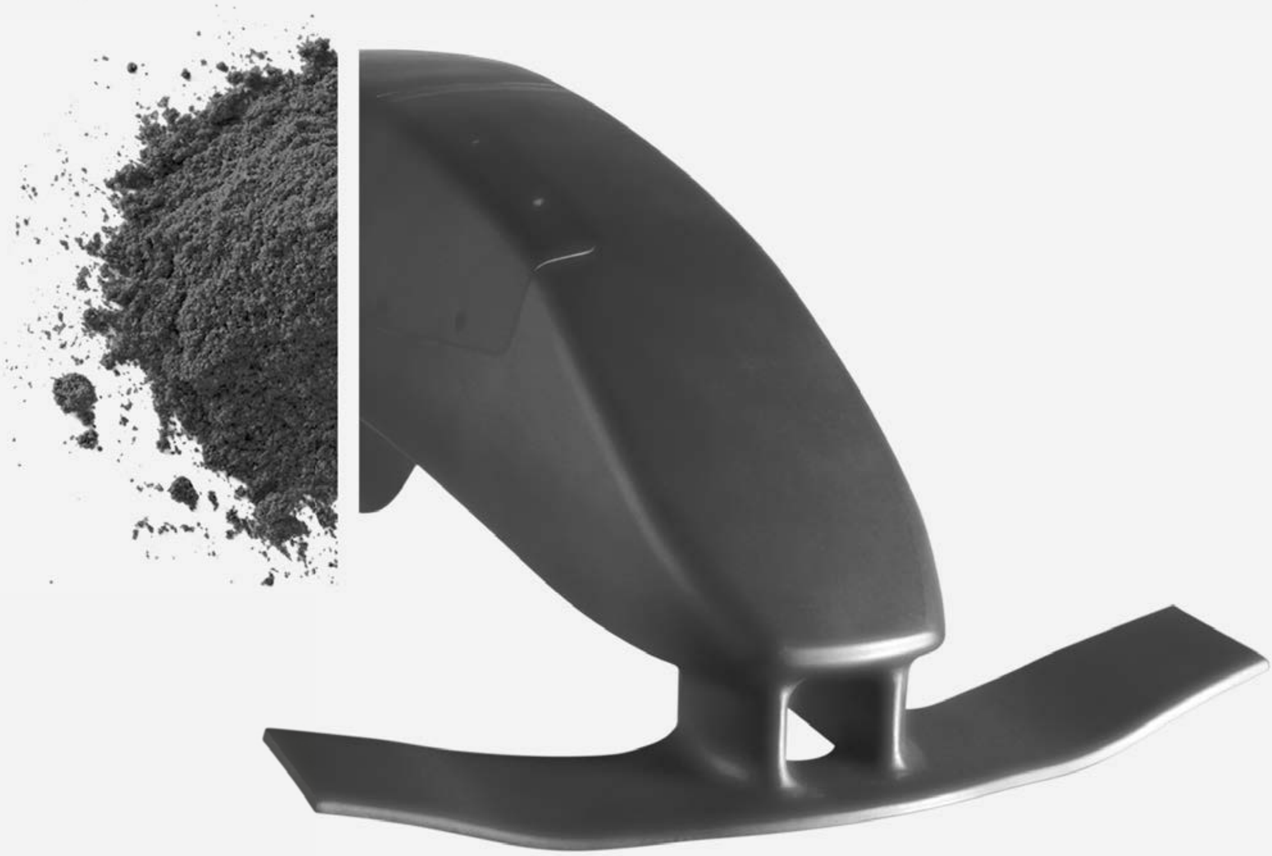

**F1 front nose:** Aerodynamic application for F1 wind tunnel.

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# The grid of the future

## Ever wondered what the top motorsport series would look like in 10 years' time? Here's one very carefully considered opinion

**By PROFESSOR STEVE SAPSFORD**


**Motorsport might look very different in the future and autonomous vehicles will surely play their part**

Many in the motorsport industry will be familiar with the motorsport technology roadmap, an attempt to map out the future technology requirements for the motorsport industry given the drivers from the regulators, the fans and the requirements of the associated automotive industry. At the MIA Energy Efficient Motorsport Conference, Chris Aylett (CEO MIA), asked me to go a step further, and predict what the grid of the future may look like, across a variety of classes of motorsport.

I was initially asked to look at the potential grid in both five and 10 years' time, but I quickly came to the conclusion that five years hence was too soon for any meaningful changes to be implemented, so I settled on 10 years.

The main purpose of the roadmap is to predict the technologies that will be required in order to help guide investment decisions regarding technology and product development. So, one method of predicting the future should be to draw a line down the roadmap (**Figure 1**) at 2025 and read off what it says. However, I did not force myself to follow this process religiously as this does not take account of disruptive policy changes or technologies – some room for independent thinking and incorporation of new drivers or technologies was allowed. However, please note that this analysis is predicated on the existing dominance of internal combustion-based powertrains, and so most comparisons are drawn from this position.

There are two main routes towards low carbon vehicles **(Figure 2)**; improve overall vehicle efficiency and reduce the amount of carbon in the fuel. For the first of these, the main focus is on downsized, boosted engines combined with hybridisation supervised by intelligent and integrated control systems.

The second method focuses on reducing the amount of carbon in the fuel, either through the use of low carbon electricity or the generation of synthetic fuels. The important point here is that it is not simply a universal move to electric vehicles. When assessing the total environmental impact, one must also take into account that the electricity and its storage (batteries, capacitors etc.) has to come from somewhere. This is a critical consideration when calculating the overall vehicle life-cycle which needs to include the carbon involved in fuel/energy production, vehicle production, through life usage and, eventually, recycling.

In this exercise I have considered four categories of motorsport, all with slightly different drivers, and then tried to determine what I think will be the main features of the propulsion system, transmission and driveline system and the energy recovery/storage. I purposely confined my analysis to the powertrain and only highlight the potential impacts of those systems on the vehicle.

So, to the grid (**Table 1**).

**Audi's experimental e-fuels are likely to be developed and proven in the motorsport arena**

### Formula 1

The powertrain is already highly integrated, so I expect this to continue. There is potential to reduce engine capacities further so it would not be surprising to see 3- or 4-cylinder engines coupled with more powerful electric motors and/or flywheel-based technology

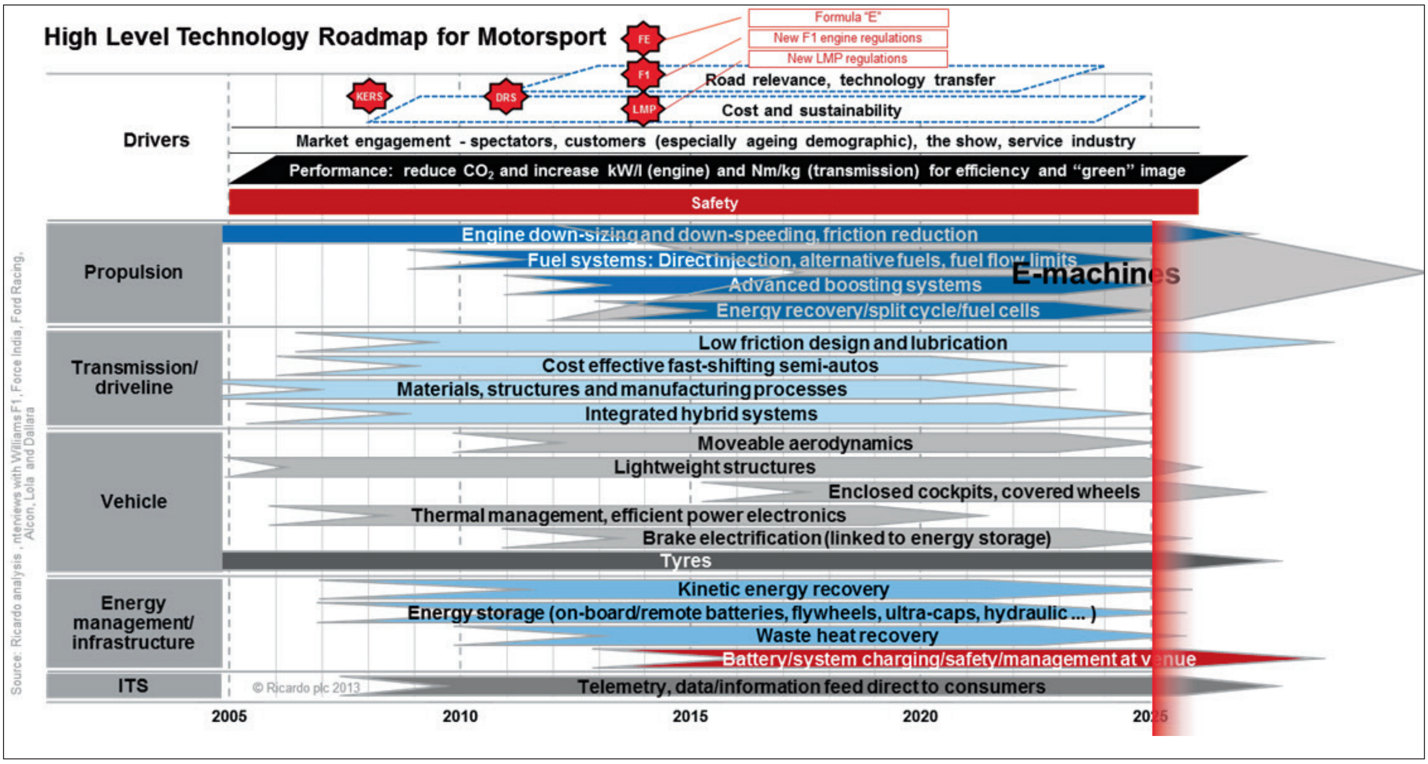


**Figure 1: Motorsport Technology Roadmap and potential technologies in 2025. The Roadmap is an attempt to map out the future technology requirements for the motorsport industry**

**World Touring Cars and other tin-top categories will continue to follow the lead of the road car industry**

**Split cycle engines could drive thermal efficiencies towards 60 per cent in the less regulated WEC**

**The main focus for Formula E must be to complete a full race distance on a single charge**

for maximum efficiency. Reducing the carbon content of the fuel is one of the main opportunities for reducing CO2. So I am proposing here the use of synthesised fuel from sunlight or other renewable sources of energy. This process basically combines hydrogen generated by electrolysis with sequestrated CO2 to generate methane, methanol and other related fuels. Effectively this means that the CO2 released during the combustion process is mostly replacing CO2 you have already captured from some other process and combined with the hydrogen to generate the fuel, and so on. It should be noted that there are biologically-based processes that achieve the same effect but take the CO2 directly from the atmosphere.

Regarding the transmission and driveline, the focus will be on further light-weighting, perhaps using metal foam-filled gears which are encased in a hardened shell.

There is still substantial energy available to be recovered, but most of that is on the front axle, so I do not think it will be long before energy recovery through regenerative braking will be available through the front wheels, even if we are not allowed to transmit torque through them, for reasons of entertainment.

Waste heat recovery will still feature, although I do expect advances in this area, especially through heat-to-electricity technologies in the exhaust and cooling systems. More intelligent cooling will result in reduced requirements for heat rejection from the vehicle and hence reduced radiator sizes and associated apertures.

## World Endurance

With the freest regulations, we may expect to see more diversity in the technologies here. We will continue with similar powertrains but I would expect to see more intense integration of those systems and more aggressive use of disruptive technologies. For example, Ricardo is currently working on split cycle engines, where we use one set of cylinders for compression and another set for combustion, that could drive thermal efficiencies towards 60 per cent. If we imagine operating such an engine under a restricted number of speeds and loads and transmitting this power through a CVT and highly electrified drivetrain, substantial improvements in performance are possible.

Waste heat recovery and cryogenics are a natural part of these split cycle engines and so these technologies would be exploited, too.

## World Touring Cars

This is included primarily to force us to think about costs. With the focus on downsized, boosted engines in production cars, it is not surprising that WTCC cars have moved to the same configuration as the base technology has become increasingly available and understood. If we project that model forward, I see a significant move towards 48V architectures for our everyday cars as inevitable, so why would we not expect to exploit this technology in even our more cost-conscious categories in the future? Powertrains will already have integrated starter/generator systems of 10-15kW and (relatively) low cost energy storage, so why not exploit/extend that to provide 'push-to-pass', 'fan boost' etc., and improve the engagement?

## Formula E

One of the main purposes of the motorsport technology roadmap was to align drivers from the motorsport sector with those of the

| | Formula 1 | WEC | WTCC | Formula E |
|---|---|---|---|---|
| Propulsion | • Fully integrated drivetrain<br>– 3 or 4 cylinder DI and heavily boosted SI engines (Miller-cycle)<br>– Electric motors/flywheels<br>• 100% biofuel or a synthesised fuel (from sunlight) | • Fully integrated drivetrain<br>– Electric motors/flywheels<br>– 3 or 4 cylinder DI and heavily boosted SI **split cycle or 2S engines**<br>• Single (or 3 mode) operating point for max. efficiency | • 3 or 4 cylinder DI and boosted gasoline engines<br>– E or hydraulic boosting<br>• BSG/ISG for electrical systems<br>• 100% biofuel | • Electric motors with no rare earth metals<br>• Liquid nitrogen cooling<br>– Improves performance, efficiency and life (super-conducting e-machines and power electronics)<br>– Boil-off keeps batteries cold |
| Transmission and driveline | • Lightweight (foam-filled gears)<br>• Even more integrated with propulsion system and chassis<br>• Rear wheel drive | • CVT<br>• eAWD with e-enabled driveline | • eAWD | • eAWD with distributed motors |
| | | It's more about torque control to the wheels through e-enabled drivelines rather than sophisticated transmission systems | | |
| Energy recovery and storage | • Combined kinetic and thermal energy recovery<br>– Re-gen braking on front wheels<br>– Waste heat recovery<br>• E-turbines<br>• Heat-to-electricity systems | • Multiple mode energy stores and system integration<br>• Waste heat recovery<br>– E-turbines<br>– Heat-to-electricity systems (high and low grade heat) | • Moderate, cost effective energy storage<br>– Advanced lead acid battery<br>– Hydraulic supercharging (re-gen through hydraulic pump) and carbon fibre tank | • Race distance on 1 battery<br>– Dynamic charging<br>• Fuel cell-based charging stations (pre-race)<br>– Low carbon $H_2$ |
| Vehicle | • Intelligent cooling<br>– Reduced radiator size and cooling drag | • Intelligent cooling<br>– Reduced radiator size and cooling drag | | • Reduced radiator size and cooling drag |

**Table 1: The grid of the future for various classes of motorsport**

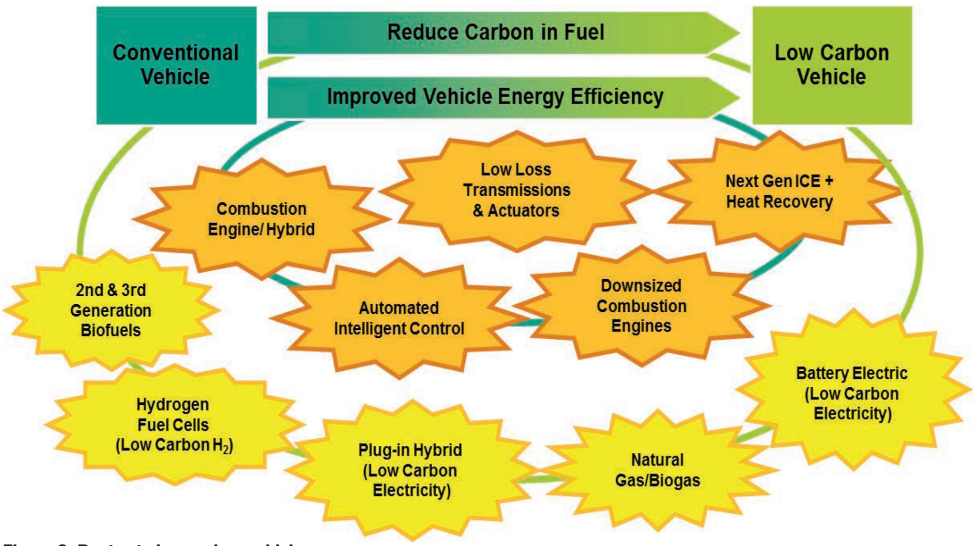


**Figure 2: Routes to low carbon vehicles**

automotive sector in order to ensure that road-relevant research and development was carried out. This was to encourage/ensure main vehicle OEM involvement in our sport. With the freedoms allowed in FE this season, teams are carrying out internal development programmes on, for example, electric motor design. In the search for ultimate efficiency and performance they are, of course, focusing on rare earth, permanent magnet machines. However, due to costs and security of supply, the automotive industry is focusing its efforts on the development of alternative motor technologies such as induction or synchronous reluctance machines. As a result, I hope that in the near-to-mid-term future, there will be some form of regulation that will encourage accelerated development of these alternative technologies such that these will be common place on the grid in 10 years' time.

That, coupled with the possible exploitation of superconducting materials enabled by a cryogenic cooling system, will enable significant improvements in drivetrain efficiency.

However, the main focus for FE must be to complete a race distance on a single charge. I suspect that this is less than 10 years away, but it is likely to require a combination of advancements in battery technology coupled with some form of dynamic charging. This is also where fuel cells may first appear in motorsport, as the basis of the initial charging system, if they are powered by low carbon hydrogen.

An important feature of the future drivetrain in many of our categories of racing will be the e-enabled driveline. With the increasing electrification of the powertrain generally, it makes sense to use the electric machines and control systems to manage the amount of torque delivered to each individual wheel, thereby creating e-AWD capabilities and reducing the requirement for sophisticated transmission systems.

The one subject we have not yet mentioned is that of autonomous vehicles. I am confident that we will see classes for fully autonomous racing in the not-too-distant future. However, I think some aspects of autonomy could easily stretch into other categories. Here I am thinking particularly of WEC, where we have different classes of vehicle racing on the same track, sometimes under difficult conditions (night, rain etc.). Autonomous driving under yellow flags would be entirely feasible, but inter-class accident prevention may also be possible, and this would provide an excellent platform for develop high speed vehicle-to-vehicle communications.

In this article, I have postulated some potential features of the grid of the future, hopefully with some reasoned arguments. The one thing I can guarantee is that I will be wrong! However, I still firmly believe that we all gain the greatest benefit when motorsport regulations are aligned with the technology roadmaps of the automotive industry. Motorsport is an ideal place to accelerate the development of relevant technologies that can then be used as a great showcase to firstly raise awareness, then enable acceptance, and finally stimulate demand for the cars of the future.

**Autonomous driving under yellow flags would be entirely feasible**


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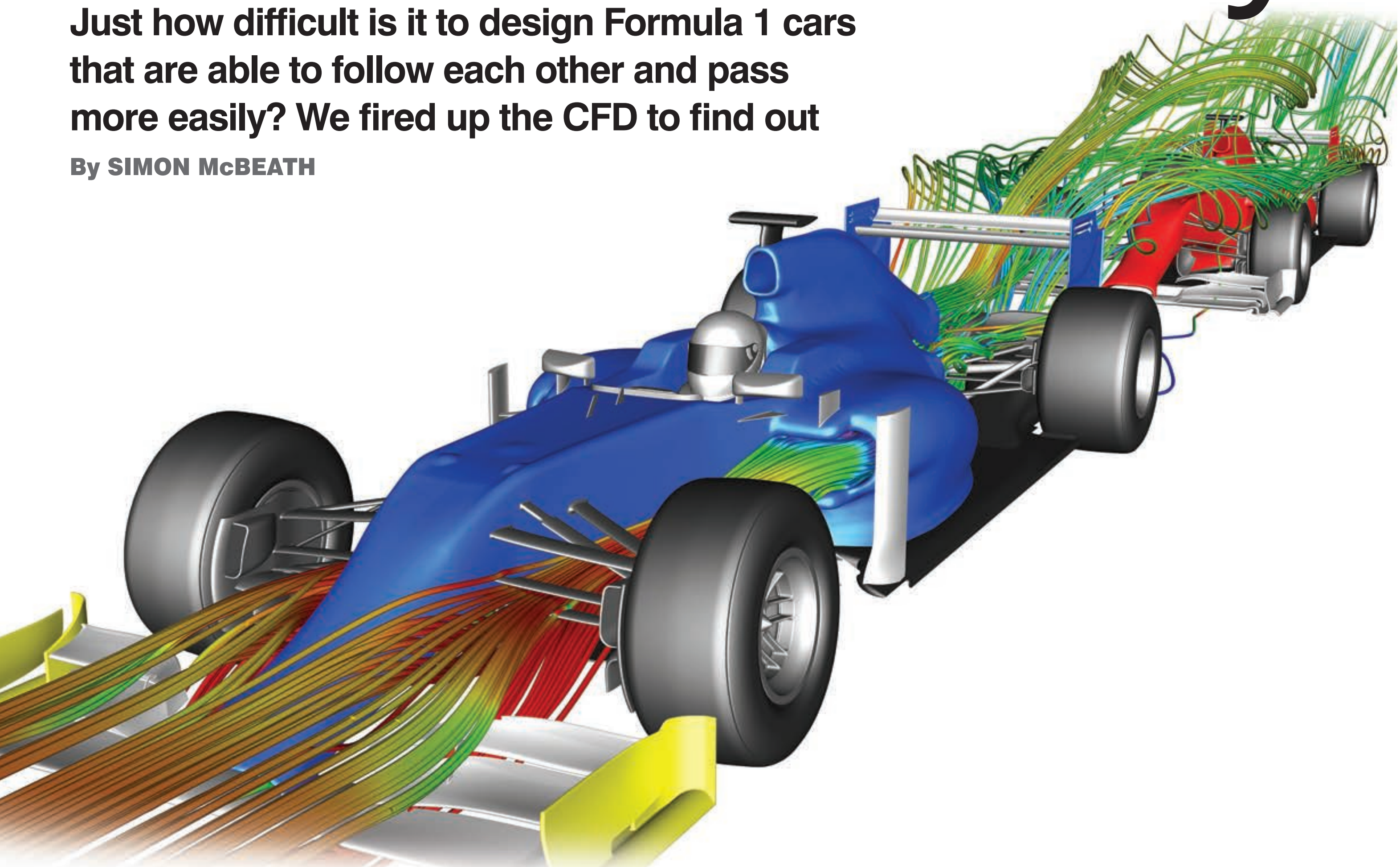
# Follow closely

## Just how difficult is it to design Formula 1 cars that are able to follow each other and pass more easily? We fired up the CFD to find out

**By SIMON McBEATH**



**Nothing makes a mess of air quite like an F1 car at full chat – as CFD spaghetti image of '2017' cars shows. This is why it's difficult for a car to chase another through fast turns**

Overtaking in F1 is not as common as many would like. But there seems to be widespread agreement that to increase the frequency of passing it is necessary to make it easier for following cars to be able to close up on the car in front.

Artificial aids such as DRS and differential tyre degradation aside, which have little to do with the execution of skilful overtakes, the issue relates particularly to higher speed corners where the aerodynamics play a large role in grip generation, since following closely on the straights (even without DRS) or in slow corners isn't a problem.

To get in position to execute an overtaking manoeuvre, by definition the following car must be close enough to the car in front in the first place, so the small extra advantage needed to draw alongside can then be implemented. The not unreasonable precept that follows is that if the cars could follow more closely on all, or at least, more sections of a track then more overtaking would result. Assuming the precept is valid, what needs to be done to achieve the aim?

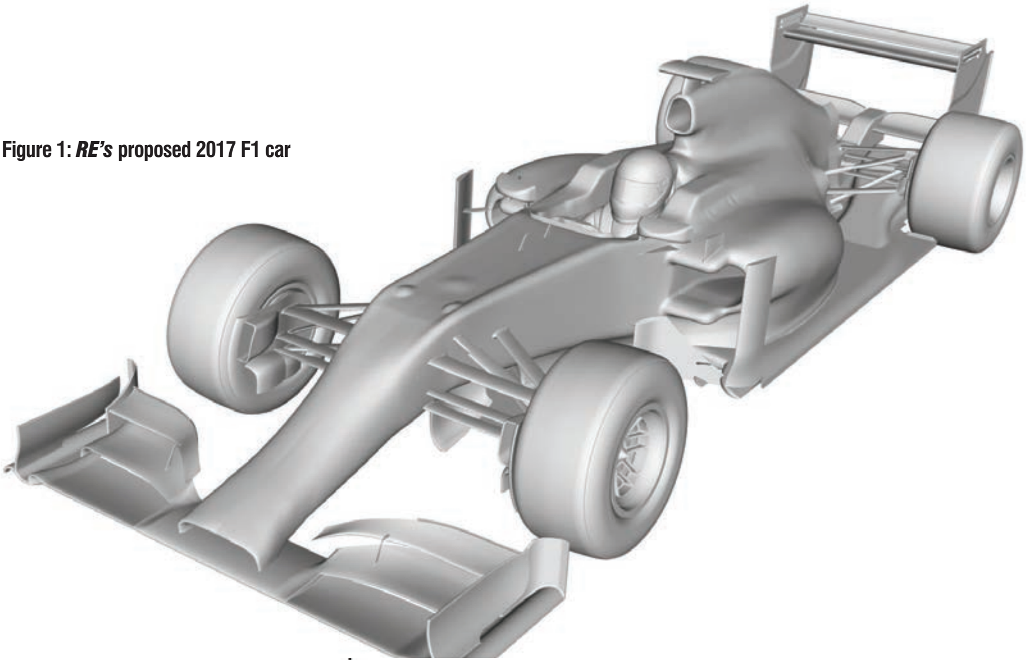
The problem is clearly a complex one if, after numerous attempts at solving or at least reducing it, artificial means such as DRS and tyres with limited durability were required to facilitate changes of track position to supplement overtaking events *per se*. Discussion in the sidebar (p61) highlights the various aerodynamic factors at which fingers are pointed, but loss of downforce and loss of aerodynamic balance on a following car are clearly uppermost. F1 seems understandably intent on maintaining high downforce, so mitigating the effects of its loss and its shifting balance on following cars is and has been the obvious focus of attention. This feature looks at the first iteration of a potential solution that would entail, in Formula 1 terms, very modest costs, and which, as promised in our last study, also sees greater emphasis on ground effects.

## First response

With such a complex problem the resources of an F1 team's aerodynamics department to study as wide a range of potential solutions as possible would be useful. Such is not the case at *Racecar Engineering*, but we are very fortunate to have the

**To get in to a position to execute an overtaking manoeuvre, then the following car must be close enough to the car in front in the first place**

Figure 1: *RE's* proposed 2017 F1 car



**The main aims were to increase the underbody's contribution to overall downforce and to reduce upwash in the wake**

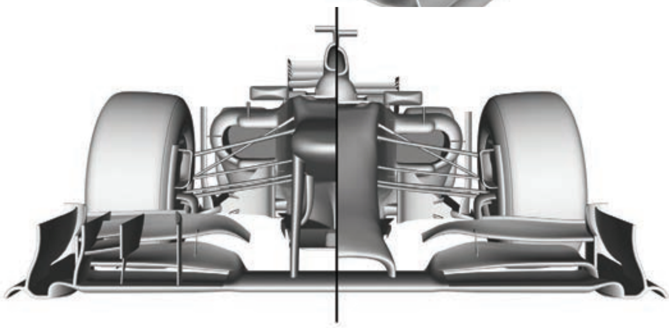


Figure 2: Differences between 2013 and 2017 car – the latter is right half of racecar

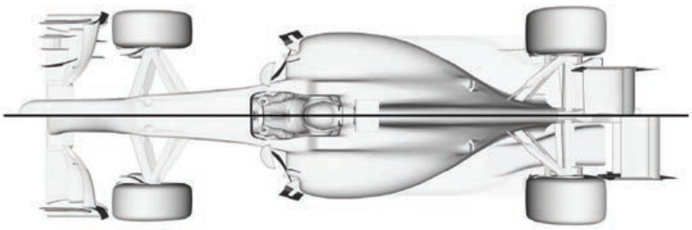


Figure 4: Bottom half of image is 2017 racecar

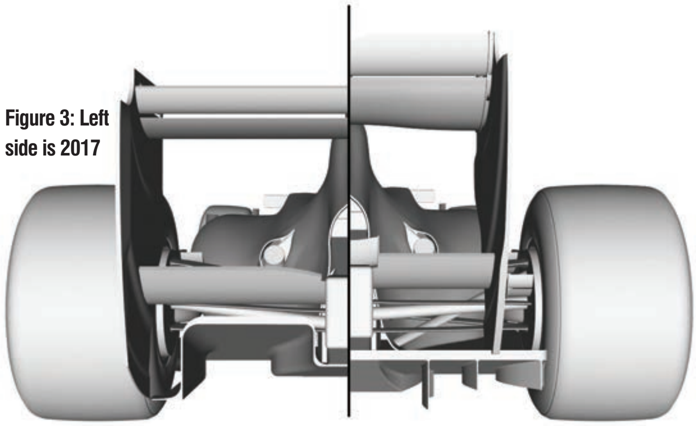


Figure 3: Left side is 2017

**Table 1: The aerodynamic data on the 2013 and 2017 F1 racecars at the same rake and ride heights**

| | CD | -CL | %front | -L/D |
|---|---|---|---|---|
| 2013 model | 1.173 | 3.89 | 45.0 | 3.32 |
| 2017 model | 0.96 | 3.95 | 45.0 | 4.11 |

resources and skills of Dynamic Flow Solutions and its director Miqdad Ali ('MA') to make some carefully thought through, selective studies on aspects that would seem to be likely contributors to the problem.

Regular readers will have seen the illuminating CFD studies that MA has carried out on a 2013 rules F1 car model using OpenFOAM CFD software in our July and October 2015 issues (V25N7 and V25N10). While working on these studies the idea occurred to MA that by using two of these 2013 models in line astern the current problem could be examined (2015 F1 cars are obviously slightly different to 2013 cars, but the basic problem appears to be ongoing), akin to the study in our October 2004 issue (V14N10) by Advantage CFD on a BAR Honda 002 F1 car. Furthermore, adaptations to the model would also enable alternative aerodynamic concepts to be studied and compared to the current situation.

For the study in this feature, MA's initial approach to creating an improved F1 car for 2017 was, he says: 'To make minimal changes to existing cars and get positive results. In our case it was a lowered nose (in line with 2015 safety thinking); a simplified front wing; a smaller rear wing moved rearwards and downwards; the floor step plane was lowered from 50mm to 25mm above the reference plane; the diffuser outlet area was doubled and the length increased; the beam wing was moved backwards; and 25mm side skirts were fitted on the underbody side edges.'

In greater detail the key changes involved are as follows:

- **Front wing was simplified, number of elements kept to three and central neutral section retained. Span kept the same (as 2013) and height above the ground was the same as before; however, its height was different relative to the step plane by 25mm.**
- **Rear wing span increased to 1000mm with a less aggressive profile and camber to fit a (smaller) 290mm x 110mm side elevation box, and it was 170mm lower than before and 250mm rearwards, measured at the flap's trailing edge.**
- **The underfloor had a 25mm step compared to 50mm before, hence the sidepods were 25mm lower, lowering the CofG. The diffuser outlet was twice the size of the current diffuser and was 980mm long with a 12-degree roof angle. There were 25mm deep side skirts to assist the underbody; these were simple extensions of the underbody side edges protruding towards the ground with a thickness of 3mm.**

The CAD renderings shown as **Figures 1** to **4** show the 2017 car compared to the 2013. The main aims then were: to increase the underbody's contribution to overall downforce, and to simultaneously reduce upwash in the wake. The first CFD runs enabled refinement of these basic modifications until the downforce and balance levels were

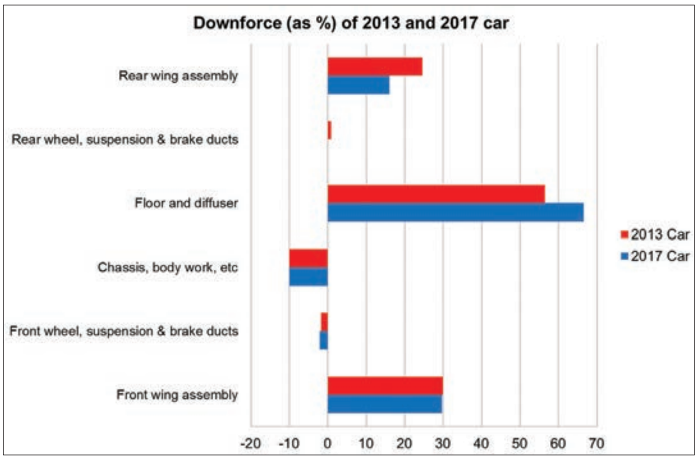



Figure 5: Downforce contributions on the two cars showing differences between them

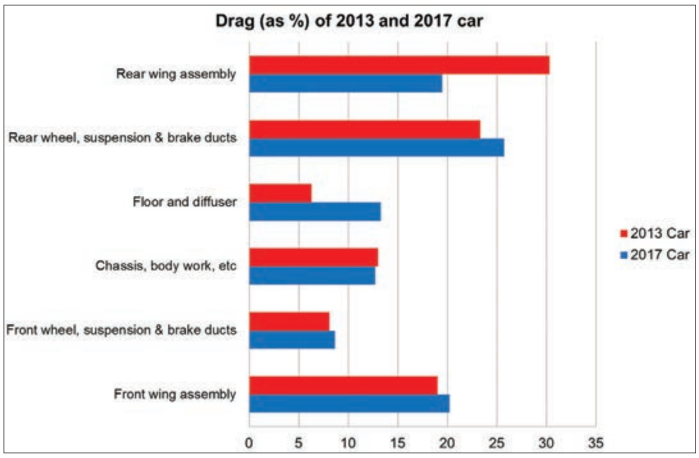



Figure 6: Drag for both – note 2017 floor contribution in both drag and downforce (Fig 5)

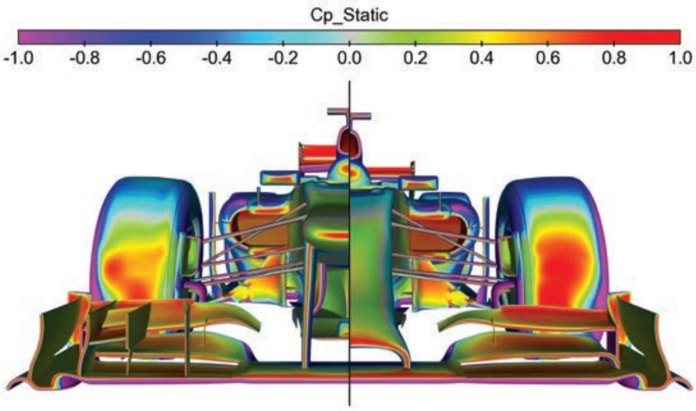



Figure 7: Front view surface pressure coefficient comparison; 2017 on right of image

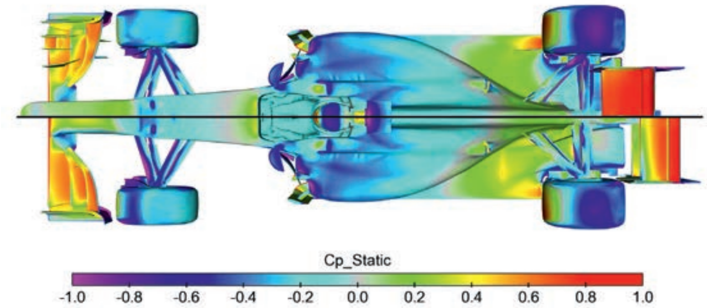



Figure 8: Top view surface pressure coefficient comparison, 2017 bottom of the image

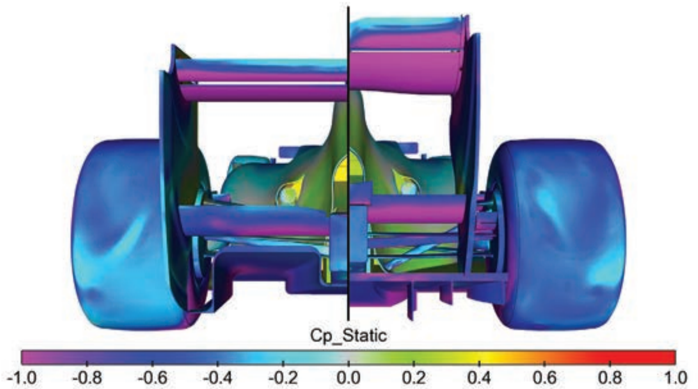



Figure 9: Rear view surface pressure coefficient comparison; 2017 on the left here

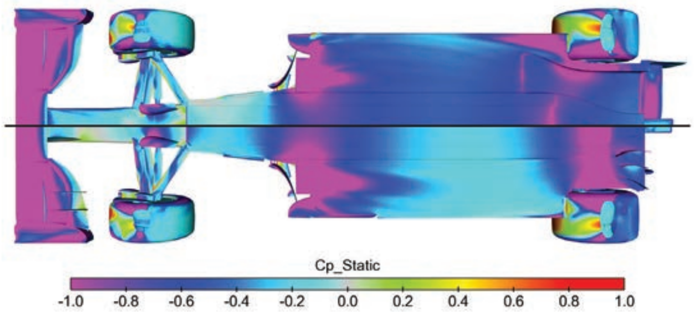



Figure 10: Surface pressure coefficient comparison; 2017 at the top of image

comparable to the previous 2013 model so that direct comparisons could be made in two-car scenarios. This produced a 2017 car with an -L/D better than the 2013 car, approximately 45 per cent front aerodynamic balance and very similar -CL to the 2013 car. **Table 1** shows the basic aerodynamic numbers.

**Figures 5** and **6** give comparisons between the sources of downforce and drag on the 2013 and the 2017 cars. The proportion of total downforce generated by the rear wing was smaller on the 2017 car but the underbody contribution was bigger; front wing downforce was roughly comparable. The main changes in drag contributions were in line with rear wing downforce decreasing and underbody downforce increasing, but total drag was lower, hence the -L/D value increased. **Figures 7** to **10** show comparisons of surface pressure coefficients on the two cars simulated in CFD. But how would this first 'F1 2017' concept fare in two-car line astern simulations? First we needed comparative data from the 2013 car…

## 2013 cars line astern

**Figure 11** shows the changes to each of the main aerodynamic metrics at a range of longitudinal car separations from half a car's length to eight car lengths, and **Figure 12** is from our 2004 article on the BAR Honda 002 showing similar but not quite identical information. Nevertheless, at first glance the plots show basic similarities; drag and downforce reduced on the following car, and the reductions were greater at smaller separations. One difference in the curve shapes shows that the reductions steepened at two car length separation on the 2013 car but this steepening did not occur until one car length on the earlier car, so in that sense things were slightly worse on the more recent car.

One key aspect is that balance (%front) shifted significantly off the front of the car in both cases from right out at eight car lengths, and in both cases this became greater at the closest separations. The reason for the balance shift is equally clear; the front end lost more downforce than the rear end with both cars. Irrespective of the losses in total downforce, if the %front reduces then aerodynamic understeer would be bound to occur as soon as a following car got close to another, making it more difficult to exploit the remaining grip to try and stay close, let alone close up on the car in front through an 'aero' corner.

## Steady balance

Next, a pair of 2017 cars were put through their paces at the same

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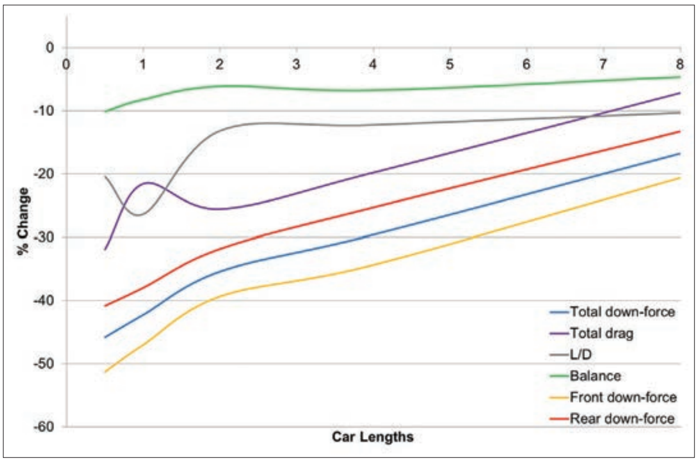



Figure 11: The changes to the aerodynamic numbers on our 2013 following car. At first glance the results seem broadly similar to our BAR 002 study (see Figure 12, right)

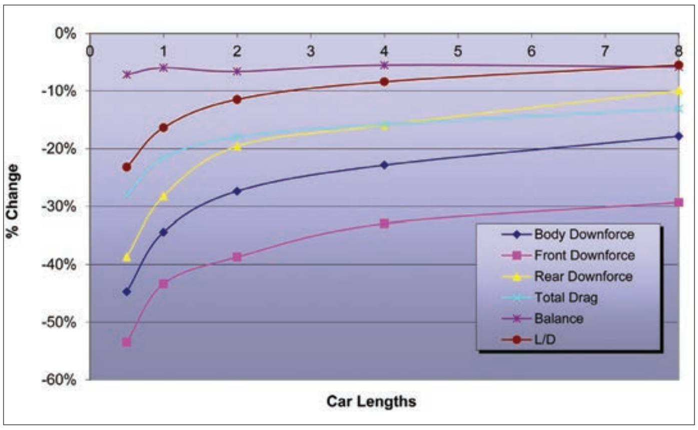



Figure 12: The changes to the aerodynamic numbers on the BAR Honda 002 (as featured in *Racecar* in 2004) following the car at a range of fore-aft separations

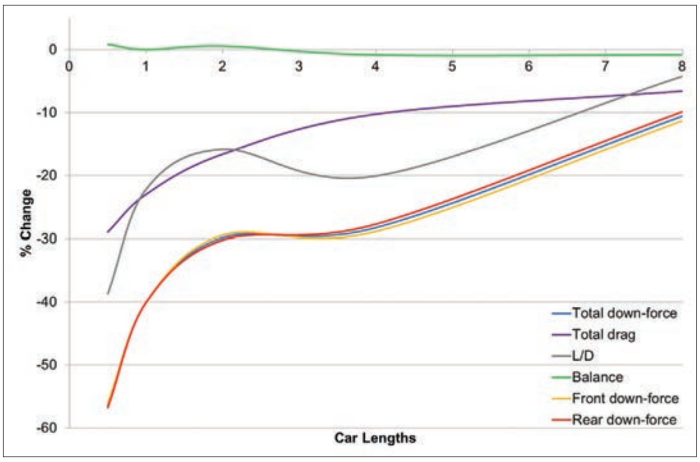



Figure 13: The changes to the aero numbers on our 2017 following car at a range of fore-aft separations. It seems that the 2017 car punches a smaller hole in the air

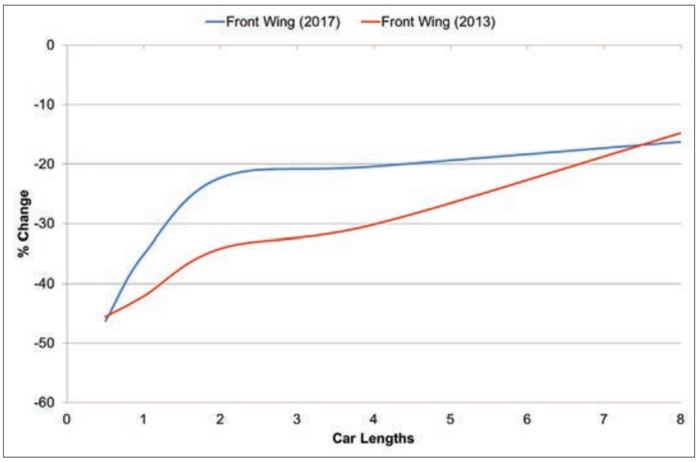



Figure 14: Changes to front wing comparison. The following 2017 car lost a lot less downforce at all the intermediate separations, which should make it easier for the driver

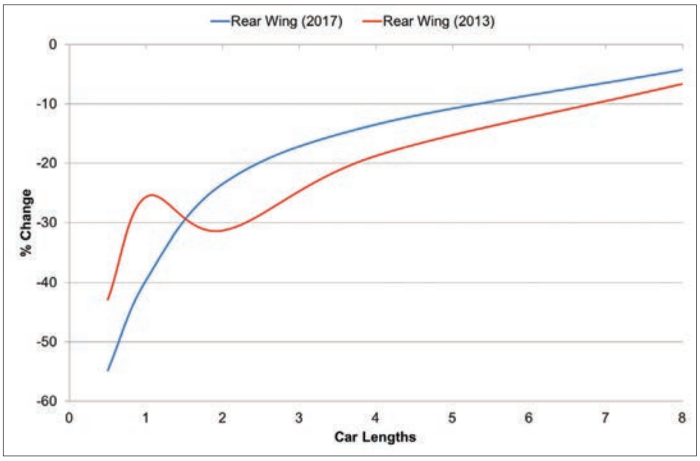



Figure 15: Comparison of changes to rear wing downforce on the racecar following another. Rear wing losses were generally less on the 2017 car than the 2013 car

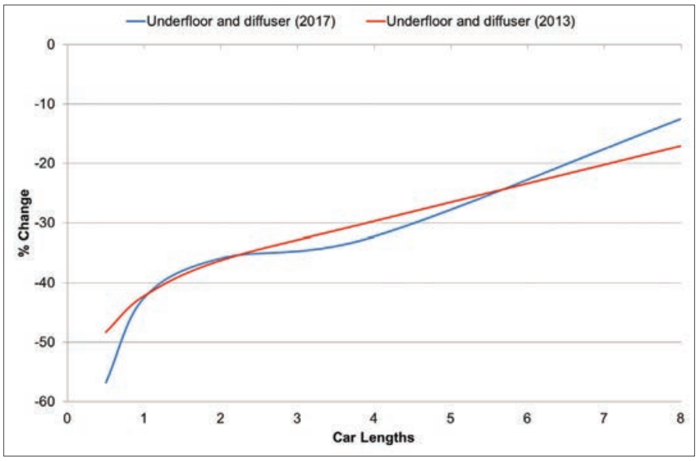



Figure 16: Comparison of changes to underbody downforce. This shows that the cars lost roughly comparable proportions of downforce across the range of separations

longitudinal separations and the plot in **Figure 13** was generated. The first and most obvious conclusion is that the 2017 car also lost downforce when following an identical car and, like the 2013 and the earlier car, it lost more downforce when closer to the car in front. Those are the least surprising of the findings, given that the leading car still punches a hole in the air. However, on closer examination it appears that the 2017 car punched a smaller hole because the total downforce reductions were, on average, smaller; at eight car lengths the 2017 car had only lost around 10 per cent of its total downforce compared to almost 27 per cent for the 2013 car; at four car lengths the figures were similar at roughly 28 per cent and 30 per cent respectively; and at two car lengths the figures were roughly 30 per cent and 36 per cent. At a half a car length the 2017 car lost slightly more downforce than the 2013 car.

Perhaps of greater significance though was the almost complete absence of balance shift with the 2017 car right across the range of separations, and this was mainly because the front and rear wing downforce decline rates were almost identical across the separation range. So although a following car to this 2017 design would still experience a loss of downforce when behind another car, that loss would be smaller and, because there would be no change in aerodynamic balance, there would not be the 'aero understeer' from which the 2013 and earlier design concepts would have suffered. The combination of these two factors – less downforce loss and no balance change – ought to make it significantly less difficult to run close behind another racecar, and hence, when the race circumstances and the driver skill allow, easier to get closer to that leading car.

The differences in how drag changed on these two cars when following another were also interesting. At eight car lengths the 2013 and 2017 cars saw roughly equal drag reductions of around 7 per cent; at four car lengths the 2017 car saw a drag reduction of about 10 per cent but the 2013 car saw about 20 per cent; at two car lengths the reductions were about 16.5 per cent and 25.5 per cent respectively, and at one and a half car separations the reductions were very similar. Would these smaller drag reductions at the bigger separations make it more difficult to 'slipstream' the 2017 car on a straight? The drag reductions were still quite significant, though, so while the rate of (unassisted) closing might be slower, hopefully the gap would be smaller in the first place.

## In more detail

Let's examine the changes and their causes in more detail. The plots in **Figures 14** to **16** show direct comparisons between downforce reductions on the 2013 and 2017 cars' main downforce-inducing components. In **Figure 14** we see that the front wing of the following 2017 car lost a lot less downforce at all the intermediate separations, which would surely make life less difficult for the driver of a following car. **Figure 15** shows that rear wing losses were generally less on the 2017 car too, although there was an interesting 'reduced loss spike' at one car length on the 2013 car, perhaps related to that car's high rear wing location. And **Figure 16** shows that the underbodies lost roughly comparable proportions of their downforce across the range of separations, except when half a car length apart, when the 2017 car actually saw a somewhat greater loss.

Using delta-Cp plots, which show the differences in surface pressure coefficients as the result of changes, we can see how the two cars responded when following. **Figures 17** and **18** illustrate the lower and upper surface delta-Cps at four car lengths separation, at which the 2013 and 2017 showed roughly similar reductions in total downforce. Looking at the underside in **Figure 17** it is apparent that the front wing on the 2017 following car saw smaller pressure increases (meaning lesser reductions in suction and

## Governing documents

The latest FIA ideas on the way forwards for F1 aerodynamics, some outlined by Charlie Whiting in summer 2015, include proposals to make 2017 F1 cars five to six seconds per lap faster. This would apparently be achieved by using wider cars; wider front and rear tyres; wider front and rear wing; and one reference suggested a reduction in height of the stepped underside plane by 25mm, to put it 25mm above the reference plane beneath the central chassis, rather than the 50mm it has been since 1995.

However, Whiting was quoted as saying that he doubted these changes would result in more overtaking and

So this proposal does not address the issue of cars being able to follow one another closely and places continued reliance on tyre degradation and DRS to facilitate position changes.

Seemingly another recent proposal from Red Bull was based on utilising large underbody tunnels, an idea that the FIA's (and *Racecar Engineering's*) technical consultant Peter Wright reported on in this magazine in our April 2000 issue (V10N3). In reference to expected rule changes at the time he said: 'On the table for 2001 is less pitch-sensitive and reduced downforce aerodynamics using venturi sidepods but no diffuser, a raised front wing and limits on the

Regulation Framework'. We reported on this in our September 2007 issue (V17N9) and, in a nutshell, the proposed aerodynamic changes incorporated a standardised underbody with a forward-biased centre of pressure that, it was hoped, would reduce an F1 car's reliance on its front wing, making the aerodynamic balance less sensitive to running in another car's wake. Front and rear wings would be constrained on dimensions and number of elements, and would also be 'active' to enable high downforce in corners but low drag on straights. Interestingly, 'aerodynamic balance' appeared in both these earlier references as a

**There is no apparent ambition to make reductions in downforce**

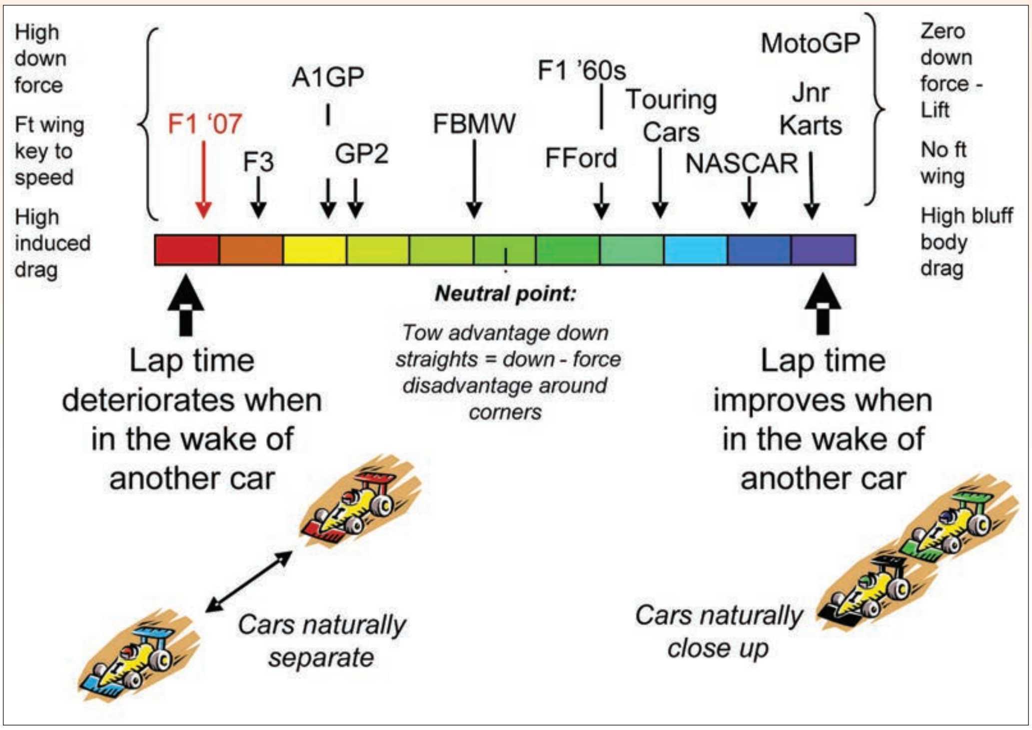
saw no reason for changes on that front anyway. 'Most of the technical guys feel the work done by the Overtaking Working Group [OWG] back in 2008, in preparation for 2009, was very small by comparison to the two major factors now, which are tyre degradation and DRS. Those two things will probably outweigh anything the OWG did, so we will still have those,' he told *Autosport.com*. 'If, as some people think, it may be a little more difficult to follow a car closely then we can increase the authority of the DRS. I don't see a big issue there.'

number of elements making up the rear wing. The rules are somewhat similar to those used in CART [IndyCar predecessor] where it has been found that not only do venturi sidepods encourage longer side impact structures but also help to maintain aerodynamic balance in the wake of another car on high speed ovals.'

Clearly that particular concept never materialised but the notion re-appeared in modified form in an FIA document Wright jointly authored with Tony Purnell in 2007 entitled 'Formula One 2011: Chassis

significant contributor to the difficulty in following closely.

The same paper also suggested in a graphic (below) that the factors involved were; high downforce; high dependence on the front wing; and high induced drag (drag generated by downforce-generating devices, especially the rear wing). Given that there is no apparent ambition to make reductions in downforce, which would threaten F1's position at the pinnacle of motorsport performance, the other parameters identified don't seem to tally with current FIA proposals …



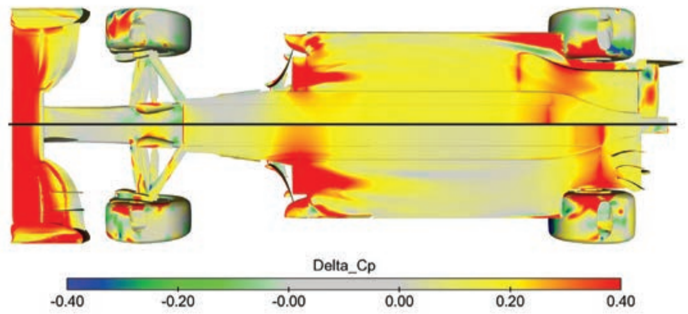



Figure 17: Comparison of changes to surface pressure coefficients on the two cars' undersides at four car lengths separation – the 2017 car is at the top in this image

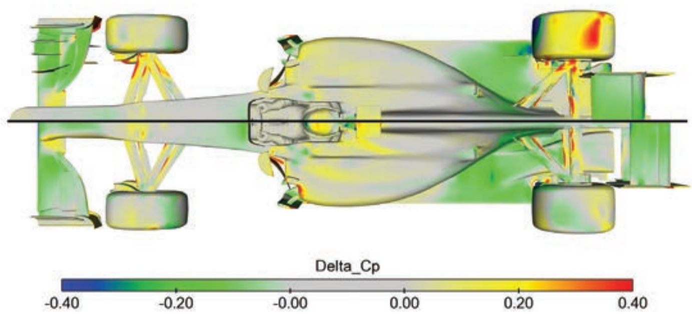



Figure 18: Comparison of changes to surface pressure coefficients on the two cars' top surfaces at four car lengths separation – 2017 is again at top of image

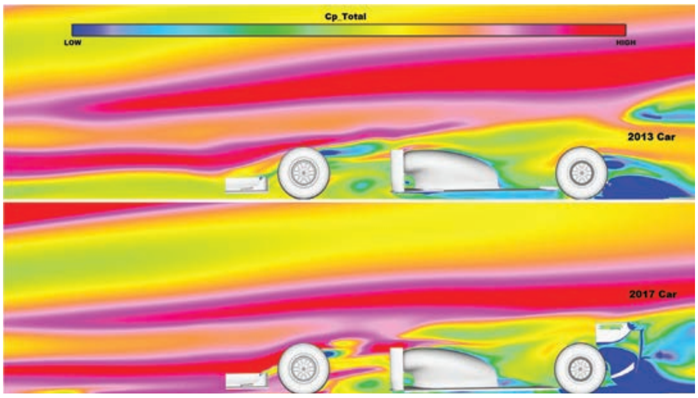



Figure 19: A slice 500mm from the racecar centreline of total pressure on the following car at two car lengths of separation – the 2017 racecar is at the bottom of this image

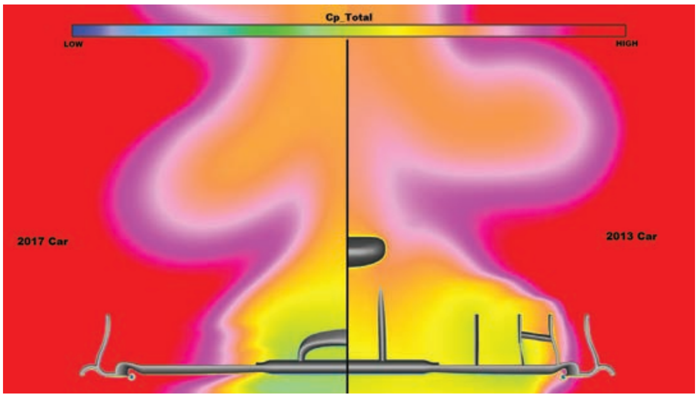



Figure 20: Transverse slice at the front wing leading edge of total pressure – the energy of the airflow reaching outer portion of the 2017 (left) front wing was generally higher

hence smaller losses of downforce). Interestingly though, these smaller losses were on the outer portions of the 2017 car's wing and flaps and under the end plate's footplate, when we might have expected the reduced upwash to have reduced the losses at the centre of the wing. Nevertheless, we can now see why and where the front end of the 2017 following car lost less downforce at these intermediate separations.

Moving aft to the floor and diffuser, the 2013 following car saw greater increases of pressure under its forward underbody, from the leading edge of the splitter to the front quarter of the wider flat floor under the sidepods. The 2017 car's underbody pressure increases were more evenly spread along its length. These two differences would have further contributed to the greater proportionate loss of front downforce on the 2013 car. **Figure 18** shows the delta-Cps on the upper surfaces and once more there are differences on the front wing, the 2013 car showing greater reductions of positive pressure, again translating into greater losses of front end downforce. Elsewhere there are relatively minor local differences between the two cars except perhaps on the top of the rear tyre of the 2013 car, which saw an increase in pressure (which would translate as a reduction in lift).

As mentioned above, the reduced downforce losses of the front wing of the 2017 car when following another car seemed from the delta-Cp plots in **Figures 17** and **18** to be the result of better performance from the outer parts of the wing. **Figure 19**, a vertical slice 500mm from the following car centrelines at two car lengths separation, shows total pressure (total energy) and gives more insight into why this was the case. It is clear that the air that encounters the front wing in the 2017 following car case at this distance from the centreline had greater energy than in the 2013 car. **Figure 20**, a transverse slice of total pressure near the front wing leading edges of the two following cars at two car lengths separation, shows the energy of the airflow reaching most of the outer portion of the 2017 car's front wing was generally higher. In other words, the 2017 design is giving the front wing of the following car an easier time.

MA is confident further modifications to the rear of the 2017 car would enable reductions in the amount of 'dirty' air reaching the front wing of the following car.

## Summary

We have clearly seen with these CFD insights why current and recent F1 aero packages make life difficult for a following car. We have also demonstrated how a straightforward re-design producing more downforce from ground effects and less from wings – that could be very cheaply incorporated onto existing cars – overcame a key part of the problem.

*Thanks to Dynamic Flow Solutions for its help with this piece.*

## Dynamic Flow Solutions

Dynamic Flow Solutions Ltd is an aerodynamics consultancy led by director Miqdad Ali, an ex-MIRA aerodynamicist who has performed design, development, simulation and test work at all levels of professional motorsport, from junior formula cars to World and British touring cars, Le Mans prototypes, up through to F1 and Land Speed Record cars.

Ex-MIRA aero man Miqdad Ali ('MA') is the boss of Dynamic Flow Solutions

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**The 2017 car's underbody pressure increases were more evenly spread along its length**

# The laps of the gods

## A view from Olympus on F1's lack of real racing – and what might be done about it

Formula 1 seems to be in such a state of schizophrenia that everyone and anyone can offer *solutions* to what is fundamentally a lack of interest in the younger generation. In fact, it is not just the young; Gerhard Berger admitted that he falls asleep watching Formula 1 once he knows who will win, usually after the first few corners.

Rather than plunge headlong into this melee, I am going to ask you to momentarily suspend belief and imagine I am the God of Sport, residing on Mount Olympus. Imagine Zeus has just given me instructions to go and sort out F1, as he is sick of the whinging of mortals. The brief is to take no account of the politics or commercial self-interests, and on no account to form a committee or working group to decide what to do. Having observed motor racing over the last 100 or so years, and seen the highest level become the Formula 1 of today, he has become annoyed.

I do wonder what has become of the 'racing' in 'motor racing'. Given the brief to sort it out quickly, I would decide to concentrate on just this issue, as overtaking means uncertainty, and uncertainty means entertainment (us gods are good at broad, sweeping statements).

My first port of call would be to go and find Jabby Crombac, the late editor of *Sport Auto*, who attended all grands prix from 1955 until just before he died in 2005. He maintained, by hand, a rigorously accurate lap chart of each GP. In 1998 (yes, really, overtaking was a subject for debate 18 years ago) he undertook to use this database to calculate the number of changes of position in each GP, each year, as noted as the cars cross the start/finish line. This data was condensed down to an average number of such manoeuvres per year, as can be seen in the chart below.

### Draft excluders

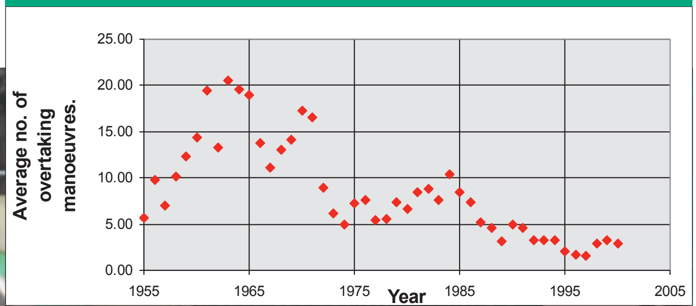
Certain features are immediately apparent. First; when the great slip-streaming circuits ceased to be used in the early 1970s, overtaking reduced by around 60 per cent from an average of 20 a race. Second, overtaking reached a minimum in the mid-1970s, and then nearly doubled again by the mid-1980s. Finally, from then on it fell steadily over the next decade to an absolute minimum of two to three per race.

Why? In the early 1970s, wing-generated downforce was being steadily developed, with drag less important, due to the absence of the very fast circuits. Overtaking reduced.

In the late 1970s, ground effect with skirts entered the arena and front wings shrunk, acting mainly as trim tabs. The overtaking then increased.

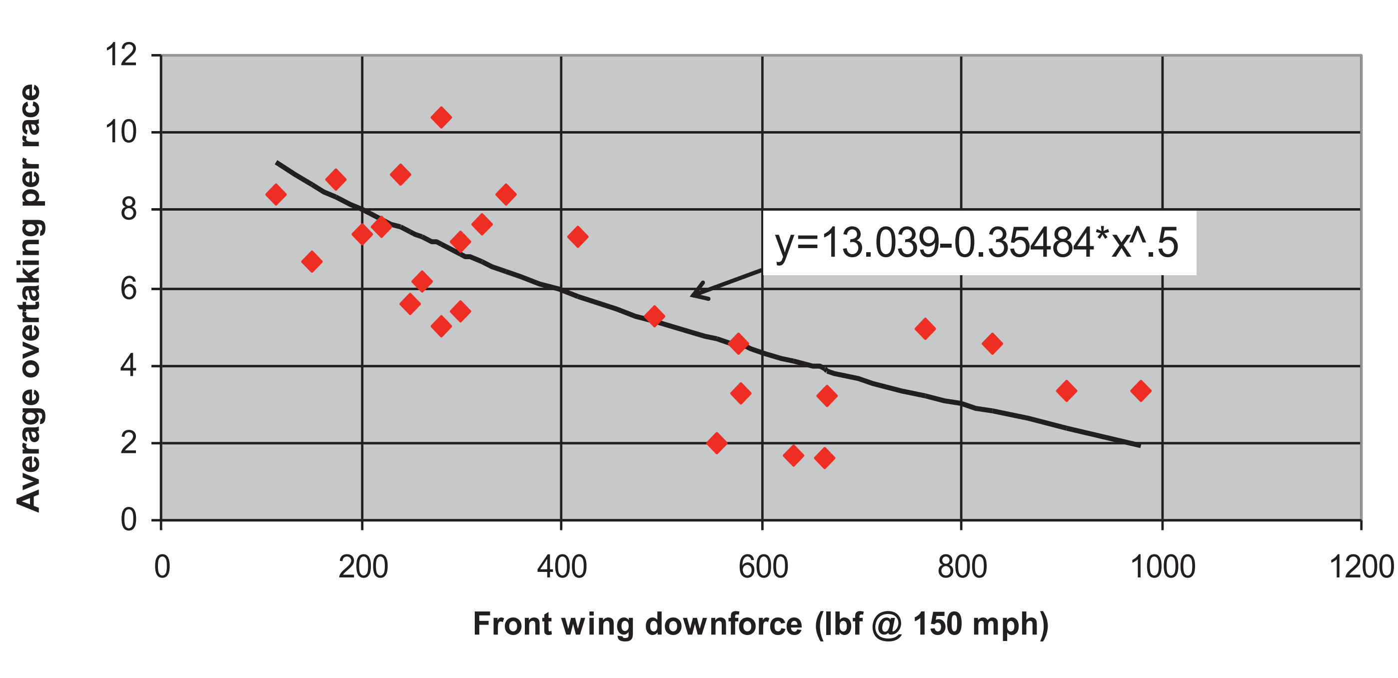
In 1981, sliding skirts were banned, though fought over until 1983 when flat bottoms were mandated. From that year on the front wing became the dominant aerodynamic feature on Formula 1 cars, and overtaking declined steadily.

**Average number of overtaking manoeuvres per race**




**Many believe F1 is not exciting these days beyond the cut and thrust of the first lap – but might there be a way to improve the racing by changing the aero regulations?**

Average number of overtaking manoeuvres per race *v* front wing downforce (1972 - 1997)




Plotting average overtaking manoeuvres/race against front wing downforce generates a clear trend, as seen on the chart on the following page.

Unfortunately, Jabby's analysis was never extended to the present day, but we can probably predict what it would look like up until the time that DRS and Pirelli tyres reinstated overtaking.

## The culprits

Most people know that the front wings, elaborate multi-element devices, are the culprits, yet F1 itself is unable to do anything about them. Time for a thunderbolt then. Limit front wings drastically, controlled by size and number of elements – max one or two at the most. Then we should limit overall CLA to, say, 50 to 60 per cent of current values, or maybe even less.

The first can be regulated dimensionally, the second requires the measurement of downforce on track, normalised with pitot pressure, and limited to an FIA-monitored, never-exceed figure. All the teams have the means to measure downforce precisely, to a level where they are able to confirm or otherwise a driver's feeling that he has lost downforce, either due to damage or rubber blocking the front wing's flap slots. The FIA can have access to this data, and the teams would have to ensure that downforce never went over that CLA value.

**Reducing downforce and drag will take the pressure off the quest for more power**

With freedom regarding the rest of the aerodynamics of the car, with the exception of no skirts and dimensional limitations such as rear wing width and overall height, the efforts of the hundreds of aerodynamicists would be re-focused onto: drag reduction at the CLA limit; minimising the effect of disturbances from the car in front in order to enable overtaking; and, inevitably, how to tune the aerodynamics to make it more difficult for the car behind to overtake.

The downforce and drag lap time sensitivity values of a Formula 1 car at a high downforce and tough-to-overtake circuit such as Barcelona, are in the ratio of around 4.3 to 1, downforce to drag. This means that the return in terms of lap time on aerodynamic research and development effort would be significantly less than at present, where the concentrated effort is on downforce, and so rich teams would have less of an advantage compared to the smaller teams.

This would focus the efforts of the aerodynamicists on to aero-efficiency, in much the same way the fuel flow regulation focuses the powertrain engineers on to thermal efficiency.

The reduction in downforce would allow larger, grippier tyres, and so the increase in overall lap time would be compensated for. Drivers complain about the heat degradation characteristics of the current Pirelli tyres, pushing for cars they can drive flat out until the tyres wear out. Drivers drive flat out in qualifying, and then line up in the order of speed. If they could then race flat out, the field would slowly stretch out, with no overtaking bar errors. What is the good of that?

Reducing the downforce, and hence the drag, which would be further reduced by aero R&D focusing on efficiency, will increase the top speeds and reduce grip under braking. Thus the area where the majority of overtakes are set up would be extended. Lap times will be increased to five to six seconds a lap by the reduced downforce, but some of this will be clawed back by reduced drag and increased mechanical grip, unleashed by the lower aerodynamic loads Why is lap time so important anyway? It is like 0-60mph times of supercars – only important on paper.

Strategy Working Group attempts to increase downforce have been thwarted by the inevitable response by Pirelli that the tyres will become harder and less grippy. So isn't it obvious that there is a need for us to go in the opposite direction?

## New direction

Reducing downforce and drag will take the pressure off the quest for more power. Current powertrains are 850-900cv, and teenagers can manage them. Does anyone really think another 200cv is going to sort the men from the boys? If powertrain changes are needed after three to four years, then I would ask the manufacturers what features they would like to change to make them more relevant to road cars and increase thermal efficiency. One day, when the bones of motorsport are being picked over, the engineering skills of the F1 manufacturers will be compared with those in WEC LMP1, and those achieving the greatest thermal efficiency will be declared the winners.

And that's it. The change towards a limited, reduced downforce would send Formula 1 in a whole new development direction. It would increase overtaking ability, make the cars more difficult to drive, prevent speeds escalating to the safety limits of the circuits, and yet be more relevant to road car technology.

Right, I wonder what Bacchus is up to …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