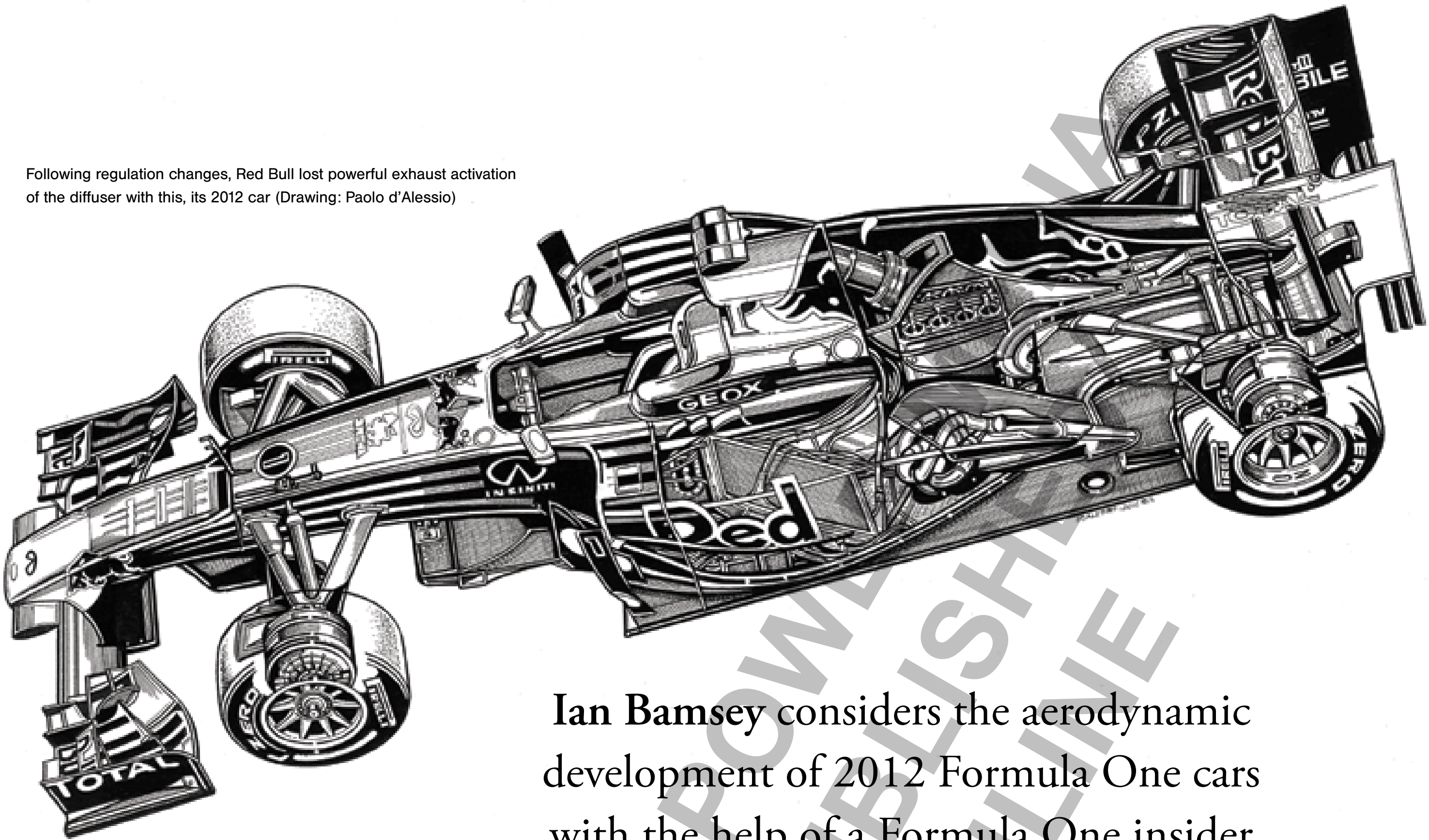
Following regulation changes, Red Bull lost powerful exhaust activation of the diffuser with this, its 2012 car (Drawing: Paolo d'Alessio)



Ian Bamsey considers the aerodynamic development of 2012 Formula One cars with the help of a Formula One insider

May the downforce be with you

Seemingly against all odds, at the start of the 2012 season, downforce for the top Formula One teams was on par with that seen during full-throttle exhaust activation of the rear diffuser in 2011, despite the loss of most of that gas energy assistance. Regular ongoing aero development work had clawed back what had amounted, at a stroke, to a loss of more than 10% (perhaps as much as 15%) of total downforce. Involving a huge amount of effort in the continuous honing of details, this recovery had been made for no loss of efficiency – that is, for the same lift-to-drag ratio. That shows the relentless progress in Formula One aero performance, particularly when the regulations are imposing new conditions for the aerodynamicists to work around each year. (If the regulations remain stable then inevitably, over time, the development curve will start to flatten out.)

New conditions for 2012

Ten of the 12 Formula One cars designed for the 2012 season were characterised by a stepped nose, owing to regulations lowering the height of the nose cone for perceived safety reasons. The step came about because aerodynamicists insisted on maintaining the existing height of the bulkhead that forms the front of the monocoque. McLaren notably bucked the trend since its aerodynamic philosophy does not require such a high location for its front bulkhead.

Those who introduced this unaesthetic step paid no real aerodynamic penalty. Of more significance aerodynamically was the new-for-2012 squarer shoulders of the Pirelli rear tyre. At a stroke this implied a small loss aerodynamically, which all the aerodynamicists had to work around given that Pirelli is still the sole tyre provider.

In another subtle change, the floor manufacturing tolerance was decreased from 5 to 3 mm, which is potentially quite significant aerodynamically. The tolerance was ±5 mm, giving a full 10 mm scope for putting rake into the floor, or even for giving it a curved (outward sloping) profile when seen in cross-section. That is the sort of scope that some teams were prepared to exploit to the limit, unlike some more conservative rivals, for whom a flat floor is just that. However, it is a scope that has been reduced by 40%.

One novelty affecting aero was Ferrari's introduction of a pullrod front suspension for 2012. The Italian team claimed it was of benefit aerodynamically, while no disadvantage mechanically, although in fact difficulties are posed in that respect; in terms of centre-of-gravity height, there is little in it. Aerodynamically running a conventional wind tunnel model without pushrods is a gain of no more than 1%, so logically a switch to pullrods cannot be worth more than that.

Compared to pushrods, pullrods provide a cleaner surface for the 'cake tin' sealing the inside of each front wheel (complete with the brakes) and might open up a new and improved front brake cooling strategy. On the other hand, the use of pullrods implies the introduction of an inboard pick-up that will impact negatively on aero. All told, whereas pullrod rear suspension can provide clear aero gain, it is difficult to fathom the logic of pullrod front suspension, although Ferrari had clearly found what it considered a worthwhile advantage.

Loss of exhaust activation

New rules for 2012 dictate that the exhaust pipes (one for each bank of the V8) have to be rearward facing and have to be positioned higher and tilted upwards at an angle of 10-30°, with a cone-shaped area around the outlet where bodywork is prohibited. Whereas exhausts discharged at floor level in 2011, the height now has to be no less than 250 mm and no more than 600 mm above the reference plane (at the base of the floor). At the same time came new constraints on engine mapping, curtailing the potential for off-throttle exhaust discharge. While these conditions are not conducive to exhaust gas activation of the diffuser, as exploited in 2011, some clever management of the plume could still put it to useful work.

The most successful exhaust activation approach of 2011 was that pioneered by Red Bull. Here, the exhaust discharges along the flanks of the diffuser, helping to seal it from the aerodynamic disruption caused by rotation of the adjacent tyre, acting almost as an invisible lateral 'skirt'. This flow of hot gas also helps reduce the 'base pressure' behind the diffuser, which in turn helps suck more air through it.

At the same time, small aerofoil sections are positioned on the inboard side of the rear-wheel cake tins, since the downforce they generate acts directly on the adjacent tyre contact patch. Discharging exhaust along the flanks of the diffuser can assist the operation of the aerofoils.

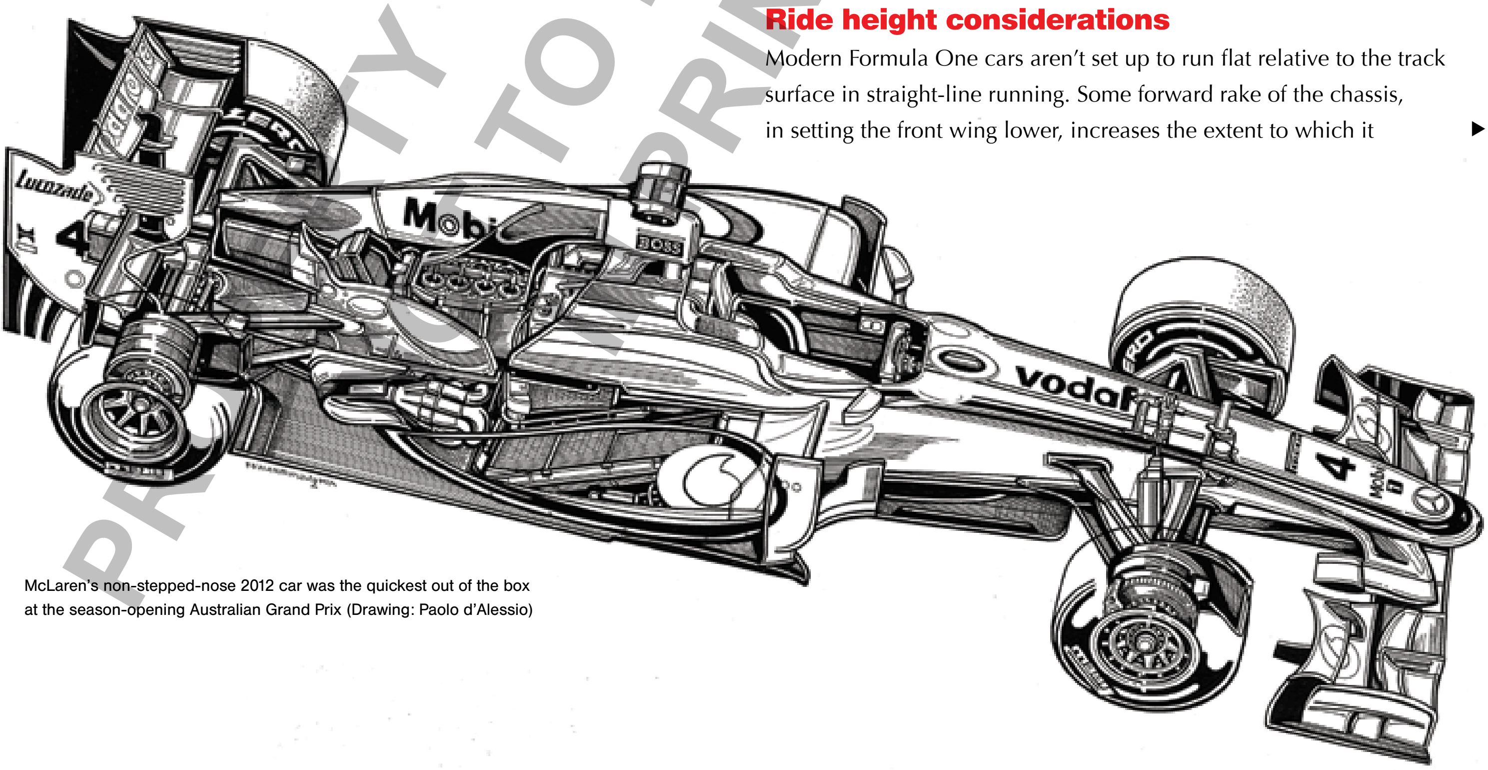
In 2012, what happens to the plume is heavily influenced by the airflow into which it has been discharged and how that flow is subsequently controlled by the rear bodywork. It was still possible to pull at least part of the plume down to the area between the tyre and the floor. Complex strakes and fences just inside the rear tyre suggested that Red Bull's 2012 car was still getting some benefit from exhaust energy where it counted. The geometry of those elements pointed to the exploitation of on-throttle discharge conditions.

Under the 2012 constraints, Red Bull is likely to have lost two-thirds of the benefit it previously had from exhaust discharge. On the other hand, rival teams with less aggressive approaches to the exhaust under the new 2012 conditions might have lost five-sixths of what they had before. To have maintained even a third of what had been attained in 2011 was a formidable achievement, underpinned by all the work Red Bull had done in conjunction with Renault since introducing the concept of an exhaust-blown diffuser in 2010. One might say 'advanced understanding' allied to no-compromise implementation, defying the general prescription of the 2012 regulations that the exhaust discharge should not have any effect on the aerodynamics of the car. Of course, all such discharge must have some sort of effect on the air flowing over the rear of the car, so there the arguments begin.

One significant impact of the loss of much of the exhaust discharge effect was an inherent worsening of car instability under braking and acceleration. In particular, under a combination of cornering and acceleration, no longer could the driver overcome rear-end instability by applying the 'loud' pedal. New means had to be sought to an old problem.

Ride height considerations

Modern Formula One cars aren't set up to run flat relative to the track surface in straight-line running. Some forward rake of the chassis, in setting the front wing lower, increases the extent to which it ▶



McLaren's non-stepped-nose 2012 car was the quickest out of the box at the season-opening Australian Grand Prix (Drawing: Paolo d'Alessio) beneficially operates in 'ground effect'. There must also be some rake for the diffuser to work at all at the lower rear ride heights associated with higher speeds. In such conditions, thanks to the regulations, the car can become under-diffused – there will be a point at which there isn't enough exit volume to pull air through the underfloor area.

Factors influencing the amount of forward rake that a car can afford to run include final drive height (the gearbox needs to be set low from the perspective of acceptable weight transfer) and suspension geometry and set-up. Of course, rake is a function of front and rear ride height, both of which are reduced as downforce increases with increasing speed (even if the suspension were made solid, tyre sidewall squash would reduce ride height).

Moreover, the level of downforce seen at any given speed and the location of its centre of pressure are a function of the dynamic ride height at both ends of the car. Since, by regulation, the car may not be fitted with so-called 'active' suspension, which constantly adjusts ride height under computer control; the aerodynamicist is forced to try to optimise the car's aero performance through a range of ride height/rake configurations. In practice their 'aero map' will have to accept compromises in some areas.

On the face of it, increasing the effective volume of the diffuser by increasing rear ride height is beneficial; on the other hand, as the diffuser moves higher from the ground it becomes more difficult to seal laterally (by aerodynamic means; the only ones permitted). In fact, given the current single diffuser regulations, the most difficult challenge facing the aerodynamicist is that of maximising rear downforce in the low speed/high ride height configuration. Given that a typical Formula One corner these days is a slow one, the significance of that cannot be overlooked.

This is where the exhaust-blown diffuser was particularly effective. It 'supercharged' rear downforce in low speed/high rear ride height conditions, permitting the aerodynamicist to concentrate on finding more downforce at medium and high speeds. Now that its impact has been much reduced, there is renewed focus on low-speed downforce.

Given that active suspension is outlawed now, Formula One teams go to great lengths to try to control car ride height and in particular attitude through the permitted passive suspension systems, including the use of third spring/damper units and inerters. In the 1990s, when Harvey Postlethwaite was technical director of Tyrrell, he worked with Koni on a (post-active) system that hydraulically linked the front and rear suspensions. It has been a long time coming but it is widely believed that these days some teams are using such technology.

One innovation that appeared over the 2011-12 off-season was Lotus' system for using brake torque to counter the transfer of weight to the front. This required development of a special front brake caliper, which was semi-floating and reacted to brake torque via a hydraulic cylinder that flowed fluid into a cylinder at the base of the attendant pushrod. Thus was the pushrod lengthened by straightforward hydraulic action under braking.

Forward weight transfer is inherent in the braking process, and the forward pitch of the car this causes is to the benefit of front grip. However, the initial loss of front ride height when the brakes are applied at high speed sets a limit on acceptable minimum front ride height, while a sudden increase in front grip leads to rear-end instability. Those were the problems the Lotus system addressed, but the FIA deemed it a moveable aerodynamic device, leaving it un-raced.

Aero-elasticity

As we have pointed out before, the exploitation of aero-elasticity to improve aero performance extends to all of a car's surfaces. The cockpit is flanked by rigid crash structures, yet the sidepods and floor don't have to be rigidly attached to that core chassis. At speed, a cleverly mounted floor might be sucked towards the ground, putting more rake into it and thus increasing downforce. Also, the edges of the floor next to the rear tyres might predictably deform; potentially that is an area of even greater gain.

Then of course there is the 'classic' planned deformation of front and rear wings. Rear wings these days are normally mounted via their endplates rather than a central pillar. The endplate approach lends itself to a system that pulls the beam wing around, in turn usefully tipping up the rear of the floor.

Some of the FIA's prescribed static wing/bodywork load tests were toughened for 2012. On the face of it, a doubling of the front wing stiffness requirement sounds highly significant, but when it comes to the exploitation of aero-elasticity it isn't a simple case of the stiffness as measured by the specified FIA tests being the key factor. On the contrary, at high speed, less deflection as thus measured can be a good thing. Deflection of the front wing endplates is another matter. Not assessed by the FIA tests, such deflection could plausibly be beneficial.

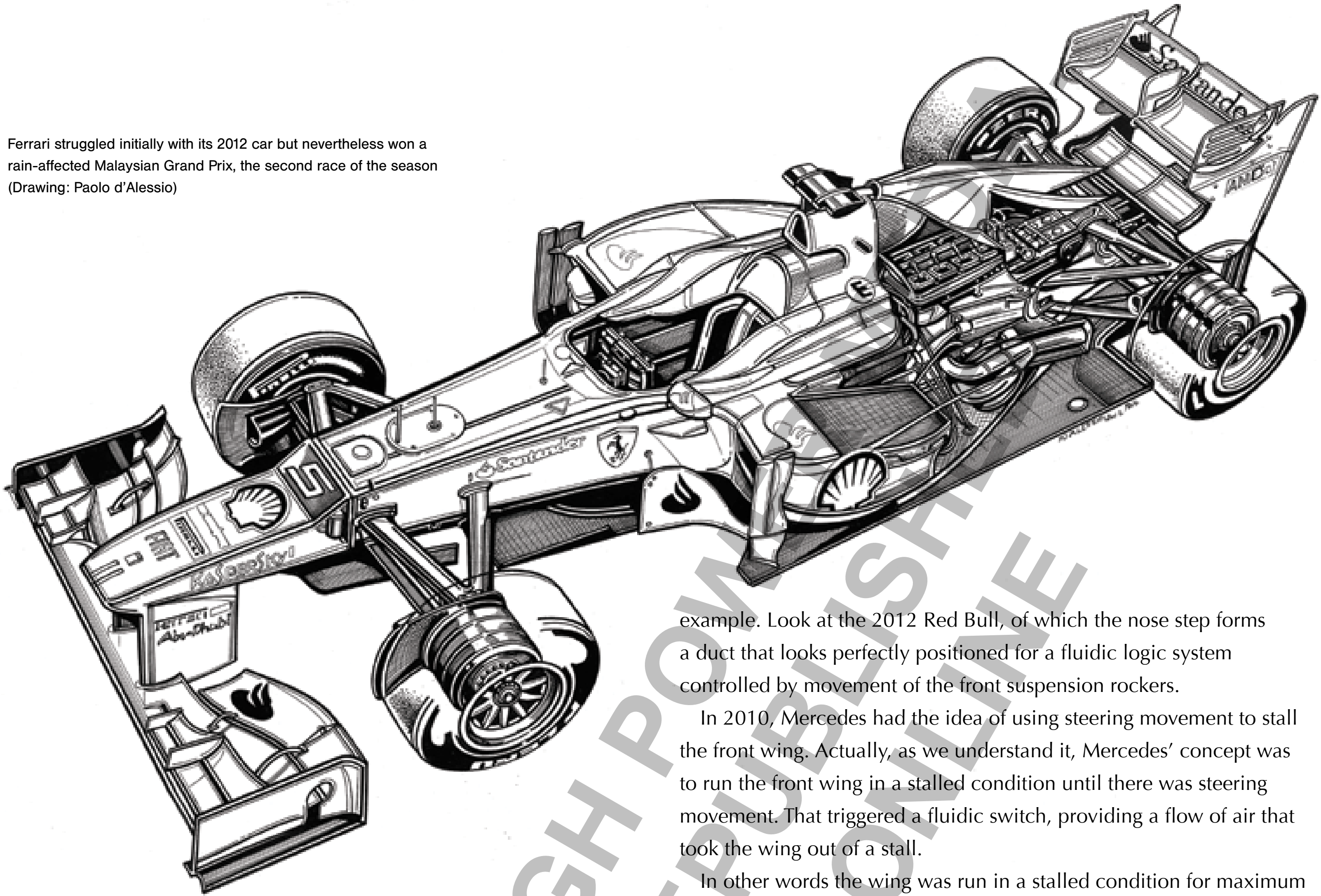
The whole question of aero-elasticity is hugely complex and very tricky to assess without putting actual mileage on the car. As proof of that, late in the 2011 season, Ferrari introduced a new front wing that fluttered notoriously. Some rivals had been exploiting the same concept for much longer, their experience going back to the days when there had been enough track testing allowed to enable them to build up the necessary knowledge away from the media spotlight.

On the face of it, what would be particularly helpful would be a front wing that moved downwards when the car was out on the track. The height of the wing assembly relative to the rest of the car is controlled by regulation, as measured in the static condition. If that height could be lowered in the dynamic state then the wing would run beneficially closer to the ground, particularly at low speed (without the danger of the chassis bottoming out at higher speed).

So we come to the concept of a front wing that moves rearwards, and with that downwards along a predetermined track controlling its position relative to its mounts. Conceivably, as the car left the pits, only a small amount of air pressure could move the wing rearwards and with that downwards. Then, when it slowed to return to the pits, some form of spring could push it back into position, so that it continued to meet the dimensional requirements as measured statically.

This suggestion of a sliding front wing controlled by some sort of cam and spring system sounds somewhat far-fetched. However, the FIA's tests don't cover the fore/aft stiffness of the wing, and teams are even permitted to produce their own tools to apply those tests that are prescribed. Moreover, the whole concept of a car running in different conditions from those measured statically is long established in

Ferrari struggled initially with its 2012 car but nevertheless won a rain-affected Malaysian Grand Prix, the second race of the season (Drawing: Paolo d'Alessio)



Formula One – it goes back at least 30 years, to the days when sliding skirts were banned and various means were devised to overcome static ride height measurement tests.

Surely though, the FIA would spot such front wing trickery and immediately outlaw it? In fact, the FIA doesn't routinely see inside the hugely complex Formula One front wing assemblies of today, and even if it did, it would be fiendishly difficult for it to appreciate what was going on. We are assured that even the necessary 'return spring' as a carbon fibre composite component would be virtually indistinguishable in its function to the untrained eye.

Mercedes F-duct

When the FIA declared McLaren's so-called rear wing 'F-duct' legal for the 2010 season, it opened up a wealth of possibilities. As we explained in the previous issue of *F1 Race Technology*, the F-duct exploited fluidic switching, a system of air ducting designed such that blocking one of two apertures giving air access to it alters the flow pattern within, causing the flow to exit from an alternative channel. Movement of the driver's hand created the necessary blockage so that air exited from an alternative channel that was carefully positioned to cause the flow to stall the rear wing.

The driver's hand was used since the regulations don't permit moveable aerodynamic devices. The concept of a fluidic logic system was not deemed a moveable aerodynamic device, and while the regulations no longer permit the driver's hand to control a fluidic switch, there are other means to operate one. Potentially anything that moves on the car could be devised to cover/uncover an aperture – the operation of the suspension pushrods, rockers or dampers, for example. Look at the 2012 Red Bull, of which the nose step forms a duct that looks perfectly positioned for a fluidic logic system controlled by movement of the front suspension rockers.

In 2010, Mercedes had the idea of using steering movement to stall the front wing. Actually, as we understand it, Mercedes' concept was to run the front wing in a stalled condition until there was steering movement. That triggered a fluidic switch, providing a flow of air that took the wing out of a stall.

In other words the wing was run in a stalled condition for maximum straight-line speed and downforce, and the necessary grip was provided as soon as the driver turned the steering wheel. At least that's the theory – fluidic switching isn't so precise that the transition from stalled to unstalled conditions is 100% predictably instant, and that's not good for driver confidence. That, as well as the fact that the FIA didn't accept the legitimacy of the concept, put paid to it.

Mercedes wasn't beaten, though. This year its front wing F-duct system runs the front wing unstalled in normal operation, with a stalling airflow supplied whenever an air inlet at the rear wing is uncovered by the operation of the Drag Reduction System (DRS). Thus the rear wing flap movement permitted by the DRS operates a fluidic switch, whereby the front as well as the rear wing becomes stalled, maximising the speed gain of the DRS (and potentially improving cornering aero balance since DRS can be employed at all times in qualifying). At the time of writing, the FIA was happy with this concept, given that it is an extension of a system specifically aimed at drag reduction.

Of course, for this system to work, air has to be channelled along the entire length of the car, and that ducting has to be completely sealed. It's no mean feat to incorporate the system, and it's hugely challenging to apply it to a car that hasn't been designed to accept it. Mercedes' rivals were not happy.

At the time of writing, after only two of the 20 races of 2012, Mercedes' solution looked set to dominate the technical landscape for some Grands Prix to come, but equally it was possible that a sudden decision to outlaw it might put the matter to rest sooner rather than later – doubtless to be followed by some other technical controversy rearing its head. Such is the way of Formula One these days, with so many clever engineers constantly looking to push the margins of the regulations! ■