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Rear wing studies

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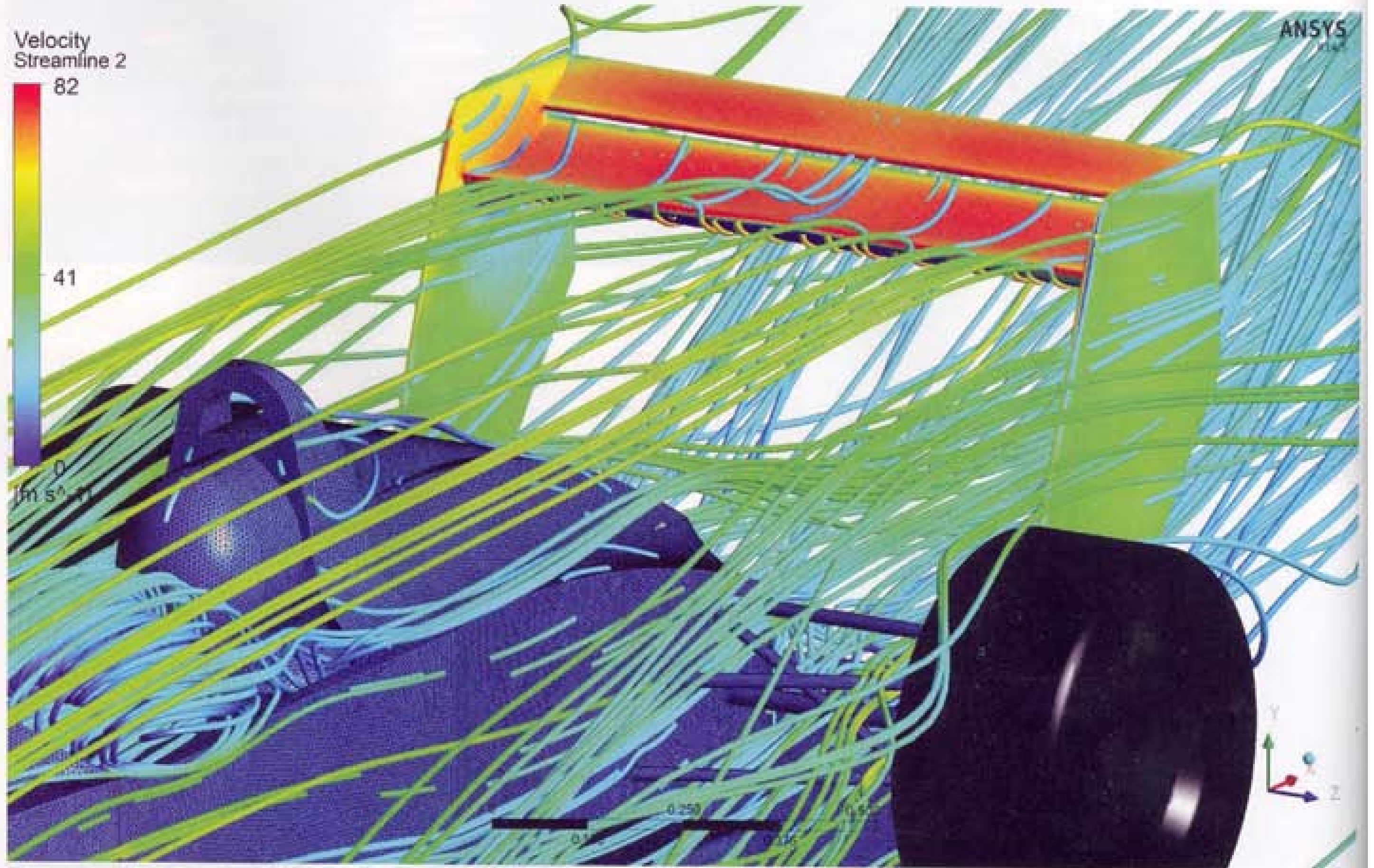
Wings and things

In the third instalment of our CFD study on the aerodynamic basics of single seater rear wings we look at the cluttered environment they have to work in

By SIMON McBEATH



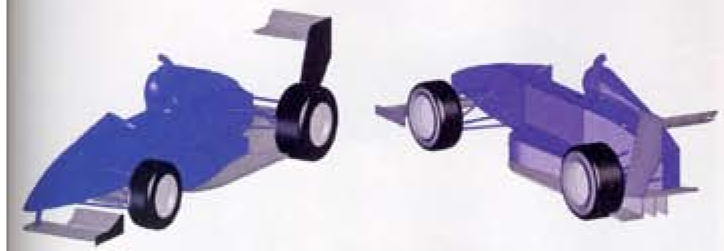
The rear wing on any racecar, but especially on a single seater, has to function in a highly compromised environment. The influence of all the upwind components, from the front wing, the open wheels, the sidepods and cooling systems, the cockpit opening, the driver, the roll-over protection system and various other necessary (and in some cases, optional) protuberances, all conspire to ensure that rear wings do not work the same on the back end of a car as they would in clean, freestream air.

This month we have used the marvels of flow visualisation in ANSYS CFD Flo to take a closer look at the rear wing's operating environment, and we've also looked at a brief sample of measures that can be taken to alter the rear wing's performance.

The model

The first two instalments of this occasional series on the aerodynamics of a simple single seater model looked at a range of parameters in the deployment of a high downforce single element wing (December 2015, V25N12) and then at a number of variables on a high downforce dual-element wing (June 2016, V26N6). For the current study we begin with the same single seater model with a baseline dual-element rear wing. To recap, our simple model (see image **CAD 1**) featured a flat underside between the wheels, a V-divider and tea tray splitter beneath the chassis at the front of the underbody, and a simple rear diffuser with the transition from the flat floor in line with the front of the rear wheels. The front wing was a 1400mm span device with a part span flap either side of the nose and a simple, flat end plate. The rear wing was supported between tall end plates and had a span of 960mm, fitting between the end plates that connected at the bottom to the outside of the rear diffuser. This wing mounting method was found to be the most aerodynamically effective during our earlier CFD studies. The fore/aft and vertical location of the wing was kept constant through the current exercise, and again at the most effective location determined in earlier runs. The top of the end plate was set at 900mm above the ground plane, matching the regulatory limit in many single seater series, and the rear wing's trailing edge was kept close to this height throughout.

As usual, your writer has been consistent with his inconsistent use of SI and Imperial units (not to mention improper orientation of the global coordinate axes y and z), air and ground speed being set at 100mph with forces reported in Newtons, N (divide by 4.459 to obtain pounds, lb). The meshing incorporated refinements around the wings and wheels to improve the capture of flow



CAD 1: The single seater model used for our rear wing studies

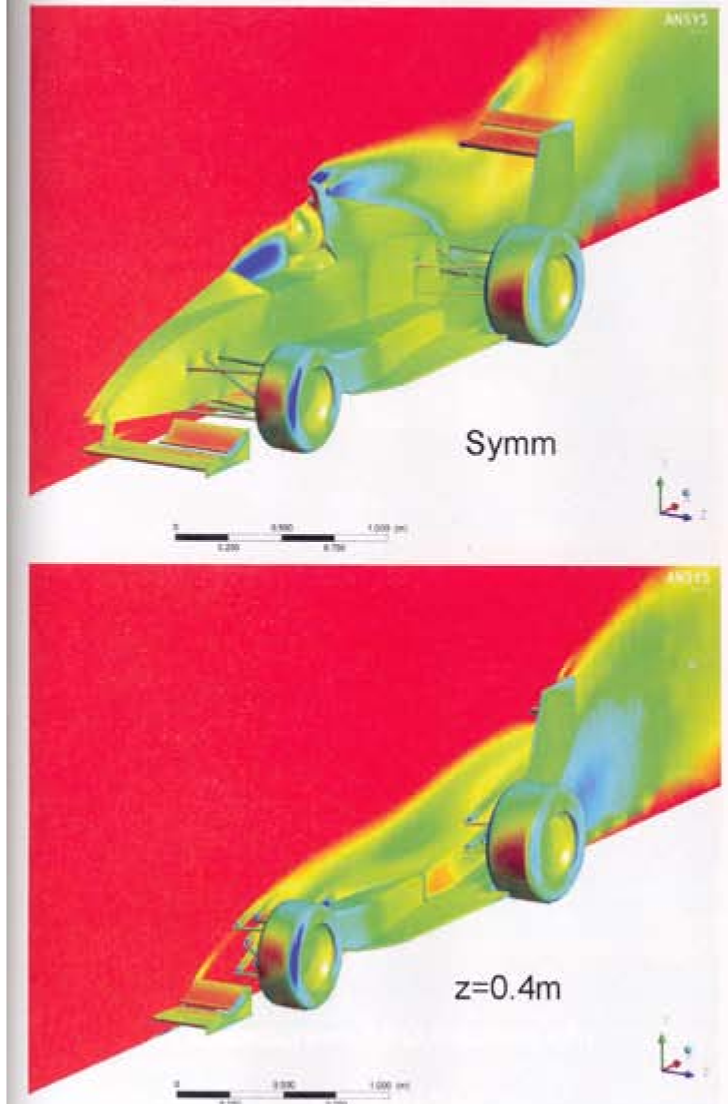


Figure 1: Total pressures on the symmetry plane (top image) and at 0.4m outboard (the bottom image) show reduced energy reaching parts of the racecar's rear wing

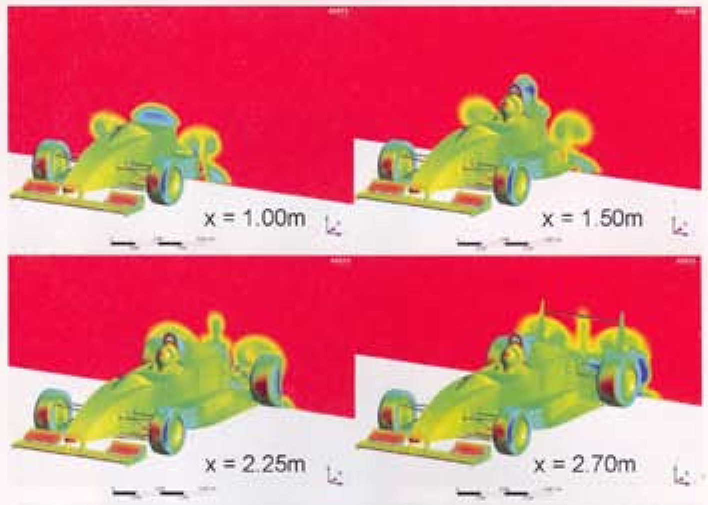


Figure 2: Total pressures on a set of transverse planes cut aft of front axle and before wing's leading edge give a different view on the air quality reaching the rear wing

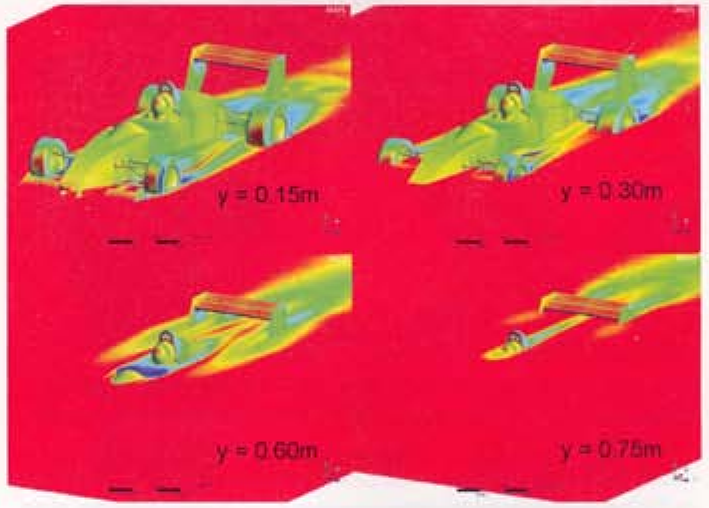


Figure 3: Total pressures on a set of horizontal planes cut at increasing heights above the ground plane provide yet another view of the flow field around the car

separations on those bodies. Moving ground and rotating wheels were utilised, and the K-epsilon turbulence model was invoked. The simulations were run until the calculated forces on the monitored bodies were deemed satisfactorily steady.

Wing environment

Our lead image illustrates some of the complexity in the flows reaching the rear wing. In this case streamlines were projected upwind and downwind from the car and from the wing itself to give an idea of the flow directions and velocities that reach the wing. The varying onset flow angles at the wing's leading edge are apparent, with the flow coming slightly downwards from above the roll hoop in the centre, but approaching more or less horizontally to the outer ends of the wing's main element. And the downwash at the leading edge is quite clear. Another flow feature to highlight here is shown by the cluster of streamlines emerging from the corner of the cockpit next to the driver's shoulder; note how these initially progress rearwards more or less horizontally but then they became entrained in the wing's downwash and turned downwards to pass well below the wing itself. We will return to this characteristic later.

Another way to visualise the flow fields around the car, and how they impinge on the wing, is to use slices on specified planes coloured by total pressure. Vertical and horizontal longitudinal planes and vertical transverse planes yield different information, but collectively they help to visualise the overall 3D picture and give a clearer impression of the air's fluid movement around the car. Looking first at the vertical longitudinal planes in **Figure 1**, the losses in total pressure (flow energy) are shown by colours other than red, where red represents freestream energy. We can see in the upper image how the roll hoop on this model caused losses on the symmetry plane so that the flow that encountered the centre of the rear wing was at reduced energy. However, moving 0.4m outboard (lower image) the air encountering the wing's main element was at freestream energy, although not far below that the flow was at reduced energy. Contributors to these energy losses, and to the direction in which they travelled,

Varying onset flow angles at the wing's leading edge are apparent, the flow coming slightly downwards from above the roll hoop in the centre

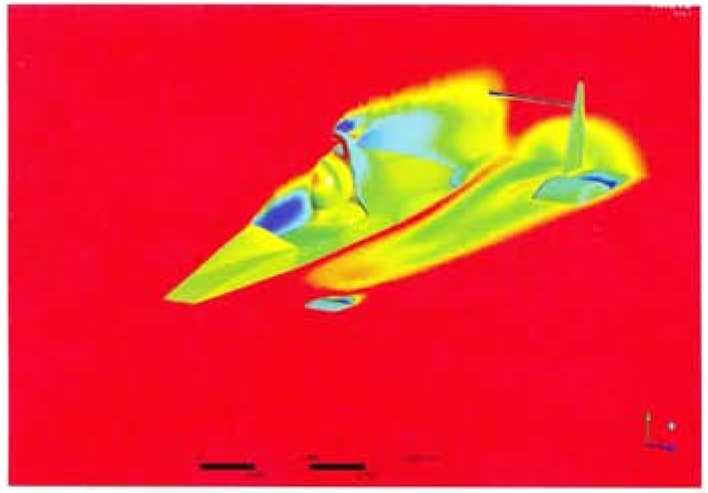


Figure 4: Combining three planes helps with 3D perception of the flows to the rear wing

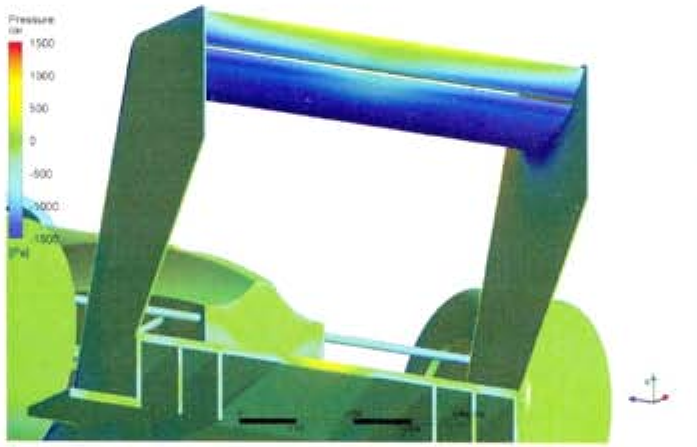


Figure 5: Static pressures on the wing's lower surface shows a central 'dent' in suction

Table 1: The effects of modifying the roll hoop and sidepod leading edge; forces in Newtons at 100mph

	Drag	Downforce	%front	-L/D
Original	954.5	2484.3	38.4%	2.603
Modified	940.3	2508.8	37.6%	2.668

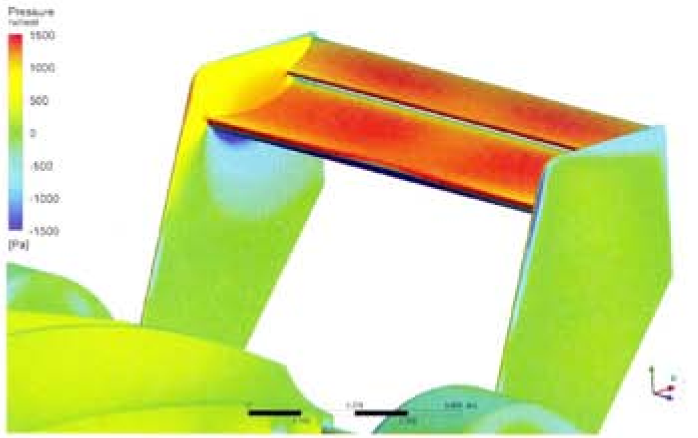


Figure 6: Static pressures on the wing's upper surface show more subtle variations; note the curved stagnation line, shown as the most vivid red strip at the leading edge

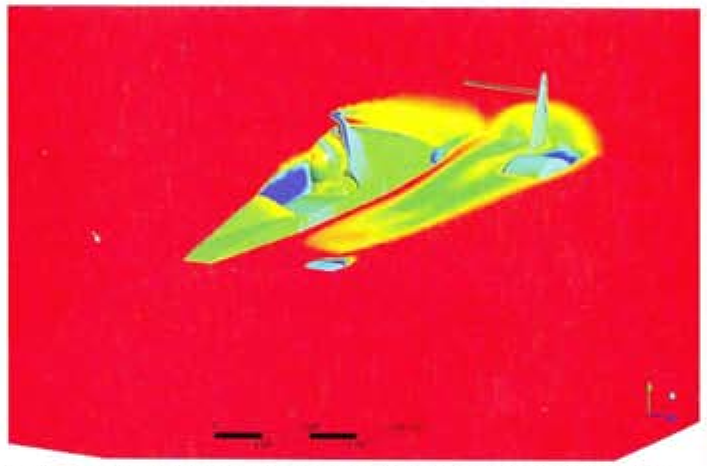


Figure 7: Total pressure losses reduced after detailed improvements to the roll hoop

include the front wing, which caused small losses but significant upwash, the front suspension and the leading edge of the sidepod, which on this iteration of the model triggered flow separation on part of its leading edge and created more widespread losses that were caught up in the flow heading rearwards.

Looking next at transverse vertical planes, **Figure 2** shows a sequence of plane cuts aft of the front axle line to just in line with the rear wing's leading edge. In the first image at x = 1.00m (the front axle was at x = 0m) we can see losses in the flow's energy above and outboard of the sidepod; the former were triggered at the sidepod leading edge while the latter primarily represent the wakes of the front wheels. At x = 1.50m these features were still present but the front wheel wakes had moved inboard slightly, but more noticeable in this image are the losses in the wake of the roll hoop and cockpit. At x = 2.25m the sidepod separation wake and front wheel wake had moved inboard of the rear wheel, while the roll hoop and cockpit wake was still clearly defined. At x = 2.70m, in line with the wing's leading edge, we see the transverse confirmation of what Figure 1 told us about the centre of the wing, and that there were also energy reductions just beneath the outer parts of the wing.

Figure 3 shows horizontal plane cuts at increasing heights above the ground plane. At y = 0.15m we see the energy losses arising from the front wing tip that passed inboard of the front wheel, but the predominant feature is the front wheel wake. At y = 0.30m the standout features are the front wheel wake and the losses caused by the flow separation on part of the sidepod leading edge. At y = 0.60m we can see the effect of the cockpit and the engine cover and also, further outboard, that the front wheel wake had risen to this height and encountered the rear wing end plate further aft. At y = 0.75m the most noticeable feature is the roll hoop and engine cover wake encountering the centre of the rear wing, and also outboard that the upper part of the front wheel wakes were still just in evidence. **Figure 4** is a composite of three planes; two longitudinal planes that give a combined view of the flows that reach the transverse plane level with the rear wing's leading edge.

The effects can also be seen in the surface pressure distributions on the wing itself, and **Figure 5** shows how the pressures on the underside of the wing have been affected, with the 'dent' in the low pressure in the centre of the wing being caused by the reduction in total pressure alluded to above. **Figure 6** shows quite subtle variations in the raised pressures on the wing's upper surfaces, and it is also possible to see the effect of the differing onset flow angles at the leading edge, as evidenced by the upward curvature in the 'stagnation line' in the centre of the wing, which can be seen as the most vivid red (highest pressure) strip along the leading edge.

It would seem that our rear wing was being compromised not only by its fundamental location but also by some details on the model which could be improved. For example, the keen-eyed reader will have spotted the simplistic, sharp edged roll hoop in the lead image, and as no self-respecting roll hoop would be manufactured in box-section, a

Our rear wing was being compromised not only by its fundamental location but also by some details on the model which could be improved

Figure 8: Surprisingly the mirror streamlines did not impinge on the rear wing

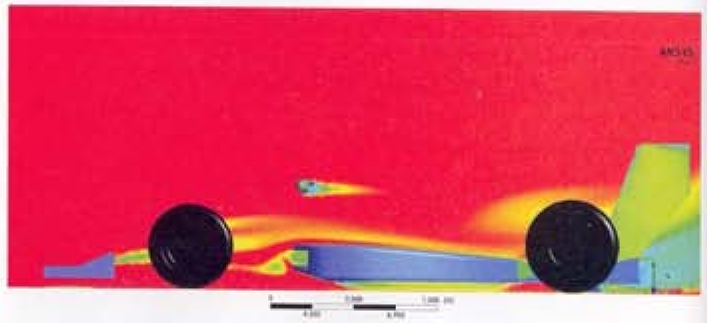


Figure 9: Total pressure losses caused by the mirrors were relatively short lived

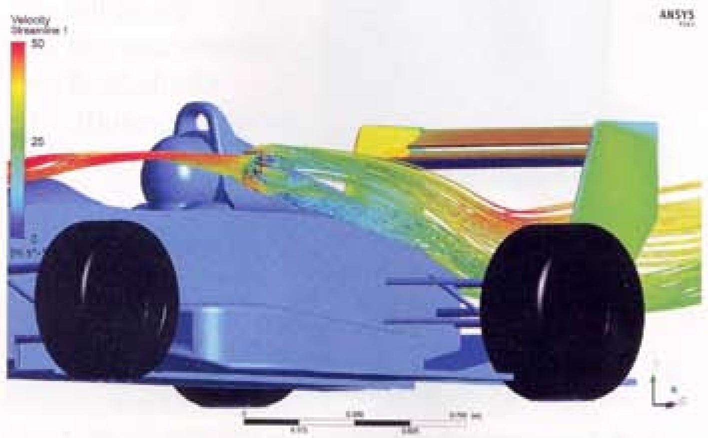


Figure 10: The camera generated more disruption but its wake passed below our wing. If their had been a lower wing tier it might well have been adversely affected by this

Figure 11: Rear wing Twist 1. Angle of attack at centre was increased by four degrees

Table 2: The effect of Twist 1 on the overall aerodynamic data of our single seater model

	Drag	Downforce	%front	-L/D
With original wing	940.3	2508.8	37.6%	2.668
With Twist 1 wing	942.1	2473.4	38.5%	2.625

generous radius was applied to the roll hoop's leading edges. Clearly this modification was not one that would be necessary in the real world of round steel tubing, but the benefit of the unrefined CAD in this instance was to highlight and amplify the potential effect of this region on the wing. And in a modest first attempt at reducing the flow separation on the sidepod's leading edge the radius on this feature was increased. There was a tangible effect in the force data, as **Table 1** illustrates, and the total pressure plots in **Figure 7** showed reduced losses compared to those shown in **Figure 4** in the flows encountering the rear wing, especially from the roll hoop.

By examining the force distributions on the individual component groups it was evident that most of the extra downforce came from the rear wing, while most of the drag reduction was from the chassis/body, which of course included the roll hoop.

A feature absent from our model was mirrors, so mirrors of representative size were modelled onto the car to examine what effect they would have on the rear wing and the overall aerodynamic data. The result was very interesting, because although the mirrors added about 9N, or just less than one per cent extra drag, there was no appreciable effect on the downforce numbers whatsoever. So while some effect might have been expected on the flow field encountering the rear wing, this was not the case, on this model and under these test conditions at least. **Figures 8** shows that the streamlines leaving the mirrors travelled a similar route to those that emanated from the cockpit sides, alluded to earlier, in that they were turned downwards by the rear wing's downwash and passed well under the wing's elements. Had a lower wing tier been in use here then the effect on downforce might have been different. However, **Figure 9** also suggests that the total pressure losses caused by the mirrors were relatively short lived, freestream energy air filling in the wakes not far downwind, well ahead of the rear wing.

An object frequently seen these days clamped to roll hoops is the onboard video camera, and while the professionals in the top echelons house their onboard cameras in aerodynamically streamlined pods, the camera of popular choice used elsewhere is shaped like a small house brick, albeit it with filleted corners, and attached with (necessarily) bulky brackets. Once again then a 'camera' of representative dimensions was modelled on to one side of our car and attached to the roll hoop base, and again the result was perhaps not as expected. There was an additional drag increment of around 0.6 per cent but, within the margin of error arising from computational fluctuations, there was no significant change to the downforce numbers. **Figure 10** shows the streamlines projected upwind and downwind from the camera, and although the camera was evidently more disruptive than the mirrors, its wake passed well under the rear wing's main element and, according to the data, it did not materially affect the wing's performance. Again, had there been a lower wing tier then potentially there may well have been an effect.

Winging the changes

It's always risky trying to mimic a design characteristic, and that is certainly true when copying features from a car designed and highly developed to a unique and specific rule set. However, when it comes to rear wing designs it's tempting to try

Mirrors of representative size were modelled onto the car to examine what effect they would have on the rear wing and the aerodynamic data

McLaren F1 rear wing from Spa 2014 was the inspiration for our Twist 1 wing – shown in Figure 11

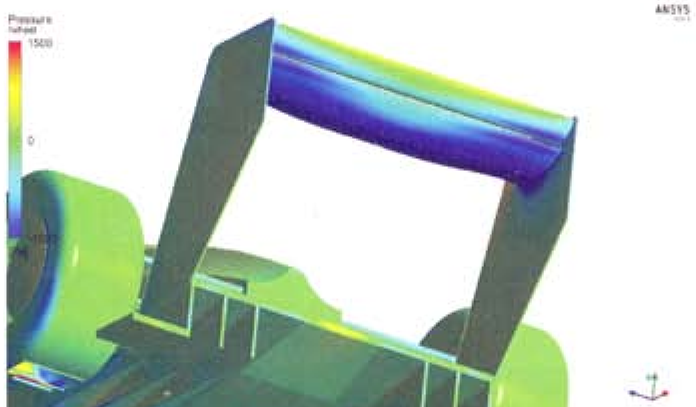


Figure 12: The dent in the suction on the McLaren-inspired Twist 1 rear wing's lower surface seemed to be larger than that shown with the baseline rear wing

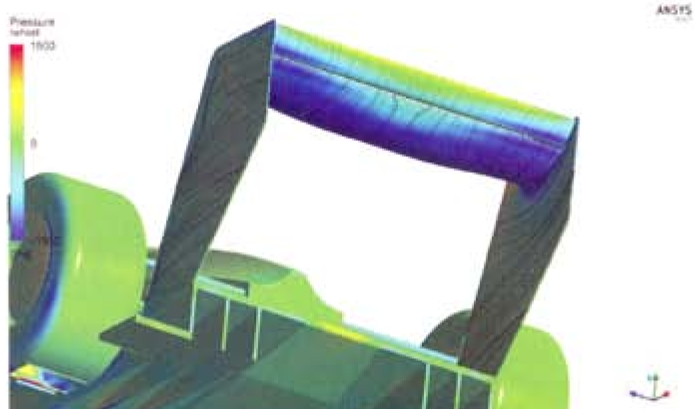


Figure 13: Surface streamlines showed that flow separation almost occurred near the trailing edge of the centre of the main element of the Twist 1 rear wing model

out a couple of features seen on F1 cars to see if they might be generically useful and thus beneficial on our single seater model. With our simple model and the limited resolution of the resources on which the CFD was being run, it would have been pointless making small changes and expecting to see their effect, so a small selection of reasonably significant changes was made so that the results could be viewed with a certain amount of confidence.

The first change that was made was to the main element of our rear wing, and the inspiration for this was a wing that McLaren ran at Spa in 2014. In order to obtain a main element approximating this shape (**Figure 11**), the angle of attack at the centre of our wing was increased by four degrees, while that at the outer ends was decreased by two degrees. The flap was left exactly as before, whereas the McLaren's flap featured small V-notches in the centre and near the tips, and the whole wing assembly sported the usual myriad details. The purpose of our trial was to see if twisting the main element (Twist 1) produced a different result on the car, and the results are shown in **Table 2**.

There was very little difference then with the Twist 1 wing installed on our model, drag barely changing and downforce dropping by about 1.4 per cent, with the net result that efficiency (-L/D) dropped by 1.6 per cent. So while one would have expected that McLaren fitted their 2014 Spa wing to either decrease drag or increase efficiency, or both, simply applying a similar-looking twist to our wing's main element didn't appear to provide any benefits at all.

However, looking at the pressure distribution on our wing's lower surface in **Figure 12** it is apparent that the increased angle in the centre of the wing was possibly slightly excessive in that the 'dent' in the low pressure in the centre of the wing was somewhat larger than on the original wing (Figure 5). **Figure 13** shows the surface streamlines were almost on the point of separating near the main element's trailing edge, confirming that this wing may have performed better with some further optimisation of the angle at the centre, although nothing in the data suggested that there would be worthwhile gains from this twist concept.

The second modification to the wing was inspired by the 'spoon' shaped device that Mercedes have run at low downforce tracks like Spa and Monza. In the F1 team's case the flap also incorporated span-wise variations in chord and angle, but in our case the flap was kept as per the original wing and the main element

There was little difference with the Twist 1 wing installed on our model, drag barely changing and downforce dropping by about 1.4 per cent

The Mercedes low downforce rear wing, as used at Spa and Monza

Figure 14: Twist 2 is based on the Mercedes low downforce rear wing

Table 3: The effects of Twist 2 on the overall aerodynamic data of our single seater model

	Drag	Downforce	%front	-L/D
With original wing	940.3	2508.8	37.6%	2.668
With Twist 2 wing	932.4	2470.9	38.8%	2.650

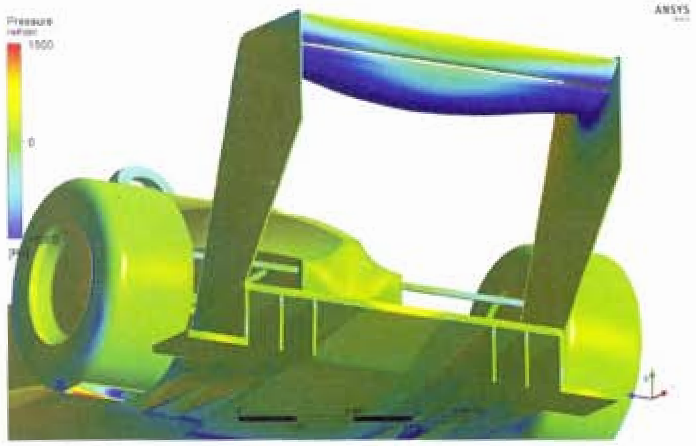


Figure 15: Twist 2 exhibited a slightly wider dent in its underwing suction

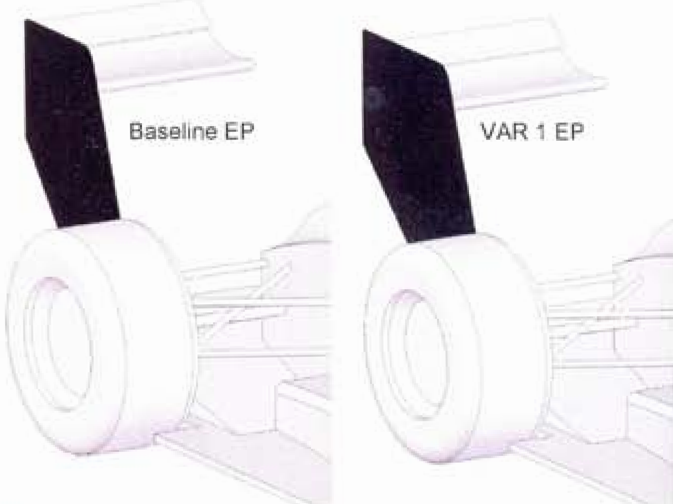


Figure 16: End plate was extended 100mm further aft of the wing (VAR 1)

Table 4: The effect of end plate VAR 1 on overall aerodynamic performance

	Drag	Downforce	%front	-L/D
With original wing	940.3	2508.8	37.6%	2.668
With VAR 1 wing	940.0	2524.9	37.6%	2.686

only was modified. The angle of the centre of the main element was increased a further two degrees on the Twist 1 wing, and the outer ends had their chord dimension reduced by 70 per cent, with a gradual taper from the centre to form our Twist 2 wing (**Figure 14**). **Table 3** gives the data compared to the baseline car.

In this instance there was slightly more than a 0.8 per cent decrease in overall drag together with a 1.5 per cent reduction in overall downforce, leading to just under 0.7 per cent reduction in efficiency. So although the wing could not be said to have helped with aerodynamic efficiency, it did generate less drag. Of course it would have been possible to have achieved a comparable result by simply backing off the angle of the flap or of the whole wing assembly, so it would be fair to assume that Mercedes achieved rather better than this with the complex shaping of its spoon wing. In reality it may not have used such a steep angle at the centre of its main element, but rather reduced its overall height in the centre so that it could interact more strongly with the devices below it, including the small central monkey seat wing and the rear diffuser, and these may have increased overall efficiency.

But the reduced chord near the tips would have contributed to reduced downforce and drag, as seen with our Twist 2. **Figure 15** shows once again the dent in the surface pressure near the centre of the wing, and this is now slightly wider than on the Twist 1 wing, so optimisation may yield improvements in efficiency.

Another aspect of F1 rear wings that might have generic applicability was the front to rear depth of the end plates. Ignoring the complex shapes, louvres, notches and vanes on current F1 rear end plates, fundamentally the rear edges extend further past the wing elements than is usually the case. Although this is at least partly driven by the technical regulations, end plate overhang is a parameter this writer has not specifically investigated where technical freedoms exist and the dimensions are optional, so a quick look-see with an additional 100mm of end plate aft of the wing elements was run as VAR 1, **Figure 16**. The data is shown in **Table 4**.

In this instance drag did not alter but downforce increased by just over 0.6 per cent, taking efficiency up to the best value in this trial. Clearly in the context of, say, a club or national category, a relatively very cheap modification like slightly bigger end plates to achieve the kind of modest aerodynamic performance increases we have seen in these trials would be much better value than tooling up for an entirely different shaped rear wing main element. End plate overhang is a parameter we may come back to in a future issue, along with other end plate modifications yet to be tried.

Summary

Having examined the environment in which the rear wing on a single seater has to work, we have also seen that significant changes to wing shape made small differences to overall aerodynamic performance. The quest for effective gains will continue …

Many thanks to ANSYS UK for providing the CFD software.

Mercedes may not have used such a steep angle in its main element