AEROBYTES

with Simon McBeath

Airdams

Often present, potentially very beneficial, but frequently misunderstood, we explain how airdams work

The textbooks agree on the benefits of airdams to both downforce and drag, but explanations of the mechanisms involved are mixed. We've used CFD to measure and 'see' what actually happens to a racecar fitted with an airdam.

Advantage CFD used a similar full-scale model NASCAR racer to that used in the study reported in V11N11. This incorporated detail such as a 'rough' underside with exhaust pipes, chassis rails and cavities, and also a rear spoiler (see figures 1 and 2). Simulations in 3D CFD were run at 50m/s (180km/h or 112mph) air speed, and three different airdam depths.

The plots in figure 3 show the results of downforce and drag (as dimensionless CDfA and CdA values, the product of frontal area and the relevant coefficient) and show total downforce increasing and drag decreasing with airdam depth. [Note: downforce is treated as 'positive' and lift and as 'negative'.] The downforce benefit dominates at the front end of the car. Furthermore, the rear end actually loses some downforce. The trend is heading towards a more even front to rear balance and greater aerodynamic efficiency (downforce to drag ratio).

As only three depths were evaluated it would be a little careless to suggest these trends would continue beyond the deepest airdam measured here, and the textbooks suggest that drag would actually start to rise again at some greater depth. However, our purpose here is to explain the effects.

Looking first at how the airflow is modified by the airdam, figure 4 shows that less air passes beneath the car and more air is pushed around the sides with an airdam. In figure 5 we can see there is a region of recirculation behind the airdam. Furthermore, the so-called 'stagnation point' – where the air hits the car head on – is lower when the airdam is fitted, more air being pushed over the bonnet (hood) and therefore less being pushed under the car.

Changes to the pressure on the upper and lower body surfaces occur because of these flow modifications. Figure 6 shows the change in pressure coefficient, ρCp (deltaρCp), plotted on the main surfaces. But only the vertical (Z-direction) component is shown, so that the effect on downforce is isolated for clarity, hence the ρCpZ designation. Thus reds and yellows indicate additional lift while blues and greens indicate additional downforce.

The forward upper surface shows a small positive (upward) change in pressure, indicating the airdam causes some additional lift over the bonnet. The underside however shows a large area of negative (vertically downward) change in pressure, indicating 'suction' on the underside caused by the airdam. This extends roughly halfway along the car then changes to a slight positive value, indicating some lift under the rear after the airdam was fitted. The net result is the gain in downforce we see, which is concentrated at the front.

Figure 7 shows the ρCpρX plot, indicating pressure changes in the X-direction, where positive (red and yellow) is an increase in rearward acting pressure (more drag) and negative (blue and green) is a decrease in rearward acting pressure (less drag). Clearly the airdam itself creates drag where the air runs into it, but there is less drag on the forward part of the bonnet above it. There is also a reduction in drag from the wheels and significant areas of the underfloor and associated clutter. The net result is the decrease in drag.

Can we explain these changes using Bernouilli's Equation? Well, the

Figure 1: NASCAR model showing three different airdam variations

Figure 2: NASCAR model showing the realistic 'rough' underside

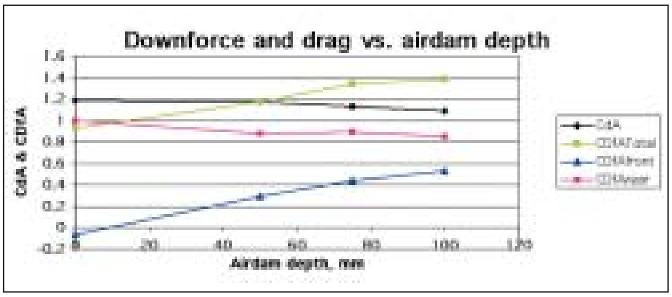

Figure 3: effect of airdam length on downforce at the front and rear, and overall drag

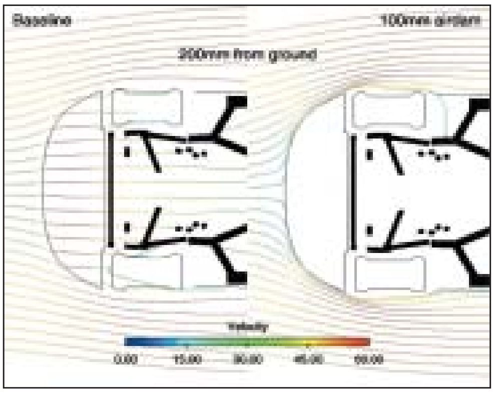

Figure 4: overhead view of streamlines for the no airdam and 100mm airdam cases at 200mm from the ground

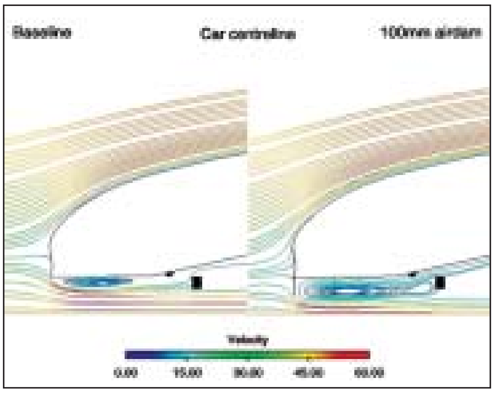

Figure 5: side view of streamlines at the car centreline for the no airdam and a 100mm airdam

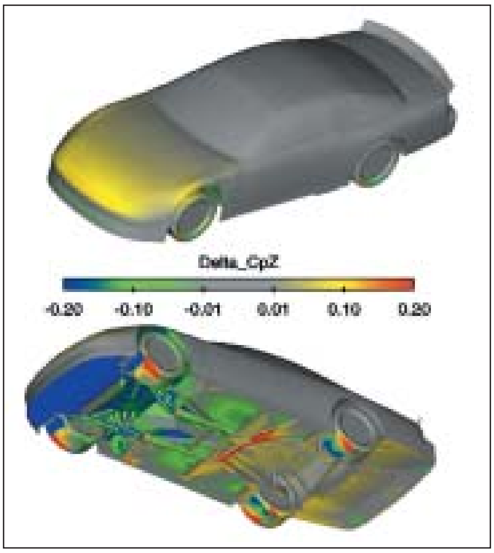

Figure 6: effect on downforce of adding a 100mm airdam

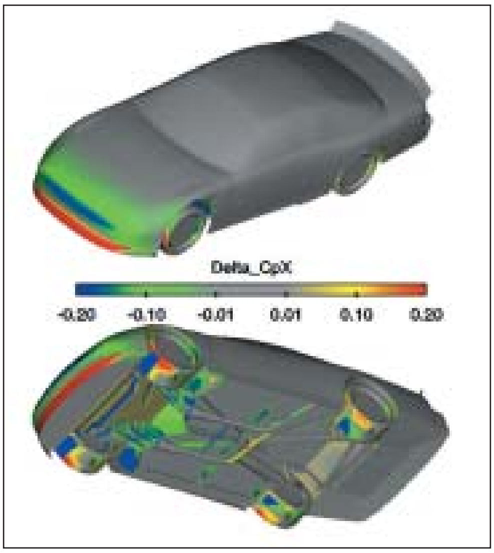

Figure 7: effect on drag of adding a 100mm airdam

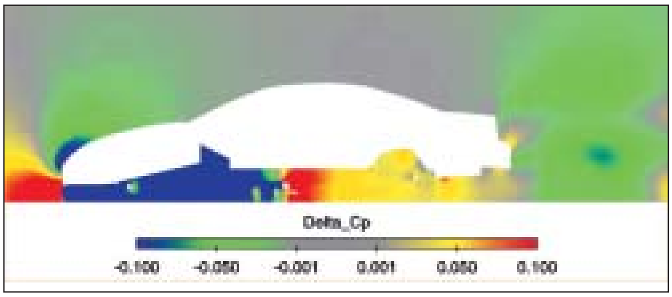

Figure 8: the effect of adding a single 100mm airdam on static pressure around the car

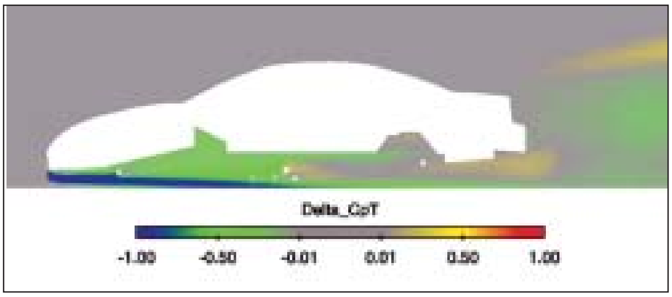

Figure 9: effect of adding a 100mm airdam on total pressure movement around the car

reduction in lift and drag over the forward part of the bonnet can both be explained by the increased flow over this area caused by the airdam, which leads to an increase in velocity and a Bernouilli-type drop in pressure. The slope of the bonnet means there are forward and vertical components to this pressure reduction, leading to decreased drag and increased lift over this region. The additional drag on the airdam is also simply explained by Bernouilli, the airflow coming to a virtual stop here, leading to low velocity and high static pressure acting rearwards.

The underside region behind the airdam is not so simple. As we saw in figure 5, the air behind the airdam is re-circulating and moving relatively slowly and yet, as we saw in figure 6, the pressure is reduced behind the airdam. This seems to contradict Bernouilli, and the effect more readily falls into what Erik Zapletal referred to in V12N4 as 'aerostatic downforce that is non-Bernouilli in nature'. Advantage CFD's explanation goes back to a modified version of Bernouilli's Equation to explain the mechanism:

ps + 1/2rV2 + losses = constant

where ps is static pressure and 1/2ρV2 is dynamic pressure (ρ, Greek letter 'rho' is air density, V is air velocity).

We tend to think of Bernouilli's equation as describing 100 per cent efficient interchange between static and dynamic pressure, so that when velocity and hence, dynamic pressure increases, static pressure decreases. As a statement based on the Conservation of Energy that's fine but, as Erik Zapletal pointed out, it assumes there will be no addition to, or subtraction (losses) from, the total pressure energy in a system. But in reality there always will be losses. Bernouilli also assumes the flow will be smooth, and around a non-streamlined device like an airdam, the airflow is turbulent.

So we've got a region of turbulent, low velocity flow that is also at low pressure. How can CFD help explain this? Figure 8 shows a ρCp plot that reveals the changes in static pressure along the car centreline that occurs when the airdam is fitted. This shows clearly that there is a very marked drop in static pressure behind the airdam, which is where our front-end downforce originates. We know that the velocity here is low, so we know that the dynamic pressure is also low. So we must conclude that losses from the flow have increased here. Figure 9, showing a ρCpρT plot, the change to total pressure, confirms this by showing that total pressure has in fact dropped behind the airdam.

Next month we'll add a splitter to the airdam.

AEROBYTES

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Splitters

A 'must have' fit on many a closed wheel racecar, there's more to the splitter's function than might be supposed…

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Splitters can be so effective at generating downforce they are banned in NASCAR events

In the previous issue we looked at airdams on the front of a generic NASCAR racer and, with the aid of CFD, found out how and why deep airdams (up to a point) create useful and highly efficient front-end downforce. Though you won't see one in NASCAR, a horizontal 'splitter' added to an airdam is a common device renowned again for producing low -drag downforce. This month Advantage CFD has added splitters of various sizes to the NASCAR model used for the airdam study.

Recapping briefly, the full scale, virtual NASCAR model incorporated such realistic details as a rough underside with exhausts, chassis rails, bumps and cavities, and also a rear spoiler (see figure 1). Several 3D CFD runs were carried out at 50m/s air speed (180km/h or 112mph) and evaluated with three different splitter lengths attached to the 100mm airdam modelled in the previous issue.

The plots in figure 3 show the results of downforce and drag (as dimensionless CDfA and CdA values, the product of frontal area and the relevant coefficient). The graph shows total downforce increasing (by just over 10 per cent compared to the baseline case) up to a splitter length of 100mm, and drag remaining virtually unchanged (it actually increased slightly but by less than one per cent). Note downforce is treated as 'positive' here in this example.

As was the case with airdams, the gains in downforce were at the front end of the car, and in fact once more the rear end actually lost some

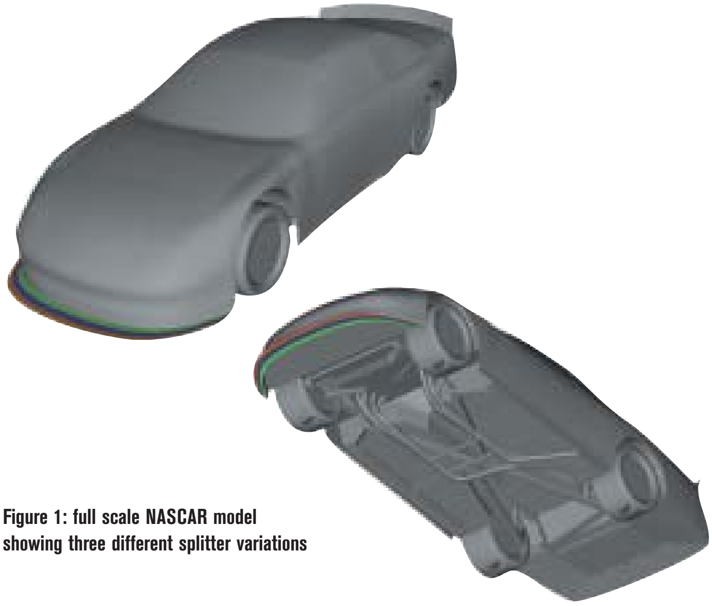

Figure 1: full scale NASCAR model showing three different splitter variations

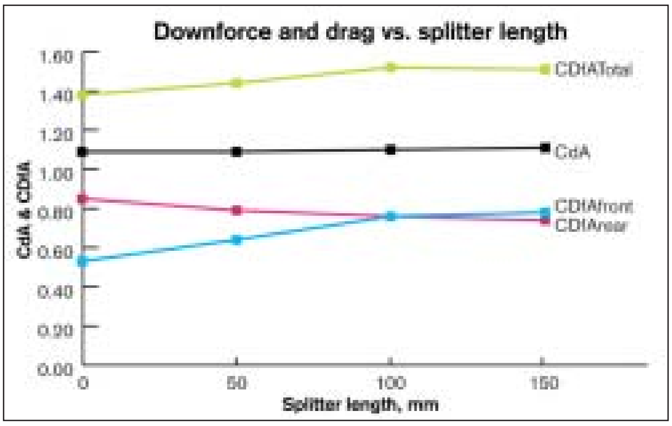

Figure 3: effect of splitter length on downforce at the front, rear and overall, and overall drag

downforce. Thus, the trend of converging front and rear downforce coefficients started by the airdams was continued with the addition of the splitter, until a 50/50 front to rear aerodynamic balance was achieved with a 100mm splitter attached to the 100mm deep airdam. This may or may not translate to an aerodynamic handling balance of course, depending on the static and dynamic mechanical loadings of the car.

It would appear then that there is a maximum splitter length that ought to be run, and this tallies with the conventional wisdom found in the textbooks. Indeed figure 4 agrees nicely with the textbook explanations of how a splitter generates downforce. It is very clear in this image that the splitter 'taps' the zone of high static pressure ahead of the nose of the

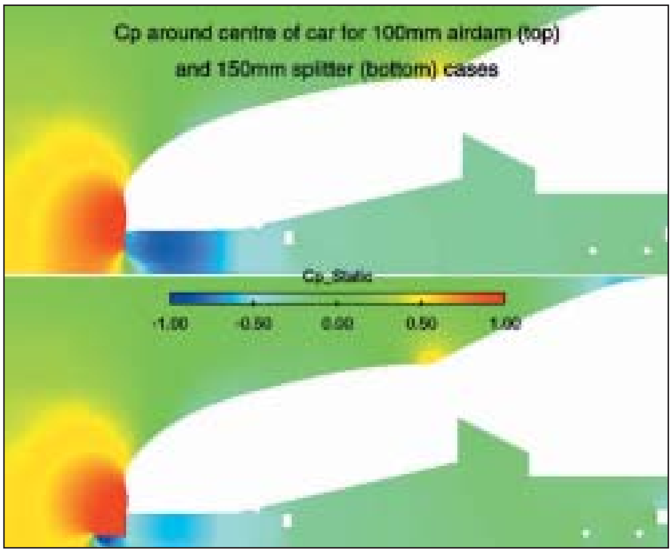

Figure 4: effect of adding a splitter on the static pressure around the front of the racecar

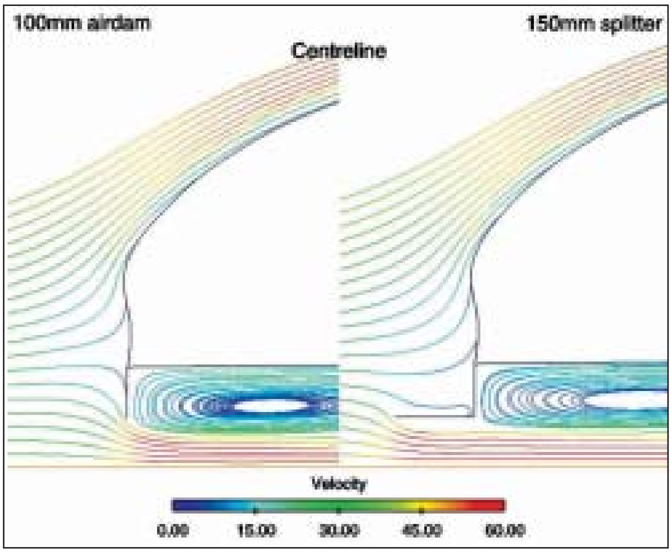

Figure 5: streamlines at the car centreline for the 100mm airdam and 150mm splitter cases

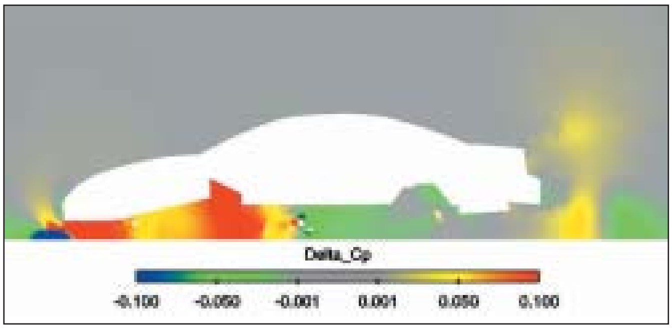

Figure 6: changes to pressure that occur by fitting a 150mm splitter to the 100mm airdam

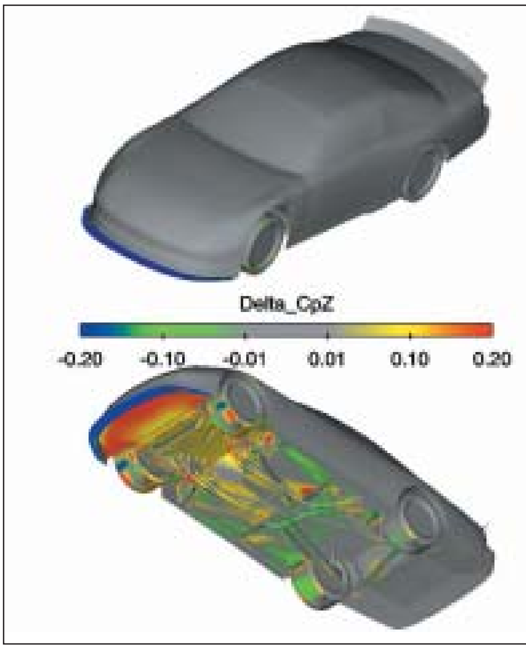

Figure 7: effect of adding a 150mm splitter on downforce

car, and furthermore that there is a very marked low pressure zone immediately under the splitter. These pressure changes add up to downforce. It is also apparent that there would be little point extending the splitter further forward than the extent of the high pressure 'bubble', and this may be at least part of the reason why maximum downforce peaks at the 100mm splitter length in this case.

Figure 5 shows that the splitter has the effect of channelling more air up and over the car, but also that the reduced volume of air going under the splitter is locally accelerated to generate the low pressure there. But going back to figure 4 again, it is also apparent that the pressure is not as low behind the airdam when the splitter is fitted, as evidenced by the paler blue colour, compared to the airdam-only case. Figure 6 shows a ρCp plot, which indicates the difference in static pressures, between the airdam only and airdam plus 50mm splitter cases. The pressure reduction (blue) under the splitter is clear, but so too is a rise in pressure (red and yellow) behind the airdam and under most of the front of the car's underside.

Thus, although there is a very useful net benefit in front end downforce achieved by fitting the splitter, there is a trade off in that the front underbody pressure is raised, which counteracts some of the splitter-generated downforce. This might also have implications for the venting of cooling air in some front-engined applications where this raised pressure works against air exiting the cooling system towards the underside.

That the splitter is a powerful device for the generation of downforce is clear in figure 7, which is a ρCpρZ plot, indicating pressure changes in the vertical or Z-direction only. From above and below the downward-acting pressure changes (seen in blue) on the splitter are abundantly clear, but so too is the rise in pressure behind the airdam. Why does this happen?

We have already mentioned that the splitter directs more air over (and around) the car, and that what went under the splitter was accelerated. This is where the downforce accrues. But this reduced volume of air passing under the splitter then slows aft of the splitter to a lower velocity than was the case without the splitter, and this is associated with the enlarged recirculation zone apparent in figure 5. So now the dynamic pressure in this region is lower than the airdam-only case, and the static pressure is higher. It's swings and roundabouts, but the swings win.

The very small increases in drag are the result of some pluses and minuses, too. There are modest reductions in drag felt by the car's body, wheels and the airdam, but these are offset by slightly less modest increases in drag felt by the underfloor and its tubes and protrusions, which result from the rearward component of the aforementioned increase in pressure in that region acting on these components.

In practical terms the splitter is an uncomplicated device that can be a very useful, efficient generator and balancer (by adjustment, where permitted) of downforce. Its ability to function will be affected by the shape of car it is attached to – clearly a blunt front end like on our NASCAR model here will have a more pronounced high pressure zone to 'tap' ahead of it than a sleek, low-line front end. And another issue to keep in mind is that, being close to the ground, there is the possibility of ride height or pitch sensitivity cropping up with a splitter.

Next month we'll add a diffuser to the airdam/splitter assembly.

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Front diffusers

Less visually obvious than some downforce-generating devices, the front diffuser can be found in various guises on a wide variety of closed-wheel racecars

In the last couple of issues we have looked at the effects of airdams and splitters on the front of a virtual model of a generic NASCAR racer with which we've taken many more liberties than the NEXTEL teams are allowed! As such, very efficient (low drag and even drag-reducing) gains in downforce have been achieved.

An extension (in both senses) of the airdam/splitter is the front diffuser which, when permitted, is a rearwards continuation of the splitter under the front of the car that then sweeps upwards. Variations that have been used on saloon/sedan and sports racecars include a single, wide diffuser, a pair of separate narrower diffusers in line with the gap between the wheels and the chassis and even four smaller diffusers. Advantage CFD modelled a single, wide diffuser as shown in figures 1 and 2. A simple 'with versus without the diffuser' study was performed in 3D at an airspeed of 50m/s (180km/h or 112mph).

The result of installing this simple diffuser on this model with a 100mm deep airdam and a 150mm long splitter (see the previous two issues) was a 3.9 per cent increase in overall downforce (the benefit was concentrated at the front, with rear downforce reducing slightly) and a 1.4 per cent increase in drag. This represents a more modest benefit than the airdam or the splitter achieved, but is nevertheless a worthwhile and reasonably efficient gain. Bigger gains could, no doubt, be achieved with optimisation,

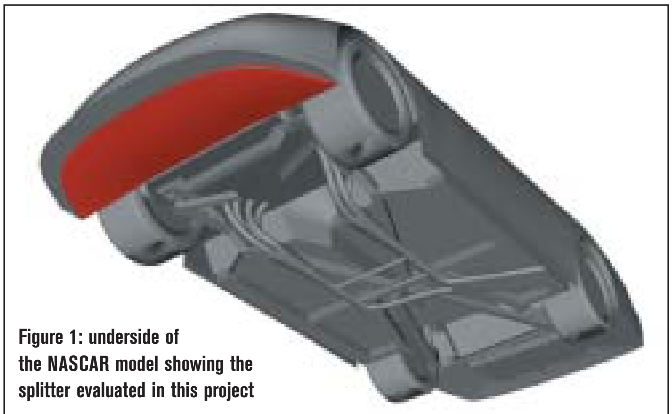

Figure 1: underside of the NASCAR model showing the splitter evaluated in this project

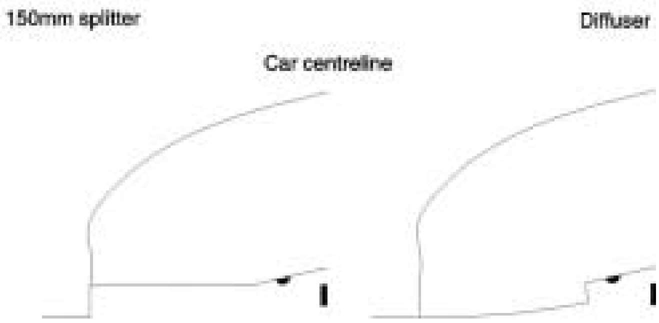

Figure 2: centreline profile showing the geometry with and without the diffuser fitted

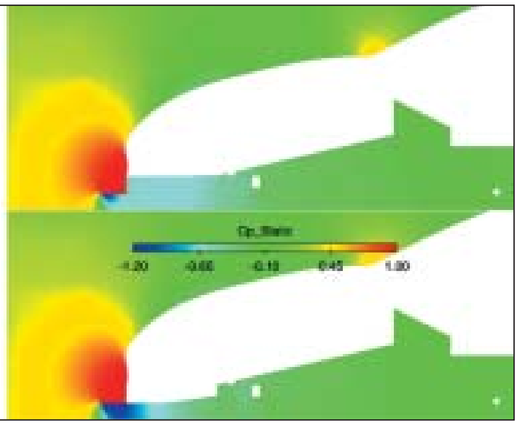

Figure 3: static pressures show the differences created under the forward underbody by fitting the diffuser

but the purpose here was to investigate why the benefit occurs.

Looking first at figure 3, it is apparent that after 'fitting' the diffuser, the high-pressure zone (red) above the splitter has remained pretty much unchanged but there has been a significant decrease in static pressure under the splitter, evidenced by the larger zone of darker blue which also extends under the forward part of the diffuser. This creates more downforce. However, under the rearward part of the diffuser the static pressure is now higher (green rather than pale blue) than it was in the underbody here with no diffuser, which means less downforce is being created here than before. So as always, the picture is not a simple one.

Moving to figure 4, showing velocity coloured streamlines, a couple of things become apparent. Most obviously the large re-circulation zone behind the airdam now has nowhere in which to develop. But importantly, the diffuser allows the airflow to expand, where the re-circulation zone previously acted as a barrier to this expansion. By facilitating →

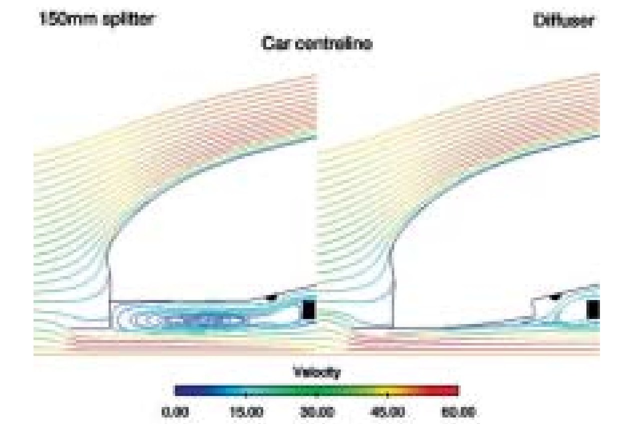

Figure 4: velocity coloured streamlines along the centreline without and with diffuser

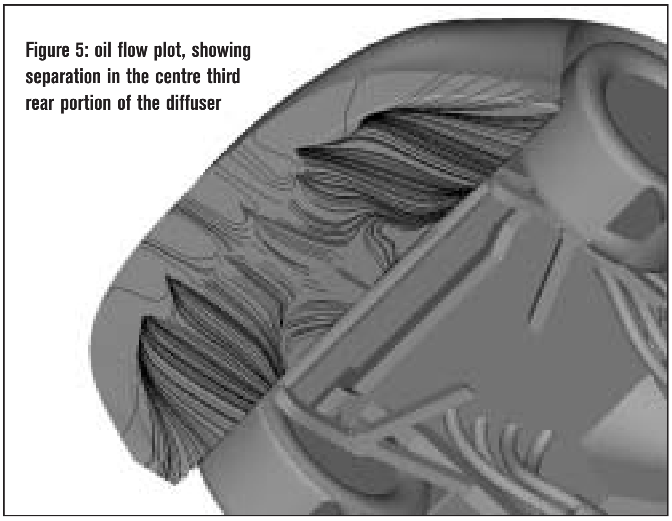

Figure 5: oil flow plot, showing separation in the centre third rear portion of the diffuser

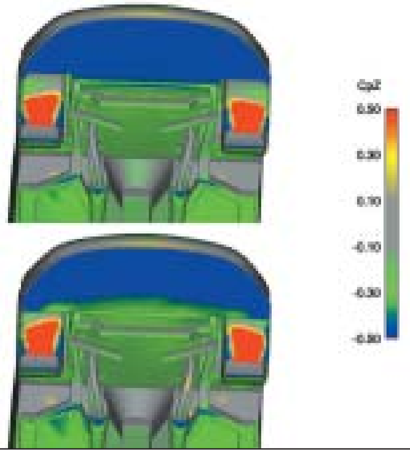

Figure 6: Cp_Z plot showing pressure was not so low in the rear part of the diffuser (bottom pic)

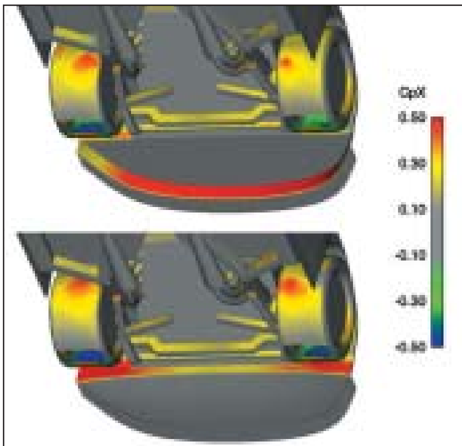

Figure 7: Cp_X plot showing how sources of drag have moved when the diffuser was fitted (diffuser case at bottom)

expansion the diffuser promotes increased flow under the splitter. This results in an increase in velocity under the splitter, which contributes to the decrease in static pressure there, in true Bernouilli fashion. There are also losses here resulting from the sharp leading edge of the splitter that cause a drop in total pressure and hence, a further drop in static pressure, though this is not evident in the diagrams here.

However, moving aft along the diffuser, a closer look at the topmost streamline in the diffuser suggests the flow might have actually separated here. Figure 5 confirms much more clearly that this is the case. This is an 'oil flow plot' which simulates the real world flow visualisation technique using an oily fluid to show surface flows. The change in the pattern of surface flow in the centre third, towards the rear of the diffuser, is the result of flow separation. So why has this happened, and what are the consequences?

We have seen in previous Aerobytes that separation can occur when fluid (including air) is flowing against too steep an 'adverse pressure gradient', that is to say where pressure goes from low to high too rapidly for the flow to be able to manage the 'climb', or to slow down in time. In this instance, the low pressure under the splitter has been amplified by the presence of the diffuser, but this has also created an increase in mass flow under the splitter which, when it expands again in the diffuser, rises to higher total pressure (and hence higher static pressure, as shown in figure 3) than it did without the diffuser. Thus the pressure goes from lower to higher as before, but the gradient has now become too severe and the flow has separated. This is an area where further study could provide improvements.

Figure 6 shows a Cp_Z plot indicating static pressures in the vertical or Z-direction only, viewed from below to show the front section of underbody. Blue and green colours show downward acting pressures (downforce production), and it is apparent that the static pressure across most of the rear of the diffuser is not as low as it is under the same region of underbody when there was no diffuser. Thus, as is often so, it's a case of swings and roundabouts again, but the swings win overall.

Figure 7 is a Cp_X plot showing the static pressure components in the horizontal or X-direction only in the front underbody region. Positive (red and yellow) colours indicate drag. An area where drag occurs can be seen behind the airdam when there is no diffuser, but this shifts to behind the diffuser when it is fitted, and calculations showed that the magnitude of the drag in this region barely changes. Notably, the diffuser itself does not create any significant drag. There was, however, a slight increase in drag overall, and this was mainly due to increases from the underfloor protuberances and the rear of the front wheelarches, presumably because of the increased mass flow under the splitter/diffuser that runs into these components. Design optimisation could again provide improvements here.

Conclusion

This simple diffuser has provided an additional increment of reasonably efficient downforce to those substantial gains already achieved by the airdam and the splitter. Improvements could of course be made, perhaps to the splitter, the shape and dimensions of the diffuser and other detail aspects (assuming technical regulations permitted) to provide further gains in downforce. Moreover, close study of where drag occurs would enable design changes that could further improve efficiency. RE

More next month on the virtual NASCAR model