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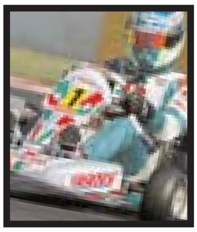

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It is well known that ground clearance, along with the shape of the underbody, is one of the principal factors that influences the generation of underbody downforce on a racecar. As we've shown earlier in this series, given some freedom to shape the underbody, even if that is limited to running a diffuser at the rear of an otherwise flat underside (the venturi throat) – perhaps with nothing more than a moderate radius to the inlet – then the mechanism by which that downforce is created is in essence, that of a venturi tube.

The principle by which air is accelerated beneath the car, so reducing the pressure there as described in Bernoulli's theorem, is that of Conservation of Mass. This states that the mass flow through the venturi must be the same along its length. Hence, where the cross sectional area of the venturi reduces, the flow velocity increases in direct inverse proportion. And as Bernoulli tells us, increases in velocity lead to decreases in local pressure.

Continuing our examinations of underbody airflow, Advantage CFD ran some trials using two mathematical models, each based on a simplified 2m (6.5ft) long racecar sidepod. One set of calculations predicted downforce values at varying ground clearances based on Bernoulli's equation, while another did the same using 2D viscous computational fluid dynamics (CFD) methods on an essentially very similar model. The differences in the predictions were illuminating, as

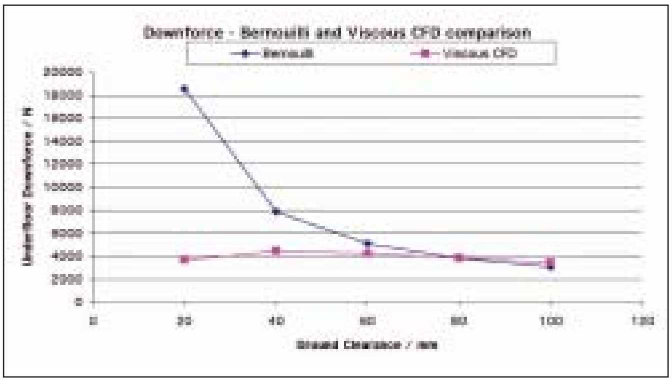

Figure 1: downforce values at different ground clearances by Bernoulli and viscous CFD

was the detail produced in the CFD runs.

Air is accelerated into the throat of a venturi by being channelled into a reducing cross sectional area. The 'area ratio', that is, the ratio of the inlet area to the throat area, tells us by how much the velocity will increase, since velocity varies inversely with the area. Clearly the cross sectional area of the throat of a profiled underbody close to the ground depends very much on ground clearance, and the area ratio will increase more rapidly with ever-decreasing ground clearance. Thus, using Bernoulli-based calculations we might expect to see downforce predicted to rise rapidly with decreasing ground clearance, and the relevant line in the graph in figure 1 confirms this, with a classic inverse relationship curve.

The results predicted by viscous CFD are also plotted on this graph, and the picture is obviously very different in this case, most significantly at the smaller ground clearances. At the larger ground clearance end of the scale, where the volume of air affected by the viscous effects of

Produced in association with Advantage CFD.

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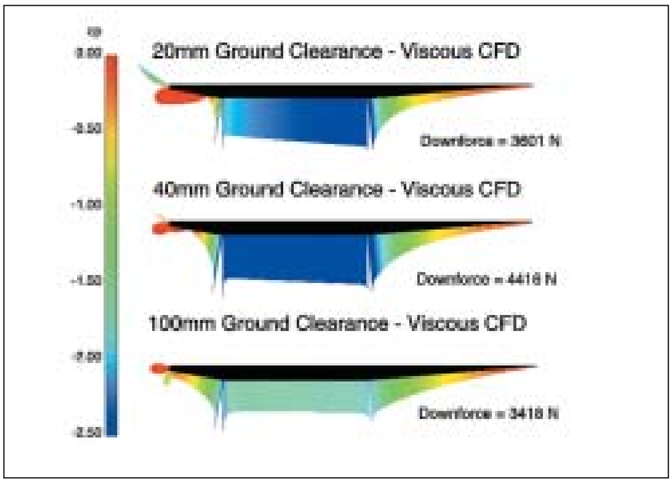

Figure 2: pressure coefficient magnitudes and distribution plot at 20mm, 40mm and 100mm

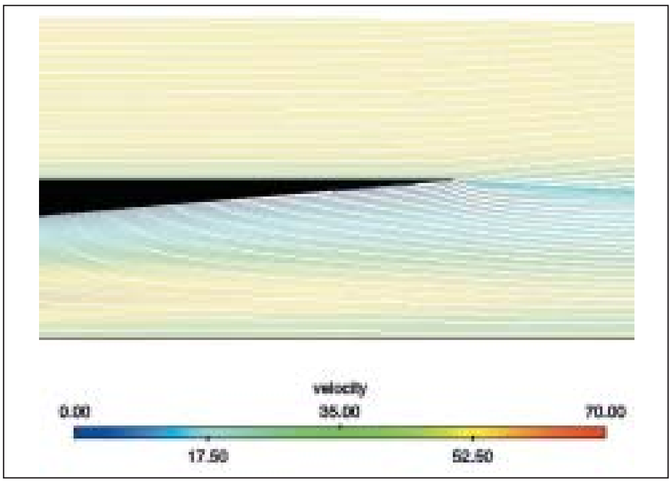

Figure 4: at 40mm ground clearance, flow separation in the diffuser is greatly reduced

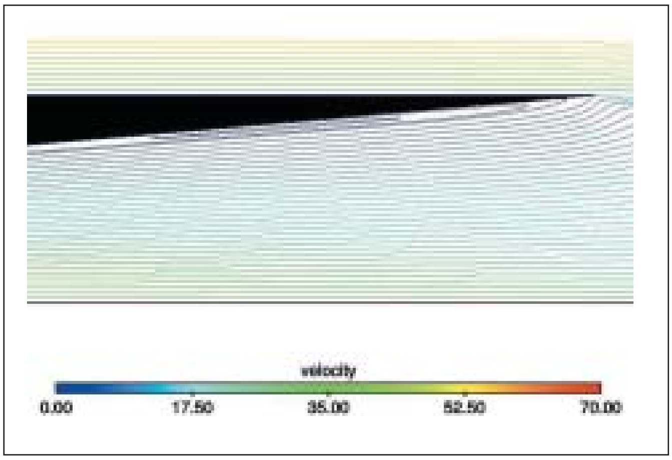

Figure 3: flow separation is clearly a problem in the diffuser at 20mm ground clearance

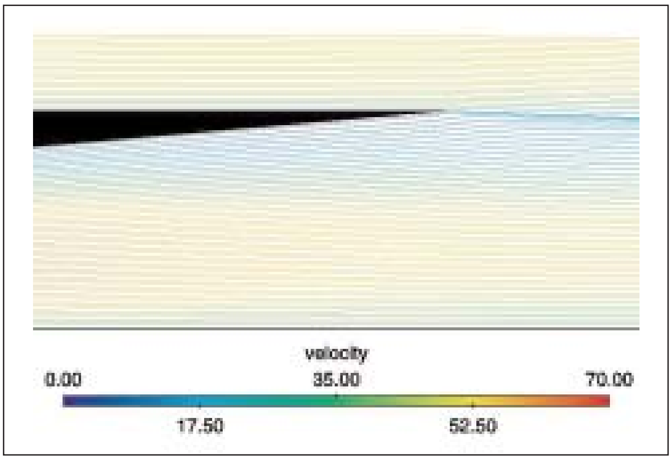

Figure 5: by 60mm ground clearance, separation in the diffuser has vanished altogether

the underbody surfaces is small relative to the overall airflow, the Bernoulli predictions and CFD predictions are actually very close. However, at ground clearances of around 70mm (2.7in) or less, the viscous effects are becoming ever more significant. By 20mm (0.79in) the air is being asked to flow through such a small gap that the viscous effects are dominant, reducing the downforce predicted by Bernoulli by about 80 per cent, and the downforce attains its maximum at 40mm (1.6in) ground clearance with this model. As a brief aside, the reason that the viscous CFD downforce value is slightly higher than the Bernoulli value at the 100mm (3.9in) ground clearance is because of necessary slight variations in the models, which meant that the effective inlet size was slightly bigger in the CFD model. Elsewhere, viscous effects masked this difference.

Figure 2 shows plots of pressure coefficients at three of the ground clearances tested using viscous CFD (the black silhouettes show the sidepod profile used here, which had inlet and diffuser angles fixed respectively at 10 degrees and 5 degrees). Looking first at the 100mm (3.9in) case, the pressure plot shows an evenly distributed, moderately low pressure along the venturi throat (flat section). At 40mm (1.6in) ground clearance significantly lower pressure is attained in the throat, and this gap achieves the highest overall downforce figure. Interestingly, in the case of the 20mm (0.79in) ground clearance model the inlet region actually sees positive pressure (and commensurate lift) before the flow steadily accelerates through the throat, attaining similarly low pressure to the 40mm (1.6in) case only at the rear of the throat. It appears that what might be called the 'viscous blockage' at this low ground clearance makes its effect felt right at the start of this downforce inducing device at 20mm (0.79in) gap.

There is also another interesting effect of reducing ground clearance. Just as the area ratio becomes more extreme at the inlet, so it does at the diffuser end of the venturi. Here the airflow is being asked to expand increasingly rapidly through the diffuser at smaller ground clearances. As the diffuser is a region of adverse pressure gradient anyway (the flow is trying to go from a low to a high pressure region, which it is only happy to do if asked nicely) the consequence of working the airflow too hard is that flow separation occurs. This can be seen in the velocity streamline diagram in figure 3, where at 20mm (0.79in) ground clearance flow separation in a distinct re-circulation region can be seen adjacent to the diffuser roof. Taking all these effects into account, the result at 20mm (0.79in) ground clearance is a downforce figure some 18.5 per cent lower than that achieved at 40mm (1.6in). Figure 4 shows the flow separation to be much smaller, and the general airflow velocity to be much higher at 40mm (1.6in), while at 60mm (2.36in) (figure 5) there is no separation apparent.

Conclusion

While initially a decreasing ground clearance does produce the expected increase in underbody downforce, it is clear that too small a gap leads to a reduction in downforce because of viscous effects. The general aim would appear to be to run the smallest ground clearance possible that maintains 'unblocked' flow and no diffuser separation. In the case of our sidepod model here, optimum downforce occurred at 40mm (1.6in) ground clearance, but fully attached flow with only a 4.3 per cent loss of downforce occurred at 60mm (2.36in), which might suggest a suitable operating range – for this model at least.

Next month: basic parameters that determine wing performance.

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