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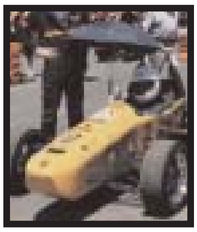

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Racecar underbodies can produce downforce by acting like venturi tubes, accelerating the airflow, and so reducing the pressure beneath the car, as described by classic Bernoulli Theory. The amount of downforce produced is related to the underbody shape, and to the influence of that shape on the airflow.

Bernoulli theory does not take account of viscous effects such as the interaction between the airflow and the vehicle surfaces, but the right computational fluid dynamics (CFD) model does. To continue our investigations into underbody flow, Advantage CFD has produced two models; one based on classic Bernoulli calculations, the other on modern viscous CFD methods. This month we're going to look at the influence of the underbody inlet angle on downforce.

Inlet angle and downforce

The principle that dictates that air is accelerated in a venturi is that of the Conservation of Mass – in steady state conditions the mass flow of air through the venturi must remain the same along its whole length. So, as the cross sectional area changes, the air velocity changes in direct inverse relation; reduced area leads to increased velocity. And, as Bernoulli's theorem tells us, increased velocity leads to reduced local pressure.

Clearly then, the angle of the inlet will affect the rate of change of velocity of air entering a venturi. Furthermore, given the constraint of fixed length of the venturi, as is the case with our 2-metre long model here (representing a simplified racecar sidepod), changes to the inlet angle alter not only its length but also that of the throat section (which is flat in our model) that follows.

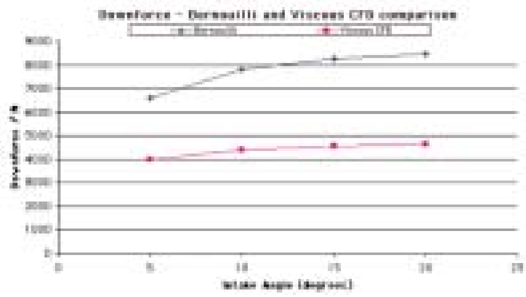

Figure 1: downforce values at different venturi inlet angles calculated by Bernoulli and then various viscous CFD

So, applying Bernoulli physics we might expect that the shortest possible inlet, which provides the longest possible throat in which the lowest pressure will occur, will generate the maximum downforce. The gains would tail off as increasing the inlet's angle makes less and less difference to its length. Figure 1 shows that this is the case, and downforce, calculated by Bernoulli's equation, has virtually peaked at a 20 degree inlet angle.

But what happens when viscous effects are taken into account? Figure 1 also shows the downforce calculation results of a viscous 2D CFD simulation on this sidepod model, and interestingly the relationship between downforce and inlet angle is similar to that calculated by Bernoulli's equation, except that the values are much lower. Viscous effects have reduced the airflow's velocity, which means the pressure reductions along the whole of the car's underbody are not as great,

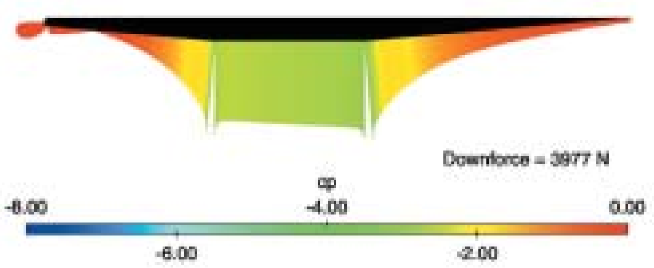

Figure 2: pressure coefficient magnitude and distribution plot with a 5-degree inlet angle

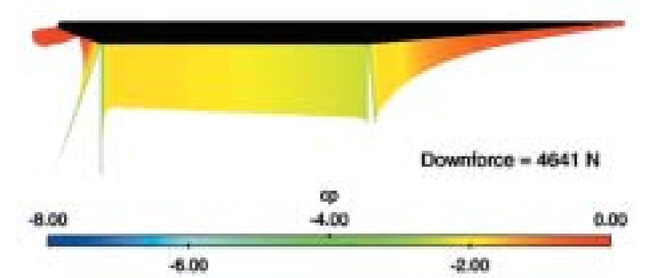

Figure 3: pressure coefficient magnitude and distribution plot with a 20-degree inlet angle

which in turn means downforce is less.

In general, over the range of inlet angles tested here, the underbody does seem to behave as Bernoulli might have expected even when viscous effects are applied, insofar as downforce increases with inlet angle. Figures 2 and 3 show plots of pressure coefficient at the two extremes of inlet angle tested (the black silhouettes show the different sidepod model shapes used in the CFD analysis). It is evident that the pressure decreases more rapidly with the steeper inlet and although, significantly, the pressure is not quite as low as in the 5-degree case, the low pressure region is longer because the throat is longer, which explains the greater downforce figure generated.

An additional significant point is that the centre of pressure (the fluid dynamic equivalent of the centre of gravity) will be further forwards at steeper inlet angles because of the aforementioned earlier (more forward) drop in pressure, and because the flat throat extends further forwards at steeper angles. This could obviously have an effect on the balance of a car as its speed enters (and leaves) the realm where aerodynamic effects become significant.

Downforce appears to have almost flattened out at a 20-degree inlet angle, and there are reasons to think, with this model at least, that this might be the maximum angle worth running. It was pointed out above that with the 20-degree inlet the pressure in the throat did not get as low as in the 5-degree case. Why should this be? Once more CFD comes to the rescue, and it becomes evident that viscous effects are again at work here.

It is the vehicle's passage through the air that promotes the acceleration of air through our venturi, but it is viscous effects that transfer that acceleration to the air that is not immediately adjacent to the vehicle surface. With a 5-degree inlet angle the acceleration of the airflow through the inlet is very gradual, and viscous forces are sufficient to pull the air nearer the ground along at a very similar acceleration to the air near the underbody.

However, at the 20-degree inlet angle, the air is accelerating so rapidly adjacent to the underbody surface that it seems that the viscous forces are not large enough to accelerate the air nearer to the ground at the same rate. The result is as shown in figure 4, which shows the vertical velocity profiles in the venturi at the inlet-throat transition at the two angles under discussion. The velocity profile at a 5-degree inlet angle is almost linear through most of this vertical section. But in the 20-degree case the more rapid flow at the underbody surface is evident, as is the lag in velocity through most of the rest of the section. Figure 5 shows the pressure coefficients in the inlets in close-up. The rapid low-pressure development and the lag in pressure reduction away from the underbody surface in the steeper inlet are apparent.

The important net result of this is that the velocity through the whole of the throat becomes lower – figure 6 shows the velocity profiles just 5cm (2in) into the throat – and the ensuing pressure reduction along the whole throat becomes correspondingly lower, at steeper inlet angles.

Conclusion

So, as with the diffuser, it seems that the way to maximise underbody downforce is to run the shortest, steepest inlet possible, but only up to a point. In the case of the 2-metre long sidepod underbody model used here that maximum angle would appear to be 20 degrees, though this should not perhaps be taken literally as an applicable generalisation.

Next month we'll look at the influence of ground clearance on underbody downforce. RE

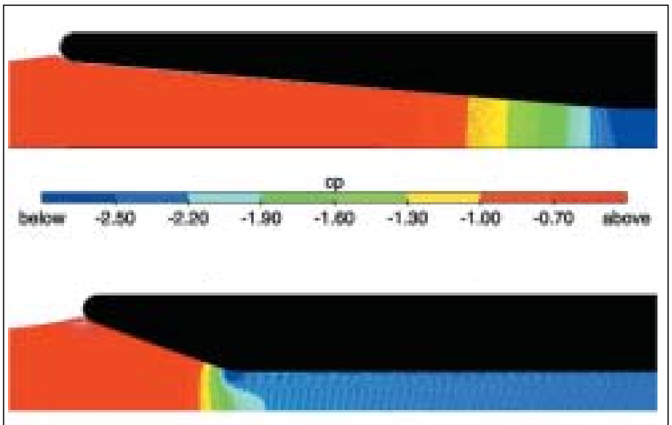

Figure 5: pressure coefficients in the inlets at 5 degrees and 20 degrees

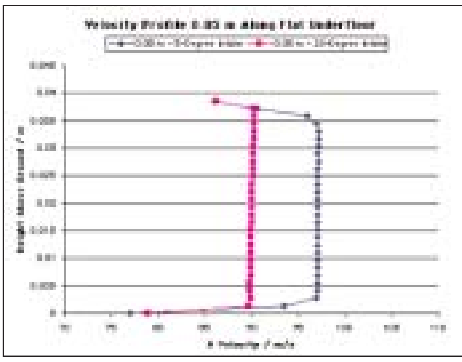

Figure 6: vertical velocity profiles 5cm along the venturi throat

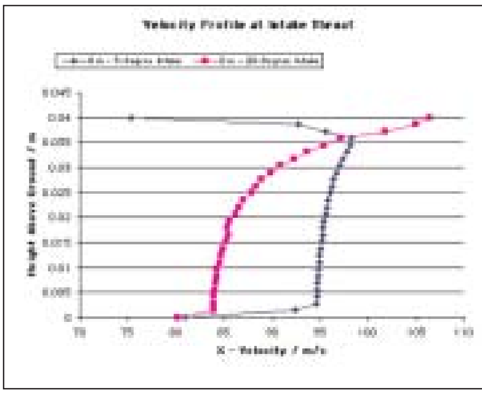

Figure 4: another rendition of the pressure coefficients in the inlets at 5 degrees and 20 degrees

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