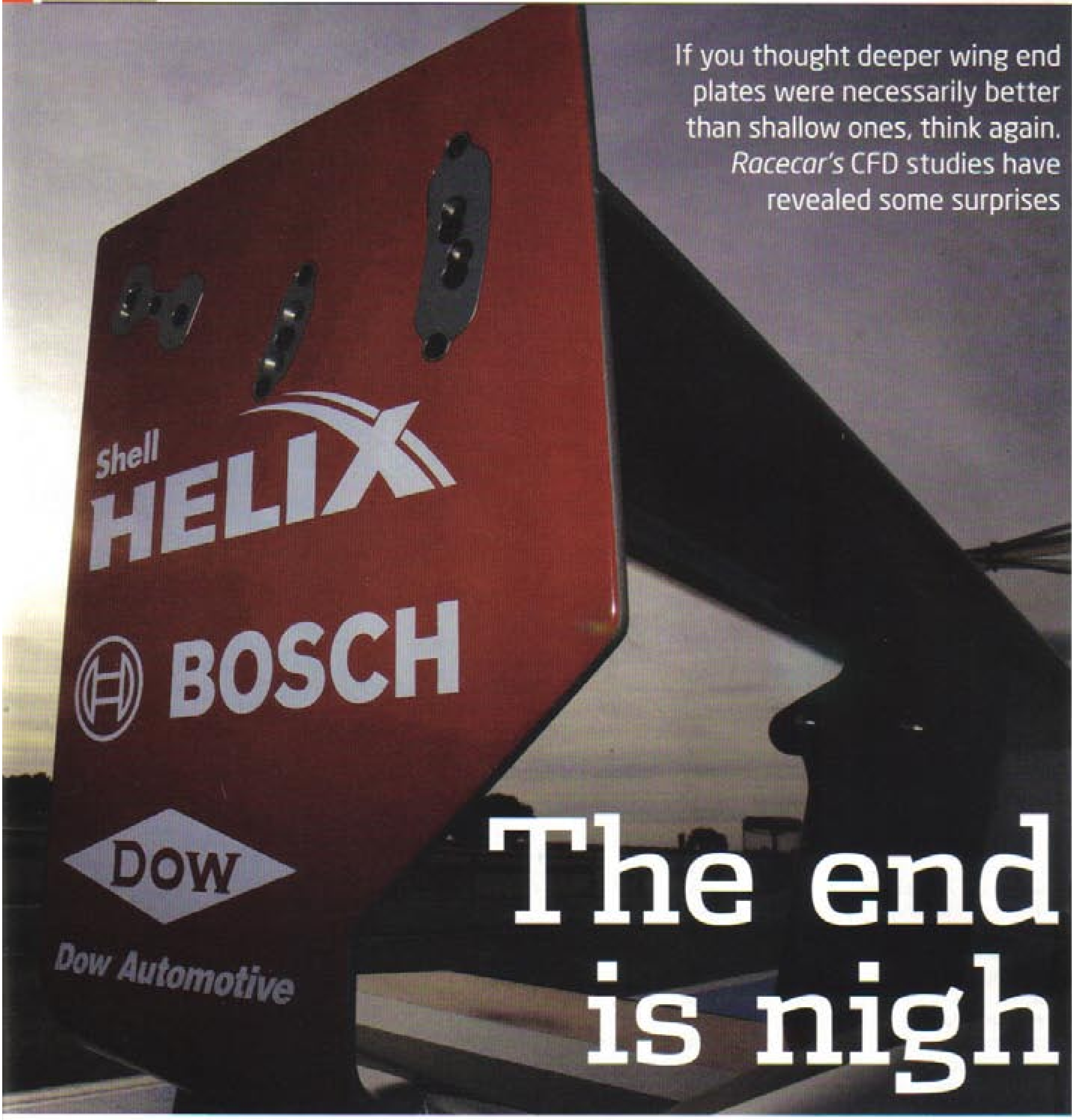


If you thought deeper wing end plates were necessarily better than shallow ones, think again. *Racecar's* CFD studies have revealed some surprises

The end is nigh

In motorsport's upper echelons wing end plates are becoming ever more complex in shape and detail, thanks to endless hours of R&D in the quest for tiny increments of aerodynamic efficiency. But in many other categories, attention is often best focused on the basics, one such being end plate depth.

One widely held belief is that deeper end plates are more effective than shorter ones and we at *Racecar*, among others, have in the past published results that support that notion. But

BY SIMON MCBEATH

it now transpires that, as with studies on this topic in available motorsport-related literature, the project we highlighted then was not detailed enough to be able to confidently generalise on end plate depth, even for a given wing configuration. But recently *Racecar* has made a start on some further research, and early results have produced surprises. Indeed, the statement at the top of this paragraph turned out to be quite untrue in the case highlighted here.

THE THEORY

The first question is how big, aerodynamically speaking, is good when it comes to end plates? To start to answer that, let's first remind ourselves what end plates do. Textbooks tell us that end plates help to maintain the pressure difference between the upper (pressure) and lower (suction) surfaces of a racecar wing by preventing the 'spillage' of air from the former to the latter around the wing tips. The important variable is the height of the end plate, h, relative to the span, b, of the wing (see fig 1).

By reducing this spillage, end plates increase the effective aspect ratio (AR) of the wing by increasing the effectiveness of the outer portions, and clearly the benefit will be felt more on wings with small aspect ratios, as are typically found on racecars (even full width sports prototype wings have small aspect ratios compared to aircraft). And this benefits both the downforce and the vortex drag (that portion of drag directly resulting from downforce generation, and the dominant source of drag from most racecar wings) generated by the wing. In relation to end plates, Milliken and Milliken tells us that the effective aspect ratio is proportional to h/b up to values of h/b ~ 0.6, when the gains begin to tail off. So bigger is better, up to a point, and this fits what we'd intuitively expect.

THE PRACTICE

The trouble is, end plates like these are not practical and technical regulations often provide limitations on the size of wing end plates. Maximum height above the ground or some reference plane is usually restricted and, if the rules don't limit minimum height too, then other practical constraints such as the ground or other parts of the racecar may do. Minimum weight must also be borne in mind - of some importance with parts that are often well beyond the wheelbase and, at the rear, high up as well.

End plates rarely protrude the same distance above a racecar rear wing as they do below it, usually because of maximum height restrictions, combined with the need to run the wing close to maximum height to find some 'clean' air above and behind the racecar. Furthermore, it probably isn't desirable or necessary to extend the end plate as far above the wing as below it, especially in the case of high-downforce wings that generate far greater pressure reductions beneath them compared to the increased pressures above.

So some simple CFD studies were initiated on the aerodynamic performance of some more practical end plate designs, with particular emphasis paid to the depth of end plate below the wing. The project started with the simplest wing configuration, a single element rear wing. This was set at a steep angle of attack so that a reasonable pressure differential between the pressure and suction surfaces would be generated, promoting strong vortex formation at the wing tips, which in turn ought to reveal the effect of different end plates in modifying this vortex formation. The wing section itself was a 300mm chord, 18 per cent thick device, drawn in this instance at 1.38m span (AR therefore 4.67).

Initially, a set of five end plates of differing depths were drawn. Each was terminated a few millimetres above the top of the wing's trailing edge, the notion being to terminate flush with the highest point of the wing, but the auto-meshing component of FloWizard using default settings seems to deal better with slight overlap. Similarly, the end plate protruded a few millimetres in front of and behind the wing section.

The only parameter that was varied in this trial was the end plate depth, and at the outset the five depths, measured below the lowest point of the wing's suction surface and relative to the 300mm chord dimension C, were 0, 0.25C (75mm), 0.5C (150mm), 1.0C (300mm) and 2.0C (600mm). Once again, to facilitate auto meshing, the 'zero' end plate actually protruded about 3.5mm below the wing, but was regarded as zero depth for practical purposes. Figure 2 illustrates the wing and end plate combinations, which covered a realistic practical range for most racecar types (short oval racers will hopefully forgive this mainstream generalisation, but some of those guys use their end plates for other reasons that we can't go into here).

> "bigger is better, up to a point..."

CFD PARAMETERS

Having constructed the 3D CAD models of each wing and end plate combination, the CFD cases were then run in turn in freestream air with horizontal onset flow at 100mph (44.7m/s), using default settings for parameters such as turbulence and accuracy vs solution time. The results are shown in table 1 and downforce figures are plotted in figure 3.

Two things are immediately apparent from the first glance

TEST DATA

Figure 1

End plate characteristics

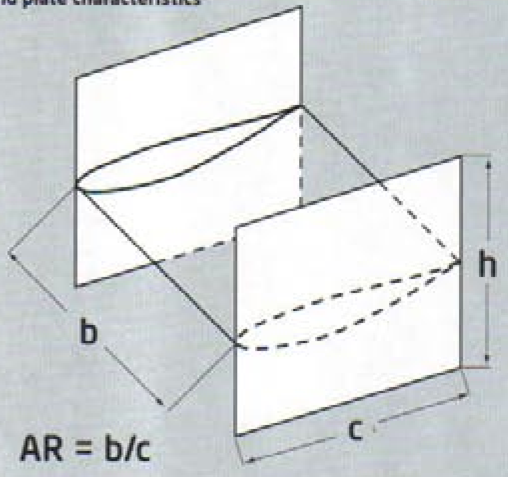
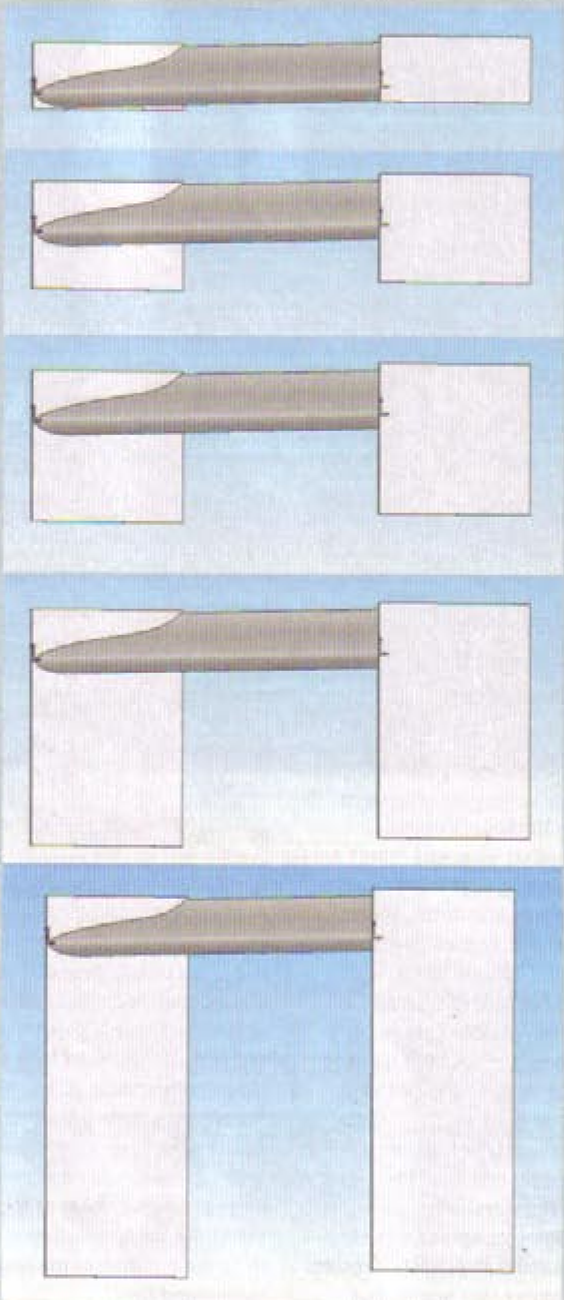


Figure 2

The five end plate configurations evaluated in this test



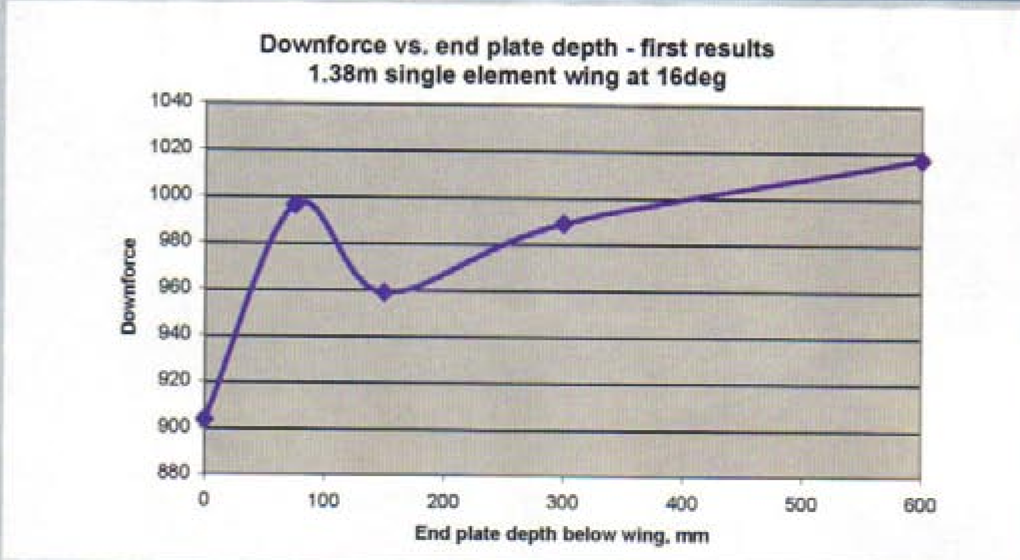


Figure 3

Initial downforce vs end plate depth data from the first five models (all runs at 100mph or 44.7m/s)

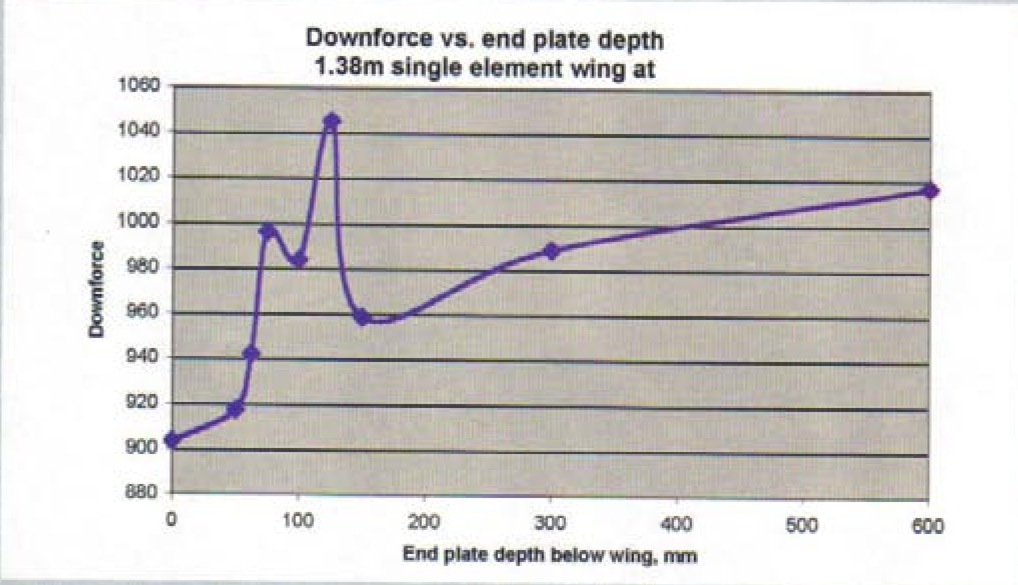


Figure 4

Downforce vs end plate depth data for all runs, including the additional cases to map the area of enhanced performance

TABLE 1

End plate depth vs forces - first runs

End plate depth, mm/chord fraction	Downforce, N	Drag, N	-L/D
0mm/0.0C	903.2	171.6	5.26
75mm/0.25C	995.9	177.6	5.61
150mm/0.5C	958.3	170.7	5.61
300mm/1.0C	988.4	171.5	5.76
600mm/2.0C	1016.6	177.5	5.73

TABLE 2

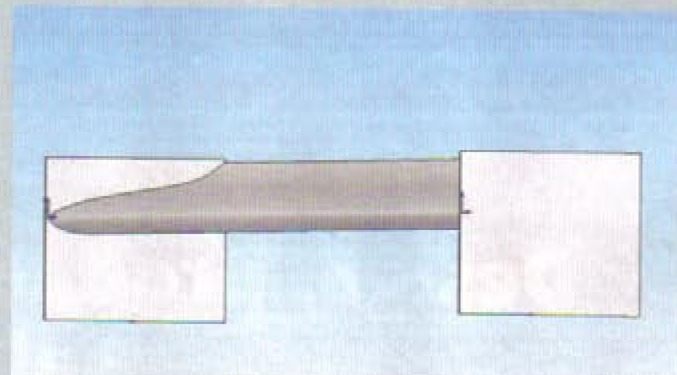
End plate depth vs forces - all runs

End plate depth, mm/chord fraction	Downforce, N	Drag, N	L/D
0mm/0.0C	903.2	171.6	5.26
50mm/0.166C	917.0	169.3	5.42
62.5mm/0.208C	941.9	171.8	5.48
75mm/0.25C	995.9	177.6	5.61
100mm/0.333C	983.5	173.8	5.66
125mm/0.416C	1045.0	180.7	5.78
150mm/0.5C	958.3	170.7	5.61
300mm/1.0C	988.4	171.5	5.76
600mm/2.0C	1016.6	177.5	5.73

Shaded data are from the first five runs

Figure 5

The end plates in this CAD model performed better than much deeper end plate variants



at this data, especially so in the graph. There is the expected upward but diminishing trend in downforce with increasing end plate depth, but an unexpected bump in the data at 75mm / 0.25C end plate depth. Had this particular case not been run, and instead the data jumped from zero to 0.5C end plate depth, then the curve would have fitted the expected pattern and a fascinating detail would have been missed, and this article would never have come to mind!

Nevertheless, the deepest end plate did produce the best downforce of these five models. Of interest too is that minimum drag occurred at 0.5C end plate depth, although the fluctuations in drag between configurations here were quite small, a situation no doubt complicated by the drag component from the end plates increasing with size.

That unexpected downforce peak at 0.25C warranted further exploration though, so four more end plate depths were drawn, two just below and two just above this depth at 50mm (0.166C), 62.5mm (0.208C), 100mm (0.333C) and 125mm (0.416C). The results of the CFD runs on the whole batch of tests are shown in table 2, with the downforce plot in figure 3.

Clearly, adding more data points has revealed that there is indeed something very interesting going on here and, whatever the exact cause, it would appear that there is an intermediate end plate depth, 125mm in this instance (see figure 5), at which downforce and efficiency (-L/D) exceeded even those achieved with the largest end plate depth evaluated here. Furthermore, the results either side of this sharp peak would imply that for a given wing configuration, the end plate depth at which this peak might occur could be very specific, meaning each case would need to be evaluated in this way. That is assuming that this effect will appear with other wing configurations of, and that it is not just some particular quirk of this configuration.

> "The only parameter that was varied in this trial was the end plate depth"

DISCUSSION

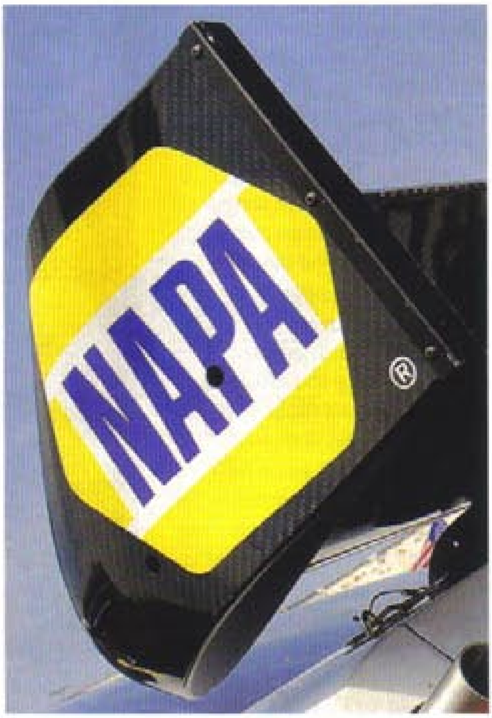
Let's use a simple visualisation from FloWizard to try to figure out what is going on here. Figure 6 shows the velocities on the lower (suction) surface of one half of the wing in two different end plate cases. On the left is our 'special' end plate depth of 125mm or 0.416C, compared to the 150mm/0.50C case. Looking closely at this plot, several distinctions become apparent that help explain why the downforce plot in figure 4 shows marked differences between these two cases.

First, the region of highest velocities (red and yellow) near the end plate (top of the figure) extends further towards the trailing edge of the wing (more to the right in this figure) with the 125mm end plate than with the 150mm one. Second, the small triangle of very slow velocity (blue) air (indicating probable flow separation in reality) at the junction of the trailing edge and the end plate in the 150mm case is absent in the 125mm case. Third, the area of slow moving (pale blue) air along the entire trailing edge of the 150mm case has narrowed considerably in the 125mm case. In short, the air is moving faster under the wing with the 125mm deep end plate, which of course generates lower static pressure and therefore greater downforce.

Why should this be so? Well, it seems probable that in the case of these special end plate depth cases, the vortex that curls in under the bottom edge of the end plate is actually enhancing the local flow, rather than reducing the suction in these regions, as in the 150mm case for example. The effect of this improvement on the outer portions has apparently extended across the entire wing. And the overall effect is more potent than simply using a deeper end plate.

A couple more visualisations from these FloWizard simulations shed further light. Figure 7 shows in side view the velocity vectors 20mm inboard of the end plate. Again the 'special' 125mm deep end plate case is on the left, the 150mm case on the right. One distinction to look for here is the way the vectors turn upwards half way along the bottom edge of the end plates. In the 125mm case the upward turn is sharper. And there also appears to be a slightly steeper angle to the upwash under the rear part of the wing. These two observations are probably related. Furthermore, there are more reds and yellows than greens under the rear portion of the wing in the 125mm end plate case, indicating higher velocities prevailing here. All these observations are indicative of the flow having been enhanced in this region in the 125mm end plate case.

Moving on to figure 8, this shows the flow vectors in the same plane as figure 7 but this



Endplate design can vary considerably, in Formula 1 (left) they are often highly complex, on the NASCAR CoT (right) they are about generating side forces

time coloured by total pressure. This is an indicator of the energy in the airflow, red showing undiminished energy while all other colours show where energy has reduced through viscous losses over surfaces or through turning the airflow, for example, under the wing. Here we can see that the airflow under both wings has lost energy along the undersides, especially towards the trailing edges, and there have also been local energy losses in the vortex at the bottom edge of the end plate.

However, the losses are not as large in the 125mm end plate case, suggesting the flow under the end plate is either bringing air with additional energy to this region, or modifying it in such a way that it simply loses less energy. Either way, the flow under and away from the wing's outer portions in the 125mm end plate case is clearly more energetic, increasing downforce.

Figure 9, a rear view of the flow vectors in plane with the wing's trailing edge, shows the vortices and energy losses very nicely. The radius of the circulation as it approaches the lower end plate edge seems greater with the 125mm end plate, which may help ease it around this edge with less losses.

NEXT STEPS

This simple exercise revealed some potentially very interesting effects that, with appropriate study, could be beneficially exploited. But it also leaves plenty of questions unanswered. What about different wing angles, different wing spans, dual and multi-element wings, increased end plate area above, ahead of and behind the wing, end plate shapes other than rectangular, end plate cut outs? You get the idea. Then what about measuring this effect on a full car model and correlating the findings in the wind tunnel?

Clearly, there is scope for further investigation, but the exercise shows there is still potential for discovering benefits by revisiting the basics, benefits that 'perceived wisdom' has told us nothing about...

Thanks: Ansys Europe for the use of FloWizard - www.flowizard.com

VELOCITY VECTORS

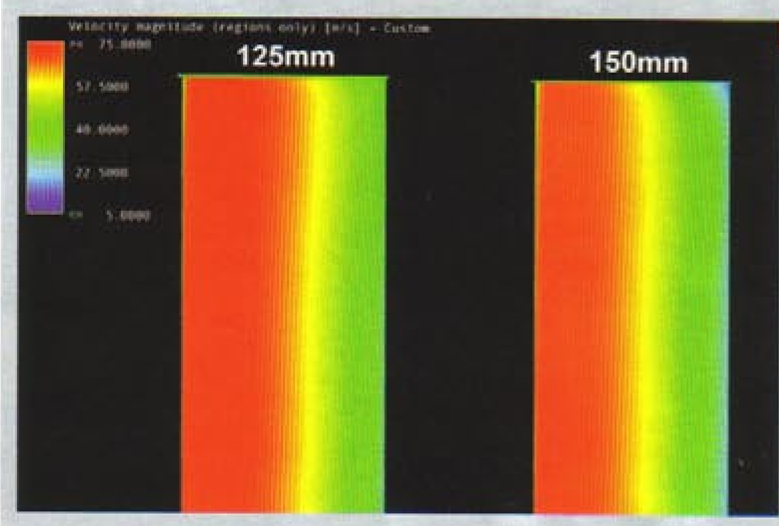


Figure 6
Plots of the velocities on the lower surface of one half of the wing in two different end plate cases (airflow coming from the left). Left is the 'special' end plate depth of 125mm, (0.416C), right the 150mm end plate depth (0.5C). Generally, the velocities with the 125mm end plate are higher and there are velocity distribution differences, too

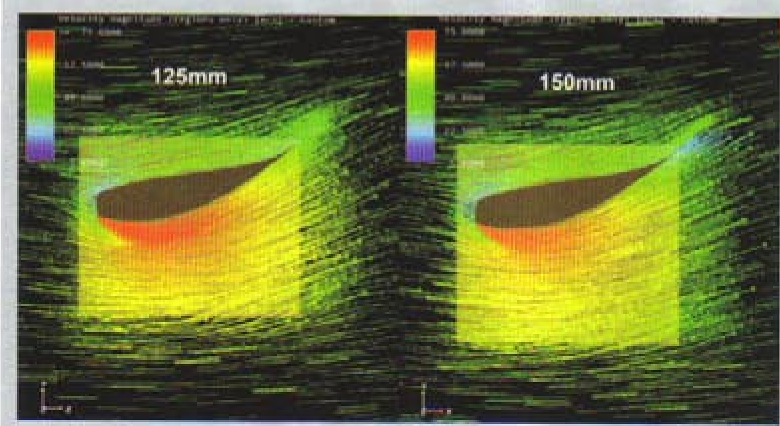


Figure 7
Side view of the velocity vectors at a plane 20mm inside the end plate from the wing tip. Note the sharper, steeper upward turn along the bottom edge of the 125mm end plate and the prevalence of higher velocities (more red and yellow) under that wing

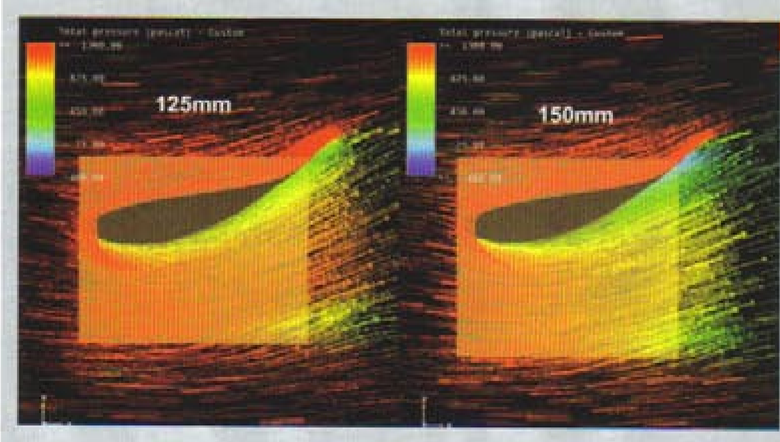


Figure 8
Flow vectors on the same plane as figure 7 coloured by total pressure, an indicator of the energy in the airflow - red showing undiminished energy while all other colours show where energy has been lost (increasing losses towards the blue end of the range)

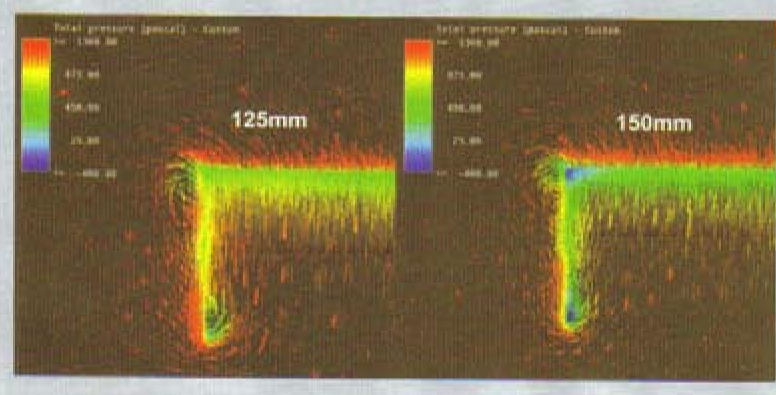


Figure 9
Viewed from the rear, flow vectors in plane with the wing's trailing edge show the vortices and resultant energy losses

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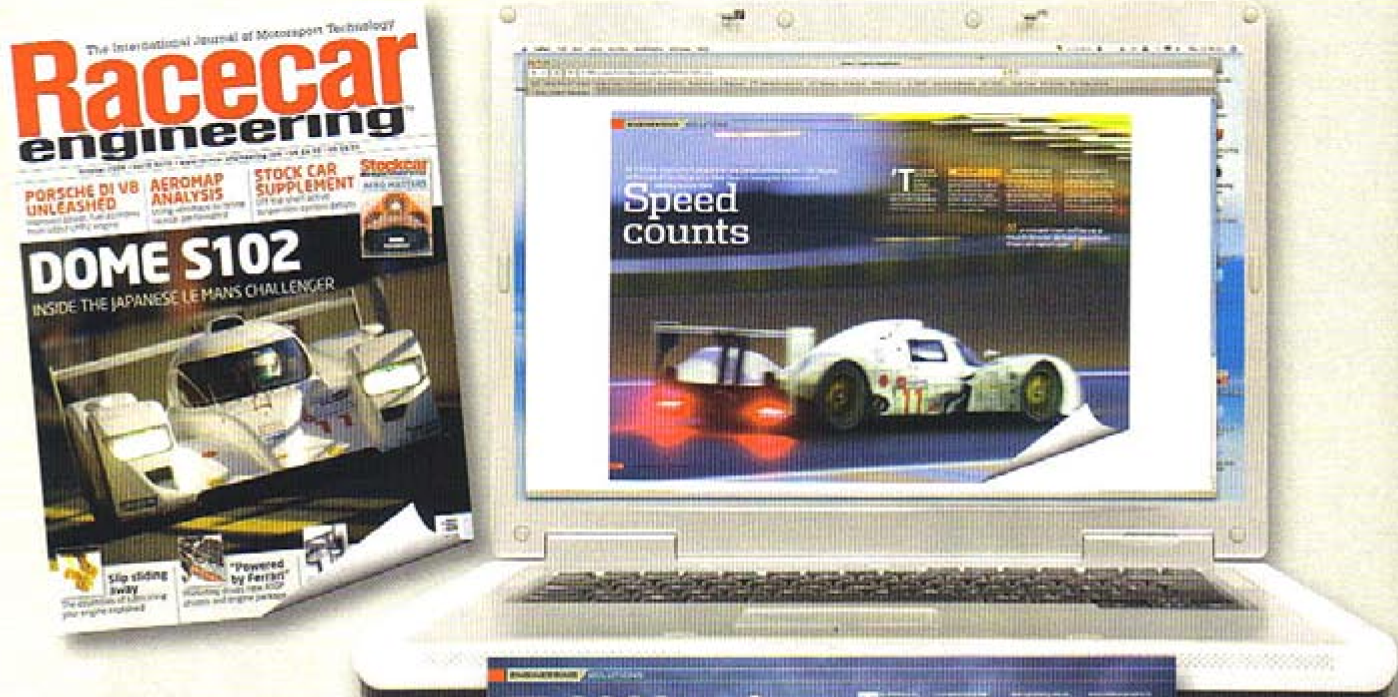

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