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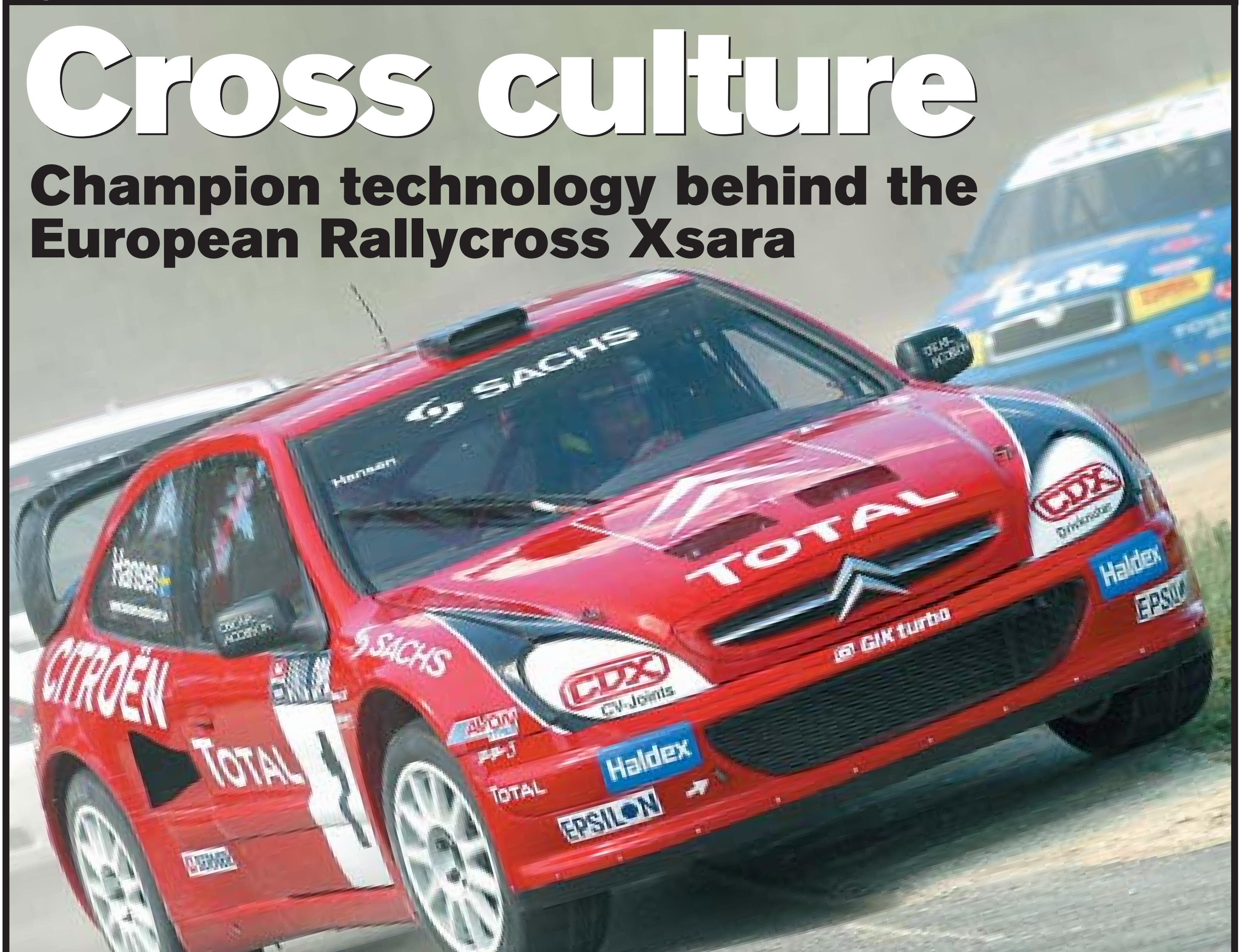

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AEROBYTES

with Simon McBeath

Wing camber

Continuing our look at fundamental wing parameters, Advantage CFD helps us investigate the effects of changing wing camber

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More camber equals more downforce, but what is the corresponding effect on efficiency?

Last month we saw that in situations that mandate a single wing element, and also the maximum dimensions of that wing element, the only way to extract more downforce from the wing is to manipulate its lift coefficient, as stated by the equation:

$$\textbf{lift (downforce)} = \rho \times \rho \times A \times C_L \times v^2$$

where ρ, the Greek letter rho, is air density, A is wing plan area and v is air velocity. Changing the wing's thickness is one way to do that, as we saw in the last issue, while changing its camber (the amount of front to rear curvature in the profile – see figure 1) is another, though caution should be exercised to ensure you don't go outside any relevant dimensions specified in the regulations.

The textbooks are a lot clearer on the effects of altering wing camber than they are on changing thickness. The indications are that more camber gives more lift (downforce in our context) at a given angle, although the suggestion is that stall may occur at lower angles. It isn't clear from the texts whether maximum downforce should be expected to change with camber.

So, how much camber is good? What happens to the airflow around a wing as camber is increased? Advantage CFD set up a range of wing models once again using the NACA 63_2-615 profile as a start point. They then manipulated this shape to put more or less camber into it, maintaining the location of maximum camber at the same position along the wing chord in all cases. And then a set of two-dimensional CFD runs at a virtual air speed of 50m/s (180km/h or 112mph) were performed at a range of angles of attack, and over a range of cambers from four to 12 per cent. Camber value is expressed as a percentage of the chord dimension.

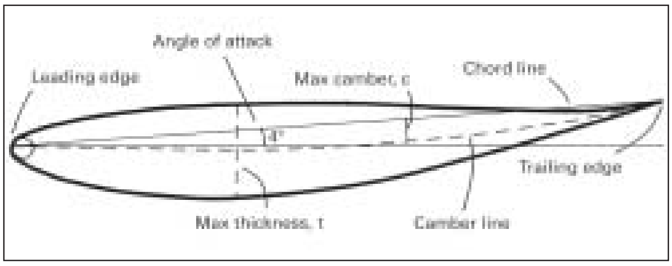

Figure 1: wing terminology

Produced in association with Advantage CFD.

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Peak downforce

Downforce versus angle of attack for the range of cambers studied is plotted in figure 2. (Note: missing points indicate that unsteady flow conditions in the more extreme cases prevented solutions being calculated). The first noticeable relationship is that, for a given angle of attack, downforce does increase with greater camber, at least up to camber values of nine per cent applied to this particular 'family' of wing profiles. Secondly, peak downforce also increases with camber, again up to the nine per cent camber value at least. Thus, the whole downforce curve is translated vertically as camber is incrementally increased. And the stall angle appears to be the same, 14 degrees, in each case, again up to nine per cent camber.

However, the highest camber value studied here does behave differently. While it follows the same slope up to an angle of attack of eight degrees, performance tails off sooner than with the lower camber wings. The 12 per cent camber wing peaks at just 12 degrees, with a lower downforce value than that achieved by the nine per cent camber wing at this angle. The obvious conclusion is that the geometry generated by giving this wing profile 12 per cent camber is pushing things too far, and nine per cent camber looks to be optimum here for maximum downforce.

Figures 3, 4 and 5 show pressure-coloured flow patterns from three of the runs performed, all of these being at 8 degrees, but at cambers of six, nine and 12 per cent. Evident features include the generation of an increasingly large low-pressure region below the lower surface as camber is increased. And the flow around the wings changes as camber is increased, too, with almost fully attached flow on the underside of the lowest camber wing here, flow separation developing at nine per cent camber, while substantial separation has developed at 12 per cent.

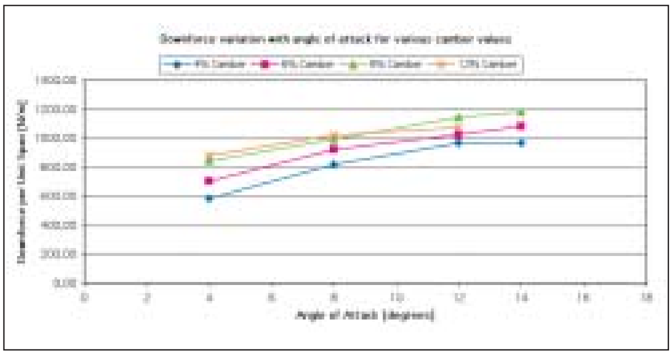

Figure 2: downforce versus angle of attack for a range of cambers

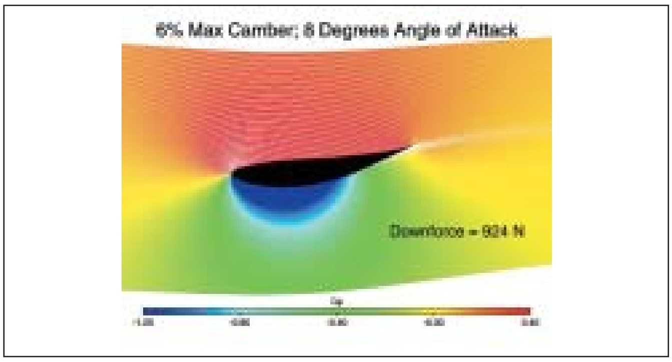

Figure 3: pressure-coloured streamlines at six per cent camber, eight degrees angle of attack – flow almost fully attached to the lower surface

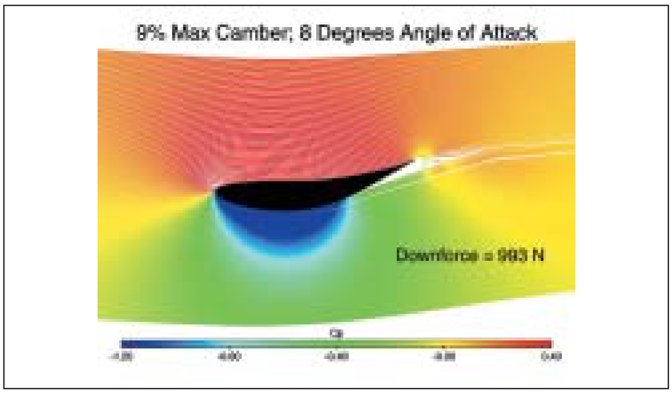

Figure 4: pressure-coloured streamlines at nine per cent camber, eight degrees angle of attack – flow separation beginning to develop

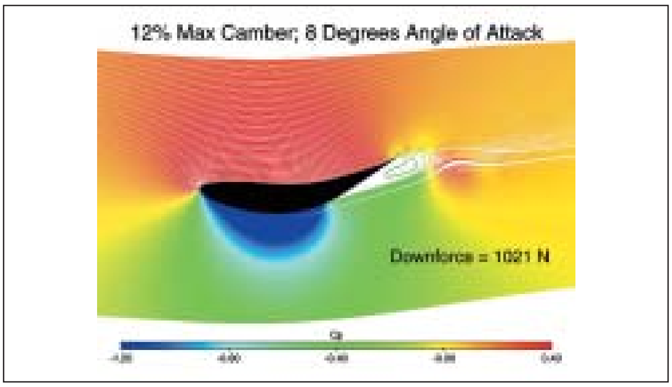

Figure 5: pressure-coloured streamlines at 12 per cent camber, eight degrees angle of attack – substantial flow separation

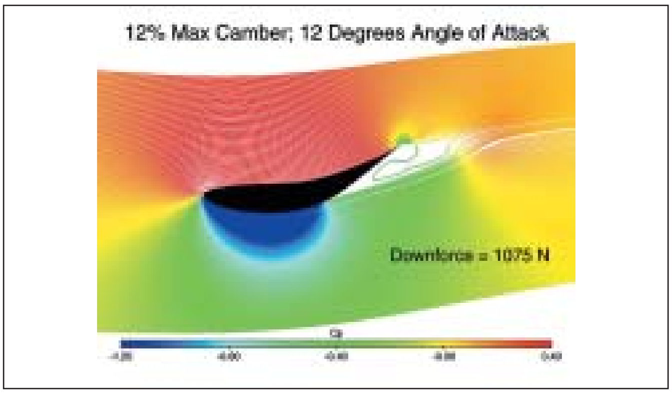

Figure 6: pressure-coloured streamlines at 12 per cent camber, 12 degrees angle of attack – downforce gains have ceased

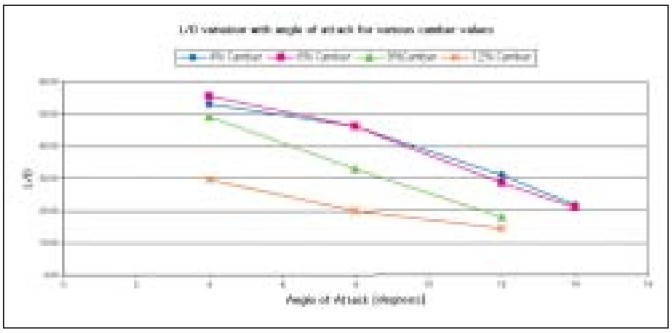

Figure 7: lift to drag ratio versus angle of attack for various cambers

Thus, although downforce increases with each additional increment of camber, it is clear that the airflow is struggling to remain attached to the wing as higher values of camber are applied.

Figure 6 shows an extreme case, where the 12 per cent camber wing at 12 degrees angle of attack is showing extensive flow separation, so that even the large increase in angle of attack over figure 5 has produced only a minor increase in downforce. The high pressure developed on the upper surface of the wing may be considerable, but the flow on the lower surface has all but broken down.

So, to get more downforce from a single element wing, add more camber, but only up to a point. The optimum value found here should not be taken as a definite figure though, rather as just an indicator that there will be a maximum camber value that any particular wing profile can be 'morphed' to.

Peak efficiency

But, as is well known, maximising downforce is often only part of the story. As discussed in the last column, drag is generally a factor, too. As this was a 2D CFD study, 3D drag effects like the vortex formation created by the generation of downforce by a finite span wing were not evaluated. But the profile drag (the sum of viscous drag and pressure drag) can be calculated using 2D techniques, and profile drag, like induced drag, does change with angle of attack. So we can get an idea of how profile drag alters with changes to camber. Figure 7 plots lift divided by drag, a measure of the wing's 2D efficiency, against angle of attack.

Again, the most obvious, and least surprising relationship shown here is that efficiency decreases as more downforce is generated, in a diminishing returns relationship with increasing angle of attack. Put another way, the best efficiency figures occur at lower camber values, although interestingly the six per cent camber profile is the most efficient shape up to eight degrees angle of attack, and only slightly less efficient than the four per cent camber wing at steeper angles.

Also, and importantly if one was searching for maximum downforce, it appears that additional camber increments at high angles of attack (and vice versa) produce proportionately smaller efficiency penalties. This might be relevant for those 'don't worry about the drag' situations where maximum speeds are not high and the corners demand as much downforce as possible.

● **Next month we'll look at two-element wings.**

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