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with Simon McBeath

Wing things

Wings are an integral part of motorsport, so it pays to know how they work. We go back-to-basics with the help of Advantage CFD

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We all know why we bolt wings onto our racecars, and that we can adjust wings to increase or decrease downforce to alter grip and/or balance where speeds are high enough to generate tangible aerodynamic forces. But do we really have a clear understanding of what happens to the airflow around a wing, particularly in marginal situations, or when a wing's basic parameters are altered? Or what the potential implications are, beneficial or otherwise, of those changes?

In this and forthcoming issues we're going to revisit some of the basics of wing aerodynamics and, by using illustrations from Advantage CFD, explain what happens as wing parameters are altered.

Figure 1 illustrates the basic descriptive terminology of a single element wing section. A simple rectangular plan shape wing has the same section profile across its span, although many front line racecar wings nowadays have complex shapes which change across their spans. Pretty much any of the parameters labelled can be changed, regulations permitting, to alter the wing's behaviour.

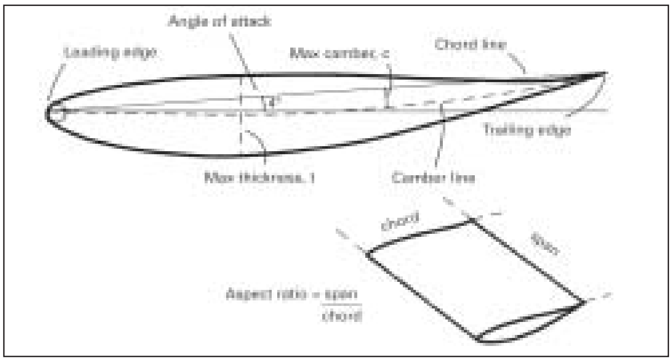

Figure 1: explanation of basic wing terminology as used in this text

The simplest wing parameter to change on a racecar is the angle of attack of the wing – or angle of incidence if you prefer – designated by the Greek letter Alpha. Changing other parameters, such as chord, thickness or camber, requires redesign and we'll look at the effects of altering these in future issues. In this issue we're going to look closely at what happens to the airflow at the adjustment of wing angle.

Angles of attack

It is well known that increasing a wing's angle of attack will increase the downforce generated, but only up to a point known as the stall angle. The stall angle will vary for any given wing section or design, and on the operating conditions. However, less well known is what happens to the airflow as the angle of attack is increased and, in particular, as the angle gets to critical higher values. To show what's really going on Advantage CFD prepared some simple two-dimensional runs on a wing section similar to that in figure 1. Note that real world three-dimensional effects, in particular the location of a wing on a racecar, complicate the whole issue, but 2D provides an adequate model for exploring basic effects.

ACFD set up a virtual airflow of 50m/s (180km/h or 112mph) over the wing section in question, and performed runs at a range of angles (between wing and airflow) from zero to 16 degrees. Downforce values at a notional wing area were then calculated, as were surface pressure coefficients and streamline velocities off the wing surface, to provide the illustrations herewith.

Figure 2 shows the basic relationship for this wing section between downforce and angle of attack. A number of conclusions are apparent. First, the maximum angle of attack to run would appear to be 12 degrees, this yielding maximum downforce. Second, the initial linear increase in downforce with increasing angle has begun to tail off after eight degrees and third, it is evident that downforce is already being generated at zero angle of attack. But how can this be?

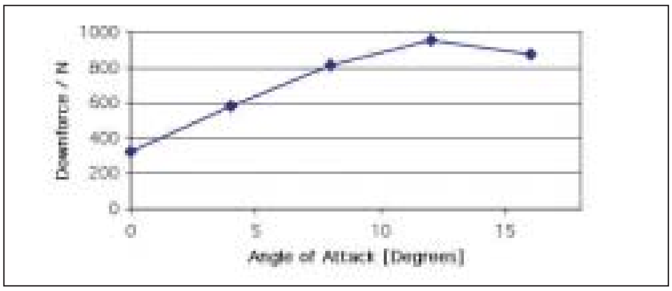

Figure 2: downforce versus angle of attack, as calculated by CFD on our wing profile

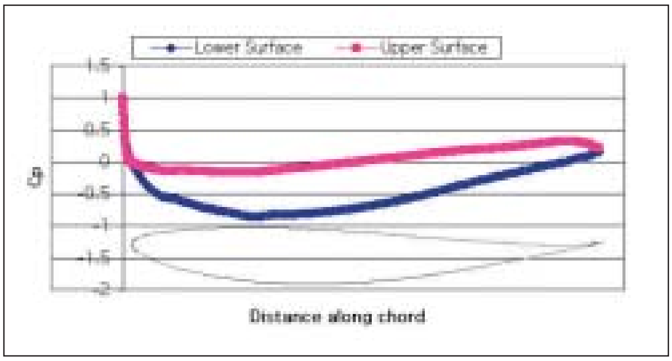

Figure 3: surface pressure distribution across the wing profile at zero degrees

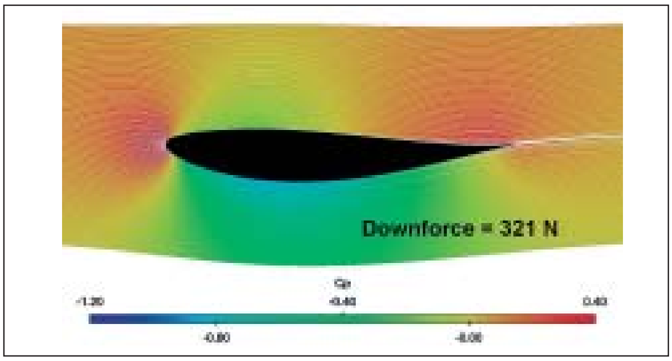

Figure 4: streamlines colour referenced by pressure, showing the airflow and the distribution of pressure around the wing at zero degrees incidence

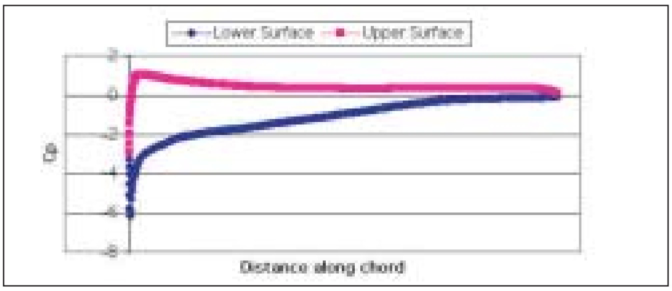

Figure 5: surface pressure distribution across the wing profile at 12 degrees

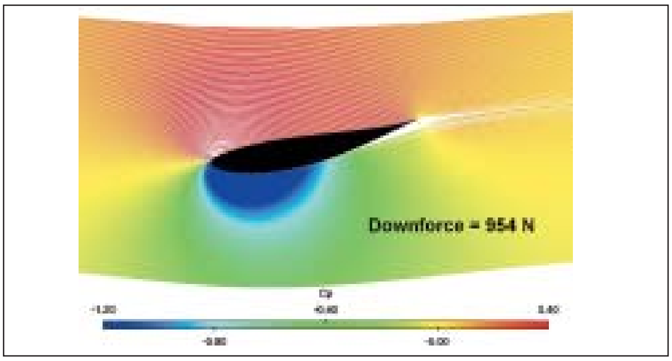

Figure 6: streamlines show the areas of partial flow separation at 12 degrees

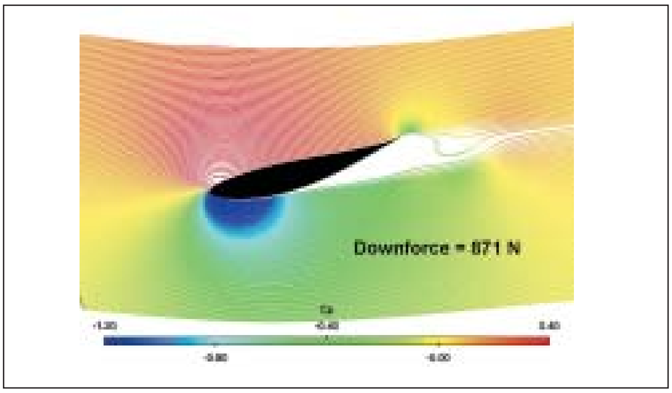

Figure 7: major flow separation has occurred at 16 degrees and total downforce falls

Starting with the last point first, many people seem to think that a wing needs a visibly positive angle on it to provide downforce. Yet if the graph line of Figure 2 were extrapolated to the left it would be evident that downforce would still be generated at small negative angles, and that the 'aerodynamic zero' – the angle at which no downforce is generated – would be about minus five degrees, that is five degrees nose up. This is because this wing is not symmetrical in profile, but is 'cambered', having more curvature below the chord line than above it, as it were. This creates a difference in the velocities over the upper and lower surfaces even at zero or small negative angles of attack. And, as we know from Bernouilli's Theorem, this generates the difference in the surface pressures that creates downforce.

Under pressure

CFD enables these features to be shown in ways that are hard to visualise otherwise, and figures 3 and 4 illustrate the zero angle case. Figure 3 is a surface pressure plot for this wing, and shows not only the negative pressure on the convex lower ('suction') surface of the wing, but also the positive pressure on the rearward portion of the concave upper ('pressure') surface. Figure 4 shows the streamlines coloured by pressure, and demonstrates even more clearly the distribution of low and high pressures around the wing.

As angle of attack is increased the suction side of the wing develops ever-lower pressures, and there is also a forward shift in the low pressure region. Furthermore, because of the increasing magnitude of the low pressure, an increasingly adverse pressure gradient (from low to high pressure) develops towards the trailing edge of the wing.

Air does not naturally want to flow from low to high pressure. A good analogy involves rolling a ball either up or down a hill. The ball happily rolls down the hill, as air happily flows from high to low pressure regions, but try rolling a ball up a hill and it only gets so far – just like air flowing into a region of adverse pressure gradient. The result is flow separation, and this can be seen developing at 12 degrees in figures 5 and 6. The surface pressure plot shows a flattening of the suction side pressure curve at about two thirds chord, and separation is clearly shown by the streamlines at this point in figure 6.

As the 12 degree case generates maximum downforce in this instance, we can conclude that some flow separation is not necessarily too detrimental, and the use of a small right-angled 'Gurney' atop the trailing edge would improve the situation. However, figure 7 shows very graphically what happens when things are pushed too far. Although high downforce is still being generated at 16 degrees, it has reduced compared to the 12 degree case, and major flow separation occurs. The wing has stalled, and it would be safe to assume drag is worse, too.

Next month we'll look at the effects of changes to other wing parameters before moving on to multi-element wings.

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