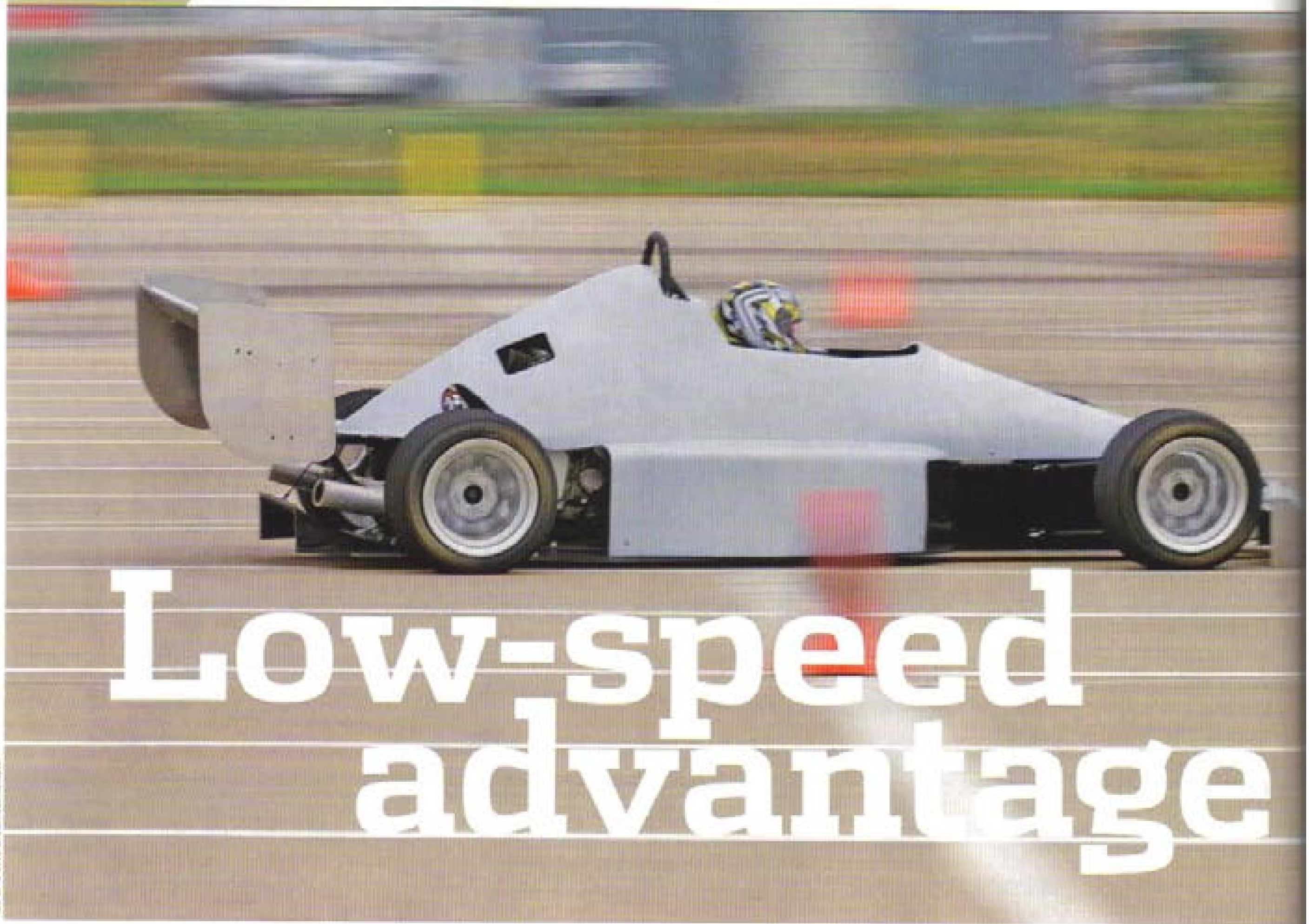


Ed Endicott/dreamstime.com

# Low-speed advantage

**Can wings generate useful downforce at the speeds encountered in the SCCA's 'Solo' category? *Racecar* uses FloWizard CFD software to find an answer**

BY SIMON MCBEATH

The Sports Car Club of America's (SCCA) Solo, or Autocross as most of its proponents call it, is a relatively low speed, against-the-clock discipline in which drivers in a wide range of car categories and classes negotiate sinuous courses marked out with cones. UK readers could think of the events as part way between autotests and sprints. Speeds are deliberately restricted to a maximum of around 80 to 85mph (129 to 137km/h) for safety reasons. As such, many curves are taken in the 50 to 60mph (80 to 96km/h) speed range, and minimum speeds in the tightest corners can be as low as 15 to 20mph (24 to 32km/h). As a result, two schools of aerodynamic thought abound: the first believes that the competition environment does not warrant the exploitation of what are often thought to be rather modest aerodynamic forces; the second believes the complete opposite. So, with the help of FloWizard CFD software, a wing design project was initiated that not only demonstrated the levels of aerodynamically-generated forces that are available, but which also highlighted methods of optimising configurations before any manufacturing or installation was undertaken.

The project related here came about during autumn 2006, after the annual SCCA Solo National Championship at Heartland Park, Topeka, Kansas. This is the end of season gathering for autocrossers from all over the USA and Canada and hundreds convene on this mid-west venue for what has been called 'the world's largest amateur motorsports championship'.

Following last September's event, an enquiry came in from car owner Dan Wasdahl and driver Joe Cheng who had, in their own words, been 'soundly thumped' by perennial front-runners, the Bowlands. George Bowland, and his son Todd (a former Champ Car and now NASCAR engineer) both run A Modified cars, the fastest single-seat specials in the sport of Autocross. Such cars typically feature unclad spaceframe chassis and highly tuned two-stroke snowmobile engines with CVT transmissions. They weigh in at around 900lb (409kg) and frequently sport some of the most radical-looking wings you'll see in motorsport, along with profiled, ground effect undersides (see figs 1 to 4).

The enquiry from the Wasdahl/Cheng team outlined various areas of the car that were going to receive attention, but the specific enquiry concerned the car's aerodynamics. The Bowlands had already obtained the assistance of Dr Michael Selig at the University of Illinois at Urbana-Champaign, who had previously worked with Newman

> WHAT MIGHT BE EXPECTED OF THIS TYPE OF RELATIVELY EXTREME WING?

Hass Racing, saying 'drag be damned, give us the most downforce you can.' Which, as it happens, also nicely summarises the Wasdahl/Cheng enquiry.

Fortunately, at about the same time we were working on a new, multi-element wing set up for the UK hillclimb market, and, coincidentally, were also evaluating a relatively new CFD software package from ANSYS, called FloWizard (see sidebar on p52). The opportunity to see what could be learned about multi-element wings using this type of software was too good to pass up. And such was the openness of the project participants that it provided the opportunity to see not just what the software could do, but also what might be expected of this type of relatively extreme wing.

It's fair to say the Wasdahl/Cheng team's reasoning for the selection of three-element front and four-element rear wings was coloured by the opposition's approach. The Bowlands had apparently tried a four-element front wing on their car, but felt that the front wing was deflecting the airflow over the rear wing. Cutting back to a three-element front seemingly helped the rear wing to work better (though this may have been a balance issue). The slightly narrower span at the front was decided upon as wings can easily get damaged when they come into contact with sturdy cones.

Practicality dictated the first step, which was to examine whether the new 300mm (11.8in) chord hillclimb main-element profile being worked on would, in concert with 170mm (6.7in) chord flaps of an existing stock profile, enable a set up that could reach the target maximum plan area and give reason to expect good performance. CAD sketches of proposed configurations were exchanged by email first to ensure the project set off on the right track (see figs 5 and 6).

**“THE TARGET WAS THREE AND FOUR-ELEMENT DESIGNS”**

#### INITIAL VALIDATION

Although the target was three and four-element designs, it was decided first to use FloWizard to evaluate a dual-element set up because there were reasonable amounts of data on an earlier dual-element design to hand from full and half-scale wind tunnel work. By running this earlier dual-element profile against the new profile in FloWizard, it would be possible to correlate FloWizard's results with the wind tunnel data, and simultaneously gain comparative data on old vs new profiles.

### PROJECT BRIEF

**Wing area**

**FRONT AND REAR COMBINED**
20sq ft ($1.86m^2$) when viewed in plan view

**FRONT VIEW AREA**
Unlimited

**REAR WING**
6ft (1829mm) span, four element

**FRONT WING**
5ft (1524mm) span, three element

**Aim**

**DOWNFORCE**
Generate the maximum downforce possible (the team would add engine power to overcome additional drag if required)

## CASE STUDY:

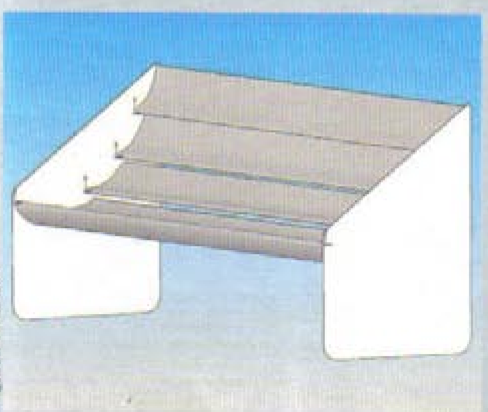
**Figures 1 & 2**
**The Dan Wasdahl/Joe Cheng car featured in the study had relatively modest three-element wings front and rear**

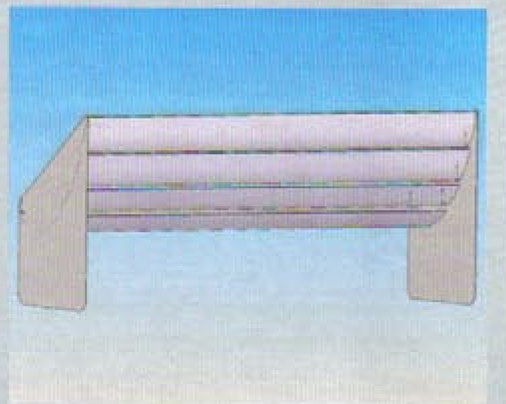

**Figure 3**
**The 'opposition'. This is George Bowland's championship-winning BBR Shark. The Shark sports a three-element wing at the front and a four-element wing at the rear**


**Figure 4**
**The Bowlands received design assistance from the University of Illinois at Urbana Champaign**

## THE PROPOSED FOUR-ELEMENT DESIGN

Figures 5 & 6





## DUAL-ELEMENT DATA

Figure 7

**Static pressures on the top surface of the dual-element wing**

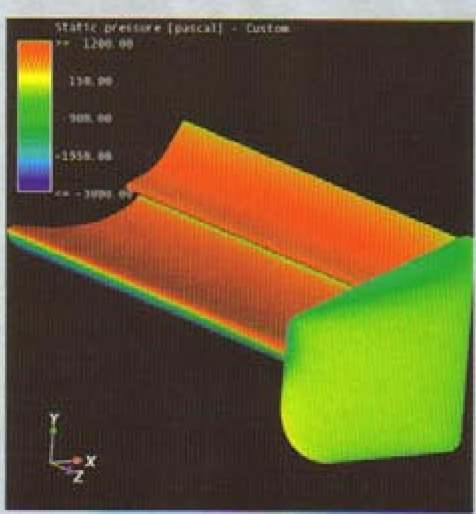


Figure 8

**Static pressures on the underside of the dual-element configuration**

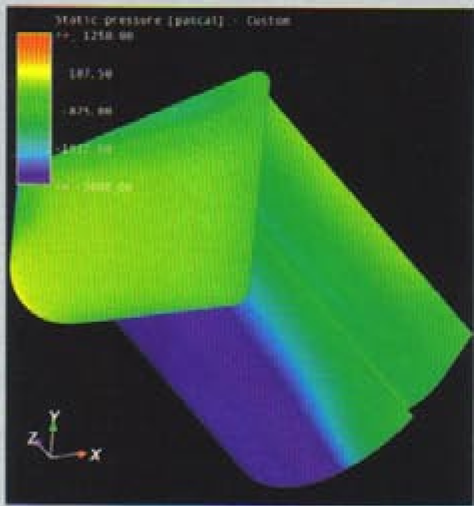


Figure 9

**Velocity vectors show the stagnation point on the leading edge of the dual-element wing to be almost ideally located**

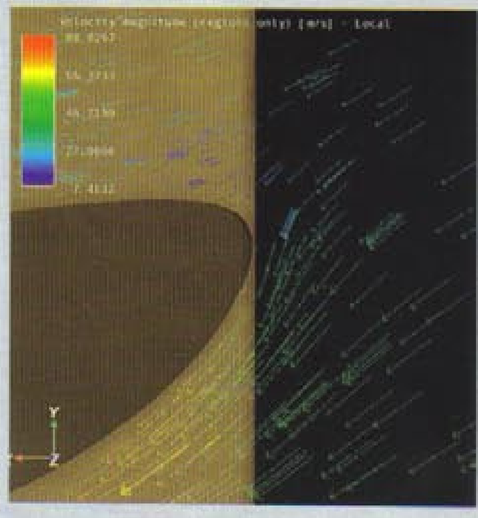
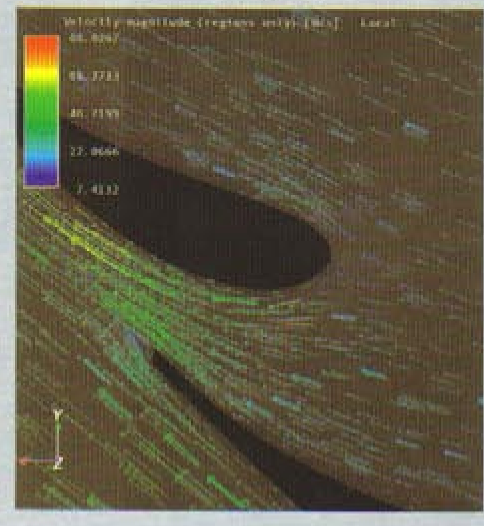


Figure 10

**And velocity vectors through the slot gap show the flow accelerating under the flap**



As described in the sidebar at the end of this article, FloWizard is extremely easy to set up, and it offers a number of user-selectable features that control the compromise between speed of calculation and accuracy of results. For most of the work shown here, the basic default settings were utilised, though it should be noted that these do not model the viscous effects in the boundary layer close to the wing surfaces as well as the enhanced settings do. This meant that when installation angles became steeper the software could not necessarily be relied upon to correctly predict flow separation and stall. However, for qualitative and semi-quantitative comparisons, and the examination of trends, it was felt that the default settings provided a very useful guide.

**“THE DEFAULT SETTINGS PROVIDED A USEFUL GUIDE”**

Furthermore, for visualising flow directions, and pressure and velocity distributions, the basic settings were felt to be adequate. Note also that all the simulations shown here were on wings in isolation and, clearly, on-car optimisation of the wings would ultimately be required to corroborate the results.

### TWO ELEMENTS

The new wing in dual-element guise was progressively increased in angle of attack, and downforce (and drag) results, plus flow and pressure distribution patterns were noted from the FloWizard simulations. The results compared to the well-characterised earlier profile were encouraging, with significantly greater downforce being generated across a wide range of angles. Also, the results calculated by FloWizard on the older profile were pleasingly close to the wind tunnel data. This first phase then produced confidence that lift and drag data from the basic FloWizard settings were probably fairly indicative, if treated with the aforementioned caution, and also that the basis chosen for this high downforce wing set up had started well in dual-element form.

The images show some of the parameters that may be plotted with FloWizard. Though not as flexible in this regard as its big brother Fluent, some very useful visualisations are still available. Of particular interest was the flow between the two elements, and the vector plot seemed to show this to be satisfactory. The total pressure plot also revealed the feed of 'fresh' air onto the flap's suction surface. The air above the wing has higher total pressure, or higher energy, and part of the function of the slot gap is to allow this higher energy air to bleed through. The vector plot then shows how this air accelerates, creating useful reductions in static pressure on the flap's suction surface to help 'drive' the flow under the element in front (see figs 7 to 10).

### THREE, THEN FOUR ELEMENTS

The next phase was to add a second flap to create a three-element wing, and an earlier 2D CFD project suggested starting points for the relative flap angles and locations. In essence, this was also to be the configuration of the front wing. Once again, one of the principal aims here was initially to try to ensure that the flow between the elements and onto the next element, as it were, was satisfactory.

The plots show the vectors through the first and second slot gaps, and small differences are apparent in the angle of the onset flow onto each flap. It was felt that this was something that could be optimised at a later stage. Furthermore, the flow off the suction (lower) surface of the mainplane was being slightly deflected, but adjustments to the slot gap would improve that later. The results of this one-off run showed that even without any optimisation, this three-element wing generated 29 per cent more downforce than the two-element variant, but also a lot more drag, with the lift-to-drag ratio (L/D) down from 3.8:1 to around 2.8:1.

Next, a third flap element was added, at a slightly steeper installation angle again than the second flap and, as a first iteration, at an overlap and separation based on the slot gap between the lower pair of flaps. The first FloWizard run showed a further nine per cent increase in downforce over the three-element wing, but with a drop in L/D to 2.2:1. However, one change was becoming increasingly apparent with each step up and that was the movement of the stagnation point on the mainplane leading edge. In the case of the dual-element wing the stagnation point, where the flow divides between upper and lower surfaces (and where the velocity is actually zero), was shown by FloWizard to be ideally located, just above the leading edge. With the quad-element wing this had moved significantly aft, meaning the air had to turn sharply around the leading edge. This is a potential cause of stall, and later trials attempted to address this issue (see figs 11 to 14).

### SLOT GAP REFINEMENTS

As one of the aims here was to use FloWizard to visualise the flows in the slot gaps and to try to improve performance using this visual information, iterations involving widening one or more of the slot gaps by a few millimetres at a time were carried out, resulting in a gain of over

"VISUALISE THE FLOWS BEFORE MAKING ANYTHING SOLID"

## VELOCITY VECTORS

**Figure 11**

**Same geometry as the dual-element slot gap, but the velocity vectors through the first slot gap of the triple-element wing were slightly different**

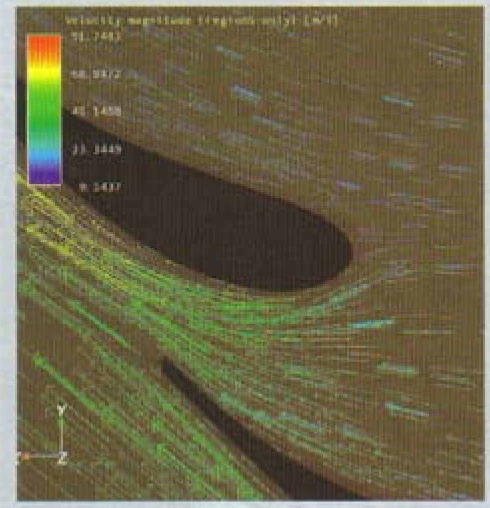


**Figure 12**

**Same set up again, but here you can see how the velocity vectors differed through the second slot gap on the triple-element wing**

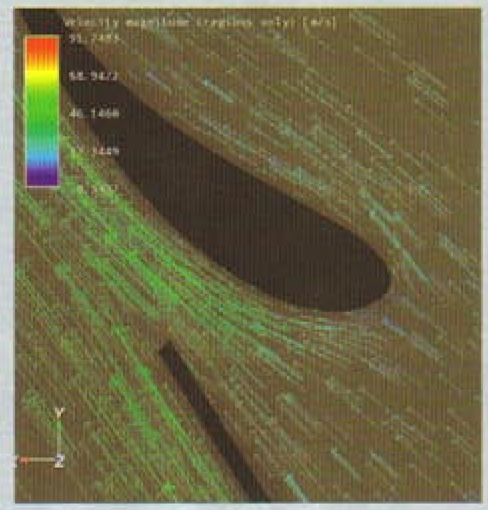


**Figure 13**

**Velocity vectors at the leading edge of the triple-element mainplane showed the stagnation point had moved aft**

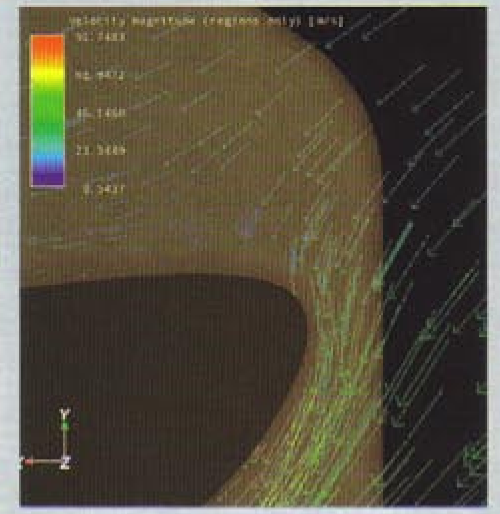
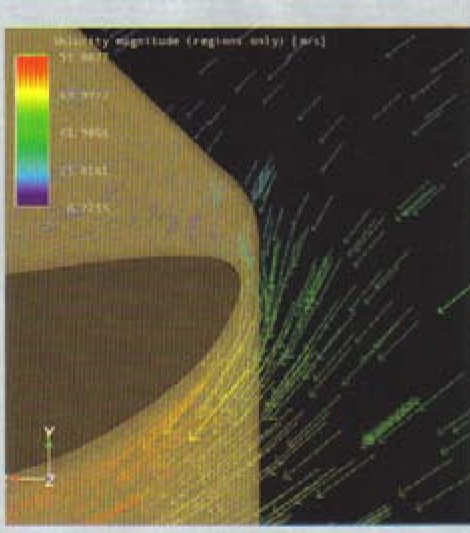


**Figure 14**

**And when the fourth element was added the stagnation point moved still further aft**



eight per cent more downforce and small improvements in the lift-to-drag ratio. A final step in slot gap widening saw the downforce reduce again, suggesting that an optimum for the set up in question had been found. Of course there are a great many possible variations that could be tried, and the benefit of CFD software like FloWizard is that you can visualise the flows and observe the trends in forces resulting from changes before making anything solid.

The above mentioned rearwards shift of the stagnation point was a cause of some concern, and a couple of things were looked at to mitigate what might be a problem in reality, even if all looked reasonable in the simulations. The first thing tried was to decrease the angle of attack of the main element by two degrees. This not only shifted the stagnation point slightly further forward, it also produced a small gain in both downforce and L/D, suggesting there may indeed have been a problem at the slightly steeper main element angle.

Secondly, and more radically, the notion of using a leading edge slat (or more correctly in aeronautical terminology, a slot) was evaluated at the request of the team. The theoretical benefit of a leading-edge slat is that it helps to turn the airflow around the mainplane leading edge and, in doing so, allows the aft elements to be pushed to steeper angles before stall occurs. In our context, this would enable more downforce to be generated. In practical terms, it is effectively a way of turning the leading edge into the oncoming airflow better, but without having to re-design and re-make a new main element. Because a CAD model and an actual mould were available, the rear flap element 'trimmed' to 110mm chord was used as the slat. This would almost certainly not have been an optimum profile, but it was available to test the idea.

There then followed a number of iterations during which the first 'eyeball guess' at the location and angle of the slat was modified according to the results obtained and by visualisation of the simulated

## FOUR AND FIVE-ELEMENT PROFILES

**Figure 15**

Though not an optimised profile, this leading edge slat did beneficially modify the flow onto the leading edge of the four (now five)-element wing

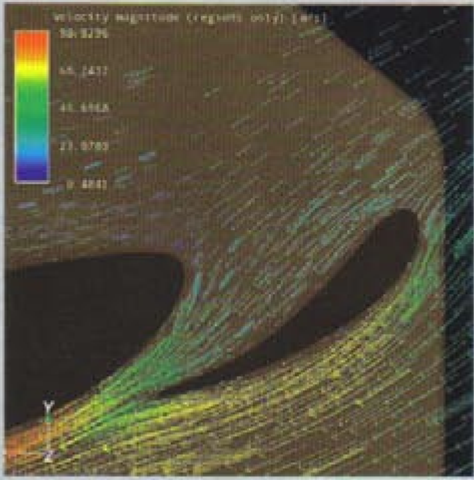


**Figure 16**

The flow through the top slot gap of the five-element wing looked satisfactory

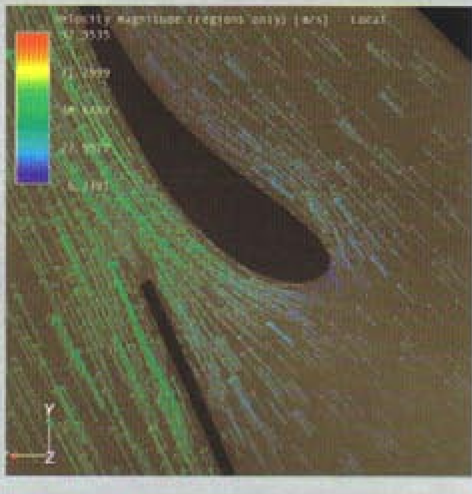


**Figure 17**

The four-element plus slat final configuration, with velocity vectors illustrating just how much the airflow is turned by this type of wing

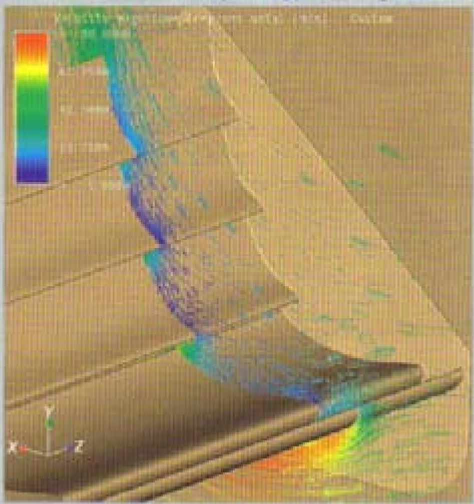


**Figure 18**

Underside view of the four-element plus slat configuration with velocity vectors

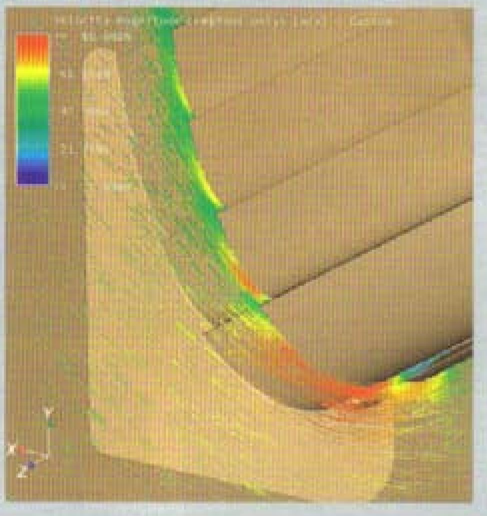


**Figure 19**

Static pressures on the upper surface of the four-element plus slat wing

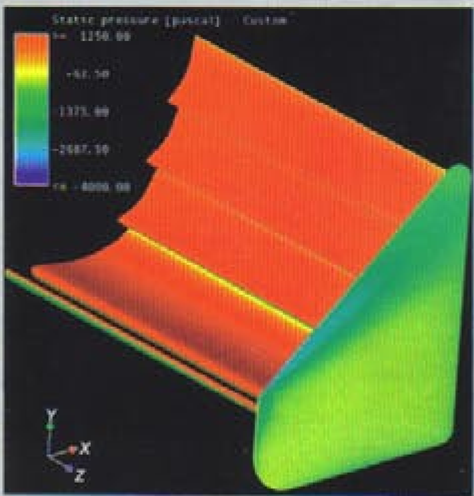
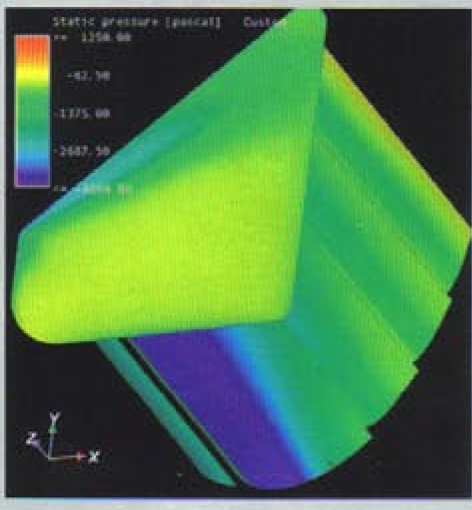


**Figure 20**

Static pressures on the lower surface of the four-element plus slat wing



flow vectors around the slat. A number of runs saw both with and without-slat configurations being swept through an angle range that captured what appeared to be the peak downforce values in each case. And it seemed that the slat would allow more flap angle to be run, too, leading to peak downforce values around three per cent higher than without the slat. However, refinements to the set up without the slat also produced more downforce and better L/D values (in the range of 2.8 to 2.9:1). As such, the difference between the set ups was apparently quite small.

Given the uncertainty surrounding the basic CFD settings and their ability to accurately predict what would happen at steep angles where flow separation would certainly be occurring in reality, no firm conclusion was drawn about the slat in this instance. However, it was clear that the modification to the flow onto the main element would almost certainly be beneficial, so it was kept in mind that the slat might be a useful retro-fit modification should more rear downforce be sought (see figs 15 to 21).

## FINAL THOUGHTS

Much additional work could have been done on this project, including such obvious modifications as Gurneys on the topmost flap, but it isn't certain if the settings in use would have picked up the proven benefits to be had from Gurneys. And as those devices are well proven, it would be simple enough to try them once the wings are on the car and some real world flow visualisation could be carried out to help optimise installed angles.

So what levels of downforce were predicted? Bearing in mind we have to treat the peak numbers with a degree of circumspection, the maximum downforce calculated for the best quad-element configuration tested in this project equated to around 200lb at 50mph (890N at 80km/h approximately). With roughly two thirds of this also available from the front wing, that represents a total of 333lb (1486N) of wing-generated downforce on a car weighing 900lb (4013N).

There's no doubt the use of FloWizard in this project offered insights into aspects of these wing configurations that would otherwise have been complete guesswork. Now, is there anyone that still doubts the potential benefit of aerodynamic forces at these speeds?

## CONTACT

**FLUENT EUROPE**
Sheffield Business Park
6 Europa View, Sheffield,
S9 1XH England
**TELEPHONE**
+44 114 281 8888

**FLUENT INC**
10 Cavendish Court
Lebanon, NH 03766, USA
**TELEPHONE**
+603 643 2600

**WEBSITE**
www.fluent.com

## STREAMLINE VIEW

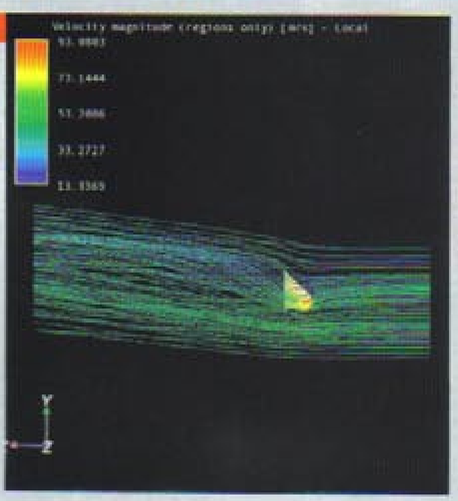
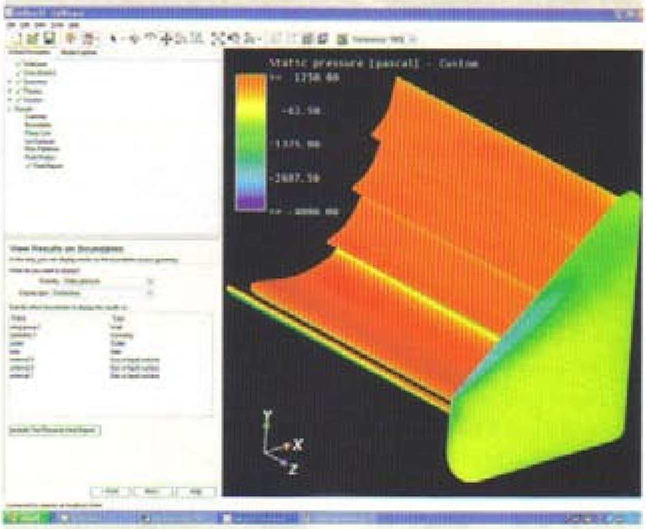


**Figure 21** Wide view of streamlines showing the effect of the wing on the downstream flow direction

## FLOWIZARD SOFTWARE FROM ANSYS



We covered the basics of what FloWizard can offer in Technical Spotlight V15N9, but the opportunity to evaluate the software on projects like the one discussed here has highlighted just how easy it is to use. The familiar Windows-based wizards guide you through the basics of CAD model import, flow region set up, boundary conditions selection and solver parameter choice.

Assuming that 3D CAD is available to create a digital model to be tested, whatever that may be, the rest is made easy and no specialist CFD knowledge is needed in order to get the software to run. FloWizard utilises the same 'solver' code as full-featured Fluent itself, so although the automated mesh generation produces a simplified form of mesh (tetrahedral cells in the default case), the underlying software is well proven. Mesh and solver enhancements

> "NO SPECIALIST CFD KNOWLEDGE IS NEEDED TO GET THE SOFTWARE TO RUN"

can also be invoked dependent on the geometry of the model under test, and externally generated meshes can be imported.

Reports and post-processed visualisation images are also easily produced and provide valuable insights into what is likely to be going on. A range of fluids other than air can be used for the tests and conditions may be isothermal or include heat transfer. Flow compressibility can also be catered for.

If computational fluid dynamic design verification is required and CAD models are available, this product could provide a viable, user-friendly solution. It won't give you downforce and drag on your Formula 1 car to plus or minus a per cent or so, but it will provide valuable pointers in the design of components along the way.

Available from £3000 ($6000) per seat per annum using the 'remote simulation facility' (RSF) and including 330 hours of solver time, FloWizard is about as inexpensive as top-brand CFD comes. Furthermore, using RSF only requires a decent laptop or PC and broadband internet connection, so there is no need for investment in more powerful hardware. If running solutions in-house is crucial, then a full FloWizard software license costs £8000 ($16,000) per seat per annum, just over half the cost of its big brother Fluent. Flexible licensing options from periods as short as 24 hours through to six plus months can also be discussed.