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# Grand Prix 2014

## F1 teams facing new power struggle


### Wing fundamentals

The basic principles of setting up frontal aero

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How the FIA plans to control Equivalence of Technology

### Volvo S60 R

First sight of the Australian V8 supercar challenger

# Front wing fundamentals

**Nowadays, the front wings on top single-seaters are festooned with intricate details – but there are numerous other crucial elements that have to be right first...**

BY SIMON MCBEATH

In a sense, the aerodynamicists in F1 have it easy when it comes to front wing design. This is because a number of the basic parameters, such as maximum span, maximum chord, maximum depth, fore and aft location, minimum static ground clearance and – in the central part at least – the actual section profile, are stipulated in the technical regulations. Within those limits there is still an essentially infinite variety of possibilities of course, but consider the situation in a single-seater category where perhaps the only restriction, if any exist, is on maximum span and the rest is free. Where do you start?

In contemplation of this question, we have taken advantage of the use of ANSYS CFD software to investigate some of the basics. We'll see, among other things, why wings stall when they're too close to the ground and what happens when they do stall; why wider spans or wider flaps don't necessarily lead to more downforce; what happens when the wing is moved closer to the front wheels; why a more potent front wing doesn't necessarily create more drag, and what happens when the overall span is changed in the manner that F1 rules mandated in 2009, and again in 2014.

**Where do you start with a front wing specification when there are few or no rules? This is the DJ Firehawk hillclimber, with a dual-element front wing**

### FRAME OF REFERENCE

The basis for this investigation is the single-seater concept design that underlies your writer's long-term hillclimb racecar project, the Vortex. Though currently firmly secured to the back burner, this project is still alive, but more importantly in the context of this feature it means a CAD model of a single-seater intended for UK hillclimbing already existed on which to try out a range of front wing variations. (The project itself morphed into a sports racing concept, but the single-seater at its core essentially hasn't changed). A front wing design also already existed. The model was also upgraded with improved wheel and suspension detail, although it remained a simplified representation.

In addition to the minimum static ground clearance of 40mm, UK hillclimb regulations only have two specific rules regarding front wings on 'racing cars':

- **Maximum width ahead of the front wheels is 1500mm**
- **Maximum height of any part wider than 1100mm ahead of the front wheels is not to exceed the top of the front wheel rim**

So there are far more degrees of freedom available in terms of the size and location of the wing than in more heavily regulated categories, and this situation also has relevance in other single-seater racing categories too, even though maximum span may be somewhat less. There are other categories and classes where there is no maximum span limit too, and we shall visit the situation where wingspan equals the car's width across the front wheels, analogous to F1 regulations from 2009 to 2013.

First, though, we are going to look at the effect of ground clearance. Although in UK Motorsports Association (MSA)-sanctioned events this parameter is covered by the 40mm minimum static ground clearance regulation, the dynamic situation can give rise to a fairly wide operating range, depending on mechanical setup. Furthermore, we need to examine a wider range than that to try and pick out a preferred static starting point.



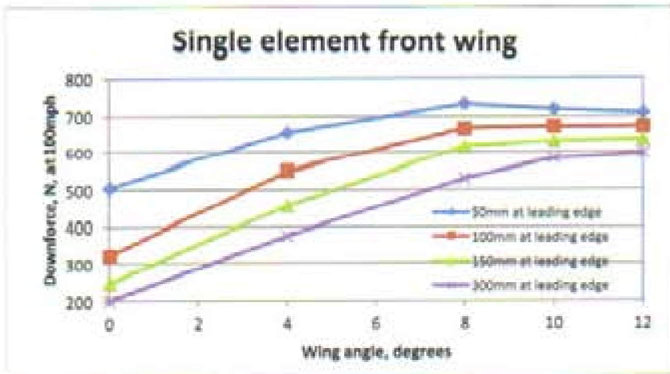



**Figure 1: downforce vs angle on a single-element wing at different ground clearances**


**Figure 2: downforce vs ground clearance on a single-element wing at different angles**


**Figure 3: downforce vs ground clearance on a dual-element wing**

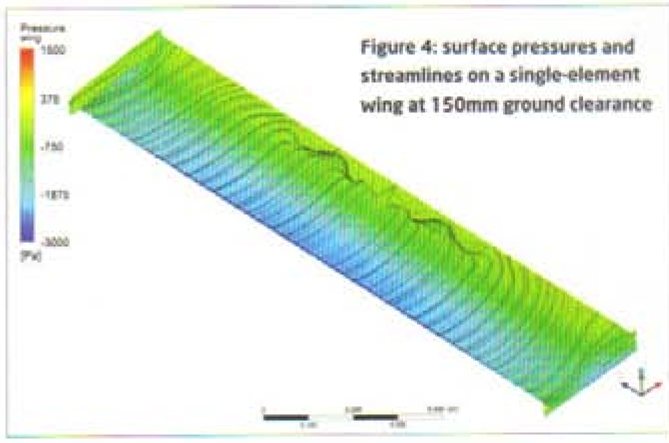


**Figure 4: surface pressures and streamlines on a single-element wing at 150mm ground clearance**

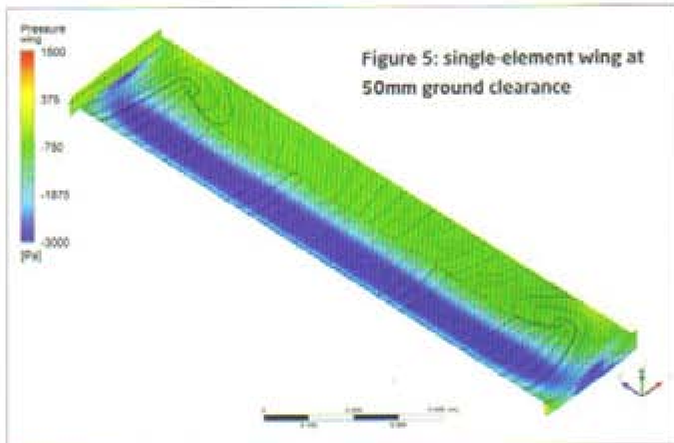


**Figure 5: single-element wing at 50mm ground clearance**

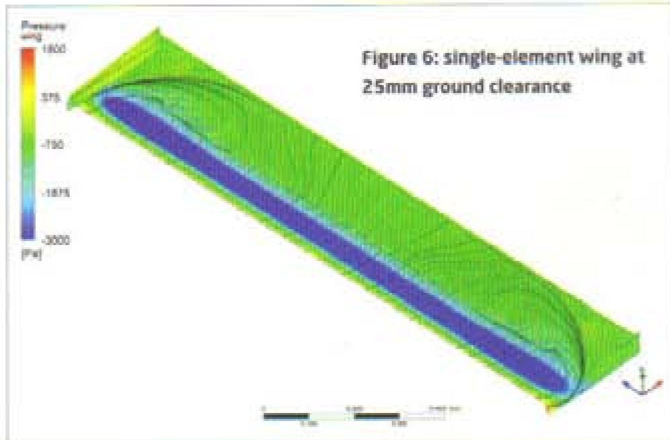


**Figure 6: single-element wing at 25mm ground clearance**

### GLORIOUS ISOLATION

As a first step we'll look at the results on a single-element and a dual-element wing in isolation from the car, to highlight the behaviour of the wings themselves as ground clearance is changed. Span was 1500mm in each case, and end plates were simple, flat sheet devices. In the case of the single-element, 275mm chord wing, overall angle was adjusted across a range at various ground clearances from 300mm (measured from the ground to the tip of the leading edge) down to 50mm (and in one case, 25mm).

With the dual-element wing, the same main element angle was fixed and the 120mm chord flap angle was adjusted, and again the wing was mapped at a range of ground clearances from 50mm to 300mm. (The latter height was unfeasibly high for installation on the car model as a suspended wing, but was tested in isolation to give a more complete idea of how ground effect influences wing performance.) **Figure 1** illustrates.

The usual pattern of increasing downforce with increasing angle, up to a point, was evident, as was the increase in downforce brought about by reducing ground clearance. The wing peaked at between 10 degrees and 12 degrees at the greatest height, but at just 8 degrees at the lowest height, with something of a transition in between.

**Figure 2** plots the same data in a different way, with an interesting additional sample point added, and shows clearly that reducing ground clearance below 50mm didn't look like a good idea with this wing at the angle tested.

Maximum downforce occurred at 50mm ground clearance for all the variations tested here, and this might seem to be the best height to select for that reason. However, it is also obvious that the lowest ground clearance would also be the most sensitive to dynamic fluctuations in ride height, so a decision always has to be made about just where on the downforce vs ground clearance curve you set your wing – at the 'peaky' maximum downforce height, or slightly higher on the more benign side of the peak? Either way, it looks like ride height fluctuations need to be controlled and that downforce levels will fluctuate dynamically.

Moving on to the dual-element wing, which featured a full span flap, first the flap angle at which peak downforce occurred was established at 100mm ground clearance (measured to the main element leading edge again), at which flap angle overall chord was 364mm, and this configuration was then adjusted to a range of ground clearances from 50mm to 300mm. **Figure 3** plots the results in similar fashion to **Figure 2**.

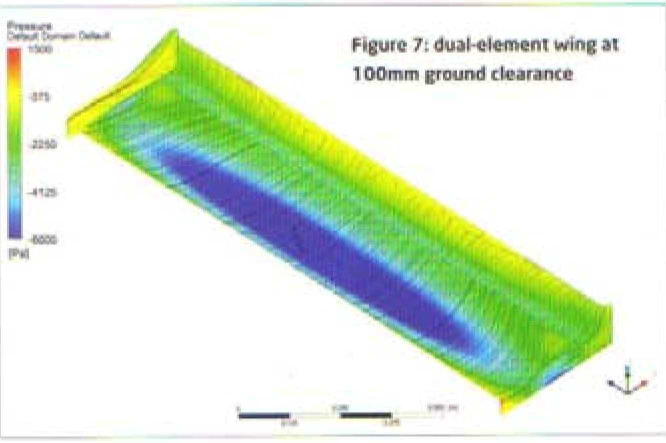


Figure 7: dual-element wing at 100mm ground clearance

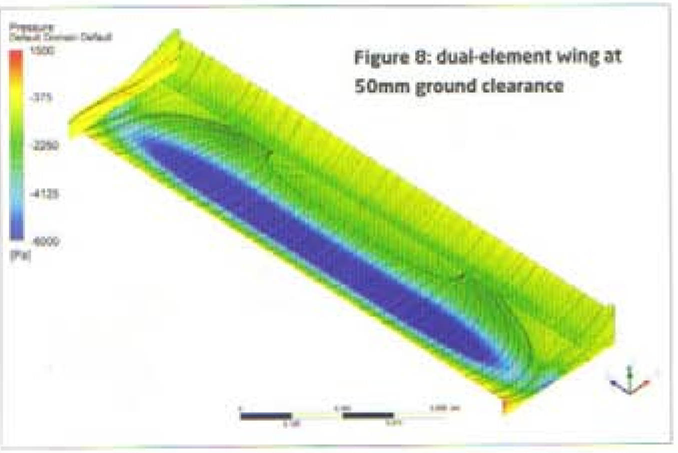


Figure 8: dual-element wing at 50mm ground clearance

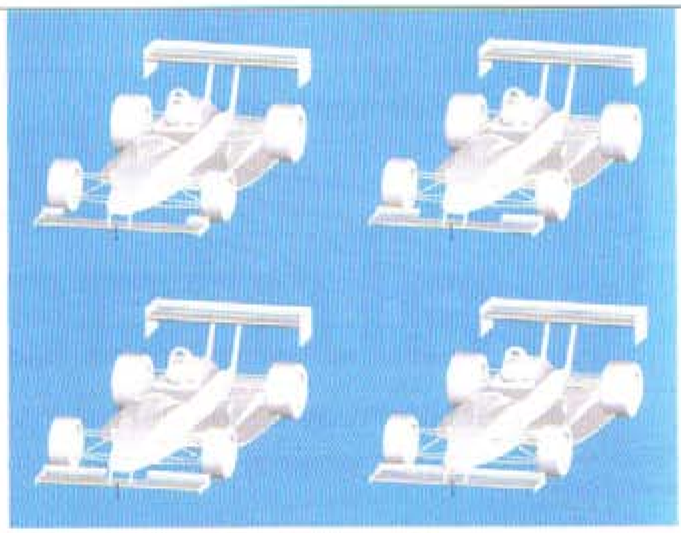


Figure 9: four flap span variations were tested

## GROUND CLEARANCE CONVENTIONS

Engineering convention is to state front wing ground clearance as the ratio of ground clearance over chord, g/c. The table below enables conversion of the ground clearance dimensions used in this article to g/c for each wing

**g/c for the single- and dual-element wings used in this article**

| Ground clearance, mm | Single-element, 275mm chord | Dual-element, 364mm chord |
|---|---|---|
| 50 | 0.182 | 0.137 |
| 100 | 0.364 | 0.275 |
| 150 | 0.545 | 0.412 |
| 300 | 1.091 | 0.824 |

**Table 1: aerodynamic data from variations in flap span**

| | | | | | Drag, N, 100mph | | | | | Downforce, N, 100mph | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flap span | Drag, N | Total Df, N | -L/D | %front | Car body | Front wheel | Front wing | Rear wheel | Rear wing | Car body | Front wheel | Front wing | Rear wheel | Rear wing |
| 0.25 | 930.3 | 2330.4 | 2.505 | 2.55% | 429.0 | 138.4 | 38.8 | 158.3 | 165.8 | 763.9 | -88.2 | 409.9 | -93.4 | 1339.2 |
| 0.50 | 946.5 | 2812.6 | 2.972 | 21.12% | 414.9 | 128.4 | 73.3 | 162.8 | 167.1 | 1032.8 | -95.5 | 685.2 | -88.3 | 1278.4 |
| 0.75 | 984.7 | 2820.2 | 2.864 | 34.21% | 421.7 | 114.2 | 108.6 | 174.1 | 166.1 | 636.6 | -81.5 | 1068.1 | -50.5 | 1247.5 |
| 1.00 | 975.4 | 3099.5 | 3.178 | 45.04% | 412.1 | 111.9 | 125.0 | 164.4 | 162.0 | 547.3 | -59.6 | 1453.7 | -79.8 | 1237.9 |

Here we see a similar pattern to the single-element wing, but peak downforce appeared to be at 100mm, with initially a gradual fall off at 75mm and a more rapid decline at 50mm. Above 100mm the decline appears to be more peaky too. Both wings would require more ground clearances to be tested at smaller increments in the regions of interest, but the general picture can be seen from the data points shown here.

### STALL MECHANISMS

So what actually happens at these critical low ground clearances that causes the apparently sudden reduction in downforce? Looking at the single element wing first at 8 degrees angle of attack, **Figure 4** shows the surface pressures and streamlines on the wing's suction surface at 150mm ground clearance. And even though the wing was just below its peak downforce angle at this height there is already some flow separation occurring in the central area towards the trailing edge (the airflow coming from bottom left). Moving on to **Figure 5**, this was the pressure and streamline pattern at 8 degrees and 50mm, at which peak downforce occurred. Clearly the flow separation has spread, yet the region of lowest pressure under the wing has also spread, and the wing's downforce peaks because of this (although the downstream flows will be modified too).

**Figure 6** shows the wing at 8 degrees and 25mm ground clearance where downforce had declined – the low pressure region has shrunk and flow separation is widespread. The wing has stalled.

As for the mechanisms at work here, there are two. Firstly, as the wing approaches the ground, the magnitude of the suction under it increases, which leads to an increasingly steep adverse pressure gradient from the region of lowest pressure to the wing's trailing edge. When this pressure gradient becomes too steep, the air can detach from the wing's surface – so-called flow separation. Then, as the wing gets really close to the ground, viscous effects start to cause blockage to the flow under the wing. This reduces the energy of the flow passing under the wing, and this makes it harder still for the air to remain attached in the now even more adverse pressure gradient towards the rear of the wing. Separation becomes stall.

We'll come back to look at what happens to the wing as it is deployed ever closer to the ground when fitted to the car later. Next though we'll take a brief tour of some other variables that might seem unrelated but which, it turns out, are highly relevant.

### FLAP SPAN

The dual-element wing tested in isolation in the previous section featured a full span flap. But flaps are often only part-span, either because of technical regulations, such as in F1 with its 500mm mandatory single element neutral centre section, or perhaps because only part-span is required to achieve a balance with a mandated rear wing, such as in F3. **Table 1** below shows the CFD results of a flap span trial with the 1500mm dual-element wing now installed on the car (at 100mm ground clearance), and **Figure 9** illustrates the front flap chord variants, referred to as full span (1.00 in column 1) down to quarter span (0.25).

Having the ability in CFD to measure the aerodynamic forces on individual components enables tremendously valuable insights into the effects of changes. And perhaps the key point here is





**Table 2: aerodynamic data from variations in fore and aft location of the front wing**

| | | | | | Drag, N, 100mph | | | | | Downforce, N, 100mph | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| x-change, mm | Drag, N | Total Df, N | -L/D | %front | Car body | Front wheel | Front wing | Rear wheel | Rear wing | Car body | Front wheel | Front wing | Rear wheel | Rear wing |
| 0 | 946.5 | 2812.6 | 2.972 | 21.12% | 414.9 | 128.4 | 73.3 | 162.8 | 167.1 | 1032.8 | -95.5 | 685.2 | -88.3 | 1278.4 |
| 100 | 959.9 | 2907.6 | 3.029 | 18.21% | 429.2 | 135.4 | 63.5 | 164.6 | 167.2 | 1180.0 | -89.9 | 628.3 | -88.7 | 1277.9 |
| 200 | 946.4 | 2782.6 | 2.940 | 15.08% | 431.8 | 135.8 | 50.3 | 161.7 | 166.8 | 1110.9 | -70.7 | 560.1 | -88.5 | 1271.2 |

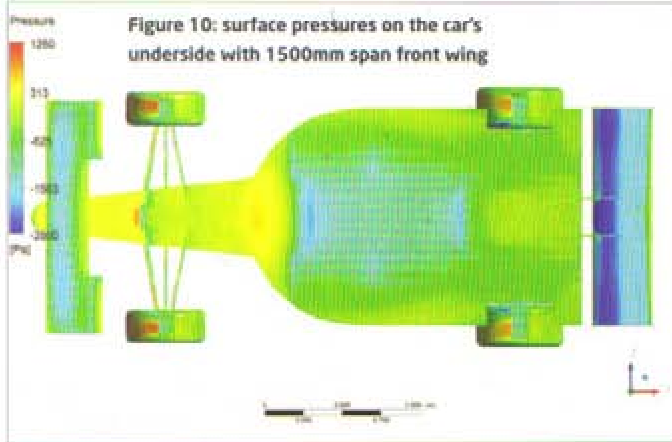


Figure 10: surface pressures on the car's underside with 1500mm span front wing

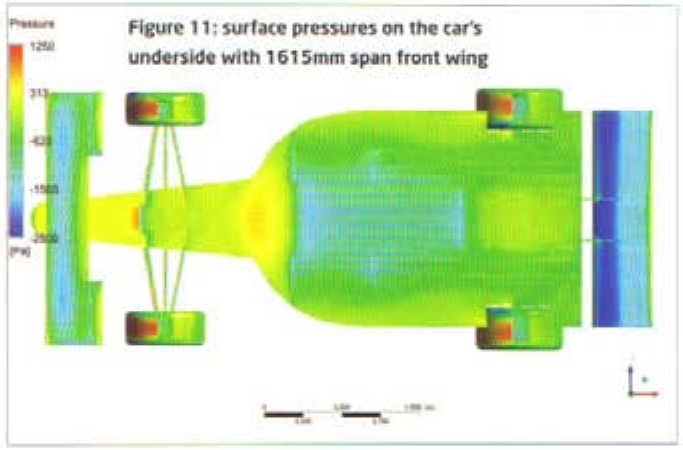
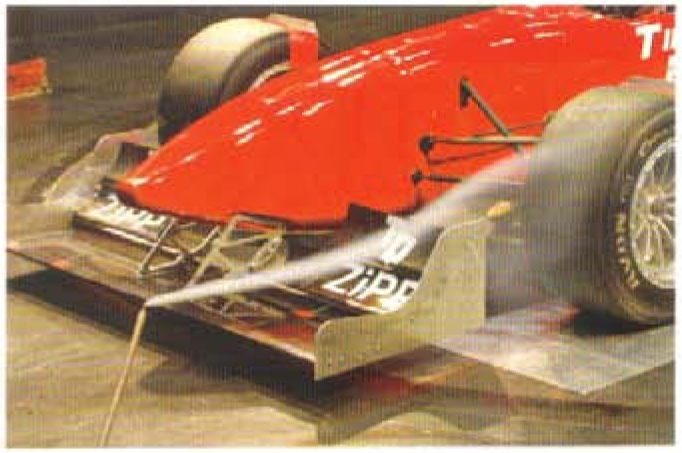


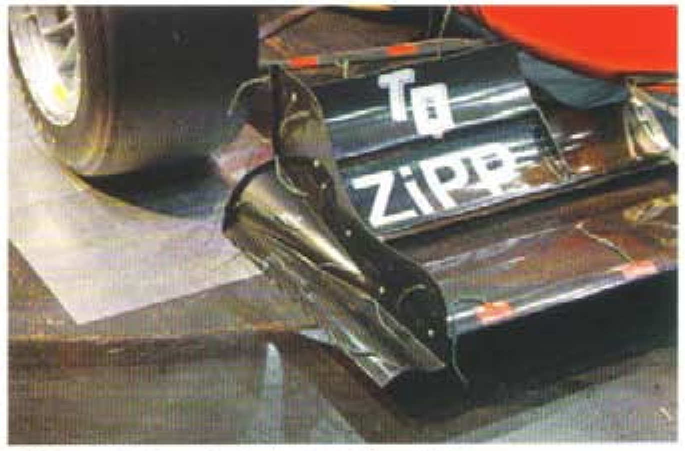
Figure 11: surface pressures on the car's underside with 1615mm span front wing

**Table 3: aerodynamic data from variations in overall front wing span**

| | | | | | Drag, N, 100mph | | | | | Downforce, N, 100mph | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Overall span, mm | Drag, N | Total Df, N | -L/D | %front | Car body | Front wheel | Front wing | Rear wheel | Rear wing | Car body | Front wheel | Front wing | Rear wheel | Rear wing |
| 1300 | 951.7 | 2309.4 | 2.427 | 7.36% | 423.1 | 139.8 | 49.7 | 171.2 | 167.9 | 711.4 | -70.1 | 467.3 | -91.1 | 1291.9 |
| 1500 | 959.9 | 2907.6 | 3.029 | 18.21% | 429.2 | 135.4 | 63.5 | 164.6 | 167.2 | 1180.0 | -89.9 | 628.3 | -88.7 | 1277.9 |
| 1615 | 968.6 | 2588.5 | 2.672 | 18.94% | 416.9 | 139.6 | 67.3 | 178.7 | 166.1 | 827.5 | -103.0 | 693.4 | -115.6 | 1286.2 |



DJ Firestorm front wing at 1300mm span plus thin end plates



DJ Firestorm 1300mm front wing plus 100mm VEEPs

that maximum overall downforce, which comes with the half-span flap, does not coincide with maximum front wing downforce, which – not surprisingly – comes with the full span flap.

Clearly the aerodynamic balance (%front) is different between those two cases too, and it's evident that the half-span flap enables more car body downforce to be generated. Examining the surface pressures on the car's ground effect underbody revealed lower pressures under here with the half flap, verifying the cause. Of special relevance in our current context though, this is evidence that the configuration of the front wing has a profound influence on the response of all the downstream components, something that will also be evident in each of the following cases.

### LOCATION, LOCATION

Another fundamental variable in non-restricted categories is the fore and aft location of the wing; not only will this affect the leverage that the wing exerts on the car, but proximity to the front wheels must surely affect the front wing's performance? The 1500mm wing with the half span flap was moved rearwards in two 100mm increments from its initial position, with the results shown in **Table 2**.

Once more, peak overall downforce did not coincide with peak front wing downforce, the former occurring in this coarse trial when the wing had been moved aft by 100mm. And again, peak downforce was the result of the car body, and more specifically the underbody, producing more downforce. Much the same relationship with balance prevailed though, the %front value being highest in the most forward wing position tested here.

### OVERALL SPAN

Although not always a variable in the sense that in most categories the technical regulations apply a maximum, it's nevertheless interesting to take a snapshot of overall span variation. The choices tested here – 1300mm, 1500mm and 1615mm – equate respectively to approximately the same relative span in relation to the overall width across the front tyres as in F1 prior to 2009; the maximum

**Table 4: wind tunnel results on VEEPs on the DJ Firestorm**

| | CD | -CL | -CLfront | -CLrear | %front | -L/D |
|---|---|---|---|---|---|---|
| Flat end plates | 0.768 | 1.481 | 0.589 | 0.893 | 39.8 | 1.928 |
| VEEPs | 0.771 | 1.778 | 0.772 | 1.005 | 43.4 | 2.303 |
| Change, counts | +4 | +297 | +183 | +112 | +3.64 | +375 |
| Change, % | +0.5% | +20.1% | +31.1% | +12.5% | +9.2% | +19.5% |

**Table 5: CFD results on VEEPs**

| | Drag, N | Total Df, N | Front Df | Rear Df | %front | -L/D |
|---|---|---|---|---|---|---|
| No VEEP | 951.7 | 2309.4 | 170.0 | 2139.4 | 7.36% | 2.427 |
| VEEP | 957.3 | 2806.0 | 484.5 | 2321.5 | 17.27% | 2.931 |
| Change, % | 0.59% | 21.50% | 185.00% | 8.51% | 9.91% (Absolute) | 20.79% |

**Table 6: full CFD results on VEEPs**

| | | | | | Drag, N, 100mph | | | | | Downforce, N, 100mph | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Drag, N | Total Df, N | -L/D | %front | Car body | Front wheel | Front wing | Rear wheel | Rear wing | Car body | Front wheel | Front wing | Rear wheel | Rear wing |
| No VEEP | 951.7 | 2309.4 | 2.427 | 7.36% | 423.1 | 139.8 | 49.7 | 171.2 | 167.9 | 711.4 | -70.1 | 467.3 | -91.1 | 1291.9 |
| VEEP | 957.3 | 2806.0 | 2.931 | 17.27% | 416.8 | 145.5 | 54.7 | 173.3 | 167.0 | 1071.5 | -59.1 | 583.7 | -93.5 | 1303.4 |

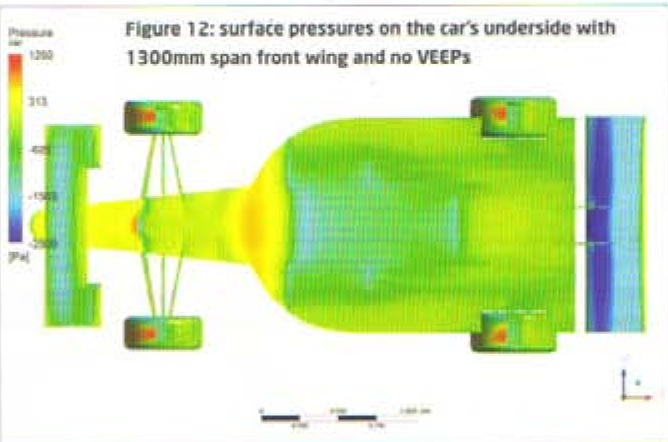


Figure 12: surface pressures on the car's underside with 1300mm span front wing and no VEEPs

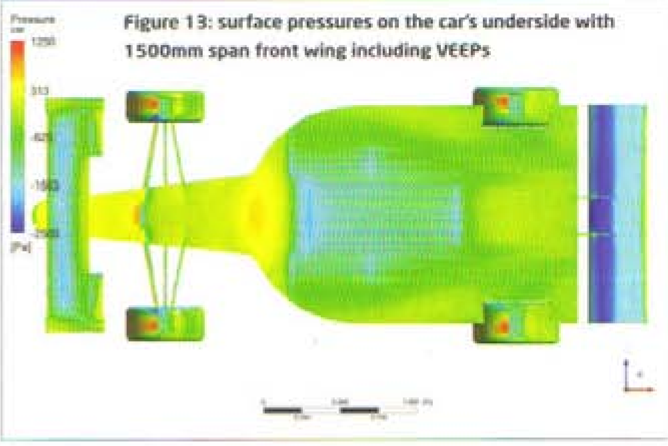


Figure 13: surface pressures on the car's underside with 1500mm span front wing including VEEPs

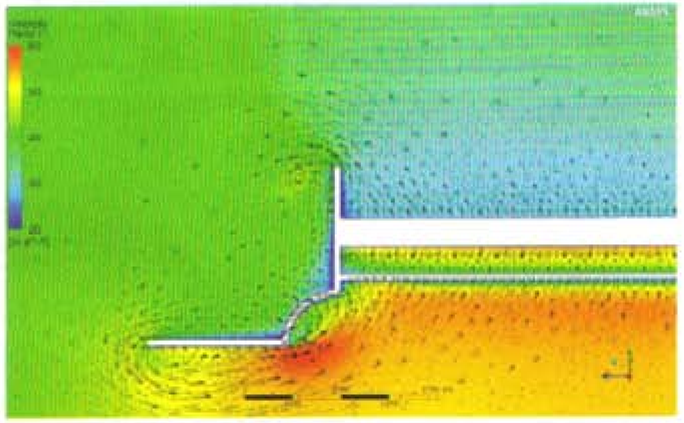


Figure 14: transverse section in line with the slot gap on the front wing (coloured by velocity), with vectors showing vortices under the footplate and within the 'vortex entrainment cone'

permitted in UK hillclimbing (and, relatively, roughly what F1 is using in 2014); and a span equal to the overall width across the front tyres, analogous to what F1 used from 2009 to 2013. The combined flap span was notionally half the total span in each case, the fore and aft location was x+100mm, and the results are shown in **Table 3**.

The range in total downforce was quite marked in this instance, reflecting not only the change in wing area from span to span, but also changes to the underbody downforce and the effect of where the flap terminated inboard, which we have already seen is influenced by the span of the flaps (although there may well be other mechanisms at work here). But visualisations (**Figures 10** and **11**) of the underbody pressures confirm that the 1500mm front wing span model did see lower pressures in the underbody.

### END PLATE VARIATIONS

The trials so far have all featured simple flat end plates, but for 15-20 years now, designers in the top echelons and increasingly in other categories have been trading off wingspan for end plate details that, seemingly, more than make up for the loss of wing area. Of these, the simplest forms are the horizontal 'footplate', and a variation featuring a quarter cone scallop at the lower rear corner of the end plate. I had surmised that these quarter cones entrained the tip vortex that spills under the end plate to allow the wing to do its job better, and as such they are referred to here as 'vortex entraining end plates' or 'VEEPs'.

We first evaluated a VEEP design when we took the DJ Firestorm hillclimber into the MIRA wind tunnel in 2010 (featured in Aerobytes in May 2011), and the results were pretty astounding, although the comparison was between a 1300mm-span wing with flat sheet end plates and a 1300mm span with 100mm-wide VEEPs, making the latter 1500mm overall span. The results were as shown in **Table 4**.

Although a gain in front downforce had been expected, an extra 31 per cent was a lot more than expected, and a gain in rear downforce was not expected either. Would a similar trial on our CFD model reveal a similar state of affairs and perhaps throw some light on the mechanisms? **Table 5** shows the results, with the wing in the x+100mm fore/aft location, expressed in similar fashion to the wind tunnel results.

The comparisons between the changes in drag, total downforce and -L/D found in the wind tunnel (**Table 4**) and in the CFD trial (**Table 5**) are remarkable, although likely to be at least partially coincidental given the differences in wing designs and many other details. The gain in front downforce in the CFD trial seems huge in percentage terms but reflects the low initial value in this case, while the gain in rear downforce was of similar order to that found in the wind tunnel. So can we deduce the mechanisms? **Table 6** gives the full CFD results component by component.

Now we can see that not only did the VEEPs enhance the front wing's performance, but there was also a large increase in car body downforce too, and since the rear wing's downforce changed very little we can conclude that the increase in rear downforce came from the car body. **Figures 12** and **13** verify this, with the latter showing the wing with VEEPs generating greater suction, but also there are lower pressures within the underbody, and the magnitude of the positive pressure in the underbody inlet under the chassis has also been reduced.

Did the VEEPs fulfil their vortex entrainment function?





**Table 7: trading wing area for VEEPS**

| | | | | | Drag, N, 100mph | | | | | Downforce, N, 100mph | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Span, end plate | Drag, N | Total Df, N | -L/D | %front | Car body | Front wheel | Front wing | Rear wheel | Rear wing | Car body | Front wheel | Front wing | Rear wheel | Rear wing |
| 1500 incl. 3mm EP | 959.9 | 2907.6 | 3.029 | 18.21% | 429.2 | 135.4 | 63.5 | 164.6 | 167.2 | 1180.0 | -89.9 | 628.3 | -88.7 | 1277.9 |
| 1500 incl.100mm VEEPs | 957.3 | 2806.0 | 2.931 | 17.27% | 416.8 | 145.5 | 54.7 | 173.3 | 167.0 | 1071.5 | -59.1 | 583.7 | -93.5 | 1303.4 |
| 1615 incl. 3mm EPs | 968.6 | 2588.5 | 2.672 | 18.94% | 416.9 | 139.6 | 67.3 | 178.7 | 166.1 | 827.5 | -103.0 | 693.4 | -115.6 | 1286.2 |
| 1615 incl. 100mm VEEPs | 933.0 | 2777.0 | 2.976 | 15.45% | 436.1 | 120.3 | 53.6 | 159.9 | 163.1 | 994.6 | -70.0 | 609.6 | -94.7 | 1337.5 |

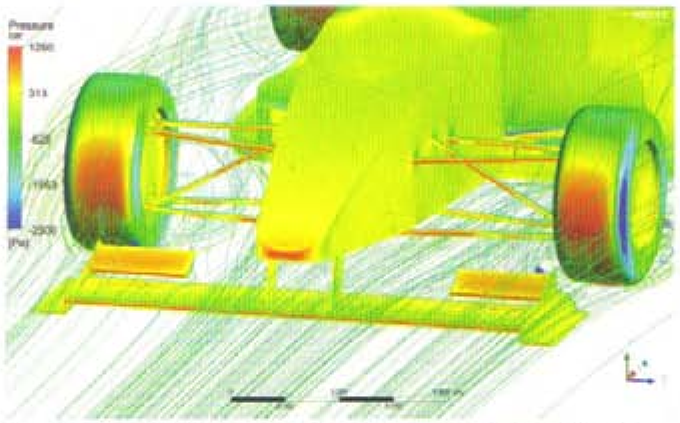


Figure 15: complex flows inboard and outboard of the front wheels with the 1500mm front wing including VEEPS at 50mm ground clearance

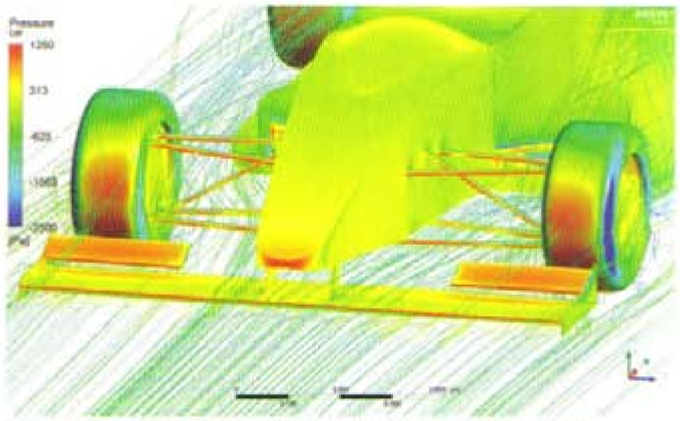


Figure 16: flow patterns (and the pressure distributions, eg on the front tyre) were different with the 1625mm span front wing, with no VEEPS at 100mm ground clearance

**Table 8: varying wing ground clearance**

| | | | | | Drag, N, 100mph | | | | | Downforce, N, 100mph | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ground clearance, mm | Drag, N | Total Df, N | -L/D | %front | Car body | Front wheel | Front wing | Rear wheel | Rear wing | Car body | Front wheel | Front wing | Rear wheel | Rear wing |
| 50 | 962.5 | 2625.8 | 2.728 | 18.14% | 406.2 | 135.0 | 69.5 | 183.7 | 168.1 | 794.8 | -64.9 | 681.7 | -98.7 | 1322.9 |
| 75 | 954.7 | 2763.4 | 2.895 | 21.34% | 405.6 | 133.0 | 61.1 | 184.2 | 166.8 | 923.1 | -58.8 | 698.1 | -106.6 | 1307.6 |
| 100 | 942.7 | 2846.2 | 3.019 | 19.75% | 419.2 | 122.3 | 61.4 | 171.9 | 167.9 | 1070.4 | -55.1 | 627.3 | -99.8 | 1303.4 |
| 125 | 952.2 | 2671.3 | 2.805 | 12.73% | 433.0 | 132.8 | 49.7 | 169.1 | 167.6 | 1039.8 | -66.4 | 495.0 | -83.6 | 1286.5 |
| 150 | 945.1 | 2572.3 | 2.722 | 7.83% | 432.0 | 142.8 | 45.8 | 156.9 | 167.6 | 997.0 | -97.2 | 436.5 | -72.6 | 1298.6 |

**Figure 14** shows a transverse section in line with the slot gap on the front wing (coloured by velocity), with vectors showing two vortices, one just inboard of the outer edge of the footplate, the other within the quarter cone, verifying the entrainment mechanism at work.

### VEEPS VS SPAN

A key question was 'would trading span for VEEPs yield overall benefit?' This was looked at for spans of 1500mm and 1615mm, using thin flat end plates and full wingspans in the one case, and 100mm wide VEEPS in place of 200mm narrower wing element spans in the other, with thought-provoking results, as **Table 7** demonstrates.

So, at 1500mm overall span the car produced more total downforce and slightly more %front with no VEEPS, but at 1615mm span the opposite was the case, with significantly more total downforce with VEEPs than not. And although the 1615mm front wing produced more downforce than the 1500mm wing in similar configuration, it also led to reduced car body downforce and increased wheel lift figures, giving less total downforce in both cases than the narrower wing. These results were not what were expected, but perhaps other combinations of variables (flap span, fore/aft location) might yield a different picture. **Figures 15** and **16** show some of the complexity of the flows from two of these front wings.

### WING HEIGHT REVISITED

For the finale in this brief study we'll return to looking at wing ground clearance as promised, this time on the car. The wing used was the 1500mm span including VEEPs in the x+100mm location, and the data is shown in **Table 8** and **Figure 17**.

As we have seen with almost every variable looked at in this study, maximum total downforce did not coincide with maximum front wing downforce. The latter occurred at 75mm ground clearance, with the wing's main element showing flow separation very similar to the isolated case in **Figure 8** below that. Peak total downforce occurred at 100mm wing ground clearance though, this leading to best car body downforce.

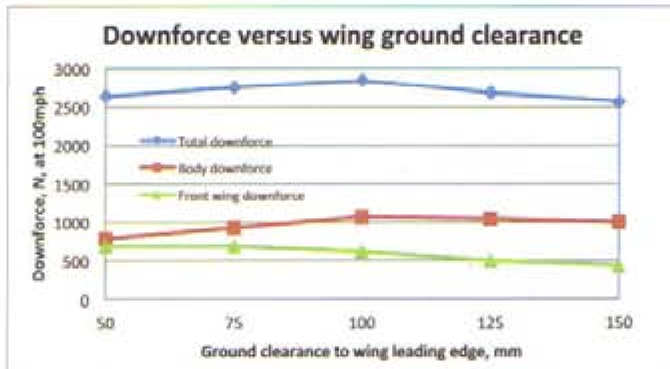


Figure 15: car body, front wing and total downforce vs wing ground clearance

### SUMMARY

We have seen that variations in wing configuration had a marked effect on the overall aerodynamic performance of the single-seater model used here. Above all, the interaction between the front wing and the underbody was very significant in these trials, even with the very coarse adjustments that have been made, and much finer mapping would be required to get a better understanding of these interactions before any design decisions could be taken.

When the technical regulations allow an almost totally free hand, selecting the best front wing configuration is no easy feat – but a tool like CFD most certainly helps.

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