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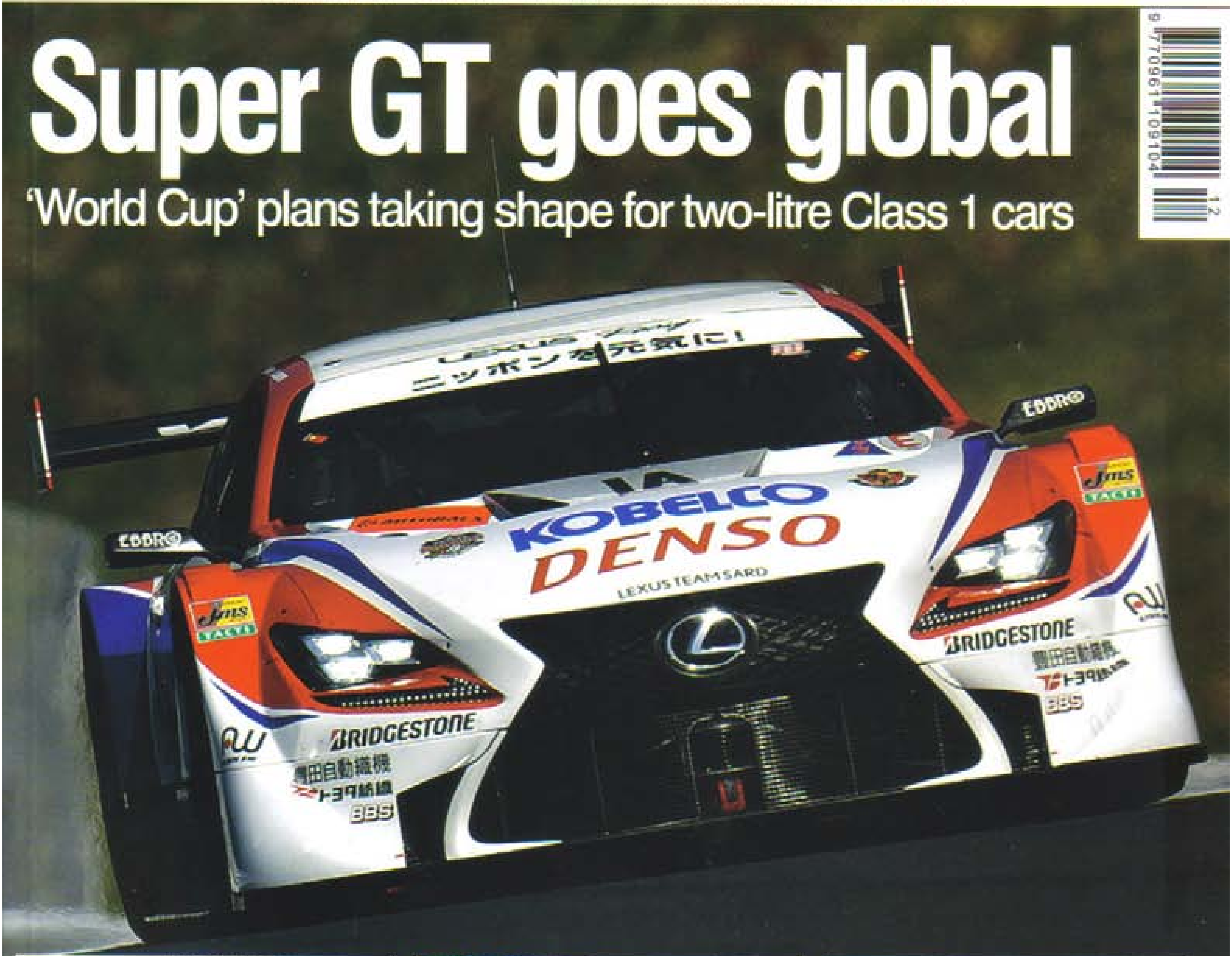
Super GT goes global

'World Cup' plans taking shape for two-litre Class 1 cars



Williams FW36

British team returns to the sharp end of the Formula 1 grid

Damping technology

We examine suspension development in Formula 3 series worldwide

Peugeot 2008 DKR

French manufacturer launches full SUV-based Rally Raid programme

How to wing it

If the technical regulations allow the requisite freedom, just where do you locate your rear wing? At the rear of course – but exactly where?

By SIMON McBEATH

A topic in which there appears to be no single answer to a simple question is always going to be interesting to study. Rear wing location on sports racing cars is, perhaps, one such area. Looking at sports racing cars around the world, a huge range of wing location solutions is on display, from high up and far back, to low down over the rear deck, to – most intriguingly of all – apparently tucked so low and far back that at first glance the wing appears to be in the wake of the main body. So, with the aid of Ansys CFD software and a sports racer model, we have taken a closer look.

We have also been privileged to speak with a well-known adherent of the low rear wing concept, Rennie Clayton at Dauntless Racing in the USA, who has shared some fascinating insights on his company's aerodynamic package for the Stohr WF1 sports racer.

Virtual assessment

The basis for the CFD exercise was one of the simple CAD models the writer originally produced for the article in our October 2012 issue (V22N10) in which a variety of fundamental layout concepts was evaluated for Project Pipedream, the writer's long-running back-burner - 'fast becoming retirement project' – to design and build his own "sports libre" hillclimb car, the Vortex. Examining rear wing location on this model was thus another short step on the long road towards that project eventually becoming a solid object…

The model (see **Figure 1**) was deployed again more recently in Aerobytes in our September 2014 issue when we looked at wing location on one of the Tiga CN cars in the MIRA wind tunnel. The brief CFD exercise featured in that Aerobytes showed that while the wing's downforce reduced as its height was reduced, the downforce produced by the body initially increased as height was reduced. And although total downforce nevertheless declined as wing height was reduced (see **Figure 2**), balance (unfortunately not portrayed in September's Aerobytes thanks to duplication of the downforce plot instead) shifted markedly forwards as the wing was lowered (see **Figure 3**, hopefully depicting balance versus wing height this time).

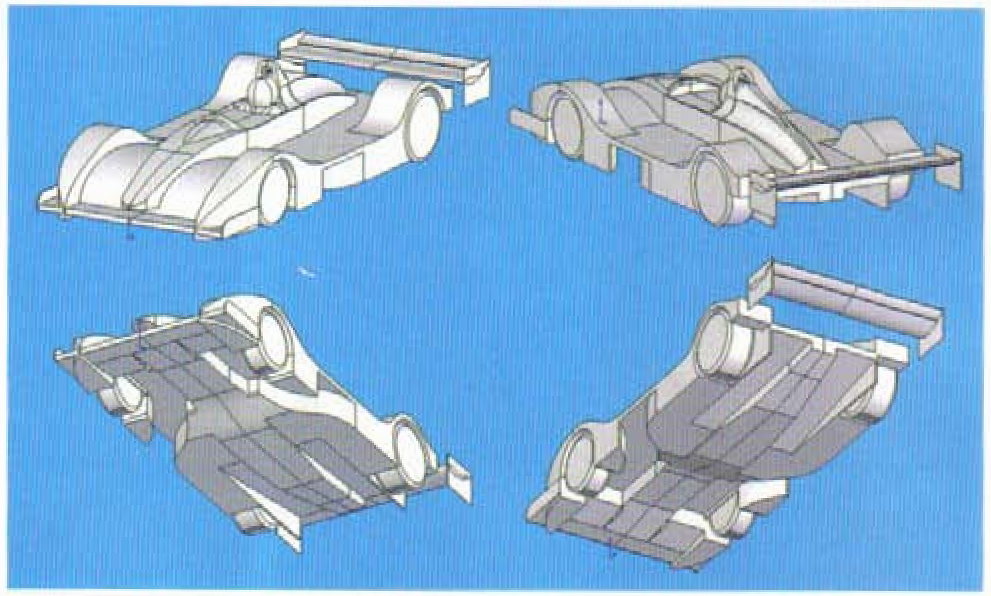


Figure 1: The sports racer model used for our simulations

Tiga A evaluated in September 2014's Aerobytes prompted this exercise

This only portrayed the situation at one fore/aft, or x-location of the wing, which had been selected using the time-honoured finger-in-the-air process that has to be applied in the absence of any better information. This saw the wing's leading edge overlapping the rear deck trailing edge by about 50mm (2in), with the datum height putting the highest part of the wing assembly at the permitted maximum in UK hillclimbing of 900mm (35.4in) above the ground plane. The reasoning behind this particular x-location was that it would have put the wing's region of maximum suction directly above the diffuser exits, and hopefully this would help to drive the flow through the underbody and diffusers in a manner analogous to the relationship between the flap and the main element of a dual-element wing layout.

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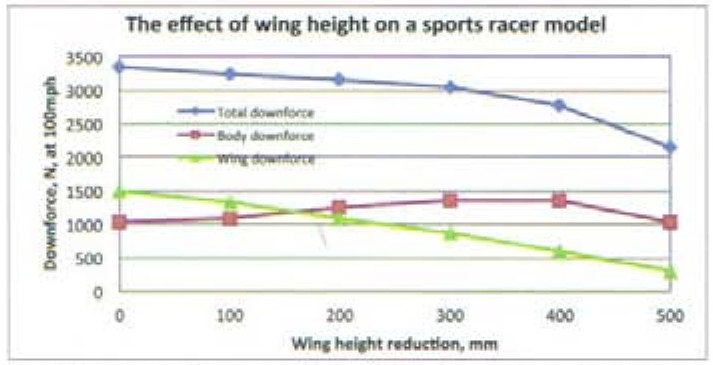

Figure 2: In our initial trial, varying wing height at the datum wing x-location affected body downforce differently from total downforce

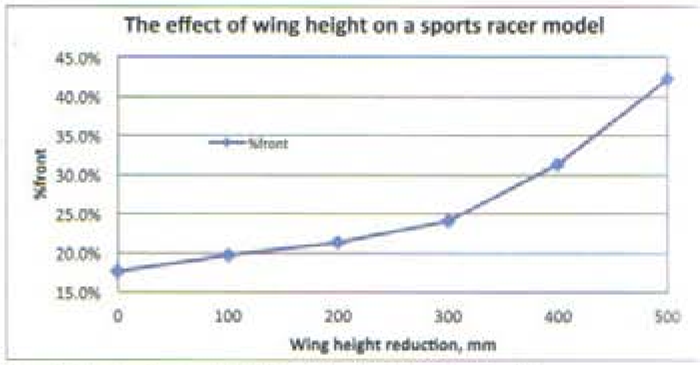

Figure 3: Varying the wing height also had a significant effect on balance

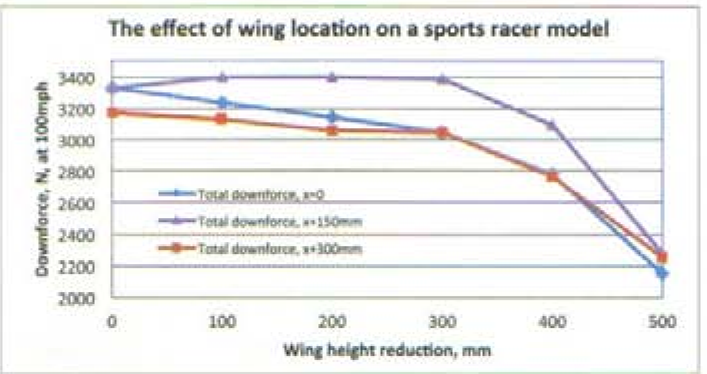

Figure 4: Adding further x-locations revealed a much more interesting picture of how total downforce varied with wing height

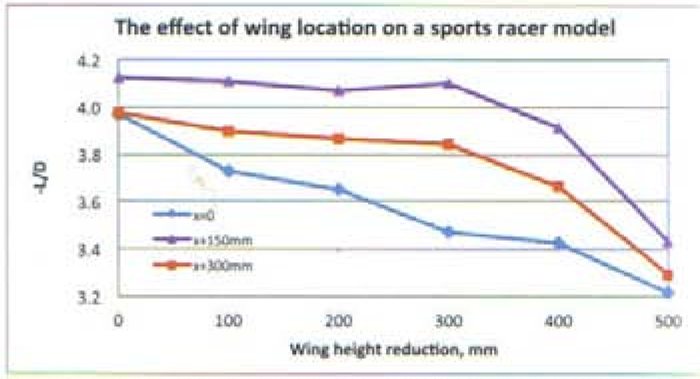

Figure 5: The efficiency plot also highlighted the potential benefit to be found by altering wing height and x-location

Table 1 – The basic aerodynamic parameters at maximum wing height and three different wing x-locations. Forces in Newtons at 100mph (divide by 4.459 to get downforce in lb)

x-location	Total Df, N	Drag, N	-L/D	%front
Datum	3330.6	839.2	3.97	17.5%
x+150mm	3332.0	808.6	4.12	15.4%
x+300mm	3172.3	798.3	3.97	13.1%

Table 2 – Separating wing and body downforce

x-location	Wing Df, N	Body Df, N
Datum	1491.6	1027.0
x+150mm	1448.1	1089.9
x+300mm	1431.0	928.5

But in making this choice it was also borne in mind that the initial vertical separation between the wing and the diffuser exit might better see the wing further aft as well as lower.

So, the next phase of work thus saw the wing moved to two additional x-locations, 150mm (5.9in) and 300mm (11.8in) further aft, and the model was evaluated once again at six different heights, ranging from maximum height to 500mm (19.7in) below maximum, in 100mm (3.9in) increments to create a matrix of data points, all at the datum static ride height of 40mm and with zero rake.

Simulated results

Available time often restricts wind tunnel evaluations to just a few variations of something relatively time-consuming like a wing location change, and in the case of Tiga A just two wing heights were tried, although in fairness this was more about validating prior background work. Nevertheless, by way of illustrating how easy it is to miss a useful development direction with just a few variations let's look initially at the CFD comparisons between the three x-locations at just the datum maximum wing height of 900mm, **Table 1** shows the basic aerodynamic parameters.

Clearly, if this was the extent of a toe-in-the-water glimpse at the effect of changing wing location then the data in **Table 1** wouldn't look too promising. Downforce had barely changed at x+150mm, and although drag decreased and efficiency (-L/D) improved, these benefits were offset by an unsurprising rearwards shift in aerodynamic balance (%front). At x+300mm downforce actually declined and although –L/D remained as at x=datum, balance had shifted still further rearwards. However the data in **Table 2**, showing wing and body downforce separated out, offered more hope.

Although wing downforce declined with each rearward increment, probably because the onset angle of the airflow to the wing reduced with each rearward step, body downforce increased at x+150mm, reinforcing the suggestion from the –L/D improvement in table 1 that there was a positive interaction at this x-location. Moving on, then to the data from the whole test matrix, **Figure 4** shows the plot of total downforce at the three x-locations and six heights evaluated.

A totally different pattern becomes visible from **Figure 4**, and the first thing to stand out is that downforce at x+150mm actually increased slightly compared to the datum location at the first reduction in wing height, h-100mm, and then pretty much levelled out until h-300mm rather than declining with each height reduction as it did at the other x-locations. Common to each x-location, though, was the rapid decline in total downforce as the height reduction exceeded 300mm. So **Figure 4** confirms that there was something important happening at x+150mm. What happened to the other aerodynamic parameters?

Figure 5 shows –L/D versus wing location and the pattern is similar to the total downforce plot, with the x+150mm location standing out as the most efficient across the whole range of wing heights. In fact efficiency at x+150mm remained pretty much at the same level from h=datum to h-300mm before declining, whereas at the other two x-locations –L/D reduced as soon as height was reduced.

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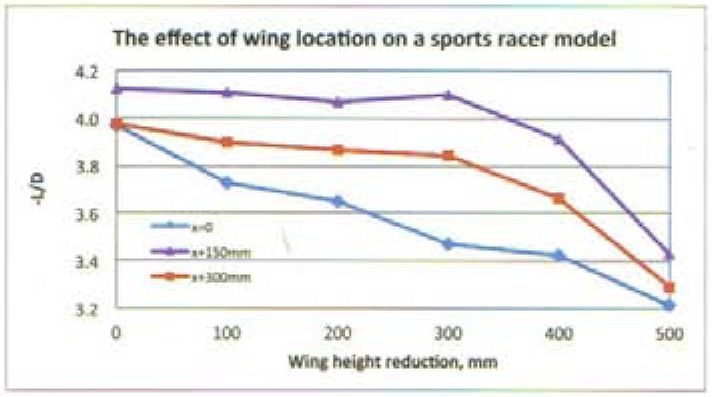


Figure 5: The efficiency plot also highlighted the potential benefit to be found by altering wing height and x-location

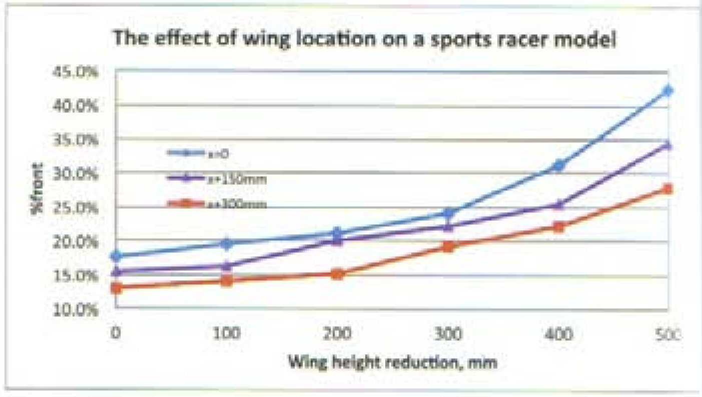


Figure 6: The balance curves of the further aft locations were slightly more rear biased but not by much

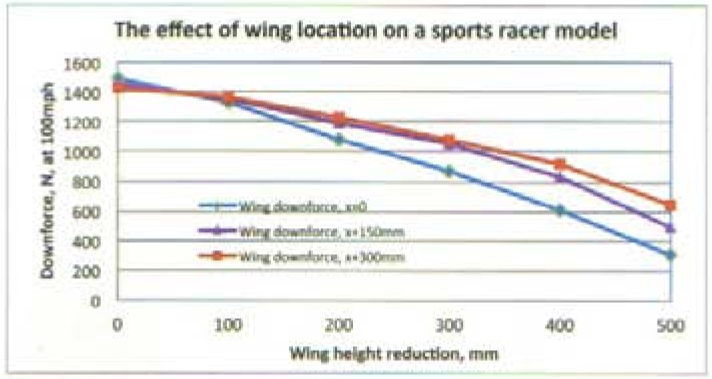


Figure 7: Wing-only downforce declined with wing height in all cases, but x-location was again significant

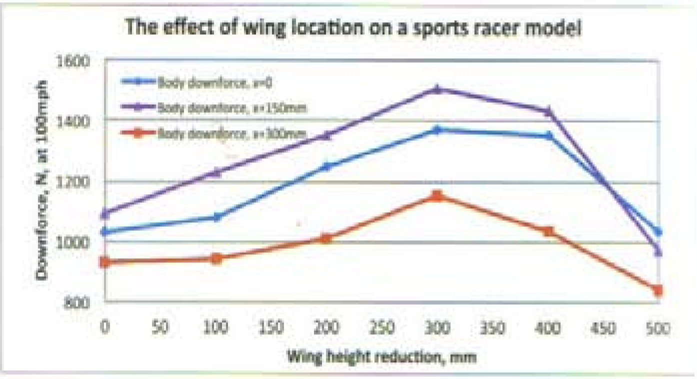


Figure 8: Body-only downforce produced the most interesting patterns

Aerodynamic balance (%front) showed a slightly different pattern, as shown in **Figure 6**. All three x-locations saw a forward shift in balance as wing height was reduced, but repeating the pattern we saw in **Table 1**, where balance unsurprisingly shifted more rearwards with each rearwards shift of the wing at the datum height, we see that the datum x-location produced the highest forward balance across the range evaluated. Nevertheless at x+150mm and h-200mm and h-300mm the %front value was quite close to the %front values at x=datum.

Next, an overall view of wing only downforce is instructive, as **Figure 7** illustrates. Clearly the downforce generated by the wing declined with each height reduction in all three x-locations. But the pattern shown in **Table 2**, where the highest wing downforce was produced at the datum x-location, downforce declining with each rearward increment, was reversed with the first reduction in height. And this reversal persisted across the rest of the range, with x+300mm yielding the highest wing downforce at each height. Perhaps the most likely explanation for this is that there was more room for reasonably energetic flow to reach the wing the further back it was shifted. But importantly, the values at x+150mm were not far behind those at x+300mm…

Finally, body downforce (not including splitter downforce, which showed only minor changes across the range) produced the most interesting plot, as shown in **Figure 8**.

Here we can see that the body produced peak downforce when the wing was at h-300mm in all three x-locations, but that the clear winner was with the wing at a fore/aft location of x+150mm. The second best fore/aft position was the initial datum location, and x+300mm was obviously the least effective across the range for body downforce.

So, given that there is clearly plenty room for optimisation to the simple shape of this model's body, and its underbody in particular, potentially also the span-wise and chord-wise profiles of the wing too, there was every reason to think that in this instance the x+150mm, h-300mm location for this wing was the best of the three evaluated here, with its combination of peak downforce, efficiency and aerodynamic balance.

Equally clear is that there must be a continuation of this exercise to better refine the wing's position, concentrating on locations close to x+150mm and h-300mm.

Having said that, there may well be applications where minimum drag is of more interest than maximum downforce or maximum efficiency, so **Figure 9** shows how drag varied across the range of wing positions. Clearly the x+300mm location achieved the lowest drag across most of the wing height range.

Assuming minimum drag with useful downforce and aerodynamic balance was the aim then the preferred location might be x+300mm and h-300mm, this generating about 4 per cent less drag than the x+150mm, h-300mm location. And addressing the slightly lower %front value this lower drag position achieved might involve a reduction in rear wing flap angle, which in turn would produce a further reduction in drag.

Interested readers may now be expecting a more specific definition of the optimum wing's location with respect to the rear bodywork of the racecar in this exercise! Well, apart from the model being far from optimised at this juncture, the optimum location on any other car is sure to be dependent on the exact shaping of the rear deck upper surfaces, the underbody and diffuser exit locations and shapes, and the rear wing's potency, profile(s) and plan-form shape. However, the x+150mm, h-300mm location puts the tip of the wing's leading edge, relative to the upper deck's trailing edge, at x+185mm y+145mm. This may or may not put you in the right ballpark with your sports racer!

This lower drag position achieved might involve a reduction in rear wing flap angle, which in turn would produce a further reduction in drag

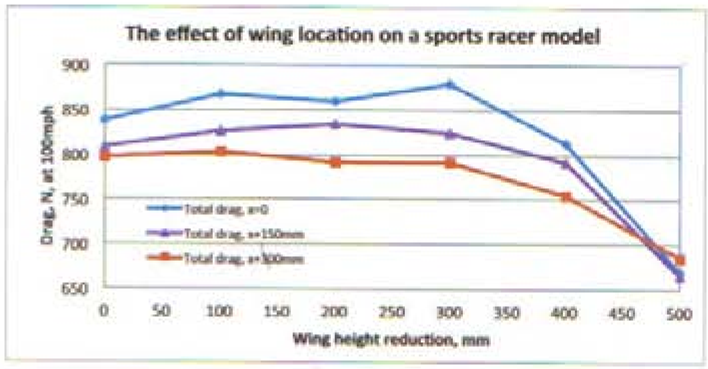


Figure 9: The drag plot showed that if minimum drag was a primary aim then a slightly different approach might be taken

Table 3 – The effects of 0.5 degrees of rake and 10mm reduction in ground clearance

Condition	Total Df, N	Drag, N	-L/D	%front
Zero rake, static ride height	3380.7	825.0	4.10	22.2%
0.5deg rake, -10mm ride height	3805.8	858.9	4.43	36.3%

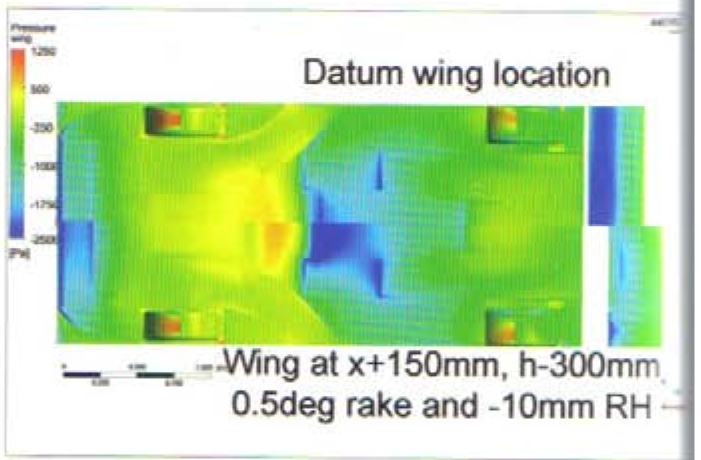


Figure 10: Surface pressure plot of the underside of our model – the upper half is with the datum wing location, lower half is with the final configuration of this exercise. The changes in pressure distribution and magnitudes are very evident

The Stohr WF1 with Dauntless Racing-developed aerodynamic package (courtesy: Pepper Bowe)

This UK-based Speads runs a Dauntless wing and a splitter devised with Dauntless assistance (Courtesy: BookaTrack.com Ltd)

As shown in **Figure 6**, found on page 60, at the favoured location the one parameter that was not what it would need to be was the aerodynamic balance. However, the trials were all conducted at zero rake and static ride height, and as both these parameters are means of addressing balance (and total downforce) a few changes to both were made, culminating in the results in **table 3**, which shows the comparison at zero rake and static ride height.

Not only did balance shift markedly forwards and well towards an ideal value but total downforce increased by 12.5 per cent and -L/D by 8 per cent. Separating out the sources of the forces, splitter downforce rose by 21.9 per cent, body downforce by 15.9 per cent and rear wing downforce increased by 0.9 per cent. Of course the whole wing location exercise ought now to be repeated across a range of rakes and ride heights.

Above all, this exercise showed that it is most definitely worthwhile trying a matrix of wing locations on this type of racecar, because making the basic aerodynamic elements work together as effectively as possible in an integrated package can bear fruit: see **Figure 10.**

Back in the real world…

A man who would definitely agree with this philosophy, and who has already implemented it in the development of what has become a real world aerodynamic package, is Rennie Clayton at Dauntless Racing. Dauntless purchased the Stohr Cars business in summer 2014, and now owns all of the design and production rights to the WF1 sports racer and F1000 single seater racecar lines. New cars are produced in its Bay Area, California facilities, and support for the existing "ecosystem" of 120+ cars comes from there. Prior to that, although separate from and independent of Stohr Cars, Dauntless designed and produced their WF1 update kits.

'The design work for the WF1 aero kit started in late 2007, and we always took a holistic approach to the design challenge,' says Rennie Clayton. 'Eventually this culminated in three distinct updates to the WF1 which could be applied separately, but were designed from the start to work together for best effect: splitter, undertray, and rear wing. Of note, our basic constraint was that the core mechanical elements and body surfaces of the car were to be left largely intact, so we had to work around such things as radiator placement and orientation with the undertray, and assume that the top – fenders, cockpit surround, engine cover and so on – were as delivered from the factory. Our pieces needed to be bolt-on, inasmuch as that could be achieved in a car like this.

'We decided very quickly to design holistically for best overall effect rather than trying to focus on areas in succession. We didn't want to be stuck in a position where we designed a mega rear wing, only to have our new front splitter not be capable of maintaining balance or worse, mucking up the flow to the rear of the car! So we designed it all at once and of course needed to isolate interaction effects as quickly as possible. Our solution to that was a DOE / factorial process with a rather large number of factors in the mix to achieve the best combination of overall downforce, overall drag, pitch sensitivity, and dynamic range of operation. No small challenge, that… it took the better part of a year to arrive at the proper combination of configurations and features.

'Our working hypothesis at the time was to try to treat the rear wing as the secondary element to the "wing" of the main body of the car; use the rear wing to activate the tunnels and front diffuser, rather than using the rear

Table 4 – Aerodynamic data on the Stohr WF1, scaled from data supplied in lbf at 150mph

Specification	Total downforce, N, 100mph	-L/D	%front
2007 spec factory WF1	~2280 – 2380	~3.2	41%
Low Df Dauntless WF1	~3170 – 3270	~5.1	45%
High Df Dauntless WF1	~3765	~4.9	44%

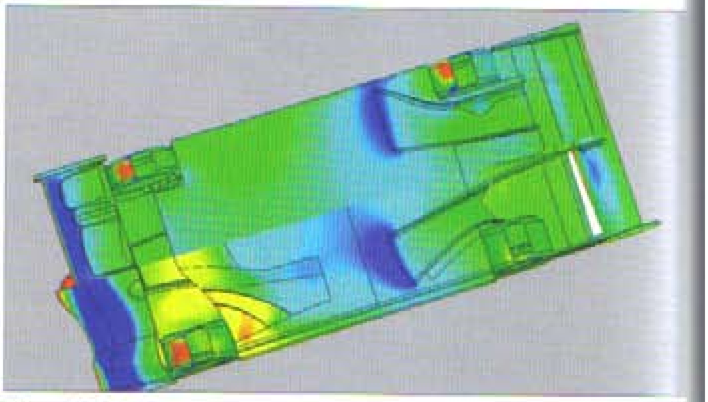
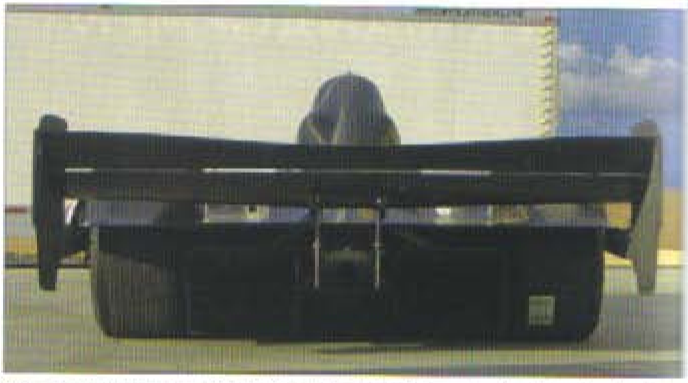


Figure 11: Surface pressure distributions of the underside of the Stohr WF1. Upper half is the 2007 factory spec, lower half is with the low wing, integrated Dauntless package. Once more, the changes in pressure distribution and magnitudes are evident. (Courtesy: Dauntless Racing)

The Dauntless rear wing has been shaped to work with the flows coming off the car (Courtesy: Dauntless Racing)



Rear shot gives a clearer idea of the wing's low position on the Dauntless Racing Stohr WF1 (Courtesy: Dauntless Racing)

"We have to run some pretty wild wheel rates in order to keep the thing off the ground"

wing as a "trim" device for aero balance. In particular, we started from the classic NACA studies on optimum flap gap positioning and distances – this turned out to not be quite correct in our application, but very illuminating none the less. The airfoils (four sections, all told) and basic layout of the rear wing were guided by CFD and track testing of the car without a rear wing to gain a better understanding of airflow patterns over and around the car. That got us into the ballpark for orientation and local wind speed and turbulence factors for choosing airfoils. The exact placement was driven by more factorial experiments for height and setback from the trailing edge of the bodywork – one to establish interaction with the undertray/splitter, and another one to narrow down the precise placement. We could quite readily get better results for the rear wing in isolation by placing it up in clear airflow 300-400mm above the tail of the car, but this always had a negative effect on overall performance numbers for the car. Since our guiding principal was a holistic approach, optimising the car as a package won out.

'CFD was followed by instrumented track testing, and we eventually managed to get a day in the Ford wind tunnel with a WF1 to test our rear wing assembly. As one might expect, the numbers did not match exactly with CFD, but the behavioural patterns were quite predictable and correlated nicely with the virtual work that we'd done on the car. Very gratifying!'

An interesting interjection here comes from UK-based owner/driver Iain Cummings, whose CTR Developments-run Speads features a Dauntless rear wing and a splitter designed with help from Clayton. Cummings said 'Rennie was very specific about the orientation of the leading edge of the wing's main plane in relation to the trailing edge of rear diffuser (90mm up and 105mm rearward).

'He also told me that the secondary plane "does most of the heavy lifting..." and this would appear to be true because when I tore it off on the Silverstone International circuit the car was completely unstuck at both ends (which I'm guessing at least demonstrates that we have good interaction between the wing and the front splitter/diffuser).

'We have to run some pretty wild wheel rates in order to keep the thing off the ground. Variation of the front ride height also has marked effects, so we have arranged for the car to, as far as possible, run at an optimum 26mm dynamic ride height. Variation of the secondary flap angle also produces quite large downforce changes at the front as well as at the rear.'

Clayton also commented on topic of the stiff platform: 'The Stohr WF1 has some interesting characteristics that influence the need for higher rates. Primary among these is that the car does not have anti-roll bars of any sort, nor are the roll centres arranged to do much in the way of inhibiting roll. The chassis is also more flexible than we would like to see at the rear of the car (this is one of the areas that we will be addressing with future updates), and taken together it demands significant spring rates to keep a stable aero platform.'

And so to the nub of the matter: how did the aerodynamic data alter between the earlier conventional wing location package and the new, low wing integrated package? Clayton is refreshingly open with some comparisons and hard data, commenting that 'the comparisons vary depending on downforce configuration.' See **Table 4** for the key data.

It's clear from these numbers that the Dauntless aero package represented a considerable advance over the 'pre-low wing' integrated package. And although it plainly isn't sensible to ascribe that entire advance to the low wing per se, it obviously played a large part in the integrated whole. **Figure 11**.

The last word then to Clayton: 'It should be noted our raised splitter (to avoid pitch sensitivity) also creates knock-on effects for the undertray and rear wing – and the philosophy behind the undertray design plays into the airflow patterns around the car, in turn influencing how the rear wing behaves. We've found there is no 'one-size fits all' approach as all can be made to work to a reasonable degree. The question is: can you put them together in a beneficial way where all of the interactions reinforce each other positively?'