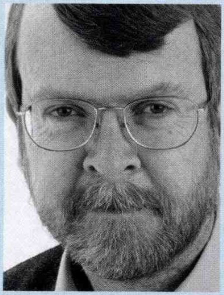
SIMON McBEATH

AEROBYTES



Simon McBeath is an aerodynamic consultant and manufacturer of wings under his own brand of The Wing Shop – www.wingshop.co.uk. He also writes articles and books on the subject of racecar aerodynamics

FIGURE 4

The wind tunnel allowed a balanced but higher downforce set up to be obtained on the modified Lotus Exige tested here compared to the standard version

Race vs road

Comparing aerodynamic modifications destined for the track against a road set up reveals some useful information

The Lotus Exige might come out of the factory as a road car, but it is also an increasingly popular platform for a racecar at all levels of motorsport, up to and including international GT series. So, in order to understand the aerodynamic differences, *Racecar Engineering* set up a comparison test in the MIRA full-scale wind tunnel between a more or less externally unmodified Exige S2, and one that carried a number of aerodynamic components developed for the racetrack (primarily for GT3 and Britcars) by UK-based Reverie Ltd.

The modified car sported a complex front splitter arrangement that essentially led into a smooth, flat underside with front dive planes. The standard rear diffuser arrangement was still fitted at test time, but 40mm wider wheelarches were installed front and rear. Lastly, a new, more aggressive rear wing profile was used, with a full car-width span and incorporating planform curvature. This wing shape permits the boot to be opened for engine access, while keeping the wing within the maximum extent of the bodywork in plan view to remain within FIA GT rules.

SIGNIFICANT OTHERS

The externally unmodified car did have one alteration that was to prove especially significant. Whereas ordinarily the exhaust system's twin tailpipes (on the un-supercharged model) emerge into the central channel of the rear diffuser, on this car the exhaust emerged in the rear panel above the diffuser. In comparison, the modified car was fitted with a standard exhaust protruding into the diffuser. Otherwise, the road car featured the standard front splitter (which did not have a smooth, flat underside), a reasonably flat bottom, the same standard three-channel diffuser as the racecar (with cut-outs in the outer channels that allow for rear suspension droop) and the modestly profiled, curved, part-width span wing.

After ensuring that both cars' ride heights were the same, the road car was run first to establish a set of baseline aerodynamic data, and to provide the opportunity to do some flow visualisation with the inevitable wool tufts and smoke. Following this, there followed a session in which various configurations on the racecar were evaluated, and the next few Aerobytes columns will focus on some of the findings in more detail. This month though, we'll review the data comparisons between the road and race versions as tested, and discuss some of the preliminary conclusions reached.

Fortunately, in the generous

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FIGURE 1
The standard road Exige used in this test session to establish baseline data

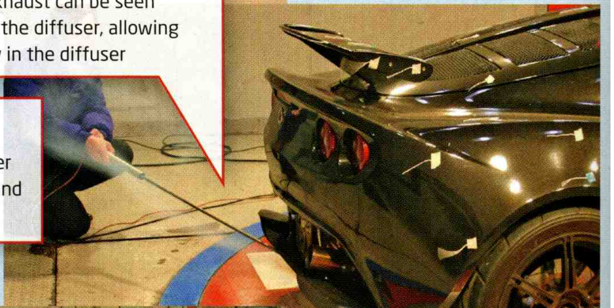


FIGURE 2
The road car's exhaust can be seen emerging above the diffuser, allowing improved airflow in the diffuser

FIGURE 3
The modified car featured a bigger splitter, dive planes at the front and a more aggressive rear wing

spirit of data sharing, we are able to publish actual coefficients and forces from this session rather than relying on percentage changes relative to some unquantified baseline configuration. So tables 1 and 2 show the data on the road car and the first data set derived from the racecar as it was delivered into the wind tunnel. Needless to say, the racecar's aerodynamic numbers changed significantly throughout the test, but the first run with any car in the wind tunnel is one that allows a quick assessment of which directions to head in, and subsequent columns will discuss those directions more fully.

DOWNFORCE DATA

The frontal area values used for the coefficient calculations were $1.7m^2$ for the road car and $1.74m^2$ for the racecar, due to the wider wheelarches. Looking briefly at the road car's data first, the CD value measured here is pretty close to those values to be found in the public domain for the Exige, typically around 0.43 or so. Interestingly, the road car actually generated a modicum of downforce, amounting to a total of about 95lb at 100mph. The downforce split was slightly forward biased in relation to its static weight split, which saw 39.2 per cent of the car's weight on the front axle when at rest.

Moving on to the data from the racecar's initial run and we see first that the drag is higher, but also that the downforce is much higher, the two parameters of course being inextricably linked. However, whereas the drag increased by 25.8 per cent (comparing CD values), downforce increased by a massive 200.5 per cent (again comparing coefficients) to over 300lb at 100mph. This level of downforce represents nearly 15 per cent of the car's own weight at 100mph, which would make a significant difference to the level of available grip at this speed.

TABLE 1

Road and racecar wind tunnel coefficients and related data during initial runs

	CD	CL	CLf	CLr	%front	L/D
Standard car	0.442	-0.204	-0.086	-0.119	42.2	-0.462
Racecar	0.556	-0.613	-0.195	-0.436	31.8	-1.10

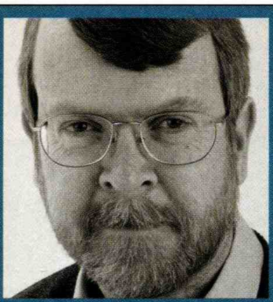
TABLE 2

Road and racecar wind tunnel forces at 100mph in initial runs

	Drag, N	Downforce, N	Front Df, N	Rear Df, N
Standard car	928.7	424.9	177.9	247.0
Racecar	1195.2	1346.3	416.2	930.0

Having said that, the aerodynamic balance was not in line with the racecar's static weight distribution in this first configuration. Statically, the racecar had 40.7 per cent of its weight on the front axle, but the split of aerodynamic forces put just 31.8 per cent on the front, which would almost certainly see understeer develop and worsen as speed increased (if nothing was changed), given the significant levels of downforce being generated on this car. Fortunately, a number of options were available to address the balance issue. For example, as mentioned earlier, in order to directly compare the racecar with the road car, the two cars were set at the same 'road useable' ride heights, nominally 120mm front and rear. This meant there was zero underbody rake angle in both cases. Clearly, in full race configuration, a lower ride height would be used, and also a positive (nose down) rake angle. As we have seen previously in Aerobytes this would have had the effect of increasing the racecar's downforce and also of shifting the aerodynamic balance further forwards.

But the purpose here in this test was simply to illustrate the basic differences between the road car and racecar in a comparable way. And this initial overview also gives an idea of how the first couple of runs in the wind tunnel serve to answer some very basic questions, but simultaneously raise very many more! More on this interesting test session next month.



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How high?

An oft-recurring question is at what height should a rear wing be mounted, especially if the racecar in question has a diffuser

Two seemingly contradictory factors come into play when trying to decide the answer to this question. The simple answer in most cases is that the wing will work best if you mount it as high as the rules permit. That way the airflow reaching the wing is as little disturbed by the rest of the car as possible, and the wing will perform as well as it can in what is still, usually, a compromised location.

However, in *Race Car Aerodynamics*, Joseph Katz cites a number of examples in which wing locations below the permitted maximum height proved beneficial. A dual-element wing on a closed sports prototype-style racecar apparently gave the greatest vehicle downforce when its height was slightly less than half the wing's chord dimension above the rear deck, measured to the wing's trailing edge, with the downforce tailing off at heights either side of this. And a single-element wing on a sedan-based racecar showed best vehicle downforce when at about 0.7 of its chord above the rear deck, again with downforce reducing at higher or lower positions. In other examples Katz illustrates how the presence of a rear wing on various racecar shapes helped to augment the static pressure reductions in the underbody to further improve vehicle downforce. So clearly there were some interesting interactions here that make it worth studying in more detail.

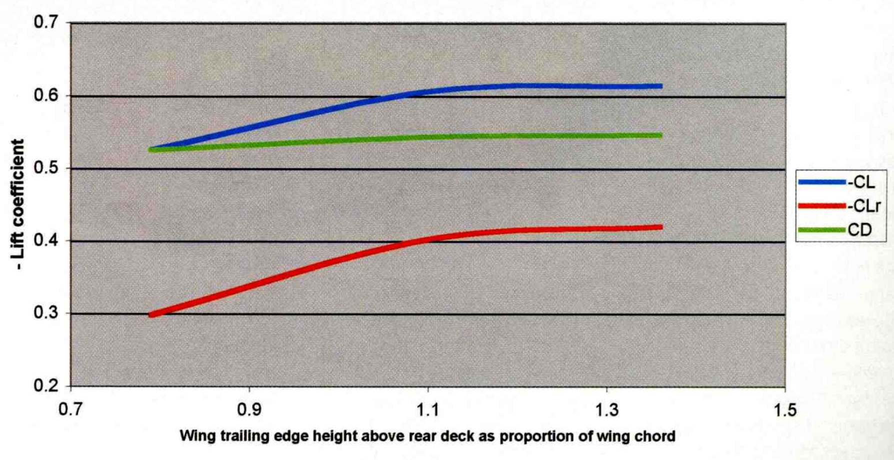
> **“Mount [the wing] as high as the rules of your category permit”**

ALTERNATIVE HEIGHTS

So when *Racecar* went into the MIRA full-scale wind tunnel with the race-modified Lotus Exige we started examining last month, the opportunity to try some different wing heights was too good to miss. To re-cap briefly on the car being used here, this particular Lotus Exige had been modified by Reverie Ltd with a number of components suitable for GT3 and Britcar-type applications. Featured were a complex front splitter that essentially led into a smooth, flat underside and front dive planes. The standard rear diffuser arrangement was still fitted at test time, as were 40mm wider wheelarches front and rear and a new, more aggressive wing profile than the standard road item at nearly full car width span and incorporating planform curvature. The wing's chord dimension was 230mm.

A set of alternative height wing support plates was manufactured prior to the test to allow reasonably rapid configuration changes to be made. The highest setting corresponded with the maximum permitted height under FIA GT3 regulations. The data derived is plotted in the graph below.

WING HEIGHT VS DOWNFORCE AND DRAG



Whole car and rear end negative lift coefficients at varying wing heights on a race-modified Lotus Exige

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The relationship here seems pretty clear at the wing angle of 10 degrees tested – downforce increased with wing height until its height was slightly greater than its own chord dimension, at which point the gains appeared to flattened off. What is not clear is what would have happened at greater wing heights. Katz plotted data at wing heights up to 5.5 times the wing chord, but, as most regulations prohibit wings to be run that high, this is in many ways academic. However, although this experiment didn't go down to very small wing-to-deck gaps, it seems very improbable there was a peak in vehicle downforce in the 0.5 to 0.7 times wing chord region as Katz had shown. What could have been the reasons for the difference in this case?

It could simply be that the particular shape of the rear deck and the profile of the rear wing produced a downforce peak at a somewhat greater height than Katz had shown, and that downforce could then have declined again if greater heights had been tested. Or it could have been that there wasn't the same degree of interaction between the wing and the rest of the vehicle, and that moving the wing away from the rear deck simply proved beneficial.

LOWEST HEIGHT
The wing angle was kept at 10 degrees for the purposes of the tests

INTERMEDIATE HEIGHT
Moving the wing away from the rear deck proved beneficial

HIGHEST HEIGHT
Downforce increased until wing height was just greater than chord dimension

OBSERVATIONS

Two observations might bear out this hypothesis. Firstly, with a wing above a surface, it follows that, as the wing is brought closer to the deck surface, the wing's suction acts on that surface, and as well as the wing sucking itself downwards, it also sucks the deck surface upwards. This would lessen the overall downward force felt by the wing and the body of which the deck surface formed a part. And the region below a wing in which the static pressure is substantially reduced extends roughly one chord's distance below the wing. Therefore, we might anticipate that overall downforce would decline as the wing-to-deck gap reduced to below this distance.

> **"Overall downforce declined appreciably as the wing-to-deck gap reduced"**

However, another observation was made in this test session that would undoubtedly have influenced this experiment, and we shall look into this in some detail in next month's column. As it transpired, the diffuser on this car was running stalled because of the presence of the OEM exhaust tailpipes protruding into the central diffuser channel. This would have precluded the possibility of any beneficial interaction between the wing and the diffuser, which might have seen greater downforce generated at a lower wing height.

Clearly, with more time it would have been beneficial to re-run this trial once the diffuser stall was eradicated. Equally, the presence of even this quite potent wing was insufficient to overcome the diffuser stall in this instance. So, all we might reasonably conclude from this trial is that in the absence of beneficial underbody interaction, it would seem that putting the wing as high as the rules allow maximises downforce.

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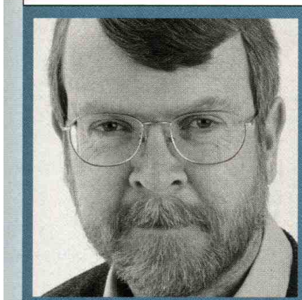

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Diffuser design

Investigating what's good and what's not so good for maintaining effective airflow through a diffuser

In the last couple of issues we've concentrated on lessons learned during a session in the MIRA full-scale wind tunnel with a pair of Lotus Exige S2s, and this month we continue to tease out a few more invaluable nuggets of information from this very interesting session. To quickly recap, one of the cars was pretty well externally standard except for a modified exhaust system that exited in a different location to normal, while the other was adorned with assorted aerodynamic aids that had been developed essentially for GT3 and Britcar. The aerodynamically modified car utilised the standard exhaust system.

> A triumph of poor detailing over aerodynamics

The initial focus of this month's column is on the exhaust system and, more specifically, where it emerges on each car. Let's start this month by looking at figure 1. This shows the standard road car's rear end, and where the modified exhaust emerges in the rear panel. This system features a single tailpipe that turns 90 degrees from the engine to protrude directly out of the rear panel, exiting above the central diffuser panel. But notice that the airflow emerging from under the 'roof' of the central section of the diffuser is remarkably smooth, illustrating that the flow has remained fully attached to the diffuser roof, in spite of a reasonably steep angle. This is as one would hope the flow from a diffuser to be.

However, and one hesitates

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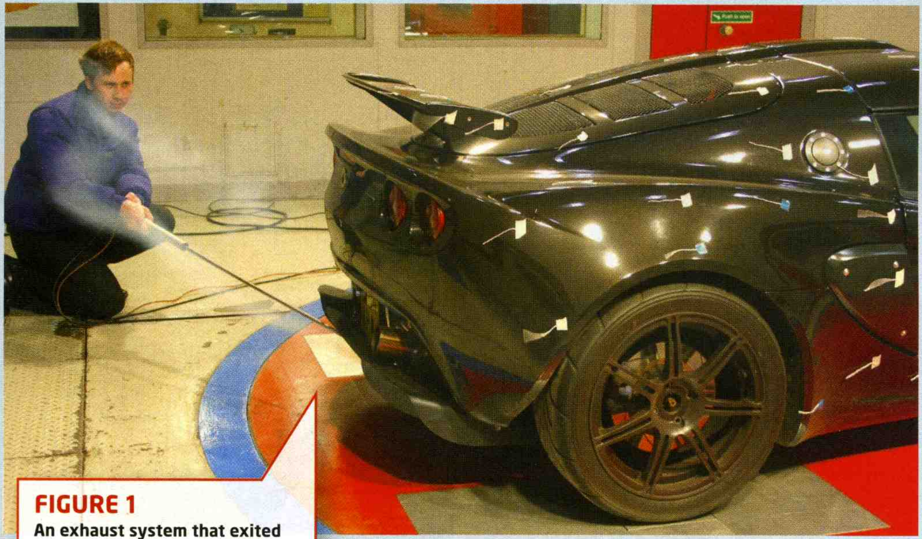

FIGURE 1
An exhaust system that exited above the diffuser allowed a clean exit for the airflow from the central diffuser section

FIGURE 2
But the Lotus Exige comes as standard from the factory with the exhaust emerging into the central diffuser section

FIGURE 3
This compromised the airflow in that section, making it very untidy near the central roofline area of the diffuser

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to be critical of something made by a company with the heritage and reputation of Lotus, the standard exhaust system doesn't do so well... Figure 2 shows such a system, which can be seen on this brand new Exige to emerge into the central diffuser. Is this a crucial detail? Well, the smoke plume in figure 3 suggests it is. Here the smoke 'wand' was located close to one of the tailpipes, and it can be seen that the airflow is very untidy near the central roofline area of the diffuser. And by running the wand across the whole centre section of the diffuser it was apparent that the flow was separated in pretty much all of this section, with the exception of the portions adjacent to the intermediate vertical fences. This, unfortunately, would appear to be a triumph of poor detailing over aerodynamics. And this from the company whose GP team 'invented' racecar ground effect!

Regrettably, we can't quantify the extent of this difference in packaging on the aerodynamics because a back-to-back comparison was not possible in a short session like this. But it stands to reason that compromising the airflow in the diffuser will have lost some potential downforce and possibly added some drag. This may not be a particular problem for the road car, but it's galling if you're looking for aerodynamic help towards quicker times. 'Fixes' obviously include installing an exhaust that does not emerge in the diffuser, while mitigating modifications might involve isolating those tailpipes with additional vertical fences either side, or with a moulded, streamlined fairing.

UNDERBODY IMPROVEMENTS

If we next examine the airflow in the outer diffuser sections (see figure 4) we can see that the flow here on the standard car is totally stalled, and in this shot is completely reversed, although very unsteady flow conditions prevailed here. This was also the case on the modified car, which in this case utilised exactly the same diffuser (apart from the exhaust exit). The first modification that was done to try and combat this problem was to panel over the gaps in the floor at the front of the outer diffuser sections that are cut away to allow the lower suspension links to droop without clashing with the diffuser. However, rather surprisingly, this made only a very small difference to total downforce, showing just 1.8 per cent less of it than in the previous configuration. Reductions occurred front and rear so balance was barely affected, but clearly this was not the expected result.

Next, wide sill extensions were added (see figure 5) in the hope and expectation that more underbody downforce would again accrue. This time total downforce was completely unchanged, but there was a slight rearward shift with a one per cent increase in rear downforce. Again, the extent of this change was surprisingly small, though the effect of the next modification may help explain why the previous two had such a small effect.

> **“The flow had to have been much improved under the whole car”**

The final configuration of this test saw the outer diffuser fences extended vertically downwards to be about 40mm clear of the ground and reaching forwards to the front of the diffuser. This time we saw a substantial change in the aerodynamic indicators: 18.3 per cent more total downforce and 10.6 per cent less drag (a combination to bring a smile to any aerodynamicist's face), along with eight per cent more front downforce, 23.7 per cent more rear downforce and a 32.5 per cent higher lift-to-drag ratio. This was indeed a successful configuration change, and it seems likely from the size of the gains that the presence of these deeper fences may have done more than just help the diffuser by isolating the adverse flow around the rear wheels. It may well be that with this final 'tidy up' the hoped-for benefits from the previous two configuration changes were also released, producing improvements from much of the rear underbody. Clearly, if more front downforce was being generated too, the flow had to have been improved under the whole car. And who knows whether a further significant gain could have been achieved if those tailpipes were not spoiling the flow in that central diffuser section?

Once more, the culmination of this session was a reminder that being able to actually measure the effects of configuration changes is incredibly valuable. And further, that there are no certainties as to what will or will not work as expected, especially where interactions occur.

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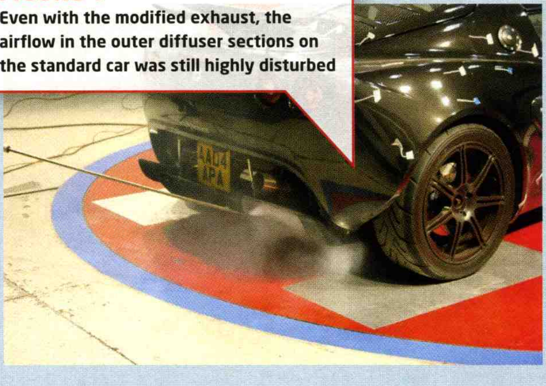

FIGURE 4

Even with the modified exhaust, the airflow in the outer diffuser sections on the standard car was still highly disturbed

FIGURE 5

Wide sill extensions were added to increase downforce. These worked well in concert with...

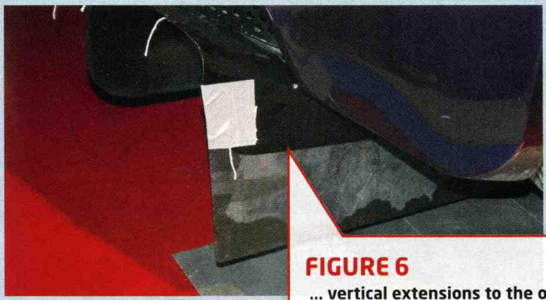

FIGURE 6

... vertical extensions to the outer diffuser fences