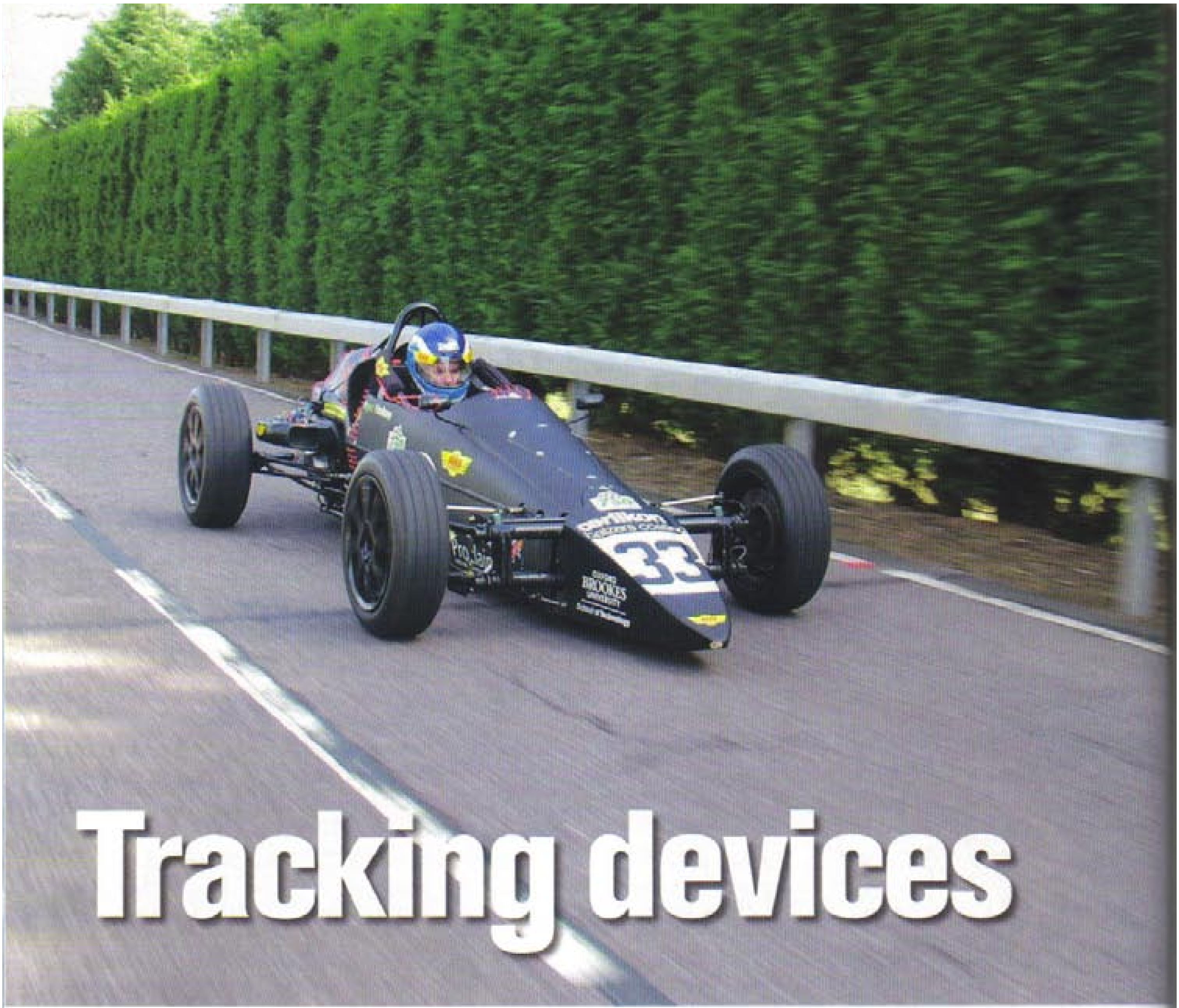


Tracking devices

Furthering our investigations into real time track testing, this month we look at how downforce and pressure data can be obtained without CFD or a wind tunnel

By **Simon McBeath**

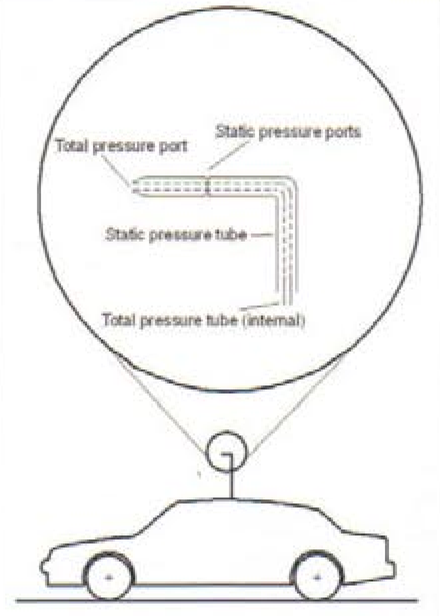
In our previous article on practical aero testing (V17N2) we looked at the aerodynamic parameters you can study and measure without the expense of CFD, a wind tunnel or anything more sophisticated than some means of recording speed and time. We saw that it was possible to visualise surface airflows, indirectly assess the effect of aerodynamic configuration changes during conventional track testing and measure drag forces using coastdown techniques. In this article the theme switches to what becomes possible if you can measure and record aerodynamic pressures and suspension parameters affected by downforce. Although a good data acquisition system and suitable sensors are invaluable, we'll also see that 'pre data logging' techniques can be used to good effect.

One of the big pluses of track testing, be it on a circuit, a disused runway, a drag strip or whatever venue is available to you, is that you test the actual racecar itself, with body panel gaps, protruding fasteners and so on. So everything you see and measure is real. While this is also true of full-scale wind tunnel testing (and could be of CFD if your digital model was sufficiently detailed), a further benefit of track testing is that the vehicle is moving over the track as well as through the air. As such, the wheels are rotating and the car is moving relative to the ground, so the problem of the boundary layer of air that develops over the floor of a wind tunnel ahead of a stationary test model is absent. CFD can provide these benefits too, but you have to create a 3D CAD model first before you can even contemplate rotating the wheels and moving the ground plane, and these facilities may not be available. So as well as being readily accessible, there are real benefits to gathering aerodynamic data on track. As with simulation techniques though, track test methods also have their shortcomings.

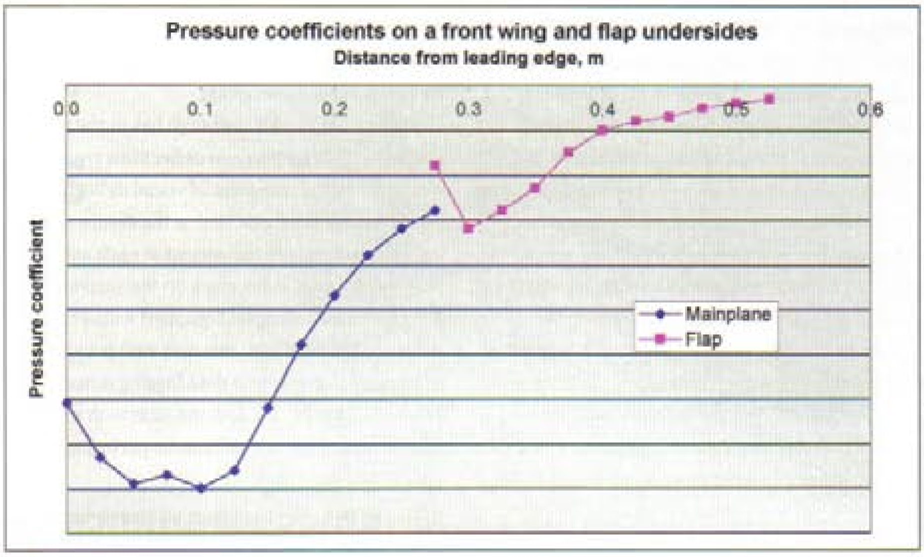
Surface pressures

It is possible to map the local static pressures over and under a racecar's surfaces, and to monitor the effects of configuration changes, using what we might call 'pre-data logging' methods – an approach covered by our contributor Paul Van Valkenburgh in *Race Car Engineering and Mechanics*. Whole body surface pressure plots could be produced, or study could be confined to areas of particular interest, such as

Straight line testing pt2



Pitot static tube: detail and potential location



Above: figure 1, a pressure plot taken on the underside of a dual element front wing and flap (illustration: S McBeath)

Left: figure 2, a 'Pitot static tube' enables total and freestream static pressures to be measured, from which dynamic pressure and hence true air speed can be calculated (illustration: S McBeath)

underbodies and diffusers or wings. And you actually only need enough space to run the car safely at the chosen test speeds, so the track requirement is as basic as it can be.

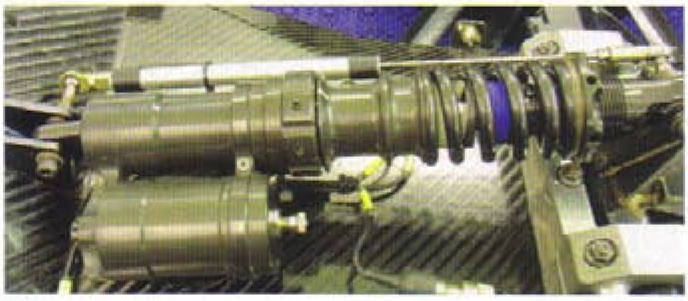
The measurements are carried out by drilling small holes through the surface(s) of interest and fitting tubes, flush with the outside surface of these holes. The tubes can then be connected to a set of traditional U-tube manometers, probably half filled with dye-coloured water, and with the other end open to atmosphere. The levels in the manometers will respond differently to the local static pressures at different locations on the car as it is driven along at the relevant test speed. This enables information on pressure distributions to be compiled (recording may usefully be done photographically), and differences between configurations determined.

If you wish to calculate actual static pressures, pressure coefficients and so forth, it is necessary to compare static pressure readings on the body surfaces with a reference static pressure in air that is undisturbed by the car's motion. With a closed car this could be measured inside the car, but with an open car the reference static pressure can only really be measured a few feet above or ahead of the car with a Pitot tube (see figure 1). This device also enables the total pressure to be measured, and the difference between the total pressure and the reference static pressure can be used to calculate dynamic pressure, as defined by Bernouilli's Equation. And, from that, the true speed through the air, including any environmental airflow (wind) can be calculated. ('Dynamic pressure' is defined as 1/2 × air density × air velocity squared, or $1/2\rho V^2$, where ρ, the Greek letter rho, represents air density).

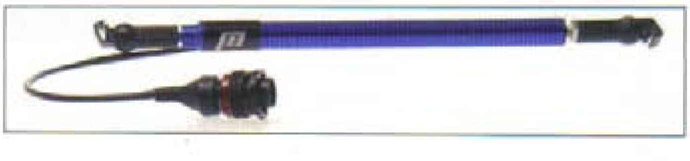
> **"[ON TRACK] EVERYTHING YOU SEE AND MEASURE IS REAL"**

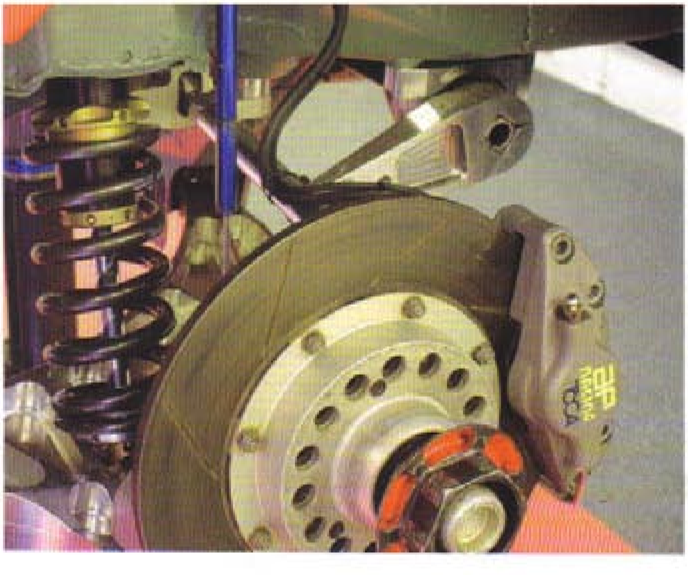
If a suitable data logging system is available, electronic aerodynamic pressure sensors can, of course, replace the manometer(s). Multi-port sensors are available, as are so-called 'scanning valves', each of which enables the rapid acquisition of pressure data from multiple points of interest. Such sensors still require connecting via narrow bore plastic tube to the surface 'ports' where pressures are to be sampled. Alternatively, surface-mounted pressure transducers are also available for the same purpose, which may not require the drilling of holes in your racecar.

In reality, measuring static pressures at a large number of locations over a racecar's surfaces will require quite a number of runs, even if a multi-port pressure scanner is available. The mapping process is therefore likely to be adversely →



Above: a linear potentiometer rigged up to log suspension displacement on a Dallara F302 (pic: S McBeath)**. Below: a linear potentiometer** (pic: Pi Research)**. Right: a linear potentiometer set up to log suspension displacement on a Honda Civic** (pic: S McBeath)





affected by environmental fluctuations. On a practical level then, this technique could perhaps be more usefully deployed to measure more localised pressure profiles, such as wing or underbody surfaces, as suggested above. But such information can provide very useful insights into the effects and interactions of configuration changes. For example, as Katz shows us in a number of illustrations in *Race Car Aerodynamics*, the effect of the presence of a rear wing or its location on underbody pressures can be plotted from a relatively small number of pressure measurements. And the pressure plot in figure 2 shows pressure coefficients measured along the underside of a development front wing and flap.

May the downforce be with you

When it comes to aerodynamic forces, racecar engineers are often far more interested in downforce than drag, and usually for good reason. It can be easier to measure downforce in many cases because the forces involved can be larger than drag (except in categories where downforce is limited by regulations). As with drag force measurement, downforce can be measured in a number of ways. Again, you just need an adequately long, flat, smooth straight that allows you to accelerate up to and run safely at reasonably high speed.

The most commonly used method of attempting to quantify downforce is to measure suspension deflection at speed, which more often than not would be done with linear potentiometers rigged to measure damper travel. Running the car at a constant, fairly high speed enables the deflections arising from aerodynamic suspension compression at front and rear to be logged. These deflections are calibrated by measuring the deflection with a known mass on each axle, throughout the range of travel if non-linear wheel rates are employed. Naturally, the 'noise' produced by track surface irregularities needs to be filtered out, but a reasonable assessment of the download acting through the suspension can be attained.

Again, Paul Van Valkenburgh has in the past suggested that suspension deflections could be measured with some form of visual deflection indicator, perhaps attached to the centre of anti-roll bars to measure movement at each axle, or via some form of index mark on the suspension bell cranks for example. Equipped with a camera to record the readings, this may well provide adequate information if data logging is not available. Needless to say, the ease with which suspension measurement can be performed will also depend on spring stiffness and available suspension travel, and also on friction within the suspension system.

> **“'NOISE' PRODUCED BY TRACK SURFACE IRREGULARITIES NEEDS TO BE FILTERED OUT”**

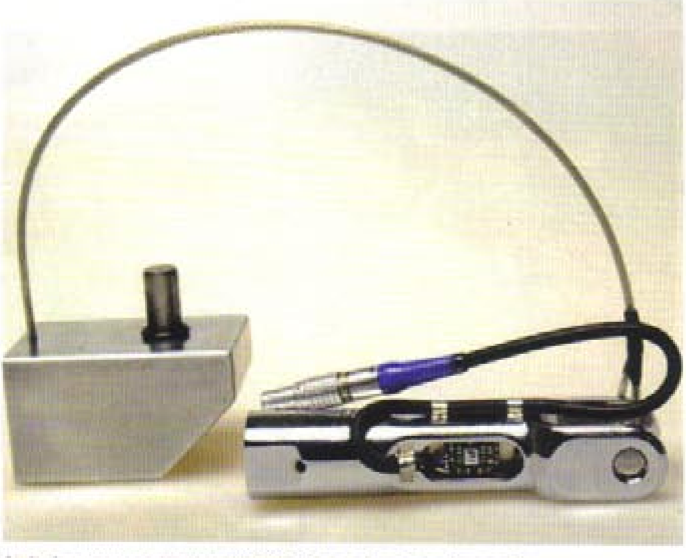
Other options for measuring downforce include using strain gauge load cells to measure directly the download through the spring/damper units or the pushrods or pullrods that actuate them. The important thing to remember about measuring either suspension deflection or loads is that they do not include the vertical aerodynamic forces generated by the wheels themselves. And with open-wheel cars in particular, but even on closed cars, these forces can be significant.

A possibly more precise (depending on the amplitude of suspension travel) but indirect means of assessing download is to use laser ride height sensors, although this includes tyre deformation too, but a basic ride height vs vertical load calibration will take this into account. The really well heeled team might have the budget to use wheel force transducers that are capable of including the wheel-generated loads, but the aim here is to examine the more accessible options.

The precision with which downforce can be measured will still be affected by environmental factors, like wind and track irregularities, as well as the precision of the sensors themselves. But if downforce is greater than drag, we ought to be able to measure it more accurately. And in such cases there is also the possibility that downforce increments resulting from configuration changes will not only be detectable but quantifiable, too. However, if we accept that our repeatability is going to be of the order of plus or minus a few per cent, we'll have to be looking for increments in excess of this to be able to quantify them. Nevertheless, it should be possible to map some balanced options ranging from low to high downforce levels. Then it will be necessary to correlate these settings, which account for body-generated downforce only, with on-track handling characteristics at 'aero speeds' so that a more precise picture of what constitutes a balanced set up may be obtained.

Real world testing

Alex Somerset is currently chief engineer at front running British Touring Car team Triple Eight Racing, and also worked at Team Dynamics in 2004 during its championship-winning 2005 season with the Hondas. He also has previous experience with other well-known touring car and single-seater teams. As a proponent of the importance of aerodynamics, even in a severely restricted category like the British Touring Car Championship, he has his own methodologies, evolved over several years, for both coastdown testing to measure drag and straight line testing to measure downforce. 'Straight line testing is →



A strain gauge, as commonly fitted to a pushrod or damper top (pic: Pi Research)

This 2002 Lola Champ Car was fitted with a strain gauge at the top of the pushrod (note the cable emerging from the insulation sheath, centre). A linear potentiometer can also be seen next to the damper body (centre top) (pic: S McBeath) still considered the most useful tool in aerodynamic testing, and is still employed by F1 teams,' he says. So his thoughts on how to carry out downforce measurements are well worth noting. 'First you have to look at the car set up. I have noted that as drivers attempt to maintain 100mph or 120mph, minor throttle changes can alter the attitude of the car. Therefore, a method of maintaining a fixed engine speed aids the driver in maintaining a constant car attitude. One solution involves a steering wheel-operated rev limiter that can be activated when the driver reaches the required speed in a certain gear.

'In terms of the chassis set up, you can run softer springs – that still prevent the car from bottoming out – to maximise the deflection for a given load and improve resolution. But don't take this to extremes because the ride height will be affected and this can affect the downforce generated.' Indeed, with softer springs the dynamic change in ride height with increasing speed will differ on softer springs so, as Alex advises, 'It's best to come up with a consistent set up that you use for all your aerodynamic test work. This will usefully include the same set of dampers whose loads are accurately known. Disconnect the anti-roll bars to isolate the effects of one-wheel bumps or any binding up or hysteresis in the system. And have four damper potentiometers that use as much of their available travel as possible. These are then calibrated to reflect spring displacement, and you can then write a maths channel in your data acquisition system (DAS) software for spring displacement x spring constant to give a direct reading of spring force [which can then be factored via the 'known mass' calibration into a direct reading of downforce].'

> **“IT'S BEST TO COME UP WITH A CONSISTENT SET UP FOR ALL YOUR AERODYNAMIC TEST WORK”**

To supplement the damper potentiometers, Somerset has also used load cells and laser ride height sensors. 'Measuring loads at the damper tops allows you to correlate with the damper displacement method. And lasers take account of suspension and tyre compression, but are prone to 'contamination' when it's wet. Nevertheless they can provide some indication of total [body-generated] downforce.

'If you don't use a Pitot tube then testing will only be meaningful on a still day. Typically, the Pitot tube should ideally be positioned

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Racecar goes aero testing

In V17N2 Simon McBeath explored a number of flow visualisation techniques, including wool tufting and *RE* decided it was worth exploring this very useful aerodynamic testing method a little more. The AHS Challenger Formula Vee has had some success in its series, but track results showed that the car was lacking somewhat aerodynamically. Whilst many teams in lower categories like Formula Ford and Vee may feel that serious aerodynamic testing is beyond their means, facilities like MIRA in England are more than capable of showing up areas that could be improved aerodynamically for less than £500 ($1000).

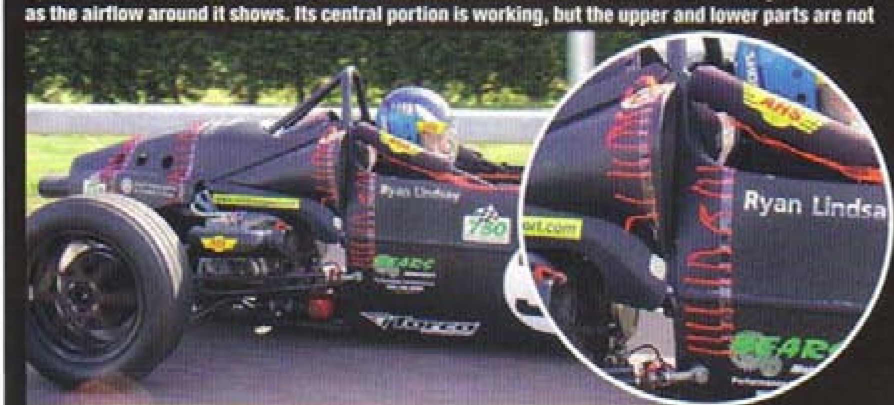
Using the twin straights at MIRA, AHS endeavoured to learn more about the car's rear end aero that is clearly not optimal in its current format. Interest was centred on the rudimentary airbox, central cooling duct and main cooling ducts, whilst the engine cover was also assessed.

Sam Collins

Appying wool tufts to the bodywork is a tedious task, but one that can be sped up by using tape to apply them in strips

Application in the workshop is recommended as it can be difficult to do on a windy day. It's also worth thinking through what areas you want to explore and tuft in advance

Runs were conducted at 50mph (above) and 60mph (below). The long tuft from the wing mirror was designed to investigate the effect that the mirror's position has on the cooling duct, but the tuft was left too long on some runs and simply behaved like one of the tufts behind the duct. Note it is only the tip of a tuft that gives good data. It was immediately obvious that the current duct design is flawed, as the airflow around it shows. Its central portion is working, but the upper and lower parts are not



approximately one metre above or two metres in front of a body (although standard tubes about 300mm above the bonnet and the roof suffice). Also calibration of the Pitot tube should ideally be performed in a wind tunnel.' If wind tunnel time were unavailable, calibration against vehicle speed on a still day would presumably be a reasonable substitute. 'Another problem with the Pitot tube involves the alignment of the tube with the flow. However, an investigation into the yaw sensitivity of the Pitot tube has revealed that for [effective] aerodynamic yaw angles of up to 12 degrees the error is less than 0.5 per cent. With this in mind, it can be said that where there is a constant aerodynamic yaw angle less than 12 degrees the error associated with the Pitot tube can be ignored.' For reference purposes, a (90-degree) side wind of 20mph and a vehicle velocity of 90mph result in an aerodynamic yaw angle of about 12 degrees.

'It's useful too to have a small weather station that records temperature and barometric pressure so actual air density can be calculated. 'The way I work,' continued Somerset, 'is to set up two beacons at 1/2 and 3/4-mile marks on our chosen test straight to enable steady state readings to come from the same section of track each time. This gives about seven seconds of data. If the car is capable of getting to a steady 120mph before the 1/4-mile mark then you can get a 1/2-mile test section and about 15 seconds of data. The driver is instructed to accelerate his car up to 120mph before the first beacon and hold the speed constant until he passes the second beacon. We do two passes up and down to give good error cancellation. You could use any section of straight on a circuit too, with the driver holding a steady speed between two markers. As long as the information is dissected from the same section of track then reasonably accurate analysis can be made. In any case, absolute values are not vital, it's the delta gains [or losses] that are important.

'With two beacons the data is split into convenient chunks. The readings taken are the average of the damper displacements (DAS software often gives you an average of any channel between two markers). And pressure, temperature and Pitot pressures can all be incorporated into the calculations. A simple Excel spreadsheet can then be written where you input all these values and it outputs downforce.'

So the extent to which you go with instrumentation and so forth depends on the precision and reliability of the data you require. But once you've obtained a data acquisition system and some or all of the sensors discussed here, the cost of additional testing is restricted to the cost of getting to and from, and hiring a suitable straight length of track. This can make it pretty good value. So long as it's not windy...

The author's thanks to Alex Somerset, chief engineer, Triple Eight Race Engineering Ltd.

Further reading

Race Car Engineering & Mechanics, P Van Valkenburgh, 2000

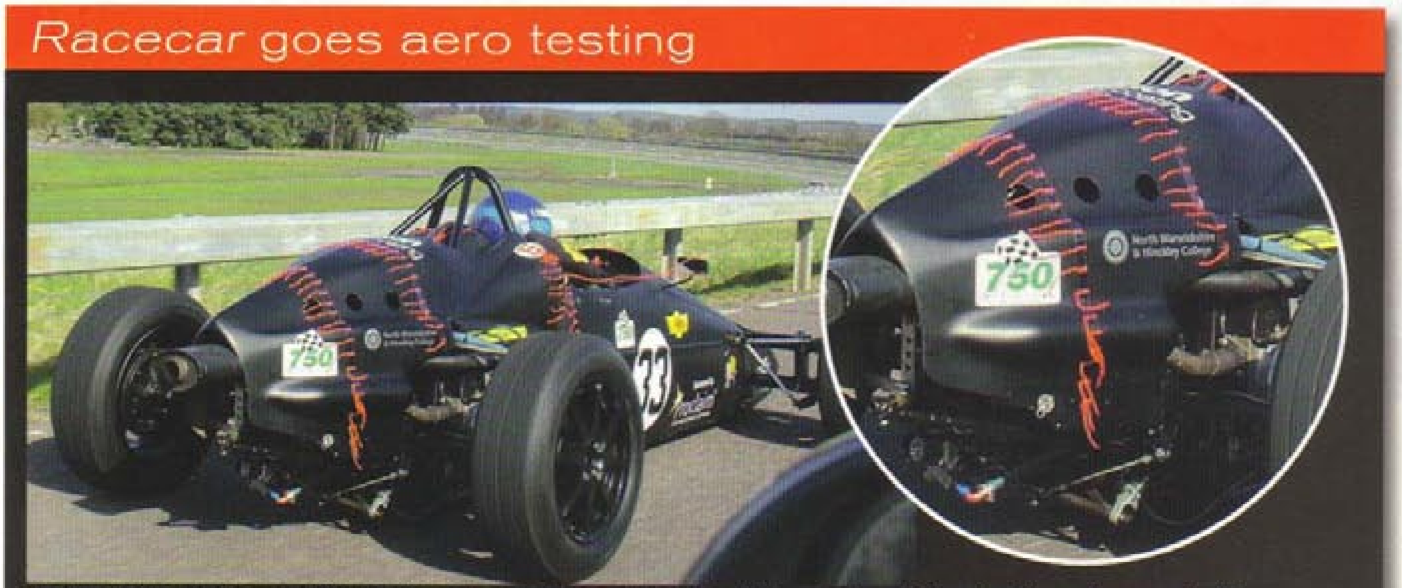
Race Car Aerodynamics, J Katz, 1995 (updated edition now available)

Competition Car Aerodynamics, S McBeath, Haynes, 2006

Competition Car Data Logging, S McBeath, Haynes, 2002

Aerodynamics application note, Pi Research Ltd, 1998

Racecar goes aero testing



The large airbox and carb assembly is clearly creating a lot of drag and the tufts on the lower bodywork (above) are limp as they are not getting any airflow whatsoever. Running at 60mph gave a good visualisaton of flow around the rear of the car, and the engine covers seems to be working well. Note turbulent flow from the wing mirror (below)

The cooling duct behind the driver's head is not working well either as tufts placed around it show that the flow is highly turbulent in the wake of the driver's head. Moving the duct or removing it completely are possible solutions.