Means testing

No budget for wind tunnel or CFD testing? Track testing can reveal a lot about a racecar's aerodynamics, even with minimal data acquisition capability

By **Simon McBeath**

There's no denying that wind tunnel or CFD time comes at a cost. And if the budget isn't there, then arguments about the cost effectiveness of such testing are just turbulent hot air. But it is still possible to make some useful observations and measurements on a racecar's aerodynamics to gather information, perhaps indirectly, about the flows and forces involved. This article aims to collate some practical ideas about what you can reasonably expect to achieve using track time only. And these methods are not just for the cash-strapped racer, they are a sensible alternative – if not a necessary supplement – to wind tunnel or CFD for any team.

Positive benefits

A big advantage of track testing, be it on a circuit, a disused runway, a drag strip or whatever venue is available, is that you test the actual racecar itself. So the flows and the resultant forces are all real. You also evaluate the realities of less-than-perfect bodywork fit, protruding fasteners, warts and all. While some of this is also true of full-scale wind tunnel testing (and could be of CFD if your digital model included such detail), another plus of track testing is that the vehicle moves over the track as well as through the air. This means the wheels rotate, and that there is no need to simulate 'moving ground', or to develop means of controlling the slow moving boundary layer of air that develops over the floor of a wind tunnel ahead of the test model. CFD allows these benefits too, but you need – or at least must create – a 3D CAD model first, and that facility is often unavailable or unaffordable. So there are positive benefits to using track time to gather aerodynamic data. As with any simulation techniques though, there are shortcomings too, as we shall see.

> “A BIG ADVANTAGE IS THAT YOU TEST THE RACECAR ITSELF”

In this Racecar Essentials we go back to the racetrack and look at practical ways of examining the aero performance of your racecar with minimal or no outlay at all.

So what kind of aerodynamic knowledge can you obtain on track? This depends fundamentally on what level of data acquisition is available to you. In this Essentials article we'll look at what's attainable with little or no data logging equipment, assuming only that basic timing and some form of speed logging is at hand.

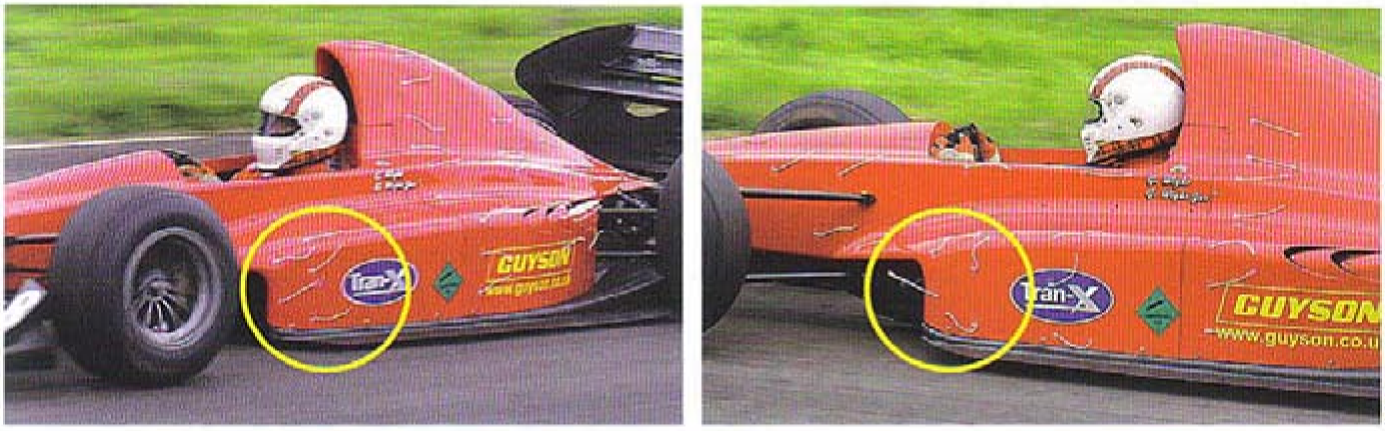
Flow visualisation

The first thing we can do though requires no instrumentation whatsoever, and that is flow visualisation. Then we can go to the racetrack to measure the effects of aerodynamic configuration changes on speeds and times. And finally we can have a crack at measuring total drag, and possibly too the effects of configuration changes on total drag. This term covers a range of methods for revealing where otherwise invisible air is flowing.

We sometimes get brief glimpses of flow patterns around racecars, even on TV. For example, on humid days, the reduced static pressure in the core of the tip vortices of high downforce rear wings can condense atmospheric water vapour, rendering the vortices fleetingly visible. And when an engine blows up we sometimes see the ensuing smoke and vapour emissions following the counter-rotating circulatory patterns in the racecar's wake.

But these transient glances are of little practical use. We need methods that allow us to visualise the airflow in specific areas of interest, and which we can record. Two media are readily available, both of which reveal flow directions on the racecar's surfaces: wool tufts and fluid streaks. Neither requires a proper racetrack.

Wool tufting is an old but very useful technique. Pieces of wool yarn 3in to 4in (75mm to 100mm) long are taped to the surfaces of interest



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Using basic wool tufts on your racecar can be very revealing. At high speed (above left – indicated by the low ground clearance) the tufts on the front of the sidepod trail backwards as you might expect, whereas at low speed (above right – with greater ground clearance visible) the same tufts show reverse flow

so that they trail along in the direction of the local flow when the vehicle moves. The tape should be thin and stuck down smoothly so as to disrupt the airflow as little as possible. The car is then driven, perhaps at different pre-determined speeds, and observers take photographs or video footage for later study. If this visual recording is done from a 'chase car' then it needs to be far enough away so as not to alter the airflow over the test car.

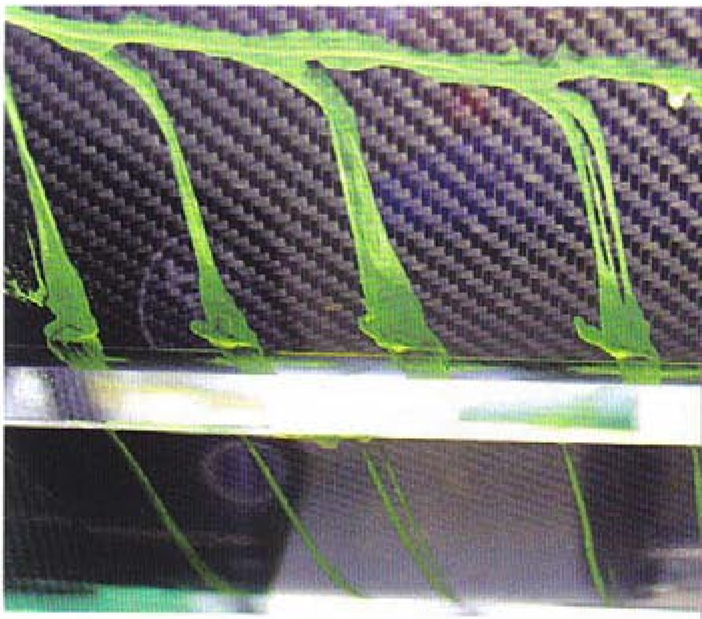
Wool tufting makes it possible to visualise not just the local flow direction over a surface but also, to an extent, the flow quality. Regions where the flow follows an unexpected direction can perhaps show where local pressures are low (the flow tending towards such areas), or maybe even where flow separation has occurred (reverse flow). And 'flailing' tufts, which show up in photos taken with a slowish shutter speed as fan-shaped blurs, can reveal where the flow is particularly turbulent or unsteady.

The undersides of critical surfaces pose more of a problem, but these days it is possible to obtain small video cameras that can be taped or tie-wrapped in the most inaccessible places to record the flows on, for example, the underside of a wing or a diffuser. Again, care must be taken that the recording device does not interfere with the flow you are recording. Even though wool tufts only reveal flows at the surfaces, you can begin to build up a mental picture of the flow field around the car. And this is incredibly useful information, obtainable for very little cost. The photos illustrate some of the detail that can be divined using this method.

> **“WOOL TUFTING IS AN OLD BUT VERY USEFUL TECHNIQUE”**

Equally cost effective is the use of a suitable fluid, possibly with a dye or colourant added, that is placed in droplet form on the surfaces of interest prior to sending the car out, again probably at a range of pre-determined speeds. If you haven't used this technique before, it is likely that you will have noticed how dirty water droplets or oil droplets from cars ahead can leave behind streak marks on your car's body surfaces that follow the local surface airflow. These constitute a 'frozen' record of where the air was flowing along the surfaces.

The deliberate use of fluid droplets to exploit this effect requires some thought, especially with regard to which fluid to use. Paraffin, diesel/fuel oil or thin lubricating oil (coloured with a dye like fluoroscein or a small amount of copper grease) are suitable, though ambient temperature plays a role. If it's too hot the fluid will evaporate too fast and not give a full or accurate picture. Too cold and it won't evaporate, and may flow back over the marks it has left to confuse the 'printed' record. Experimentation with fluid and colourings may be necessary, but be sure to avoid fluids that are corrosive to paint or bodywork! →



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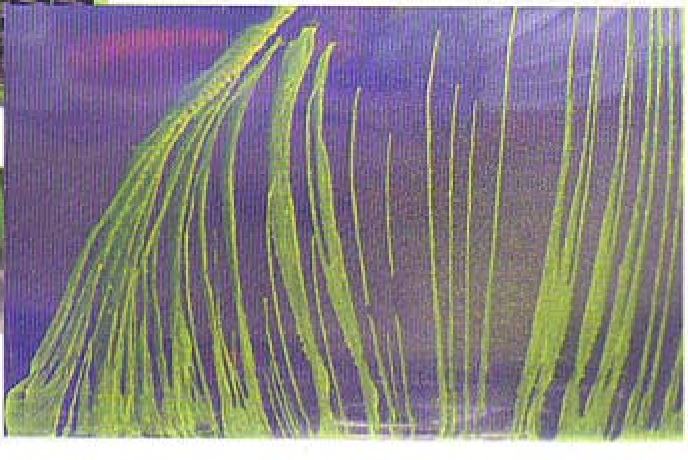
Flow visualisation fluids can be very revealing. The central mounting structure is having a very adverse effect on the flow along the underside of this wing (the wing leading edge is at the bottom of the picture)



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Paraffin coloured with fluoroscein dye shows this dual-element rear wing to be working well, but near its limit – the pattern near the flap trailing edge (top of picture) shows some flow separation occurring in the centre of the wing

This method can be even more useful than wool tufting because the 'recordings' can be studied in detail after a run. And it's even easier recording the results permanently because photos can be taken when the vehicle is static. As the examples in the photos of flows on wing undersides demonstrate, it is easy to see when things are working well, or when they are working disastrously. And as further examples of the kind of details that can usefully be visualised this way, it is possible also to see when a wing begins to stall, either because of excess angle of attack or at lower air speeds. The flow quality into duct inlets and at duct exits can be examined too, and other areas where flow separation occurs can be identified. Once again, this information helps to build a picture of the flow field around the car, especially in the vicinity of critical details.

Whilst wool tufts give obvious visual results, drag is harder to measure. But coastdown testing is an option

Racetrack testing

'Traditional' testing enables parameters affected by aerodynamics such as lap times, sector times, higher speed corner entry, apex and exit speeds (greater than 60mph or 100km/h probably, though dependent on downforce levels) and straight-line speeds to be recorded or logged when you visit the actual racetrack. With a racecar that has an optimised mechanical set up it is then possible to run aerodynamic configuration changes and generate a lot of useful information about the effects of those changes, supplemented by driver feedback on aerodynamic handling balance.

For a practical methodology we could do worse than follow the advice of the late Carroll Smith in *Engineer to Win*, where he documents a test in which two different wings were compared. Each configuration was run over five laps, and only wing configuration changes were made. Averages of lap times were recorded, with what were called 'abnormally high or low times' being discarded (a crude but effective statistical approach!).

The data revealed much useful information about the effects on the car's handling balance and its performance in various sectors of the track. With the relatively low cost, basic data loggers available nowadays, this type of test is very easy to execute – but it does need a disciplined approached, as outlined by Smith, to generate meaningful results. And, especially if weather or track conditions change during the session, it is also crucial to return to the baseline set up periodically during the session. Ideally, conditions will be consistent, but some variables can always be relied upon to change the baseline, such as tyre deterioration.

Drag measurement

Indirect measurements of the effects of configuration changes are very valuable, and are often all we really need to know. But what about directly measuring aerodynamic forces? It is possible to begin to do this with surprisingly little investment in instrumentation. And again you don't need a racetrack – but you do need a long, straight, flat and smooth piece of road. In terms of the minimum tools needed, drag is the easiest to measure of the two forces we are interested in.

There are various ways to measure drag on track, though one method is more commonly used than all the others. Two of the more sophisticated techniques require measurement of either suspension loads in the horizontal plane or driveshaft strain (torque). In both cases the sensors and the data acquisition systems required to log and enable analysis may be beyond budget. Nevertheless, both methods provide the ability to measure total vehicle drag. A third option (available space, gearing and reliable at-the-wheels brake horsepower and frontal area figures permitting) is to measure the car's maximum speed, and calculate the drag coefficient using a form of the equation shown here (though rarely are all the elements required to do this available):

> **“SMALL DRAG CHANGES REQUIRE HIGHER MEASUREMENT PRECISION”**

$$\text{BHP absorbed} = \frac{C_dAv^3}{1225}$$

(A = frontal area in square metres, and v = vehicle speed in metres/second).

Probably the most widely used technique to measure drag is the deceleration or coastdown technique, something our columnist Paul van Valkenburgh has written of in these pages (see V5N3 and V14N1 as well as his book *Race Car Engineering and Mechanics*. This provides a measurement of the total drag force. The observant readers will have spotted the drawback of these methods though – that the total drag force includes a mechanical resistance component as well as an aerodynamic one – but we'll come back to that shortly.

But first, how is the coastdown method used? Simply put, the vehicle is taken up to a reasonably high speed (aerodynamic forces being proportional to the square of speed), de-clutched, and allowed to slow down. The rate of deceleration, which is proportional to the total drag force as defined by Newton's Second Law of Motion, is either measured by accurately timing between two reference speeds, or calculated from logged speed versus time data. As such, the simpler data logging systems that measure speed via wheel rotations or by using GPS technology *could* be utilised. It sounds straightforward, but it is a method prone to various drawbacks. For example, if absolute drag forces or coefficients are required, then some means of measuring or estimating the mechanical resistance (mostly rolling resistance) and the rotational inertia of wheels, brakes, gears and so on are also required.

There are methods detailing the mathematical treatment of these aspects, such as that within the standard SAE J1263 *Road load measurement and dynamometer simulation using coastdown techniques*. Other more practical suggestions include low speed coast down runs to give an indication of the rolling resistance (though transmission losses are speed dependent). And then there's the idea of towing the car at the relevant speeds in a 'sealed' bottomless trailer and measuring the total non-aerodynamic towing force, mentioned in Joseph Katz's *Race Car*

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Aerodynamics. More practically, rolling road chassis dynamometers can be used to measure mechanical resistance forces, including tyre and transmission resistance, over a range of wheel speeds. And there are entirely mathematical approaches to factoring out the rolling resistance component from coast down test data, such as that highlighted by Hitoshi Takagi and Yutaka Narita at the 2004 MIRA Aerodynamics Conference (full details in the reference list).

But if it's the incremental changes arising from alternative configurations that you're interested in, it isn't actually necessary to factor out the mechanical resistance component. Changes to the total drag that arise from changes to the aerodynamic configuration can be safely assumed to be aerodynamic in nature in our context, unless the changes so dramatically increase the vertical forces that rolling resistance is affected, too. Even then, it's better that we measure it.

But one of the evident drawbacks of track testing, assuming a sufficiently long, flat section of test track is available, and factors such as tyre temperatures and chassis ride height are carefully controlled, is environmental fluctuations, otherwise known as wind. The professionals measure air speed using a Pitot tube high above the car. And SAE J1263 includes some mathematical and measurement corrections that can be applied to cater for wind fluctuations, although criticism has been levelled at this approach. But the cheap, practical remedy is to test in still, or near still conditions, which often means sometime between sunset and sunrise. And run the car several times in opposite directions, if necessary applying some statistics to the results to smooth out data fluctuations. Or use the Carroll Smith pragmatic approach!

Another important factor is the actual level of drag. A high drag car will decelerate more rapidly than a low drag car when coasting down, and thus will require less measurement precision to obtain a reasonable result. The corollary of this is that low drag, and small drag *changes*, require higher measurement precision. And drag increments from configuration changes may either not be sufficiently large to be detected, or they may not exceed the levels of environmental fluctuations, so with the same result will not be picked up. The level of precision you aim for, and the extent to which you are prepared to go in the estimating of rolling resistance, transmission losses and so forth, will depend on how crucial drag is to the performance of your racecar.

> **“IT NEEDS A DISCIPLINED APPROACH”**

So practical, track-based aerodynamic testing is available to all, and the methods described here require very little financial outlay, yet the insights to be gained can be beneficial. Needless to say, we are generally more interested in downforce, and to measure that directly using track testing requires further investment in data acquisition, which will be the subject of a future article.

References

Competition Car Aerodynamics – **S McBeath**, Haynes, 2006

Engineer to Win – C Smith, MBI Publishing Co, 1984

Race Car Engineering & Mechanics – **P van Valkenburgh**, 2000

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

Road load measurement and dynamometer simulation using coast down techniques, **SAE J1263**

Extraction of the coefficient of drag from coast down data using velocity-time integration – **H. Takagi & Y Narita**, Proceedings of the MIRA Aerodynamics Conference, 2004

Figure 1: a much simplified coast down methodology

To measure total drag:

Find or hire a long, straight, flat section of road/track, pick a day with little or no wind blowing and then, once you're fully prepared, run the racecar up and down at high speed to warm tyres etc to running temperatures, then perform high speed coast down runs as follows:

1. Drive the car up to a relevant, reasonably high speed.
2. De-clutch/put into neutral.
3. Allow car to slow down with no braking effort.
4. Time between pre-determined speed intervals eg 120 to 110mph, 110 to 100mph etc.
5. Repeat in opposite direction to account for environmental fluctuations or gradient differences.
6. Repeat steps 1 to 5 as many times as required to obtain a reliable data set (for each aerodynamic configuration being evaluated, if relevant).
7. Keep an eye on wind fluctuations and stop testing if significant wind develops.

To measure 'running resistance':

1. Drive the racecar up to a lower speed, at which the aerodynamic drag component is relatively low eg 30 to 40mph, depending on how 'draggy' the car is
2. Repeat steps 1 to 5 above but starting each time at the lower speed

NB – these slow speed runs could be undertaken as an integral part of the runs from higher speed, space and time permitting.

Force calculation:

Aerodynamic drag force, Fd = total drag force, Ft – running resistance force, Fr.

$$Ft = m \times (V1 - V2)/t \quad \text{and} \quad Fr = m \times (v1 - v2)/t$$

Where m = total car mass, including fluids, driver etc, V1 and V2 are the initial and final speeds of each increment timed in the high speed runs (v1 and v2 are from the low speed runs), and t is the time it takes to slow from V1 to V2 or v1 to v2.

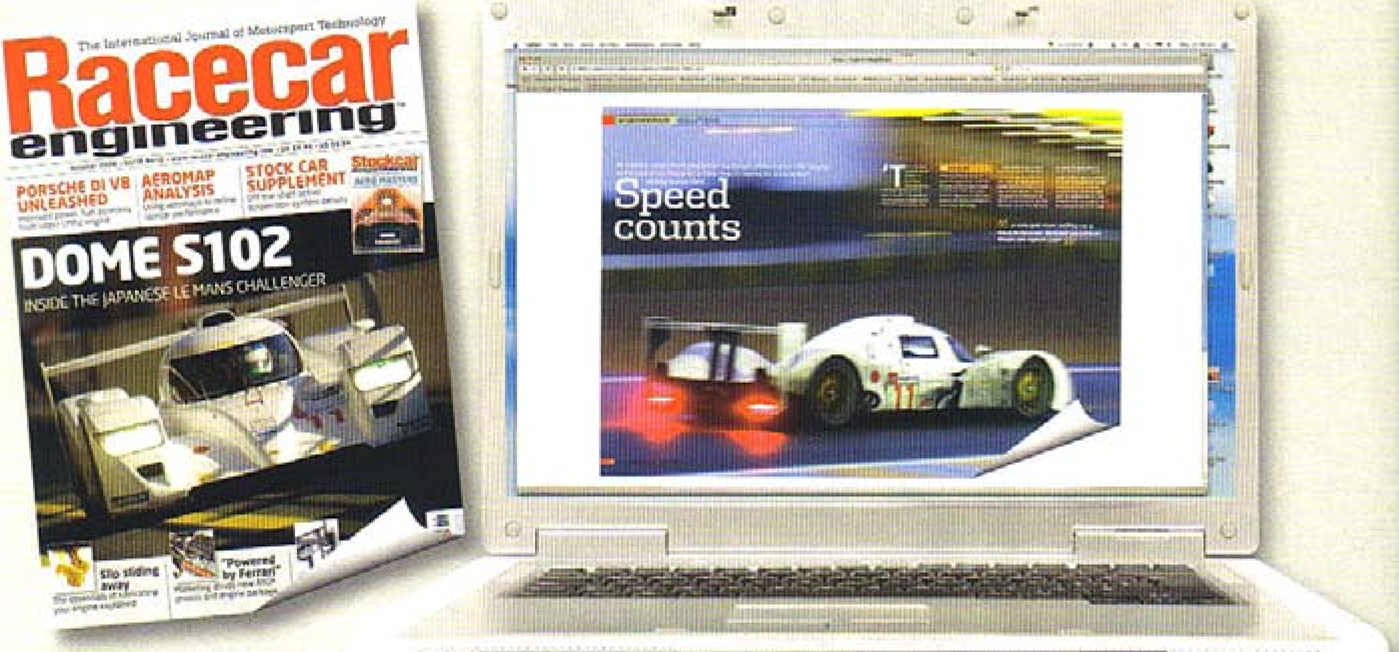
As the deceleration is non-linear, aerodynamic drag being proportional to the square of speed, the time taken to slow through each speed increment will also be non-linear. Thus, calculate for each speed increment to determine the total drag force at the average of each of those speed ranges. Anomalous data can either be discarded, or dealt with by more sophisticated statistical methods!

C_D calculation:

If required, calculate the drag coefficient indicated by your aerodynamic force measurements using the re-arranged equation for aerodynamic drag, vis:

$$C_D = 2Fd/\rho A v^2$$

Where Fd is the aerodynamic drag force you've previously determined from your coast down runs, ρ is air density, 1.225kg/m^3 (can be adjusted for ambient temperature and pressure), A is the car's frontal area and v^2 is the square of the mean speed over the increment in question.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