Optimising tunnel time

Full-scale wind tunnel time isn't cheap, but *Racecar Engineering's* practical techniques and tips will help you maximise the benefits

BY SIMON MCBEATH

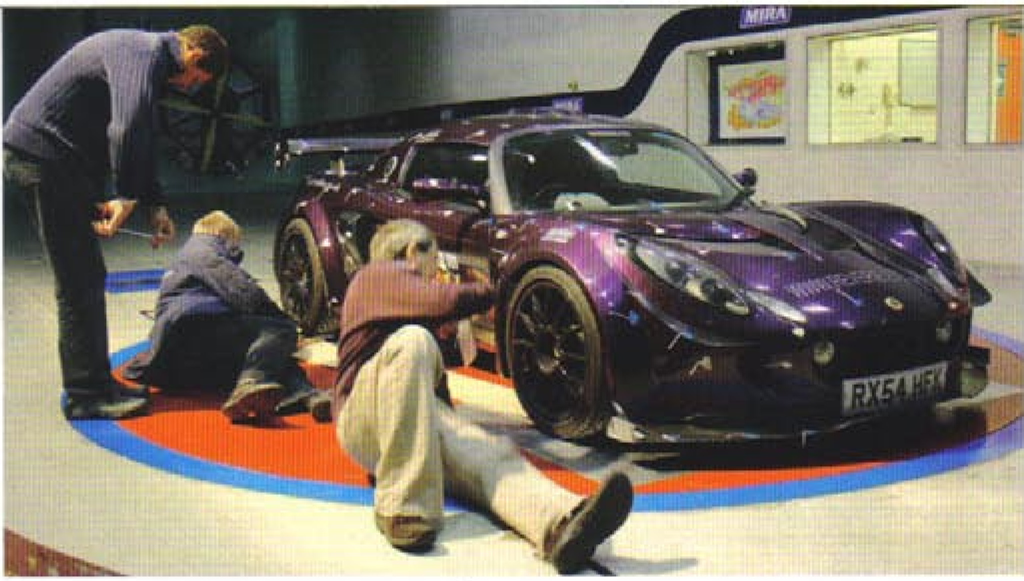
It's all about preparation, according to Alex Somerset, race engineer to 2007 British Touring Car champion Fabrizio Giovanardi, and a design engineer at BTC champion manufacturer Vauxhall/Triple Eight Race Engineering. Somerset also engineered Matt Neal to the 2005 Drivers' title in the Team Dynamics Honda Integra (featured in Aerobytes V16 N6 and N7), and it's probably no coincidence that he's a great believer in the role of aerodynamics, even in a series supposedly offering limited scope for such developments. So wind tunnel time features high on his R&D priority list, and we'll hear more of his practical tips during this article.

However, for the first time visitor to the wind tunnel, the initial approach may need to be a little more basic, as David Wain, manager at the UK's only commercially available full-scale wind tunnel at MIRA suggests: 'Until baseline figures are established, you may not know where to concentrate your efforts. So we suggest that new customers with no data come in for a couple of hours to measure this. After they've analysed the baseline data they can then make parts to try out and come back for a development session.'

Once you know the total forces, and especially the front-to-rear split of vertical forces, you are in a better position to design a development programme. But it isn't always going to be viable

Ensure the best boundary layer control available is used. This shot shows MIRA's boundary layer fence, which creates a fresh boundary layer ahead of the car

Photos: MIRA; S McBeath



A small, well-organised team is all that's required to make configuration changes efficiently

or possible to make two visits, in which case you just have to prepare for all eventualities. The key at the outset is to define what you hope to achieve, prepare a plan and gather the requisite materials and tools. But before you head off to the wind tunnel, there's a lot more useful preparation to be done.

PLANNING AND PREPARATION

First, prioritise the configurations you want to evaluate, and then work out how many runs you hope to fit into the allotted session duration. One of the first questions then is how long does a run take? At MIRA it takes about a minute to accelerate and stabilise the airflow, a minute to sample data, and a further minute to decelerate the air again before entering the test section to make a configuration change.

But of more significance is the time it takes to make the configuration changes themselves, and this is key to optimising your session. If possible, install as many test parts as possible on the car beforehand, because removing them will almost certainly be faster than fitting them. If, for experimental reasons, this can't be done – if strong interaction between parts is likely for example – then spend time ahead of the session pre-fitting parts to minimise fitting time in the tunnel. Our professional adviser, Alex Somerset, suggests rehearsing changes and timing how long they take so you can refine your schedule, adding 'allow time and a half for each change, especially if they involve jacking the car up'. Chances are some modifications will be made up on the day too, so take plenty of suitable materials (see panel on p58) with you. Once you've prepared your schedule in this way, bear in mind that you may have to deviate from it in response to the results.

Plan in time for 'flow visualisation' too, using smoke if available, wool tufts (which will have been stuck on previously, of course...) and test fluid if applicable. Time spent recording this with still and video cameras can be very worthwhile, but eats into your allotted test period all too quickly.

> "prioritise the configurations you want to evaluate"

ADVANCE INFORMATION

There is some basic information that the wind tunnel team will require from you in advance. The maximum and minimum track widths (to the inside and outside of the tyres) and the wheelbase enable the pads that sit atop the load cells to be pre-adjusted to fit. And a value for the frontal area (see panel above) will enable the data acquisition software to calculate coefficients from the forces measured by the load cells.

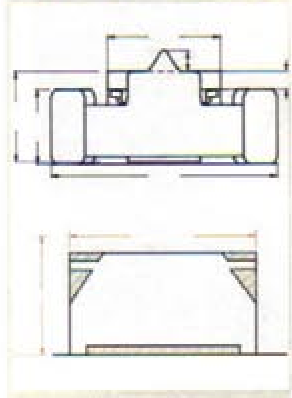
Other measurements usefully done ahead include the front and rear ride heights, ideally at easily accessed reference points that enable rapid verification in the tunnel. Another time saver is to work out what effect a turn on the spring platforms or push/pullrods has on ride height so that predetermined incremental changes can be quickly made. Or if ride height is not easily adjustable, an alternative if the tunnel floor under the wheels is fixed is to pre-set the car to its lowest envisaged ride heights and prepare some tyre contact patch sized 'shims' from plywood, say 5mm thick, so that a range of ride heights and rakes may be tested. Also check with your tunnel team to see if they can provide weights to simulate the driver aboard and, if it's an open car, a suitable crash helmet-wearing dummy to put in the cockpit. An idea of the weight on the front and rear axles will enable you to compare your scales to those of the tunnel (which have, of course, been properly calibrated).

One last important preparation task is to have a means of strapping the brake pedal firmly down to render the car immovable, if it doesn't have an efficient parking brake that is.

TESTING

An organised team is required for a test session, with a designated leader/decision maker, a configuration notes maker/photo taker (possibly the leader) and a small group (probably two to four people, as appropriate) to carry out configuration changes. The session leader may well be a team aerodynamicist but, if

ESTIMATING FRONTAL AREA



Having this data in advance enables data acquisition software to be used to calculate coefficients. To calculate this on an open-wheel car requires breaking the frontal 'silhouette' down into rectangular and triangular areas that are more easily calculated.

Estimating frontal area of a closed car can be done by subtracting the approximate area of the shaded portions from the area given by the (height x width).

Setting the car up on the load cells and aligned with the airflow is crucial

ESSENTIAL MATERIALS

Making sure you have the following items with you will save you time and money:

- Heavy gauge card
- Medium to low-density tooling block or builders PU insulation foam panel
- Aluminium foil tape (various widths and gauges)
- Race tape, lots of
- Quick set super glue
- Foam sealing tape
- Fasteners
- Aluminium sheet
- GFRP sheet
- MDF, plywood
- 'Flow vis fluid', which can comprise paraffin coloured with a little copper grease or talc.
- Tools to work with the above (check in advance that your wind tunnel workshop has band saws, guillotines, folders etc.)

Pre-fitting parts saves valuable tunnel time. Plan your programme well so parts that are interactive can be removed (or added) in the correct order

your team does not have one available, your wind tunnel can probably provide one if pre-booked. Although an accessible, qualified aerodynamicist will probably incur an extra fee, they will be a valuable asset, especially in the early stages of baselining and development.

Different wind tunnels have different methods of dealing with the boundary layer of stagnant air that develops along the wind tunnel floor through viscous friction (see panel). The important thing with racecars with generally low ground clearances is to specify the best boundary layer control that's available. And if rotating wheels is an option, then it's clearly better to utilise that facility, too.

> "rehearsing changes and timing how long they take"

At MIRA it's usual to start a session with a couple of baseline runs at different speeds to establish whether there are any 'Reynolds effects', that is to say any significant difference in the calculated coefficients at different air speeds. Such differences might arise, for example, if a particular car shape creates flow separations in different locations at the different speeds. If not, then it's more economical to run at the slower speed, and it also takes less time to accelerate and decelerate the airflow. These initial runs also serve to indicate what level of repeatability is to be expected.

Coefficients are generally reported to three decimal paces, and one would expect duplicate readings from a single run to be within one per cent. For example, on a GT car recently tested for Racecar at MIRA, the drag coefficient was around 0.500, so on any pair of duplicate results from a run, variation between results should be no greater than 0.005, or 'five counts'. In practice, duplicates from this session were nearly all within two or three counts. If variation consistently exceeds this level, stop to look for reasons – something may be loose on the car and interfering with the airflow.

Once underway, it's then a case of running through scheduled configuration changes, taking notes and photos, and logging results. The wind tunnel data acquisition system generates an electronic file or paper print out at session's end. But it helps

Make time in your schedule for flow visualisation with smoke and wool tufts, especially if the learning curve on the car under test is steep

TESTING DOs AND DON'Ts

Do

PLAN AHEAD AND PREPARE WELL

- Forward track and wheelbase dimensions to the wind tunnel in advance
- Pre-fit parts where possible
- Have a means of clamping the brakes on
- Ensure all temporary parts are securely affixed
- Predetermine exact effects of ride height adjustments
- Have packs of 'tyre shims' to alter ride height if required
- Be methodical, work through your schedule a step at a time
- Have one person to take notes and photos
- Have one person to make decisions
- Have a small group to make changes
- Always have materials and tools ready for the next configuration change
- Test a baseline set up periodically
- Allow time for flow visualisation
- Run repeats on key or suspect tests
- Investigate the cause of poor duplicate results
- Use the best floor boundary layer control available
- Analyse data fully *after* the session
- Be prepared to track test to validate conclusions

Don't

TURN UP WITHOUT A PLAN

- Squander valuable tunnel time in discussion or decision making
- Change more than one thing at a time
- Place absolute faith in the results from parts near the ground in a fixed floor tunnel, especially if there's no boundary layer removal. Treat trends with caution.

to understand the results if the team's note taker writes down the key data as well or types them into a laptop-based spreadsheet. It helps too, where appropriate, to plot the results of parameters mapped over a range of angles, heights or distances, and this again can be done with pencil and paper or spreadsheet at the time. Trends - and deviations from trends - are much easier to spot using graphs.

BTC engineer Alex Somerset advises that 'should a configuration lead to suspect, contradictory or just plain surprising results, if time permits then flow visualisation using a smoke generator can help indicate what the flow in the area of interest is doing, and increase understanding.' In any case, on a first visit with a car it helps enormously to allot 10 minutes during the session to run the smoke plume all over the car and video and/or photograph the results for later study.

Note that if ambient temperature is below 'comfortable', then standing in a wind tunnel at 25-30mph for flow visualisation runs will cause major wind chill, so take a warm coat!

Sometimes an idea doesn't work as hoped, so if some parts show poor results, be prepared to abandon that development route. It is no less valuable to discover which ideas don't work, and negative results shouldn't necessarily be disappointing.

As a final task during a session, return to a baseline configuration for the last run. This will increase confidence in the results, as long as the baseline is more or less the same as it was earlier anyway.

INTERPRETING RESULTS

On that first visit to the wind tunnel it can take a while to home in on the numbers that matter on the data acquisition PC screen. MIRA provides a print out of the on-screen results during the session, and examples are shown on page 62. There are two basic formats, displaying either forces or coefficients, and each has its uses.

> "negative results shouldn't necessarily be disappointing"

Be cautious of the results of ground-proximity devices, but assess trends

The load cells under the wheels measure absolute aerodynamic forces exerted horizontally, vertically and laterally at the tyre contacts. The coefficients are calculated using the basic aerodynamic force equations, which include the frontal area of the car. This is why an accurate estimate of frontal area makes the coefficients meaningful. Let's run through the print out to see what each column means and determine which numbers you are most likely to focus on.

Looking at the force print outs overleaf, from left to right, the run/configuration number, wind speed and yaw angle are self-explanatory. The next three columns are the basic total forces: drag, side force and lift (negative when it's downforce). Here the major forces are drag and downforce, with small side force being logged. Side force arises either from a yaw angle or from vehicle asymmetry. In this case side force is very small compared to the drag and downforce, and can be ignored.

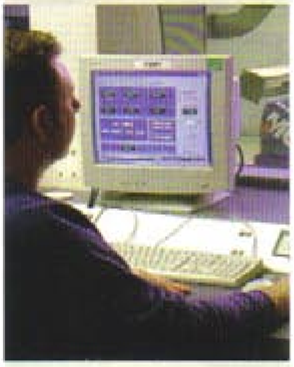
The moments MX, MY and MZ arise from the distribution of the aerodynamic forces around the centre of gravity. Here there's a large pitching moment (about

TABLE 1

Commercially available full-scale wind tunnels

Name (Country)	Test section area, m²	Maximum speed	Comments
Aerodyn (USA)	21.0	209km/h	Closed jet, contoured wall (option for slotted wall), boundary layer suction, rotating wheels. Optimised for stock cars eg NASCAR
DNW LLF (Germany/ Netherlands)	90.25 max, configurable	547km/h (depending on configuration)	Closed or open jet configurations, various boundary layer controls including moving ground, tripping, blowing
Langley FST (USA)	167.0	130km/h	¾ open jet, fixed ground, 'ground board' or 'active secondary boundary layer control'
Langley '14 x 22' (USA)	29.3	370km/h (270km/h in open jet configuration)	Closed jet or ¾ open jet, single belt moving ground in late 2008
Lockheed Martin (USA)	35.1	321km/h	Closed jet, fixed floor with tangential blowing boundary layer control
MIRA FSWT (UK)	35.0	133km/h	Closed jet, fixed ground, boundary layer trip fence
NRC (Canada)	82.8	198km/h	Closed jet, boundary layer removal by upstream suction, and lengthened ex-Pininfarina moving central ground belt plus wheel rollers to allow two cars on belt in 2008
Pininfarina (Italy)	40.3	250km/h	¾ open jet, moving ground 'T-belt' comprising long central belt plus short belts under front wheels
SAA GIE S2A (France)	24.0 at nozzle	'>240km/h'	¾ open jet, moving ground central belt plus driven wheels (max. speed 200km/h)
Windshear (USA)	16.7 at nozzle	289km/h	¾ open jet, single belt moving ground. Coming on line during 2008
WindtunneleXtreme	13.4	288km/h	Closed jet, adaptive wall, moving ground, scheduled to be on line in 2009

AERODYNAMIC COEFFICIENTS



Your results will appear as a set of numbers on a spread sheet or printout (see right). The figures will be referenced by abbreviations explained in our glossary here.

CD (or **CX**): drag coefficient
CY: side force coefficient
CL (or **CZ**): lift coefficient (negative for downforce)
CMX: aerodynamic roll moment coefficient
CMY: aerodynamic pitch moment coefficient
CMZ: aerodynamic yaw moment coefficient
CYF: side force coefficient at front axle
CYR: side force coefficient at rear axle
CLF: lift coefficient at front axle (negative for downforce)
CLR: lift coefficient at rear axle (negative for downforce)
XCP: centre of pressure location along x-axis (fore/aft) as percentage of wheelbase

the y-axis) arising from more downforce at the rear.

The axles loads, YF and YR, are the side forces measured at each axle, and are negligibly small. The vertical loads LF and LR are important though, showing the split of downforce on the front and rear wheels (LF + LR = total lift).

Drag is often more comprehensible in terms of horsepower absorbed, and the next column shows this in kilowatts (divide by 0.746 to convert to bhp). And aerodynamic efficiency is frequently expressed as lift divided by drag (L/D). The final column indicates it is possible to amend the frontal area used to calculate the coefficients should a configuration significantly alter the area. Although coefficients are just a mathematical treatment of forces, they can make it easier to quickly spot trends and quantify gains or losses. Note that as with the forces, CYF + CYR = CY, total side force, and CLF + CLR = CL, total lift.

This printout format also offers to calculate the centre of pressure, which is the point at which the total of the aerodynamic forces is effectively exerted. But the lift per cent front is perhaps a more useful way of expressing the aerodynamic balance, calculated as [CLF / (CLF+ CLR)] x 100.

Of all these figures, the ones to concentrate on in most cases will be lift and drag. Balance is key in just about every case where cornering is concerned, whereas the trade off between downforce and drag is very much down to your racecar and its competition arena.

Once you've started generating wind tunnel data, the next questions will centre on what those trade offs should be, and on what aerodynamic configurations you plan to test at your next session...

MIRA Full-Scale Wind tunnel
Aerodynamic Forces and Moments

FIRM: REVERIE

MAKE
MODEL LOTUS
TYPE RACE CAR
CONFIGURATION 9
TRIM HEIGHT
FRONT 0.0
REAR 0.0

MEASUREMENTS STARTED 13Apr2007 09:23:49

OVERALL LENGTH 3785 mm (12.42 ft)
OVERALL WIDTH 1719 mm (5.64 ft)
OVERALL HEIGHT 1163 mm (3.82 ft)
WHEELBASE 2300 mm (7.55 ft)
TRACK FRONT 1510 mm (4.95 ft)
TRACK REAR 1570 mm (5.15 ft)
FRONTAL AREA 1.74 Sq.m (18.73 Sq.ft)
GROUND BOARD HT. 0.0 mm
B. L. FENCE INSTALLED

VEHICLE WEIGHT 996.4 kg (2196.7 Lb)
E LOAD: 405.7 kg (894.4 Lb), REAR AXLE LOAD: 590.7 kg (1302.3 Lb),
CENTRE OF GRAVITY 214 mm (0.70 ft) Behind Reference Centre
Ref. offsets. Vehicle Position Offsets: X= 25.0 mm, Y= 0.0 mm.

ALL SCALED TO A WINDSPEED OF: 67.10 m/s (150.10 mph, 241.56 kph)

WIND SPEED m/s	YAW ANGLE Deg	FORCES Newtons DRAG	SIDE-F	LIFT	MOMENTS Newton.m MX	MY	MZ	AXLE LOADS YF	YR	LF	LR	DRAG POWER kW	Lift/Drag L:D	FRONTAL AREA Sq.m
.50	0.0	2691.1	-39.3	-3031.8	-27.0	1323.9	-36.3	-35.4	-3.9	-940.3	-2091.5	179.1	-1.127	1.740
.50	0.0	2687.1	-34.0	-3026.5	-22.6	1335.1	-39.5	-34.2	0.2	-932.8	-2093.7	178.9	-1.126	1.740
.52	0.0	2625.0	-27.2	-2903.7	-9.3	1085.7	-52.0	-36.2	9.0	-979.8	-1923.9	174.7	-1.106	1.740
.51	0.0	2637.3	-25.4	-2912.1	2.7	1096.6	-49.8	-34.3	8.9	-979.3	-1932.9	175.5	-1.104	1.740

MIRA Full-Scale Wind tunnel
Aerodynamic Coefficients

FIRM: REVERIE

VEHICLE MAKE
MODEL LOTUS
TYPE RACE CAR
CONFIGURATION 9
TRIM HEIGHT
FRONT 0.0
REAR 0.0

MEASUREMENTS STARTED 13Apr2007 09:23:49

OVERALL LENGTH 3785 mm (12.42 ft)
OVERALL WIDTH 1719 mm (5.64 ft)
OVERALL HEIGHT 1163 mm (3.82 ft)
WHEELBASE 2300 mm (7.55 ft)
TRACK FRONT 1510 mm (4.95 ft)
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FRONTAL AREA 1.74 Sq.m (18.73 Sq.ft)
GROUND BOARD HT. 0.0 mm
B. L. FENCE INSTALLED

ASURED VEHICLE WEIGHT 996.4 kg (2196.7 Lb)
ONT AXLE LOAD: 405.7 kg (894.4 Lb), REAR AXLE LOAD: 590.7 kg (1302.3 Lb),
ASURED CENTRE OF GRAVITY 214 mm (0.70 ft) Behind Reference Centre
has been reduced by 0.004 due to BBL factor of 0.700
Moment Ref. offsets. Vehicle Position Offsets: X= 25.0 mm, Y= 0.0 mm.

RUN/CONF NO.	WIND SPEED m/s	YAW ANGLE Deg	FORCE COEFFICIENTS CD(-CX)	CY	CL(-CZ)
1/ 1	27.50	0.0	0.556	-0.008	-0.632
2/ 1	27.50	0.0	0.555	-0.007	-0.630
3/ 2	27.52	0.0	0.543	[illegible]	[illegible]
4/ 2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MOMENT COEFFICIENTS CMX	CMY	CMZ	AXLE LOAD COEFFICIENTS CYF	CYR	CLF	CLR	CENTRE OF PRESSURE XCP	Lift% Front %	FRONTAL AREA Sq.m
-0.002	0.120	-0.003	-0.007	-0.001	-0.196	-0.436	0.0	31.0	1.740
-0.002	0.121	-0.004	-0.007	0.000	-0.194	-0.436	0.0	30.8	1.740
-0.001	0.098	-0.005	-0.008	0.002	-0.204	-0.401	0.0	33.7	1.740
0.000	0.099	-0.005	-0.007	0.002	-0.204	-0.403	0.0	33.6	1.740
-0.002	0.145	-0.002	-0.007	-0.002	-0.184	-0.475	0.0	28.0	1.740
0.003	0.145	-0.002	-0.007	-0.002	-0.184	-0.474	0.0	27.9	1.740
0.000	0.113	-0.005	-0.008	0.002	-0.194	-0.420	0.0	31.6	1.740
0.001	0.113	-0.004	-0.008	0.001	-0.193	-0.420	0.0	31.5	1.740
0.002	0.035	-0.002	-0.007	-0.002	-0.227	-0.297	0.0	43.3	1.740
0.002	0.035	-0.002	-0.007	-0.003	-0.228	-0.299	0.0	43.2	1.740
.002	0.093	-0.003	-0.007	-0.001	-0.207	-0.392	0.0	34.5	1.740
.001	0.092	-0.003	-0.007	-0.002	-0.208	-0.392	0.0	34.6	1.740
.000	0.089	-0.002	-0.006	-0.001	-0.205	-0.384	0.0	34.9	1.740
.002	0.089	-0.003	-0.006	-0.001	-0.205	-0.383	0.0	34.8	1.740
.003	0.094	-0.001	-0.007	-0.005	-0.201	-0.380	0.0	34.0	1.740
.003	0.093	-0.002	-0.007	-0.004	-0.200	-0.386	0.0	34.1	1.740
.011	0.131	0.005	-0.002	-0.012	-0.216	-0.479	0.0	31.1	1.740
.011	0.132	0.005	-0.002	-0.011	-0.217	-0.481	0.0	31.1	1.740

The control room and the data acquisition PC are the heart of any wind tunnel. Here's where the results of all your testing will come to life

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