



automotive engineering specialists



MIRA AERODYNAMIC WIND TUNNEL FACILITIES

Users' Handbook
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For more information on the services offered by the Fluids Engineering department see www.mira.co.uk.

Initial Enquiries

In general, initial contacts and enquiries should be made through the Wind Tunnel Manager or Aerodynamics Consultant, but many enquiries will be answerable by any of the department staff.

Cover picture: Lamborghini Gallardo pictured in the Full Scale Wind Tunnel in 2005

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1 Introduction

The MIRA Full Scale Aerodynamic Wind Tunnel (FSWT) is located on the Motor Industry Research Association's Proving Ground near Nuneaton, Warwickshire. This site is well served by road, rail and air transport systems, as Figure 1 shows, and there are several well-equipped hotels nearby (see Appendix B).

Access to the wind tunnel is by a one-mile long private road leading off the main A5 road (Watling Street), past the MIRA laboratories and the Department of Transport's VTAC testing station (see Figure 2). Visitors are required to report to the MIRA No.1 Security Gatehouse on arrival to sign-in and drop off any camera equipment, including mobile telephones with imaging capability. These items can be retrieved by a member of MIRA staff and transferred to the wind tunnel or may remain in the possession of the visitor if they are escorted to the wind tunnel by a MIRA staff member.

The FSWT is housed in a large hangar building adjacent to the Fluids Systems Engineering Centre (FSEC). The wind tunnel facility is briefly described in the following sections, and an indication is given of the type of work that can be undertaken and of the expertise of the staff employed. Further information of particular value to users of the facilities is included in the final section together with instructions which must be followed in the interests of safety and security.

The wind tunnel facility is supported by MIRA's workshop and garage services as well as instrumentation, photographic and Information Technology departments, a library and information section specialising in automotive engineering subjects and a canteen. Whilst the wind tunnel may be hired, on the basis defined in this Users' Handbook, MIRA's main purpose is to carry out research and development on a contract basis for clients worldwide, both inside and outside the automotive industry.

In addition to the aerodynamic wind tunnel described here, MIRA's Fluids Engineering department has two Climatic Wind Tunnels, one notionally for cars / motorbikes and the other notionally for larger vehicles, and an associated Thermo-fluids Laboratory for component or system bench-testing. These are covered in separate descriptive literature.

Visitors should be aware that use of cameras on MIRA premises is restricted. Any photographic equipment (including mobile telephones with imaging capability) should be declared upon arrival at the Security Gatehouse. This equipment must be deposited with the security staff. A receipt will be issued and the equipment collected, on behalf of the client, by MIRA staff members. A similar arrangement will apply upon departure, where the equipment will be handed to Security for collection by the client.

2 Description of the Full Scale Aerodynamic Wind Tunnel (FSWT)

2.1 Wind Tunnel

This wind tunnel is designed for testing full-scale road vehicles (roughly up to the size of a large transit van or 50% scale HGV), though its use is by no means confined to vehicle work. With a high-precision 6-component aerodynamic balance and a chassis dynamometer installed in the test section, the tunnel can be used for a wide variety of tests, as indicated in section 3.1.

As Figure 4 shows, the wind tunnel is of the open-return type but, by its enclosure within a large building, it enjoys some of the benefits of the closed-return configuration. In particular, the air passing through the tunnel recirculates within the building, free from the influence of the natural wind and other adverse weather conditions.

Air is drawn into the wind tunnel through a rectangular bell-mouth entry containing an air straightener before being accelerated through a moderate contraction into the parallel-sided test section. From here the airstream is slowed initially in the first diffuser, which leads into the four four-bladed fans, and its speed is then further reduced in the short wide-angle diffuser ducts which lead to the exits.

Each fan is driven by an electric induction motor mounted behind the exit, and its speed can be set to one of nine fixed values (see Section 4.1.4 for limitations on maximum air speed). When required, further adjustment of the wind tunnel air speed can be achieved by allowing the fans to run at unequal speeds.

2.2 Aerodynamic Balance

The aerodynamic balance is mounted under a turntable set flush in the floor of the test section (see Figure 4), and this complete assembly is rotated with the test vehicle when the latter is yawed to represent cross-wind conditions. The balance is essentially of the platform type, supported on three vertical load cells, and constrained horizontally by links to one longitudinal and two lateral load cells. Six Schenck-type RT load cells are used and the signals from these are input to six Digital Signal Conditioning Units (DSCUs) which then feed information to the main data acquisition program which calculates and displays the aerodynamic coefficients (as defined in Section 4.3).

Cars and light vans are mounted on the turntable on four small plates which are adjusted to match the wheel positions (see Figure 6), flush filler plates being used to cover the remainder of the balance. A further single mounting point can be provided at the centre of the turntable, and this is used when necessary for tests of three and two-wheeled vehicles or non-vehicular items. Vehicles or other test specimens which exceed either the maximum weight capacity of the balance or the maximum dimensions acceptable on the standard mountings can be mounted on additional air bearings positioned on the tunnel floor outside of the turntable periphery and the horizontal forces measured.

Motorcycles are accommodated by rotating the balance turntable by 90° and mounting the vehicle across the two rear floor pads using a special U-shaped frame which connects through the rear wheel spindle.

2.3 Chassis Dynamometer

The dynamometer rollers are mounted flush with the floor with the floor of the test section and downstream of the balance turntable (see Figure 5). Vehicles with single or twin tyres can be accommodated and with either front or rear-wheel drive. Wheel rotation can be either forwards or in reverse and, being an electric motor-generator, the dynamometer machine can be used for both absorbing and motoring duties. The machine can be operated in either constant-speed and constant-torque modes, both of which are under electronic control. Digital read-outs of 'road' speed and tractive force are provided.

2.4 Ancillary Equipment

Air speed and Pressure Measurements - A precision pressure transducer, connected to a Pitot tube and a ring of static pressure tapings at the upstream end of the test sections (see Figure 5) is used for the reference dynamic pressure measurement, from which the wind tunnel air speed is derived. When the aerodynamic balance is in use, the reference dynamic pressure is sampled at the same frequency and averaged over the same period as the load cell signals.

Further measurements of air speed can be made where necessary with vane and hot-wire anemometers or with additional Pitot and static pressure tubes. Specially developed mini-vane anemometers or pairs of Pitot and static pressure tubes are used for determining the total airflow (and its distribution) through a radiator matrix when installed in a vehicle. Pressures sensed by these and/or other individual pressure tubes are measured on a 64-tube pressure transducer system. Where static pressures on the exterior surface of a vehicle are required, flush tapings are recommended, but, alternatively, special probes (as shown in Figure 6) can be supplied and attached to the vehicle with adhesive tape.

Frontal Area Measurements - The test vehicle is located in front of a special background which is suitably marked to provide a reference scale and a photograph is taken using a SLR camera from a distance of 60m away, in order to minimise parallax errors. A planimeter is then used to measure the frontal area of the vehicle on the photograph in accordance with the procedure detailed in Section 4.4.

Please note that frontal area measurements are charged for separately but may be done during the wind tunnel hire period.

Plan view photographs can also be taken by means of a camera mounted in the roof of the wind tunnel hangar at a height of 8.85m.

A camera is also available for taking photographs or short movie clips in the test section of the FSWT.

Flow Visualization - Three different techniques are employed involving the application of either wool tufts or a fluorescent oil film to the vehicle surface or the injection of a single filament of smoke into the airstream around the vehicle.

Radiator Heat Dissipation Measurement - A 200kW radiator heat dissipation rig can be connected to a test vehicle in the wind tunnel to allow the radiator heat dissipation to be determined without running the engine.

Boundary Layer Thickness Reduction - For vehicles with ground clearances less than 150mm, a significant improvement in the representation of actual road conditions may be

achieved by the installation of a V-form boundary layer fence which is available for this purpose. The fence reduces substantially the thickness of the boundary layer on the floor of the wind tunnel, as the data in Section 2.5 indicates,

Data Processing - All aerodynamic coefficient data is calculated immediately and displayed on a computer terminal in the control room. The client interface also allows for the aerodynamic force information to be displayed in metric or imperial units at a speed selected by the customer. Tabulated print-outs, in both coefficient and dimensional formats are available. Although this facility can be used for the analysis of dynamometer data, manual input is required.

Pressure coefficient data are computed automatically when the Scanivalve pressure measurement equipment is in use and the results can be provided in both electronic and hard-copy formats.

The reduced data acquired during a wind tunnel test can be provided to the customer in a universal electronic format (i.e. tab-delimited ASCII text files). USB ports are available for the transfer of data to memory keys or alternatively compact discs or floppy disks can be supplied with the information on. MIRA utilise secure memory key technology where data is stored with 128-bit encryption and password-protected.

Vehicle Preparation and Storage - Two heated garages, situated in a building adjoining the wind tunnel building, are available for customers wishing to prepare or store vehicles, or equipment, outside wind tunnel working hours or whilst the wind tunnel is occupied by another customer.

The larger garage, which has an inspection pit plus four-post vehicle lift, has a floor area of 19.0m x 7.2m and a door size of 4.9m wide x 4.85m high. The smaller garage has a floor area of 7.2m x 4.5m and a door 4.5m wide x 4.85m high.

Both garages contain compressed air supplies and work-benches with vices but customers are advised to supply their own tools or specialist equipment.

2.5 Dimensions and Performance Data

Wind Tunnel

Test Section	Length	15.24m	(50ft)
	Width	7.94m	(26ft)
	Height	4.42m	(14.5ft)
	Cross-sectional area	34.93m	(376sqft)
Installed motor power		987kW	(1300bhp)
		4 x 247kW	(4 x 325bhp) motors
Maximum wind speed		130km/h	(80mph)
Velocity distribution		±2%	
Turbulence intensity (u/U)		1.8%	
Turbulence length scale (L _u)		0.25m	
Boundary layer displacement thickness		17mm without boundary layer fence	
		6mm with boundary layer fence	

Balance

Turntable and mounting arrangement dimensions are as shown in Figure 5.

Vehicle or Model dimensional limitations:-

Maximum weight	4000kg	(8800lb)
Maximum height	4.3m	(14.10ft)
Maximum wheelbase	3200mm	(10.50ft)
Minimum wheelbase	1500mm	(4.92ft)
Maximum track	1800mm	(5.91ft)
Minimum track	1200mm	(3.94ft)

Drag force	3300N	(700lb)
Side force	6600N	(1400lb)
Lift force	24000N	(5400lb)
Yawing moment	4000Nm	(3000lbft)
Pitching moment	4000Nm	(3000lbft)
Rolling moment	4000Nm	(3000lbft)

The maximum aerodynamic force and moment limitations are applicable in both positive and negative loading directions.

Rotation $\pm 180^\circ$ from the straight-ahead position.

Maximum single wheel load within the wind tunnel: 5 tonnes (5 tons).

Dynamometer

Single-axle chassis dynamometer, capable of absorbing 225kW (300bhp) and motoring duties. Motoring power output is limited for operational reasons.

Rolls	Diameter	1.525m	(5ft)
	Width (each)	0.813m	(2ft 8in)
	Separation	0.864m	(2ft 10in)

Range of speed and tractive effort as indicated in Figure 7.

Maximum speed	150km/h	(93mi/h)
Maximum tractive effort	9000N	(2000lb)
Natural inertia of dynamometer (vehicle weight equivalent)	1980kg	(4370lb)
Maximum coefficient of friction between drums and tyres	0.8	
Maximum axle load on dynamometer	10 tonnes	(10 tons)

Equipment is available to restrain both front and rear-wheel drive vehicles. Fuel consumption measuring equipment is also available.

2.6 Heavy Lifting Equipment

A number of items of ancillary equipment are available. Heavy lifting equipment can be provided, but prior notification may be required for certain items and other clients' security

and testing time could preclude access to some equipment. The following is a summary of the available equipment.

2.6.1 Overhead Hoist

An overhead hoist is available in the FSWT building.

Height clearance	4m	(12ft)
Maximum load	1 tonne	(1 ton)

2.6.2 Mobile Crane

A mobile crane with a maximum lift of 6 tonnes (6 tons), depending on the position of the jib, can be made available. Prior notice is always required for this facility.

2.6.3 Mobile Hoist

The department has a mobile hydraulic hoist with a capacity of 1 tonne (1 ton) with the jib in the minimum length position and the 508kg (1120lb) with the jib fully extended.

2.6.4 Slings and Chains

A small selection of slings and chains are available. These items are regularly checked and rated to comply with the requirements of Health and Safety at Work.

2.6.5 Fork Lift Truck

A Fork Lift Truck is available by prior arrangement.

All equipment provided by MIRA is regularly checked and certified. Any lifting gear provided by a client must be accompanied by a copy of a valid certificate showing compliance with the requirements of the Health and Safety at Work Act.

3 Scope of Work Undertaken and Expertise Available

3.1 Types of Development and Testing Carried out for and by Customers

- Determination of six components of aerodynamic force and moments on vehicles, buildings and other objects, either at full scale or model scale (e.g. 50% scale trucks, 1% scale buildings).
 - Correlation of aerodynamic measurements with other wind tunnel facilities on a world-wide basis.
 - Determination of flow patterns around vehicles and models of all kinds by flow visualization techniques (tufts, oil-film techniques, smoke).
 - Evaluation of vehicle body ventilation and air leakage.
 - Determination of the pressure distributions around vehicles and models of all kinds in the wind tunnel or on track.
 - Aerodynamic noise measurements on vehicles and models of all kinds.
 - Evaluation and development of vehicle engine cooling systems for vehicles up to large vans.
 - Measurement of fan performance characteristics.
 - Measurement of noise characteristics of fans and radiators and complete cooling systems.
 - Measurement of thermal and aerodynamic performance characteristics of heat exchangers.
 - Evaluation of vehicle engine bay ventilation efficiency up to large vans.
 - Determination of tractive effort vs. speed characteristics.
 - Performance estimation for cars.
 - Determination of airflow around vehicle brakes and associated thermal management investigations (including thermal imaging capability).
 - Evaluation of brake fluids by brake tests.
 - Brake tests using dynamometer inertia.
 - Measurement of vehicle projected frontal area.
 - Evaluation of aerodynamic test facility designs by computer simulation, model testing and by correlation of pressure distributions on typical test vehicles or models.
 - Investigation of drive-line vibration problems.
 - Evaluation of tyre rolling resistance.
 - Consultancy on aerodynamic aspects of vehicle design, including heating, ventilation and cooling systems, and on the design and operation of aerodynamic test facilities.
 - Measurement of temperatures in the engine, brakes, cooling system, exhaust and on the bodywork of vehicles during dynamometer tests and correlation with track test data.
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4 Notes for Users of the MIRA Full Scale Wind Tunnel

4.1 Operational Information

4.1.1 Availability

The wind tunnel is available for testing purposes during the normal working week and, by special arrangement, on some weekends. The table below gives more detail of the hours of availability. The typical unit of hire is one 8-hour shift but 4-hour shifts are available, subject to some restrictions which are listed below.

Please note that the start and finish times listed here include all set-up and removal activities. Any time used outside of these periods may be charged as overtime.

	Nominal day shift ¹		Nominal night shift	
	Morning shift	Afternoon shift	Evening shift ²	Night shift ³
Monday - Thursday	08:30 - 12:30	13:15 - 17.15	17:30 - 21:30	21:30 - 01:30
Friday	08:30 - 12:30	13:15 - 16.15		
Saturday / Sunday	By arrangement		Not available	

1/ There is a priority system in place for bookings. Requests for 8-hour day shifts will normally take priority over 4-hour half-shift, however this does not mean that an existing booking will be over-ruled.

2/ Normally an evening shift cannot be booked on a date where the day shift is vacant.

3/ The late evening shift cannot be booked in isolation but only as a full night shift from 17:30 to 01:30. Occasionally the mid-shift meal break can be relinquished and the shift ends at 00:30 instead of 01:30. This can be arranged with the wind tunnel operator during the session.

4.1.2 Bookings

Although provisional bookings may be made by telephone, all bookings must be confirmed in writing at least seven days before the proposed test date. Confirmation can be made by letter, email or fax addressed to the Wind Tunnel Manager. The contact details are:

David Wain
MIRA Wind Tunnel Manager
Tel: 024 7635 5413
Fax: 024 7635 8413
email: david.wain@mira.co.uk

Without confirmation, availability of the facility and the associated test equipment required cannot be guaranteed.

Confirmation should be accompanied by a formal Purchase Order or, for customers new to MIRA, payment may be required in advance before the confirmation can be accepted.

Appendix A contains information on local hotel accommodation.

4.1.3 Charges

Use of the Wind Tunnel and Dynamometer

The charges include the services of the wind tunnel operator. Additional technician assistance will be charged for at an appropriate hourly rate. MIRA engineering and consultancy staff are available for consultation (by prior arrangement), again at an appropriate hourly charge. However, no charge will be made for an initial introduction to the facilities and the techniques employed. It is recommended that customers new to wind tunnel testing that they opt for an introductory discussion with one of MIRA's Aerodynamicists in order to maximise the benefits from their time in the wind tunnel.

The charges quoted are applicable to test session format previously described in section 4.1.1.

The rates for test session are defined as follows:-

Half day	4 hours, either between 08:30hrs and 12:30hrs or between 13:15hrs and 17:15hrs*
Full day	Any time between 08:30hrs and 17:15hrs beyond 4 hours duration.
	Overtime of up to 4 hours beyond 17:15hrs* may be worked by special arrangement and will be charged additionally.
*	Except on Fridays, when the afternoon test session normally ends at 16:15hrs and charges are proportionately less.
Evening	4 hours between 17:30hrs and 21:30hrs, Monday to Friday.
Night shift	Any time between 17:30hrs and 01:30hrs beyond 4 hours duration. The operator is entitled to take a half-hour meal break at a time approximately mid-way through the session. If this break is not taken, then the overall length of the session is decreased accordingly.

Occupation of the Wind Tunnel

if the wind tunnel is occupied during a test session but without the use of the facility (and without the services of MIRA staff), the occupation charges shown in the separate price list will be applicable.

These charges are for Monday to Friday, including Friday night. No charge will be made for occupation during Saturday or Sunday, unless another customer wishes to use the wind tunnel during the weekend period, in which case the occupation charge will be that appropriate to night occupation.

Cancellation of Bookings

If a booking is cancelled a charge will be made to cover MIRA's administration costs. When a cancellation is made within 28 days of the reserved test session an additional charge will

be made, consisting of the occupation fee for the period booked, unless the session is used by another customer.

MIRA reserves the right to charge the full price for a test session which is abandoned after the start of the session. A test session not previously cancelled but for which the customer failed to arrive, would fall into this category.

Frontal Area Measurement

The assessment of the frontal area of a vehicle or test subject using facilities within the wind tunnel building will incur a charge.

Storage

Overnight storage of test vehicles in a garage adjoining the wind tunnel is available for an additional charge to the main facility hire. The charge is made on a daily basis but special arrangements can be made for long-term storage if required.

Photographic and Video Work

A photographic record of test configuration changes or airflow patterns during a test programme can be made using either a customer's own camera (subject to the security measures described in the introduction), or the camera resident in the FSWT. In addition, the services of a professional MIRA photographer are available to assist in the aforementioned record keeping or the generation of marketing material from photographs and posters up to video sequences with audio commentary. The charges applicable for this service naturally depend on the type of work undertaken.

4.1.4 Limitations on Wind Speeds

MIRA has a responsibility to the local residents to keep noise levels to a minimum at certain times. The wind tunnel generates a considerable amount of noise and so the maximum allowable wind speed is limited during those periods.

Shift	Period	Maximum Wind Speed
Day Shifts	Monday to Saturday	130km/h (80mph)
Day Shift	Sunday	100km/h (60mph)
Night Shifts	All days, midnight - 08:30hrs	100km/h (60mph)
Evening / Night Shift	17:30hrs - midnight	130km/h (80mph)

4.1.5 Arrival and Admission to the Facilities

Admission of Vehicles

The FSWT is located inside the MIRA Proving Ground and access is via the internal MIRA road network. All inbound vehicles enter the Proving Ground using the bridge over the High Speed Circuit. The bridge has a single carriageway controlled by traffic lights and limited to a maximum weight of 42 tonnes. Egress is normally via a tunnel under the High Speed Circuit at the Southern end of the Proving Ground but there is a height limit of 2.9m (9ft 3in). Vehicles higher than this limit may exit via the entrance bridge.

Arrival

Customers' personnel must always report first at the MIRA Gatehouse on arrival and must wait there until instructed to proceed to the wind tunnel. An escort will be provided when necessary.

Admission into the Wind Tunnel

During normal working hours customers' personnel should report to the door at the front of the wind tunnel building, inside the area enclosed by a wooden security fence. There is a switch for a bell to the side of the door which will call for a wind tunnel operator to open it.

The main roller-shutter door provides access for test vehicles. A higher degree of confidentiality can be maintained either by unloading test vehicles inside the wind tunnel building itself or by closing the gates to the enclosure at the front of the facility.

In the interests of safety, pedestrian access through the main roller-shutter door is to be discouraged. The wind tunnel operators will normally be awaiting the customers' arrival at the facility.

Late Arrival for Night Sessions

If, for any reason, the test team is delayed and unable to arrive by the time specified for the commencement of testing, every effort should be made to notify the wind tunnel operators since they will only normally wait for 1 hour past the agreed time before leaving. If no notification is received within this period, the booking will be taken to be cancelled and the appropriate charge made.

Outside of the normal MIRA working day the telephone number for the wind tunnel is +44 (0)24 7635 5413 and the Gatehouse number is +44 (0)24 7635 5377.

4.1.6 Preparation, Removal and Storage of Test Vehicles and Equipment

Preparation and Setting-up of Test Vehicles and Equipment

The test sessions defined in section 4.1.3 include preparation and removal of the test vehicle and equipment. Any additional preparation in the wind tunnel that may be required before the start of the test session can only be arranged if a member of MIRA staff is present at that time.

Test equipment in the control room is to be placed only in positions agreed with MIRA staff. This is to avoid marking or damaging painted or polished surfaces by equipment placed on or against such surfaces. Tools and test components must be stored in the workshop area.

Removal and Storage of Test Vehicles and Equipment

All test vehicles and equipment must be removed from the wind tunnel and control room before the end of a session to avoid delay and inconvenience to other customers using the facilities in the following session. Test vehicles and/or equipment required for any subsequent work may, however, be stored (at the customer's risk) in one of the external garages described in section 2.1.4. A charge is made for the overnight use of these areas.

4.1.7 Security

Customers' Security

All MIRA wind tunnel staff have been instructed on the necessity and methods of maintaining commercial security. Under normal conditions, the doors to the wind tunnel hangar may only be opened from within, or by a Card-Key system in the cases of the personnel door at the front of the hangar and the side door opposite the Fluids Systems Engineering Centre.

Except for immediate entrance and exit of vehicles or personnel, all access doors are kept closed at all times.

Under normal conditions of security, which are provided unless the customer requests otherwise, the only personnel allowed in the wind tunnel areas are the MIRA wind tunnel and maintenance staff, and personnel cleared specifically by the customer using the wind tunnel.

The security required can be guaranteed only if the above procedures are followed by all concerned, including test personnel from customers' companies.

Security as detailed above only applies during test sessions, and the security of test vehicles and equipment at other times shall be the sole responsibility of the customer.

Other Firms' Security

Customers' personnel are expected to respect the security requirements of other firms using the wind tunnel facility and the MIRA Proving Ground. In particular, vehicles and equipment belonging to other firms must not be examined or photographed.

4.1.8 Use of Cameras

The following statement is applicable to the use of cameras

1. No cameras may be taken onto the Proving Ground by users; MIRA does, however, offer a photographic service which also covers the Proving Ground.

Exceptions to the above rule may be allowed by the Managing Director of MIRA if the user is accompanied by a member of Proving Ground staff, which will need to be arranged in advance and will be charged for.

The only exceptions that can be granted by the Proving Ground Manager are for certain cameras fixed in vehicles to photograph instrumentation. Such installations must be declared to and inspected by the Proving Ground Manager or his deputy before permission can be granted.

2. Cameras may not normally be taken into an office or laboratory area by visitors (customers or otherwise) except where expressed permission has been granted by the Managing Director of MIRA.

The only exception to the above rule will be in the case of cameras used for high-speed photography, where the cameras will only be used in a laboratory and under controlled conditions where it is not possible for confidential items to be inadvertently photographed.

As the wind tunnel is located in the laboratory area within the Proving Ground, it is subject to the above restriction on the use of cameras, Customers' staff (and any other visitors) must

therefore declare, on arrival at the Security Gatehouse, any cameras in their possession and must leave these at the Gatehouse.

In most cases it is expected that customers' photographic requirements in the wind tunnel will be met either by employing a MIRA photographer or by using the camera provided at the wind tunnels for customers' use.

Where these arrangements are not sufficient for the customer's particular requirements, however, it will be possible for a member of the wind tunnel staff to fetch the customer's camera from the Gatehouse and to return it there after the test for collection by the customer on leaving the MIRA premises. In this case, and when the wind tunnel camera is used by a customer, photography will be allowed only within the wind tunnel buildings and under MIRA supervision.

4.1.9 Safety

Safety of Customers' Staff on MIRA Premises

For their own safety, customers' staff are required to follow the procedures laid down in these notes and to accept the authority of the wind tunnel operators if they deem that any procedure suggested by the customers' staff is unsafe.

PAT Testing

All electrical equipment brought in by the customer must have current electrical safety certification.

Lifting Equipment

The provision of safe lifting equipment for use in the wind tunnel is the responsibility of MIRA.

All equipment available for use by the customer whilst working in the facility is certified and regularly checked by a specialist contractor.

To maintain this standard and to comply with the Factories Act, 1961, customers should refrain from supplying their own lifting tackle unless a current Test Certificate is provided and the tackle has been examined by a competent person within the previous six months.

Jack and Axle Stands

Vehicle or hydraulic jacks should not be regarded as sufficient support for a vehicle if it is intended to work under the vehicle. In these circumstances axle stands must be placed under the vehicle in approved locations to fully support the vehicle. This equipment will be made available by the MIRA staff assigned to work with the customer.

An exception to the use of axle stands will be permissible, e.g. in the event of a need to change a wheel, when no part of the worker's body is beneath the vehicle or if the need arises to move a vehicle using a trolley jack.

Brake Testing on the Chassis Dynamometer

All brake testing carried out in the FSWT must be restricted to asbestos-free friction materials. Any customer proposing to carry out such tests is asked to provide a written assurance that this restriction will be strictly observed.

Fire Precautions

Two types of fire extinguisher are provided; foam extinguishers for petrol fires and Carbon Dioxide (CO₂) extinguishers for other fires.

On Discovering a Fire

If the fire cannot be extinguished quickly using the portable fire extinguishing equipment without risk or injury:-

- Activate the local fire alarm by breaking the glass of the nearest fire alarm point. Using the internal telephone system dial 5555 for 24-hour answering service and tell Security the location of the fire and the action taken. The Security Officer will call the Fire Brigade. In the event of no reply, contact the Nuneaton Fire Brigade by dialling 9-999 and inform Security on 5555 as soon as possible thereafter.
- If two or more people are present, they can then try to contain the fire, using the portable fire extinguishing equipment provided.
- If the situation becomes hazardous, ensure, as far as possible, that no-one is trapped by the fire. Shut down or render safe all machinery and exit by the nearest escape route, closing doors behind you to prevent the spread of fire and smoke, and report to the assembly point which is behind the wind tunnel hangar.

An emergency exit is provided in the hangar wall opposite the control room, and both personnel doors (i.e. those fitted with Card Key locks) can be opened, at any time, from inside the hangar using release buttons mounted to the sides of the door frames.

On Hearing the Fire Alarm

- Shut down any machinery that you are involved with. Unless you are involved in fighting the fire, make your way to the assembly point behind the wind tunnel hangar regardless of where you are at the time.
- Close all doors behind you to prevent the spread of fire and smoke.
- Make sure that everyone you meet, who is not involved in fighting the fire, is leaving the building.
- Do not re-enter the building to collect personal effects.
- If and when it is safe to enter the buildings, an announcement will be made at the assembly point.

Tunnel Operation

- (a) A warning bell is sounded whenever the main fan motors are going to be started, as a signal to personnel in or around the wind tunnel.
 - (b) No personnel are allowed to remain inside the tunnel (except in a test vehicle) at wind speeds greater than 65km/h (40mph).
-

-
- (c) Ear defenders are available and should be worn by all personnel who are not within the protection of the control room or the workshop when the wind tunnel air speed is above 80km/h (50mph).
 - (d) Guards are provided to prevent trapping in the dynamometer rolls, and these must always be in position when the dynamometer is in use.
 - (e) It must be ensured that all small loose items (screws, nuts, washers, spanners etc) are removed from the working section of the wind tunnel before every test run.
 - (f) Test vehicles or models must be structurally capable of withstanding the air pressures imposed, particularly with regard to removable panels and small items.
 - (g) Tyres must be in good condition for dynamometer tests. For high power or high speed tests, the tyre pressure should be increased by 0.4bar (6PSI).
 - (h) For dynamometer tests of vehicles with drum brakes, the brake shoe adjusters must be released on the test axle to prevent accidental application of the vehicle's brakes.

4.1.10 Care of MIRA Equipment and Premises

- (a) Customers will be responsible for all loss or damage attributable to their staff.
- (b) To avoid the possibility of damage to the measuring equipment of both the balance and the dynamometer, all vehicle movements within the wind tunnel working section should be carried out as gently as possible.
- (c) Care should be taken to avoid any substantial spillage of oil or water on the balance turntable or the dynamometer cover plates.
- (d) If clay modelling work (or similar) is done inside the wind tunnel working section then care must be taken not to deposit any material near to the balance pads in the floor as this may interfere with the operation of the balance.

In addition, any vehicle movements within the hangar and wind tunnel should be made at low speeds only, and horn warnings should always be given on entry to the hangar.

4.1.11 Insurance

Customers are advised of the absence of any MIRA insurance for damage to their equipment during tests or use, etc and when it is not caused by MIRA negligence.

MIRA expects the customer to insure all equipment supplied by them whilst it is here unless arranged otherwise with MIRA. If MIRA is to take out special insurance, the following details will be required to be confirmed in writing:

1. A description of the equipment sufficient to identify it.
2. The value for which it is to be insured.
3. The period for which the insurance should last.
4. The purpose for which the equipment is at MIRA.

It is preferable that insurance arrangements be made by the owner of the equipment, since the cost will usually be less than if MIRA undertakes it.

4.1.12 Tools

Test teams are required to provide their own tools for work on vehicles.

4.1.13 Canteen Service

Lunches can be obtained at Lindley's Restaurant on MIRA's main site between 12:00hrs and 13:30hrs from Monday to Friday. A breakfast service is also available from 08:00hrs to 10:30hrs, Monday to Friday.

Hot drinks are available at all times from a dispenser outside the control room in the FSWT and a microwave oven is available in the wind tunnel for heating pre-prepared food.

Cold drinks are available from a vending machine in the reception area of the Fluids Systems Engineering Centre adjacent to the wind tunnel.

4.2 MIRA Wind Tunnel Terminology

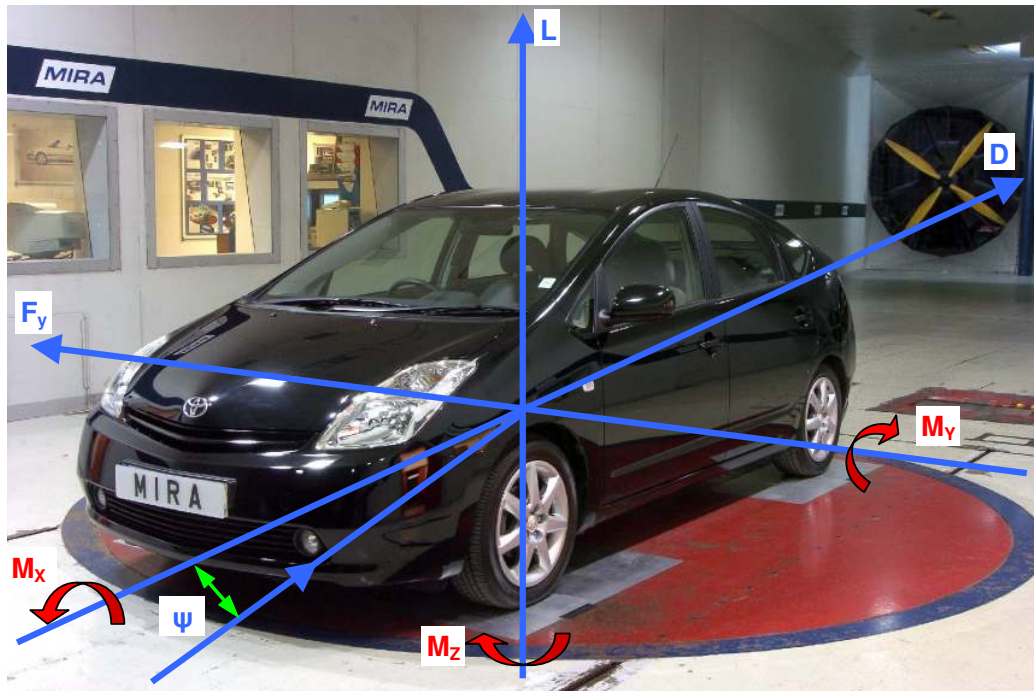


Figure 1: Wind Tunnel Axis System

Notation	Meaning	Notation	Meaning
D	Drag ($-F_x$)	MX	Rolling moment
L	Lift ($-F_z$)	MY	Pitching moment
F_y	Side force	MZ	Yawing moment
V	Relative wind velocity	ψ	Yaw angle

All forces and moments are shown in their positive directions.

The moment centre is taken to be at the centre of wheelbase, track and in the plane of the ground.

If an alternative moment centre has been used, this is indicated by quoting the X-axis and Z-axis offsets, respectively forward from and below (both positive) the standard moment centre specified above.

X-axis offset is **positive** if **forward** of the standard moment centre
negative if **aft** of it.

Z-axis offset is **positive** if **below** the standard moment centre
negative if **above** it.

Derivation of Aerodynamic Coefficients

C_D	Drag coefficient	$D / (q \cdot A_F)$	[1]
C_L	Lift coefficient	$L / (q \cdot A_F)$	[2]
C_Y	Side force coefficient	$F_Y / (q \cdot A_F)$	[3]
C_{Mx}	Rolling moment coefficient	$M_X / (q \cdot A_F \cdot L)$	[4]
C_{My}	Pitching moment coefficient	$M_Y / (q \cdot A_F \cdot L)$	[5]
C_{Mz}	Yawing moment coefficient	$M_Z / (q \cdot A_F \cdot L)$	[6]
C_{YF}	Front axle side force coefficient	$\frac{1}{2} \cdot C_Y + C_{Mz}$	[7]
C_{YR}	Rear axle side force coefficient	$\frac{1}{2} \cdot C_Y - C_{Mz}$	[8]
C_{LF}	Front axle lift coefficient	$\frac{1}{2} \cdot C_L + C_{My}$	[9]
C_{LR}	Rear axle lift coefficient	$\frac{1}{2} \cdot C_L - C_{My}$	[10]
X_{CP}	Lateral Centre of Pressure forward from moment centre, expressed as percentage of reference length (wheelbase)	$100 \cdot C_{Mz} / C_Y$	[11]

Where:

- q Reference dynamic pressure, $\frac{1}{2} \rho V^2$
- ρ Density of air, taken as 1.226kg/m³ for the standard atmosphere (15°C, 101325Pa)
- A_F Projected frontal area of test vehicle / object
- V Reference wind speed
- L Reference length for moments, normally taken as the wheelbase of the vehicle

Aerodynamic force and moment coefficients may be converted back into forces and moments at any given speed by means of the following equations:-

Force	$F = 4.73 \times 10^{-2} \cdot C_F \cdot A_F \cdot V^2$	Newtons	(N)	[12]
	$F = 2.56 \times 10^{-3} \cdot C_F \cdot A_F \cdot V^2$	Pounds-force	(lb)	[13]
Moment	$M = 4.73 \times 10^{-2} \cdot C_M \cdot A_F \cdot L \cdot V^2$	Newton-metres	(Nm)	[14]
	$M = 2.56 \times 10^{-3} \cdot C_M \cdot A_F \cdot L \cdot V^2$	Pounds-feet	(lbft)	[15]

Where:

- C_F Any of the above aerodynamic force coefficients
- C_M Any of the above aerodynamic moment coefficients

For S.I. units of force and moment, the frontal area is given in m² and the wind speed in km/h.

For Imperial units of force and moment, the units used in the calculations are ft² and mph.

Note that it is necessary to be consistent with the use of units in these calculations.

Similarly, the power requirement to overcome aerodynamic drag at a given speed can be calculated thusly:

$$P_D = 1.313 \times 10^{-5} \cdot C_D \cdot A_F \cdot V^2 V_v \quad \text{kW} \quad [16]$$

$$P_D = 6.83 \times 10^{-6} \cdot C_D \cdot A_F \cdot V^2 V_v \quad \text{bhp} \quad [17]$$

where V and V_v are as defined below and for zero wind speed $V=V_v$. The relative wind speed V and the yaw angle ψ are functions of the vehicle's road speed (V_v) and the natural wind speed and direction (V_w and θ) thus:

$$V = \sqrt{\{(V_v + V_w \cos \theta)^2 + (V_w \sin \theta)^2\}} \quad [18]$$

$$\psi = \tan^{-1} \left\{ \frac{V_w \sin \theta}{(V_v + V_w \cos \theta)} \right\} \quad [19]$$

4.3 Frontal Area Measurement Procedure

A camera with a long-focus lens is set up in front of the vehicle at a distance of 60m from a plane at the approximate maximum cross-section of the vehicle (typically around the mid-length of the front doors). The camera is aligned with the plane of centreline symmetry of the vehicle and is at approximately half the vehicle height above the concrete floor that extends from the camera to the scale background behind the car. This background is at a distance of 65m from the camera lens and is at present marked with a striped pattern to allow easy identification of the outline of the vehicle, particularly in areas where the surface is predominantly flat. A scale is also marked on the background.

The photographic print thus obtained shows the outline of the car against a scale which is taken to represent a 2.40m by 1.20m rectangle at the assumed plane of maximum cross-section. On this print a planimeter is used to measure first the area of the rectangle on the scale board which is visible around the vehicle outline. Then the area within the vehicle outline is measured and is scaled in accordance with the result of the first measurement.

The accuracy of the planimeter is reckoned to be within $\pm 1\%$ and the errors due to perspective effects are estimated to range from -1% to $+3\%$.

A detailed explanation based on the US Environmental Protection Agency specification OAWM/MSAPC/AC73 is available on request.

4.4 Derivation of Aerodynamic Force and Moment Coefficients in the FSWT

In the standard MIRA notation the forces and moments are resolved about a moment centre at ground level, mid-track and mid-wheelbase (see section 4.3).

The reference dynamic pressure, q , is evaluated from a measured dynamic pressure value at the entrance to the wind tunnel test section with a correction factor to account for the increase in flow speed local to the vehicle due to the effective constriction formed by the partial blockage of the test section by the vehicle. The correction applied is the simple 'Solid Blockage' dynamic pressure correction as described by Herriot¹

The measured dynamic pressure is corrected based on the ratio of the vehicle frontal area to the test section's cross-sectional area:

$$q_{corr} = q_m \cdot \left(\frac{A_r}{A_r - A_F} \right)^2 = q_m \cdot b^2 \quad [20]$$

¹ Herriot, J.G., "Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels with Consideration of the Effect of Compressibility", TR995, 1950.

Where:

- q_{corr} Corrected reference dynamic pressure
- q_m Measured reference dynamic pressure
- A_T Cross-sectional area of the wind tunnel test section (34.93m², or 376ft²)
- b Blockage ratio

The aerodynamic forces are measured on 6 load cells in roughly the following arrangement:-

Load Cell	Force or Moment
1	Lift force at front
2	Lift force at rear, right hand side
3	Lift force at rear, left hand side
4	Front side force and yawing moment
5	Rear side force and yawing moment
6	Drag force

The geometrical layout of the balance is such that these load cells do not normally coincide exactly with the vehicle's wheel positions, and therefore the vertical and lateral wheel loads are not measured directly. The interactions between the six load cells are determined by calibration of the balance and are allowed for in the computer-processing of the measurements.

4.5 Horizontal Buoyancy Correction

The static pressure gradient which creates the 'horizontal buoyancy' effect is the result of the growth of boundary layers along the walls, roof and floor of the parallel-walled test section. The boundary layers reduce the effective cross-sectional area of the airstream, forcing the flow to accelerate, with a commensurate drop in static pressure along the length of the test section.

The mechanism by which the drag is modified by the static pressure gradient is that (δA_F) of the projected frontal area of the vehicle is subject to an additional pressure differential which is proportional to the longitudinal distance (L_{FR}) between the front and rear-facing surfaces at that point. Thus, the total incremental drag is given by:-

$$q \quad \Delta D_B = -\Sigma \left(\delta A_F L_{FR} \frac{dp}{dx} \right) = -Q \frac{dp}{dx} \quad [21]$$

where Q is the volume of the complete vehicle and, hence, the incremental drag coefficient is:-

$$\Delta C_{DB} = \left(\frac{-Q}{\frac{1}{2} \rho V^2 A_F} \right) \cdot \frac{dp}{dx} = -\frac{Q}{A} \cdot \frac{dC_p}{dx} = L_m \frac{dC_p}{dx} \quad [22]$$

Where L_m is the 'mean length' of the vehicle, such that $Q = A_F \cdot L_m$

In the application of this correction to data in the MIRA FSWT, the measured value of dC_p/dx of -0.0028 per metre has been adopted, and the correction has been made a function of overall length (L_0), thus:

$$\Delta C_{DB} = 0.0028 \cdot L_0 \cdot (L_m/L_0) \quad [23]$$

where L_0 is in metres, and the ratio (L_m/L_0) is taken to be a constant for each type of vehicle configuration, as follows:-

Vehicle Type	L_m/L_0
Pick-up trucks or sports cars	0.7
Notch-back, fast-back or hatch-back saloon cars, station wagons / estates and vans with bonnets	0.8
Forward-control vans	0.9

Since the likely range of values of ΔC_{DB} is only from 0.006 to 0.013, it will be seen that the broad categorisation of vehicle types above is adequate for practical purposes. It is also considered sufficiently accurate to assume a constant value of ΔC_{DB} over the normal test range of yaw angles, i.e. $\pm 30^\circ$, and to ignore any effects on side force and yawing moment coefficients. The correction applied to all data from the wind tunnel (since 1st May 1981) is therefore the subtraction of ΔC_{DB} as defined above, from the measured values of C_D together with the consequent changes in pitching moment, as indicated in section 4.5.

4.6 Calculation of Vehicle Weight Distribution

In the FSWT the weight and centre-of-gravity position of the test vehicle are measured and recorded.

The data is reported in units of kilogrammes and metres of displacement from the vehicle reference centre. Note that the displacement value is positive in the following directions:

forward	(X)
right	(Y)
downward	(Z)

To derive the axle loads from the weight (W), wheelbase (WB) and reported centre-of-gravity position (both in metres), the following formulae are used:-

$$\text{Front axle load (kg)} = W \cdot (1/2 + X_{CoG} / WB) \quad [24]$$

$$\text{Rear axle load (kg)} = W \cdot (1/2 - X_{CoG} / WB) \quad [25]$$

4.7 Calculation of Static Pressure Coefficients

The static pressure, p , at any point on a vehicle, either in motion on the road or stationary in a wind tunnel, is dependent on:

- (i) The static pressure, p_0 , of the surrounding air, undisturbed by the presence of the vehicle.
 - (ii) The dynamic pressure, q , experienced by the vehicle as a result of the relative velocity between the vehicle and the surrounding air.
-

The pressure coefficient, C_P , is a non-dimensionalisation which takes into account these factors and thereby gives a generalised representation of the static pressure around a body. It is defined as:

$$C_P = \left(\frac{p_{local} - p_0}{q} \right) \quad [26]$$

In wind tunnel pressure measurements it is usually required to determine the values of the pressure coefficient at various points on the vehicle, so that the pressures on these points can be estimated for any speed of the vehicle on the road. The above equation is therefore reversed to:

$$p_{local} = p_0 + (C_P \times q) \quad [27]$$

where p_{local} , p_0 and q are obtained usually from readings of either a pressure transducer or an inclined-tube manometer. Now p_{local} can be obtained directly from the pressure measurement for the static probe at the point of interest on the vehicle, but p_0 and q must be calculated from the pressure readings from the reference Pitot-static head on the wall of the wind tunnel working section. These reference readings must also be corrected to allow for the effects of solid blockage due to the presence of the test vehicle in the wind tunnel. The corrections are as follows:-

$$q_{corr} = b^2 \cdot (H - p_1)_0 \quad [28]$$

Where H is the reference total (Pitot) pressure, p_1 , is the reference static pressure and b is the blockage ratio, as defined in section 4.6. The blockage ratio has no effect on the total (Pitot) pressure so it can be assumed that the total pressure at the vehicle is the same as the reference value, H . The static pressure, p_0 at the vehicle will then be given by:

$$p_0 = H - q_{corr} \quad [29]$$

The values of q_{corr} and p_0 obtained using these equations can then be used for calculating the values of C_P at all the static pressure probe positions on the vehicle.

4.8 Calculation of Tractive Effort, Power and Rolling Resistance on the Dynamometer

To derive Tractive Effort, Power or Rolling Resistance, it is necessary to measure:

- (i) The torque reaction on the roller axle casing
- (ii) The dynamometer roller speed.

Tractive Effort (TE) at the wheels is given by:

$$TE = (K.R) + \text{drum windage} \quad [30]$$

where:

K	Calibration factor (force/division) for the dynamometer load cell link position in use
R	Increment above the load cell zero reading with the vehicle off the dynamometer and the rollers running at very low speed
drum	Proportional to the square of the simulated road speed (V). equal to 93.5N (21lb)
windage	at 100km/h (62mph)

Power at the wheels is given by:

$$\text{kW} = \text{TE} \times \text{V} / 3600 \quad \text{or} \quad \text{hp} = \text{TE} \times \text{V} / 2683 \quad [31]$$

where V is in km/h and TE is in N.

$$\text{kW} = \text{TE} \times \text{V} / 808 \quad \text{or} \quad \text{hp} = \text{TE} \times \text{V} / 603 \quad [32]$$

where V is in mph and TE is in lb.

Rolling Resistance of the tyres, bearings, transmission etc, is given by:

$$\text{RR} = (\text{K.R}) - \text{drum windage} \quad [33]$$

where K, R and drum windage are as defined above.

5 Appendix A - Travel & Accommodation Information

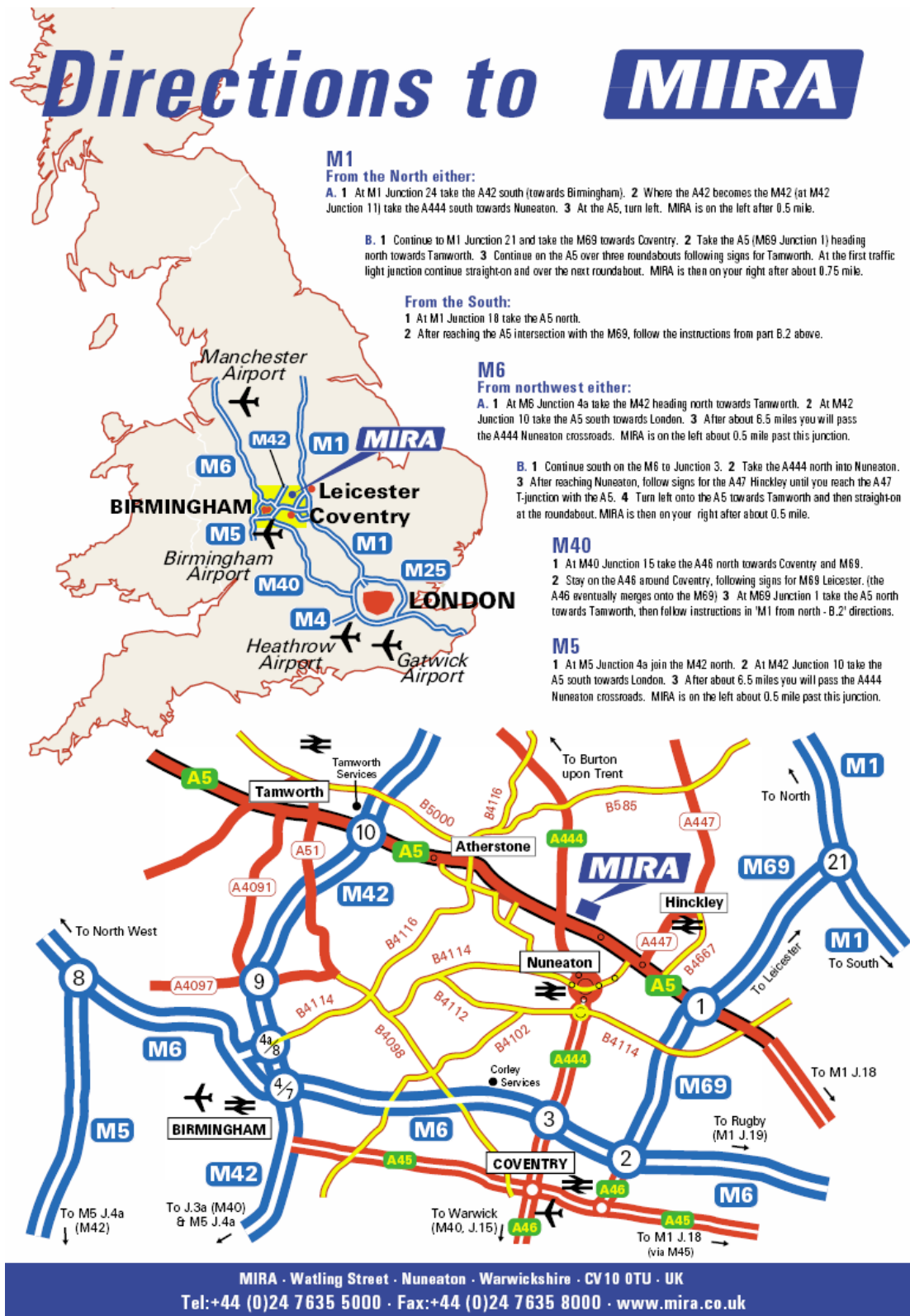


Figure 2: Location map and directions to MIRA.

Hotel Accommodation

A fairly comprehensive list of accommodation local to MIRA is given in the table below, but some alternatives, or more information about those in this list, can be obtained from the following websites.

www.smoothhound.co.uk
www.accommodationsuk.com
www.hotels.uk.com

www.bedandbreakfasts.co.uk
www.hotelsguesthouses.co.uk
www.where2stay.uk.net

Name	Phone Number	Distance From MIRA (miles)	*Rating (approx)	Approximate Rate for mid-week Single Room/ night (£)
The Allesley Hotel	02476 403272	12	3*	MBN
Ansty Hall Hotel	02476 612222	10	3*	75:00
Apple Orchard Farm (Dadlington)	01455 213186	5	N/A	20:00
Bosworth Hall	01455 291919	8	4*	75:00*
Brandon Hall	0870 400 8105	10	4*	85:00*
Britannia Hotel	02476 633733	15	4*	60:00*
Brookside	01455 637089	5	N/A	20:00*
Burbage Guest House	01455 615990	10	N/A	55:00
Chapel House	01827 718949	3	N/A	52:50
Chestnuts The (Grendon)	01827 331355	5	N/A	38:00
Coombe Abbey	02476 450450	10	4*	MBN
Coventry Hill	02476 402151	22	4*	55:00*
Forest of Arden	01676 522335	20	N/A	107:00
Hinckley Island Hotel	01455 631122	5	4./5*	82:00*
High Cross House	01455 220840	7	4*	25:00
Hill House (Caldecote)	02476 396685	1/2	N/A	25:00
Hilton - Coventry	02476 603000	10	4*	95.00*(MBN)
The Hyland Hotel	02476 501600	18	N/A	86:00
Leicester Holiday Inn	0116 531161	15	4*	145:00
Le Meridian (Formally known as Chesford Grange)	01926 859331	18	N/A	85:00*(MBN)
Lloyds White Wing	01827 716100	2	3*	60:00
Manor Farm (Upton)	01455 212374	5	N/A	22:50
Manor Hotel The	02476 343300	3	N/A	20:00
Millers Hotel	01827 880223	5	3*	55:00*
Novotel (Coventry)	02476 365000	12	3*	65:00
The Old Red Lion Hotel	01827 713156	5	2*	35:00*
Park Farm House(Barnacle)	02476 612628	6	N/A	39.50*
Forte Posthouse Coventry	02476 613261	22	N/A	87:00
Royal Arms The	01455 290263	10	N/A	50:00*
Royal Court The	02476 334171	10	3*	55:00*
Sketchley Grange Hotel	01455 251133	4	N/A	79:00*
Sparkenhoe Farm House	01455 213203	4	N/A	25:00
Stakis Birmingham Metropol	0121 7804242	25	4*	96:00*
Stakis Leicester	01162 630066	10	4*	145:00
Forte Travelodge (A444)	0870 1911562	5	N/A	44:95
Forte Travelodge (St. Nic.Park)	0870 1911594	3	N/A	44:95
Ullesthorpe Court Hotel & Golf Club	01455 209023	12	3*	80:00
Vale Farm (Higham on the Hill)	01455 212236	1	N/A	30:00
Woodlands Guest House The	01455 617434	3	N/A	20:00
Ye Old Red Lion	01455 291713	8	1*	20:00

MBN – May be negotiated at time of booking

* denotes MIRA Corporate Rate

6 Appendix B - Wind Tunnel Technical Information

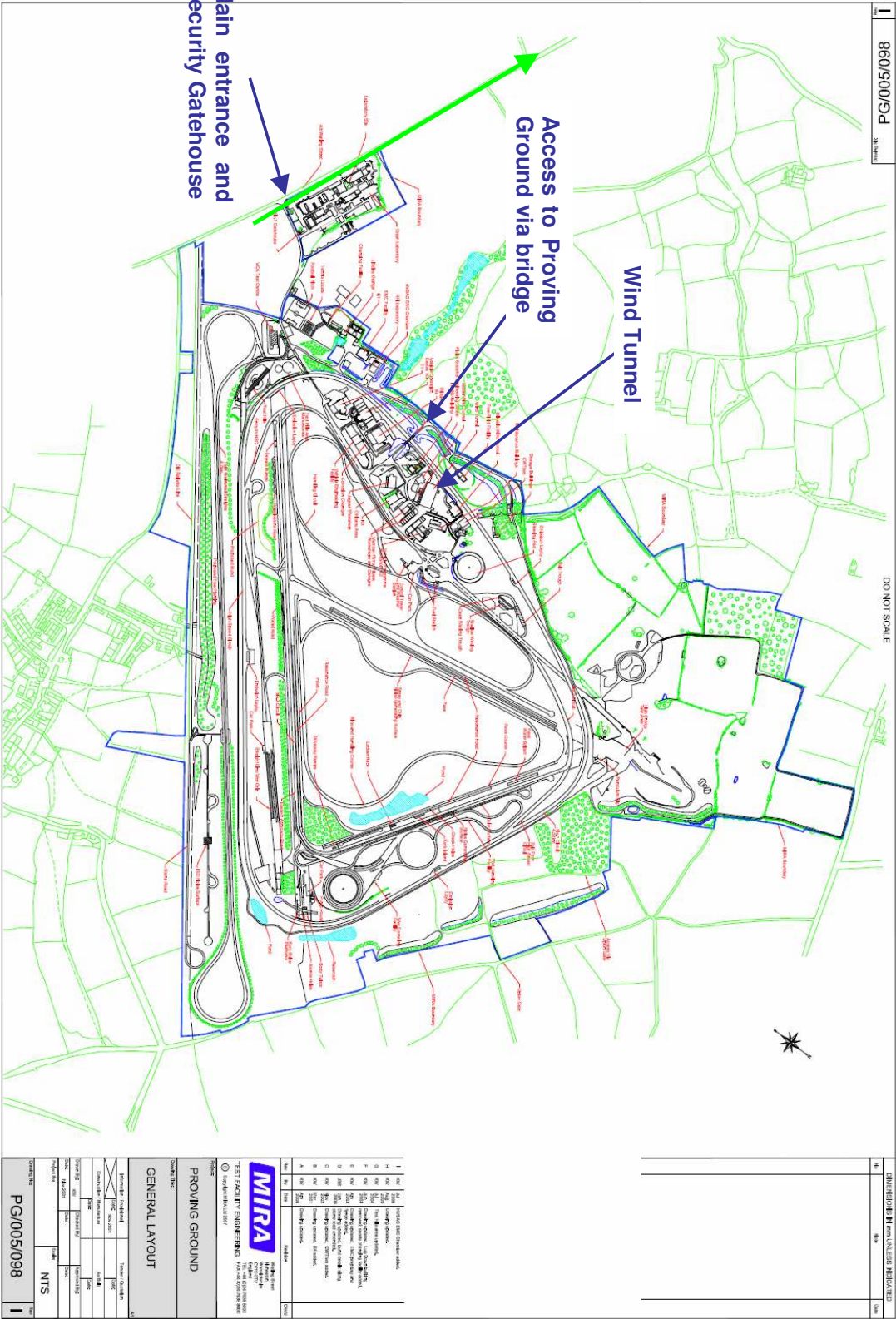


Figure 4: Full Scale Aerodynamic Wind Tunnel schematic

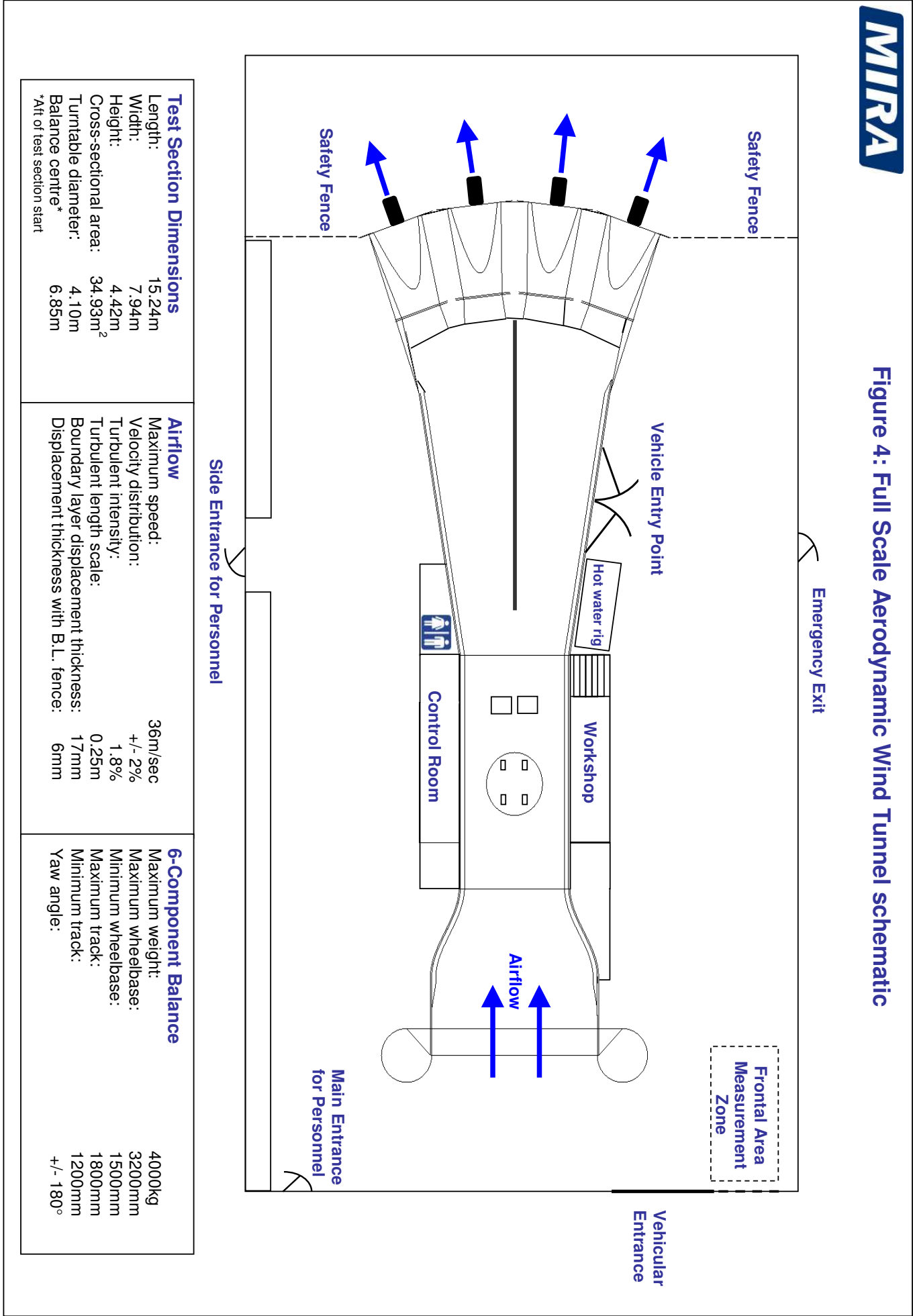


Figure 5: FSWT mounting points and connections

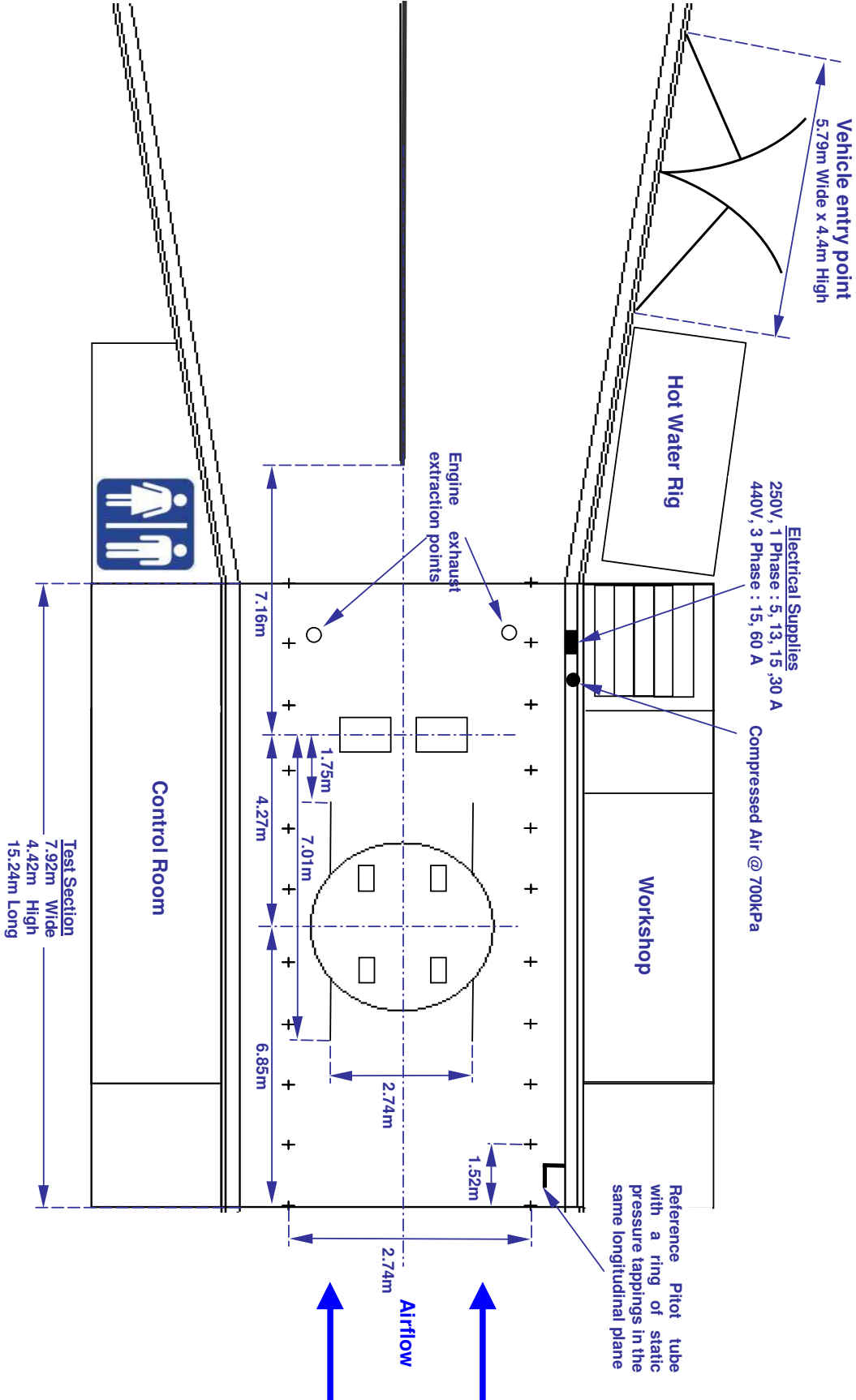


Figure 6: FSWT balance turntable & mounting arrangements

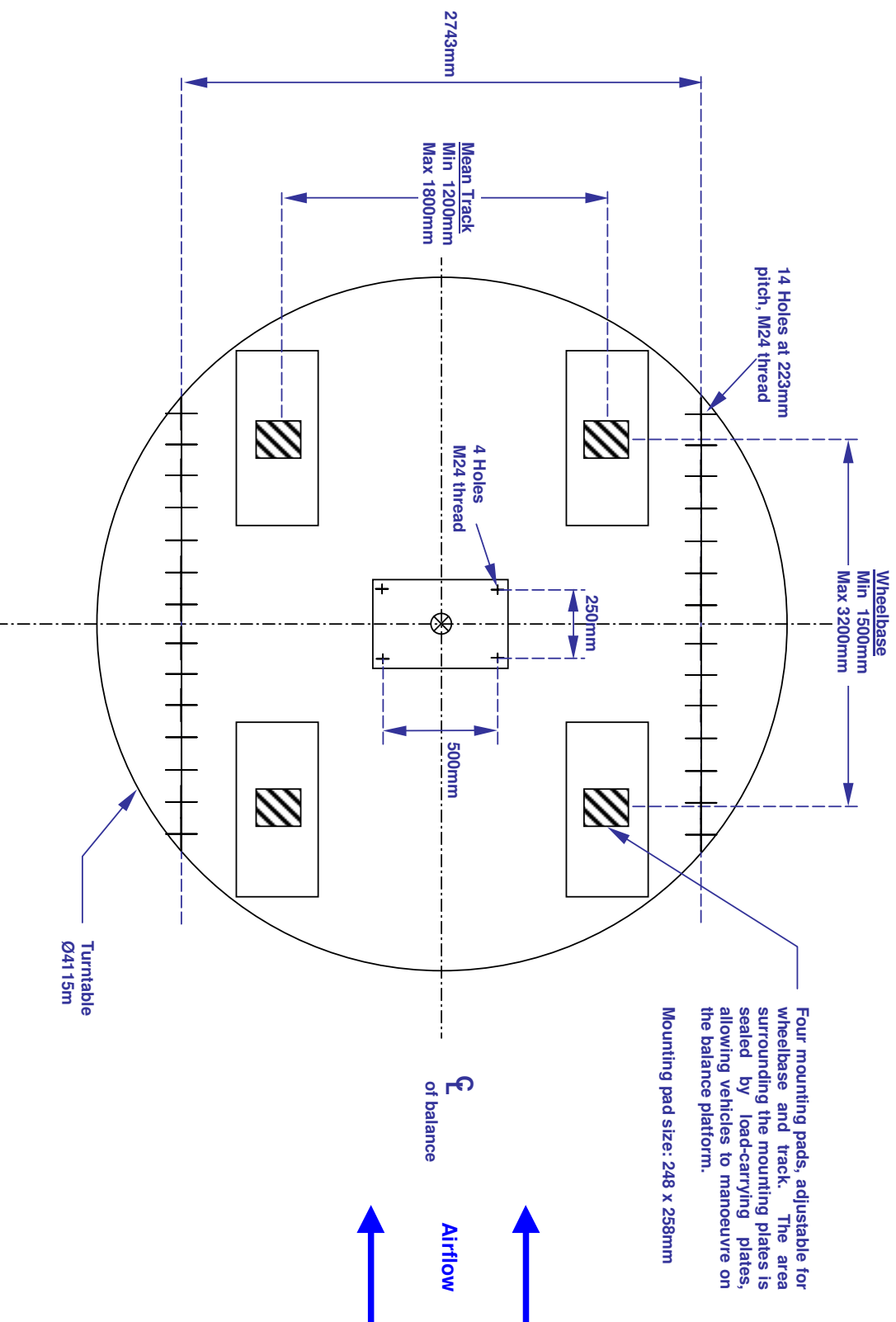


Figure 7: Surface-mounted static pressure probe dimensions

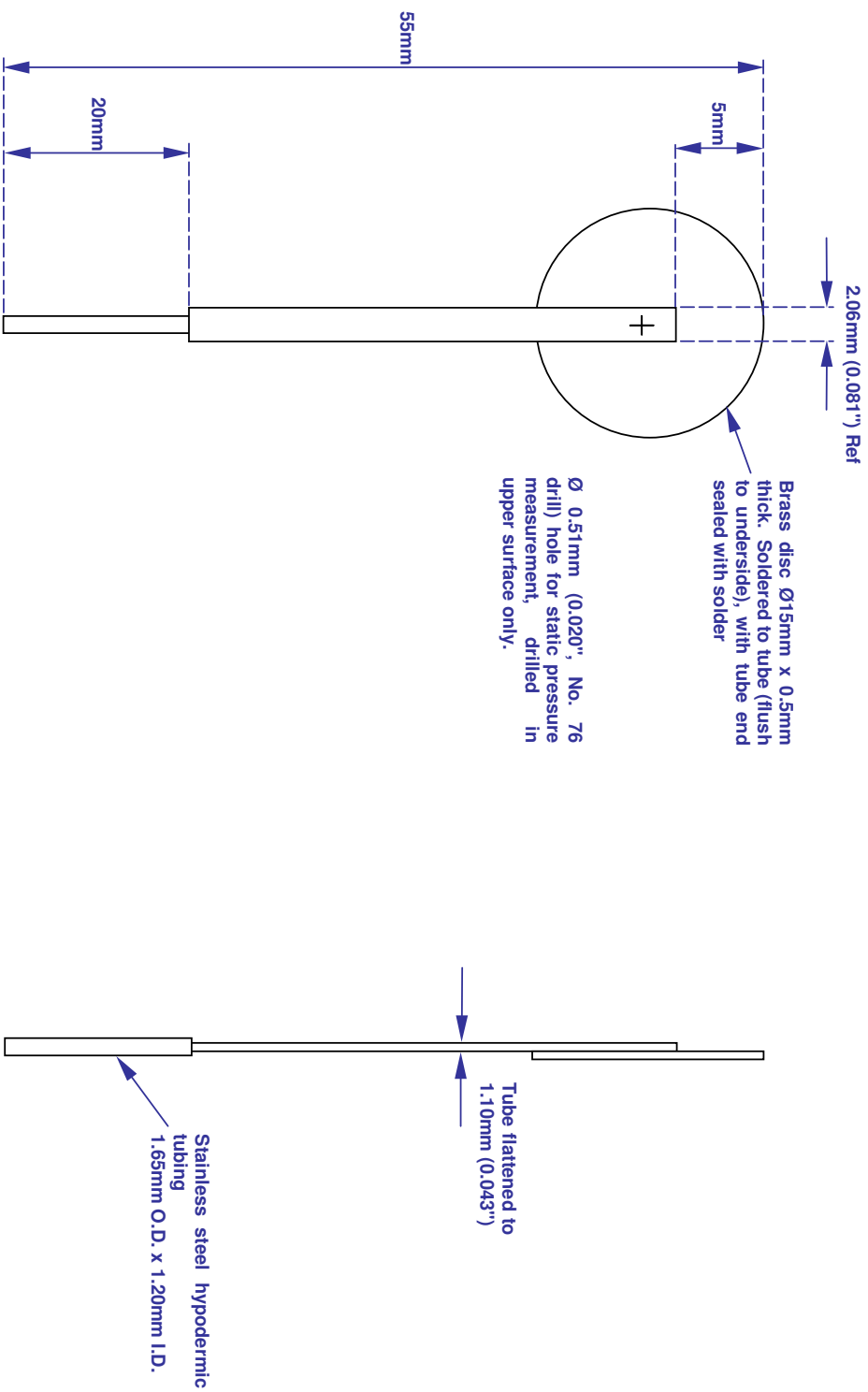


Figure 8: Dynamometer envelope of tractive force absorbtion vs. speed

