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Technical Report 93014

April 1993

A Guide to the DRA 13ft × 9ft Low Speed Wind Tunnel Facility

by

M. H. Hunter

Bedford, Bedfordshire

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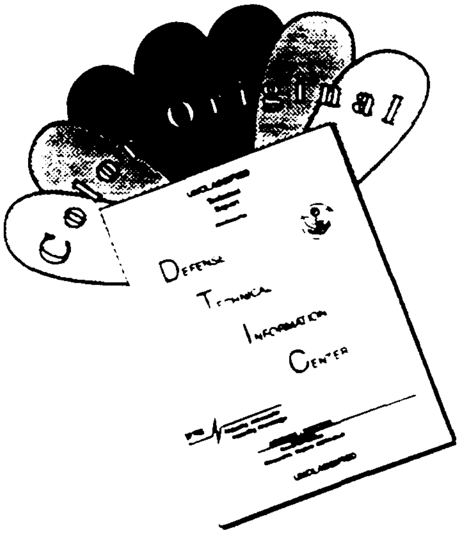

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A GUIDE TO THE DRA 13ft × 9ft LOW SPEED WIND TUNNEL FACILITY

by

M. H. Hunter

SUMMARY

This Technical Report is intended to provide a guide to the 13ft × 9ft Low Speed Wind Tunnel facility. It details the model support and balance assemblies, provides an insight to the instrumentation and computing capabilities and indicates the different flow visualisation techniques available. A description of the tunnel and local facilities is included, along with contact numbers for customers' use.

Facing page: The 13ft × 9ft Wind Tunnel facility operating into the night.

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Defence Research Agency
Farnborough Hampshire GU14 6TD UK

LIST OF CONTENTS

LIST OF CONTENTS (concluded)

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1 INTRODUCTION

This Report describes the DRA Bedford 13ft × 9ft Low Speed Wind Tunnel, and provides a comprehensive reference guide for all those wishing to use the facility. Details are also provided covering the wide range of auxiliary equipment normally used for model testing.

The Tunnel was constructed in the late forties to provide a low turbulence test facility. It formed part of a post war building programme of several such facilities at Bedford. The tunnel first ran in January 1954.

The facility is a closed circuit atmospheric tunnel with a maximum airspeed of 91 m/s. The tunnel provides an ideal low speed research test facility for both whole and partial models, offering a wide range of model support options from sting mounted, strut mounted and wire supported whole models to floor mounted half-models. Both static and dynamic measurements can be made, along with a variety of flow visualisation techniques, such as microtufts, oil flows and laser-smoke screens. The tunnel has a short startup/shutdown time, requires minimal user supervision and has (relatively) low operating costs.

2 LOCATION AND INFORMATION

DRA (formerly RAE) Bedford is located in rural Bedfordshire 5 miles north-east of Bedford (Fig 1). DRA Bedford (Tunnel Site) forms part of the Aerodynamics and Propulsion Department of the DRA (Defence Research Agency). The 13ft × 9ft Tunnel is located to the south of the Tunnel Site, separate from the other facilities. Access to the site is controlled and protected by Ministry of Defence Police (MDP) and access by non-UK nationals is subject to clearance by the Security Section. All DRA staff are subject to the Official Secrets Act and as such, are well versed in the confidentiality of third party commercial information. Accommodation is available in Bedford, from family run Guest Houses to 3 Star Hotels. Rail links to London (St Pancras) provide a frequent service, with air travel via Luton or London and major road links via the M1, A1 and A6.

Contacts at DRA are:

Head AP4 Division	- (0234) 225840
Tunnel Manager (13ft × 9ft Wind Tunnel)	- (0234) 225990
Fax (Head of AP4 Division)	- (0234) 225848
Fax (13ft × 9ft Wind Tunnel)	- (0234) 225180
Telex	- 82117
Address	- Defence Research Agency Bedford, MK41 6AE

and in Bedford:

British Rail	- (0234) 269686
Tourist Information	- (0234) 215226

Tunnel access:

Equipment access to the 13ft × 9ft Wind Tunnel is via the loading bay, then by cargo lift to second floor model rigging area. Cranes and lifting gear are available as required. 110V ac, 240V ac and 3 phase power is available for users' equipment in the control room.

NB. Restrictions apply to the use of radio broadcast equipment on the site due to the number of electronics systems on-site, and proximity of the nearby airfield.

2.1 Tunnel geometry and construction history

A view of the tunnel exterior and office block is shown in Fig 2, whilst a sectional drawing, Fig 3, illustrates the overall size and layout of the tunnel. Total circuit length is 244 m (800 ft). Construction started in 1948 and it was the first large, low speed tunnel in the country to incorporate design features to ensure low turbulence levels in the working section airstream.

Most of the tunnel shell is made from reinforced concrete, cast in eleven sections. To allow for expansion and movement each section is fixed at one end and supported on oil immersed roller bearings (each rated at 250 tons) at the free end. Steel bellows expansion joints couple the free and fixed ends. These sections were all cast on-site. The interior of the concrete walls have been smoothed down to prevent the air from separating from the wall. At each corner, concrete guide vanes with fixed wooden trailing edges are provided.

The diffuser angle is 5° and, at its beginning, eight vortex generators are evenly distributed around the floor, roof and walls. These are tapered fin-like structures of root chord 1.17 m, with a maximum thickness of 0.15 m and span 0.4 m. They have rounded-off tips and their lower surfaces are inclined at 12° to the airstream. They were installed to improve the uniformity of velocity distribution across the working section.

Eight spring loaded 'down wires' provide the first stage protection against damage from model departure. Their function is to deflect any large pieces of the model towards the floor, where the air velocity will decrease as it proceeds along the diffuser. At the end of the diffuser, before the first turning vanes, a 50 mm^2 mesh steel catch net is designed to stop large debris travelling any further. A final 150 mm high net is situated at the start of the second vanes, to trap any small debris.

A circular steel section houses the 6 bladed drive fan which is 9.35 m in diameter. The wooden blades are made of laminated mahogany with balsa tips. Maximum fan speed is 330 rev/min. Trip switches are mounted in the walls around the axis of rotation to shut down the drive should a blade start to detach from the hub (radial clearance is approximately 9.5 mm).

The settling chamber (maximum section) is octagonal in cross-section, with a breadth of 14 m , giving a contraction ratio of 16:1 to the working section. Provision was made for five turbulence reducing screens to be installed, but to date, only four have been fitted. The first two screens are 30 mesh × 33 SWG, (0.254 mm wire every 0.85 mm) and the second pair 14 mesh × 27 SWG (0.442 mm wire every 1.82 mm), all made of phosphor bronze material. To prevent the screens clogging and 'choking' the tunnel, two screens are removed and steam cleaned during the annual maintenance shutdown, in rotation. A grease band traps any small objects from accelerating into the working section and damaging the model.

The final section is a steel framed, timber lined test section, known as the working section (Fig 4). Measuring 13 ft (3.96 m) wide and 9 ft (2.74 m) high, it has corner fillets approximately 0.74 m across at the mid-streamwise station. The fillets taper slightly over the length of the working section to ensure negligible static pressure gradient. The point midway between the walls and roof and floor at the mid-streamwise station is the tunnel working section centre and hence the tunnel centre. Models are tested at (or near to) this centre.

It has been established that in a 2 m^2 reference plane, normal to the axis of the working section, the dynamic pressure is constant to within 0.05%. Turbulence levels (rms fluctuation) in the longitudinal direction were found to be 0.02% of $\bar{u}$ at 50 ft/s (15 m/s), rising to 0.04% of $\bar{u}$ of 200 ft/s (61 m/s). In the vertical and horizontal (transverse) directions, 0.02% of $\bar{u}$ rising to 0.1% of $\bar{u}$ for the same speed range[1].

Both the roof and floor are fitted with turntables (2.98 m and 3.18 m respectively) which revolve about the common axis of the tunnel centre. Some of the wood panels have been replaced with clear perspex to allow the use of a CCTV camera to monitor the model. Windows in both walls of the working section permit visual observation and allow for laser light sheet projection (see section 7.1).

At the downstream end of the working section, atmospheric vents are provided which take the form of streamwise slots, 260 mm long by 50 mm wide. 118 of these ring the tunnel at a fixed streamwise station. The vents are ducted to a chamber above the tunnel, where three one-way flaps allow the passage of air to the outside world. Two of the flaps are used to allow excess air to escape from the tunnel, and the third is used to allow air to enter. Thus air will enter or exit as required in order to maintain atmospheric pressure in the working section (the maximum pressure difference between the working section and the settling chamber is 37 mmHg = 0.71 psi = 103 lb/ft^2 = 4.93 kPa).

Aft of the vents are two braking flaps, which when retracted lie flush in the roof and floor. Each flap is 2.5 m by 1.1 m high and these rapidly reduce the airspeed to near rest when deployed. Activation is automatic or manual, but only initiates when the fan speed drops below a set level (20 m/s). This is to prevent flap deployment whilst the fan is still being driven.

2.2 Main drive - power and control

An 11 kV ac feed drives a 1144 kW ac synchronous motor via a solid state control system. The fan is coupled to the ac motor by a spiral bevel gearbox of ratio 3.37/1.0. Maximum power is 1.1 MW. A dedicated SCADA (Supervisory Control And Data Acquisition) system in the observation room is linked to the drive system and allows the tunnel operators to select the desired speed. Control of the drive and auxiliaries is automated with fault detection and diagnostics provided for the Engineering staff.

The speed control uses the relationship between the pressure in the working section and the pressure in the settling chamber. After the annual maintenance shutdown, a series of calibration runs are used to produced a speed v pressure difference equation. This is used as the basis for the following year's tests. Two modes of operation are available:

Auto - which uses the pressure relationship mentioned above,
or Manual - which drives the fan at a fixed rev/min.

The maximum controllable wind speed is 91 m/s (tunnel empty) and the minimum is 15 m/s. In addition to the computer calculation of speed, a secondary display of lights (red, yellow, white) gives a visual indication of percentage speed error, with 'on condition' being indicated by two whites.

Display	**Accuracy**
Two white lights	within 0.1% of set speed
One white light	0.1% < set speed < 0.15%
One amber light	0.15% < set speed < 0.2%
One red light	outside 0.2% of set speed

2.3 Tunnel specification

Commissioned:	1954
Working section:	3.96 m wide × 2.74 m high with corner fillets Total length 19.2 m (63 ft) Parallel section 10.97 m (36 ft)
Type:	Continuous, atmospheric, Closed return circuit

Speed:	15 to 91 m/s (Mach 0.27)
Reynolds number:	5×10^6 m^{-1} (maximum)
Power:	1.1 MW
Contraction ratio:	16:1
Turbulence:	Longitudinal 0.02% to 0.04% of $\bar{u}$
(bandwidth 2 Hz to 1 kHz)	Lateral 0.02% to 0.1% of $\bar{u}$
(Speed 15 m/s to 61 m/s)	Vertical 0.02% to 0.1% of $\bar{u}$.

3 MODEL SUPPORT AND CONTROL

This section describes the model support systems (Rigs) and their controllers. Details of the balances are given in section 4.

3.1 The sting rig

Model type:	Whole
Pitch:	±17° (plus offset)
Yaw:	±22°

Probably the most frequently used support mechanism of the 13ft × 9ft is the sting rig, which is designed to support whole models, via strain gauge balances (see section 4.1). The rig consists of two driveable leadscrews and a vertical pillar around which is the slide assembly (Fig 5). Both the leadscrews and pillar are mounted top and bottom on platforms, which in turn are connected to the upper and lower turntables. Thus the whole rig can be moved about the tunnel centre to produced yaw. The yaw angle is ±22°.

Height (distance of the model datum point above the floor) is adjusted by driving the two leadscrews in the same direction and at the same speed. This will cause the slide assembly (and hence the model) to rise or fall around the pillar. Pitch is adjusted by driving the leadscrews in opposite directions or at different speeds. The pitch range of the slide assembly is ±17°.

A sting (tubular steel shaft) connects to the slide assembly at one end, and to the balance at the other. The sting is usually cranked, to increase the model pitch angle. Several different cranks are available, but care must be taken that the balance axial load is not exceeded by too high an incidence. The sting/balance connections allow the balance to rotate for the in-stream calibration (see section 4.5).

A 2 inch bore pipeline runs from a connection mounted in the tunnel floor to the slide assembly. This consists of a series of pipes connected by swivel pipe joints. This is to allow HP air (high pressure air) to pass to the model for jet exhaust experiments. The pipeline is usually rigged even when HP air is not being used, as it forms a convenient route for the signal cabling from the model to the control room.

The two leadscrews are driven individually, via two chains, by stepper motors. The stepper motor and gearbox assemblies are mounted just below the lower turntable. The chain and sprocket system is enclosed within the lower platform. On the upper platform, two 100 turn BCD encoders are mounted on the leadscrews.

The sting rig is controlled by a microprocessor controller. The present unit contains three processors, one for pitch, one for height, the third for communications. The unit takes in the encoder values, calculates the rig, crank and model geometry (using values provided prior to the start of the test) and displays the calculated pitch and height to the test supervisor. A desired pitch or height may be entered and the unit will drive the stepper motor via PKS design stepper motor drive modules. The closed loop control is a demanding task as alterations to pitch mean that the height also has to be continually re-adjusted. Height and pitch data are fed into the data highway.

At the time of writing a contract is being placed for a new microprocessor controller. This will offer more control options to the test supervisors.

3.2 The missile rig

Model type:	Whole
Pitch/yaw:	±90° (subject to model length)
Roll:	±180°

This smaller, simpler rig was designed for whole missile models (Fig 6). The rig connects directly to the top and bottom turntables and is fitted with a roll drive. If the missile is mounted top uppermost, then roll and yaw are available, but alternatively it may be offset by 90° to give roll and pitch.

The stepper motor, gearbox and encoder are housed in the centre of the rig and controlled by a microprocessor controller. This is of a much simpler design than the sting rig controller, as it is only concerned with one degree of freedom (roll). The roll angle is fed into the data highway.

3.3 The high incidence (quadrant) rig

Model type:	Whole
Pitch:	+90° to -10°

This is a high stiffness sting rig which may be used with conventional straight stings or more usually, with an oscillatory or rotary, sub-rig[2]. The design utilises a pair of very large quadrants or arcs which extend from the tunnel floor to the roof (Fig 7). A sting carrier assembly moves around the arc between the two quadrant plates. The carrier is chain driven by a stepper motor and gearbox. The pitch angle available to a sting model is subject to the model length. Ideally the model datum point should be at the centre of rotation, which coincides with the centre of the working section.

The quadrant is mounted on the upper and lower turntables, so that yaw is theoretically possible, but experiments have shown that rotating the twin arcs into the flow causes too much disruption to the air stream. Thus the turntables are usually physically locked into position and yaw changes are not recommended with this rig.

The high incidence rig uses the same microprocessor controller as the missile rig, but the memory card is changed to use the correct constants.

3.4 The rotary rig

Model type: Whole
Roll: Continuous
Pitch: +90° to -10°

This is an hydraulically driven motor which drives the model, using a rotary arc[3] (Fig 8). The model is connected via a short sting to one arm of the arc and counterbalance weights fit on the other arm. The model can be connected to any position around the arc arm (thus altering pitch angle), but an equivalent counterbalance must be fitted to the other arm. Rotary speeds of up to 500 rev/min can be reached, giving a force of 80g at the arc tips (see section A.2 on Safety). Data signals pass through a slip-ring arrangement in the centre of the arc.

The rotary rig is mounted on the sting carrier of the high incidence rig, but its weight is such that the carrier drive is insufficient to raise the rotary rig without external assistance. Care must therefore be taken when setting up the experiment, so that the carrier starts the test series near the top of the quadrant and descends to the lower angles as required. It is powered by a hydraulic power pack mounted external to the tunnel and has its own controller.

3.5 The oscillatory rig

Model type: Whole
Pitch: +90° to -10°
Heave or sideslip: Continuous

This rig uses the hydraulic motor of the rotary rig, but, when driven through an eccentric cam, produces an oscillatory motion which is transmitted into the base of a semi-rigid tower (Fig 9). The tower consists of a gridwork of struts which are free to move in one axis. The model is mounted at the apex of the tower. Depending on which axis the tower is mounted, it will oscillate in pitch or yaw to give heave or sideslip. Excitation frequency ranges from 2 to 10 Hz.

This oscillatory rig is mounted on the sting carrier of the high incidence rig, and its lighter weight allows the carrier to be driven up and down the quadrant. This rig uses the same power pack and controller as the rotary rig.

3.6 The free-to-yaw rig

Model type:	Whole
Pitch:	0, +30°, +35°, +40°
Yaw:	±180° (free movement)

Used with lightweight models, this rig consists of a pillar attached to the centre of rotation of the lower turntable (Fig 10). The top of the pillar can be offset by fixed steps of pitch. The spline at the top fits into a bearing connected to the underside of the model, thus the model is free to rotate in the yaw plane, at fixed pitch angles.

A precision potentiometer attached to the spline in the model gives the yaw angle. Two restraint wires, attached to the rear of the model to stop excessive yawing, provide force data by means of load cells between the wires and tunnel walls. Only one load cell will be under tension at any time during yawing and at 0° of yaw, neither cell will be tensioned.

3.7 The overhead mechanical balance rig

Model type:	Whole or partial
Pitch:	±30°
Yaw:	±180° (depending on model length)

Heavy models or models which cannot be mounted by a rear sting are suspended (either erect or inverted) in the working section below the Overhead Mechanical Balance (OHMB), either by wires (low interference) or struts (heavy models) (Fig 11). The current trend is toward struts.

Strut mounting involves the use of two tubular supports, enclosed within earthed fairings, mounted equi-distant about the lateral centre line (separation distance is adjustable between 0.92 m and 2.15 m). The model is attached to the supports at convenient points, (*eg* wing tips) with swivel fittings.

The model can be mounted on the tunnel centre line or 0.3048 m (1 ft) above it, to allow itself to be closer to the centre line at high incidence (*ie* models with pivot points not at or near the centre of rotation).

A variety of wire rigs are available, but the most common uses two 'V' wires in place of the struts. An additional wire is required on one side only to measure side force. All wire rigs should be rated at 3 × model maximum force, and checked between runs for damage and attachment.

Pitch is available for either strut or wire mounted models, by mean of a wire attached to the nose or tail of the model (between 0.4572 m and 1.0668 m fore or aft of the centre line) to a remotely operated beam within the OHMB, giving ±30° of pitch.

Below the attachment point on the model, a second wire descends downwards to a ballast weight, immersed within an oil bath attached to the underside of the lower turntable. This is to overcome aerodynamic lift causing the model to rise or bounce within the support rig.

3.8 The half model rig

Model type Half model or vertical wings
Pitch: ±180° (depending on model length)

Half models are mounted on the floor of the tunnel through the lower turntable (Fig 12), with the port wing extending toward the tunnel centre. The model sits just above the tunnel floor (approximately 6 mm clearance) and a root block passes down through the centre of the earthed turntable to mechanical balance suspended below. Rotating the turntable (and the attached balance/model) gives pitch, the range of which is limited by the model length.

Vertical wings are also mounted through the lower turntables but may connect (either directly or via struts) to the upper turntable for support.

Some special rigs have also been used, including a vertical strut extending from the balance to the tunnel centre-line, from which parachutes have been deployed.

NOTE: In the parachute rig configuration, the turntable/mechanical balance combination is rotated through 90°, to allow axial force to be measured on the larger normal force channel.

3.9 The wake traverse rig

Model type: Whole
Movement: X, Y, Z

Originally designed to carry a set of pitot probes across the tunnel air stream (Fig 13), this rig has over the years more usually been used to carry a slender sting with a bomb or store model, usually in conjunction with a half wing, to simulate a store departure. An auxiliary balance is usually mounted in the store.

The traverse gear is located downstream of the turntables. The store can move fore and aft (X), laterally across the working section (Y) and vertically (Z). X and Z uses rack-and-pinion arrangements whilst Y uses the leadscrew and nut principle.

Control of this rig involves three separate drives, each connecting to their own stepper motors and position encoders, with checks to prevent the various actions of the rig moving out of sync and causing distortion of the rig.

The encoders are not absolute and therefore the X, Y and Z positions must be re-input into the control system after each power-up. This involves driving the rig to known datum positions, or else measuring the rig position where it last stopped.

Signals from the encoders and to the motors are transmitted via slide tracks. (**NOTE**: care must be taken to clean the tracks prior to testing to remove any tarnishes which will result in position data corruption), whilst the balance signals use low-level signal cabling, freely trailing behind the rig.

3.10 The turntables

Three turntables exist, which can operate either individually, in pairs or all together, depending on the model support used. Two of the turntables are situated in the working section (upper and lower), whilst the third is mounted above the working section and controls the orientation of the moment weighbeams of the Overhead Mechanical Balance. All three have the same centre of rotation. All are stepper motor driven and use absolute encoders to return position information back to the common controller.

The upper and lower working section turntables both have parallel beams 0.5 m apart, equi-distant about the centre-line. It is through this gap that the quadrant fits and to which the sting rig attaches. When not required, removable wooden panels cover the floor gap, and clear perspex the roof gap. Other panels in the turntables can be removed for additional access if required.

A microprocessor system controls the turntable movements, offsets and limits, as well as passing position data to the highway and the user. When more than one turntable is being driven, the controller will nominate one as the master and the others as slaves. It will then keep the slaves in sync with the master (to a user-selected tolerance) and halt the drive if this is exceeded. The selection of the master depends on which combination of turntables is being used. It is the position of the master that is passed to the data highway.

As a guide, half models tend only to use the lower turntable. Missile, quadrant and sting rig models tend to use the upper and lower turntables, whilst models suspended from the overhead mechanical balance tend to use all three.

4 FORCE MEASUREMENTS

Force and moment measurements on a model can be made using either an underfloor or overhead mechanical balance system, or by means of strain-gauged balances used to connect the model to the sting support system. Strain-gauge balances can be mounted internal or externally to the model.

During its calibration the balance is subjected to known loads and its outputs monitored. A matrix of balance sensitivities and interactions is produced which is then used to convert the outputs recorded during the test runs into measurable loads.

Mechanical balances use self balancing weighbeams with pulse counters measuring the movement of the jockey weights. The weighbeams are attached to the balance flexures. Any compression or tension in the flexure causes the weighbeam to move and the amount of correction applied by the jockey weight movement is measured.

Electrical strain gauge balances use precision Wheatstone bridges which are bonded to the spring flexures forming part of the balance. Any compression or tension in the flexure appears as a change in the bridge resistance, and hence the voltage, which can be measured.

4.1 Strain gauge balances

All the 13ft × 9ft Wind Tunnel strain gauge balances are sting mounted, *ie* they are mounted on and co-axial with the tubular stings. They are all 6 component and 2 inch in diameter (Fig 14). The components are defined as:

Z	normal force
M	pitching moment
Y	side force
N	yawing moment
L	rolling moment
X	axial force

Current balances in service are L/2/C and L/2/D. The 13ft × 9ft Tunnel can also use the 8ft × 8ft Tunnel 2¼in balances, usually 2¼L. All balances use a standard 31 pin plug and socket to connect to the sting harness (the signal cable that passes down the centre of the sting). A specialised balance, 747, is 1 inch square and is used in bombs or stores. (See section 3.9 Wake Traverse Rig.)

The maximum permissible loadings are summarised in Tables 1a and 1b. At present the balances are periodically calibrated using the recently modernised site balance calibration facility[4] to produce first and second order interaction matrices. The first order matrices are held in the 13ft × 9ft computer. Prior to use in the tunnel, the primary sensitivity factors (microvolts/load) must be determined for each of the 6 components. This is the instream calibration (see section 4.5).

4.2 Mechanical balances

4.2.1 Overhead mechanical balance

This is a 6 component mechanical balance, situated above the tunnel, in the axis of the tunnel centre. The balance has a fixed and a rotating section. The upper fixed section contains the force measuring frames, the lower section is built on a turntable (which can be driven in sync with the working section turntables) containing the pitch beam and the moment measuring frames.

Two load ranges are available for each component, which may be mixed. The ranges are summarised in Tables 2a and 2b. Change-over from Light (X1) to Heavy (X2.5) involves changing the weighbeam jockey weights. The balance design ensures that interactions are effectively non-existent. Balance overload limits are set at three times the maximum load range (which should not normally be exceeded). At present, the balance is calibrated by applying certified deadweights to each component and comparing the computer output.

The model is suspended below the balance in the working section, and may be either erect or inverted. Either wire rigs (low interference) or support struts (heavier model weights) may be used. The current trend is towards struts.

Strut mounting involves the use of two faired struts, mounted equal distance from the lateral centre-line (separation distance is variable between 0.92 m and 2.15 m). A multiplier acts on rolling moment and yawing moment when the distance is other than 1.524 m (60 in).

$$\text{L, N FACTOR} = \frac{\text{Distance between suspension point (m)}}{1.524\text{ m}} .$$

When live, the weighbeams will detect any out-of-balance deflection and drive the jockey weight to return to a stable balanced condition. The jockey weights are driven by leadscrews, which also send pulses to counters in the control room. These are zeroed prior to starting up the tunnel, so the model and rig weights are removed. Any counts generated after wind-on are due to the forces on the model. The 6 components and the pitch beam angle, are passed, via the data highway, to the computer.

Because of its mechanical nature, the balance cannot respond to rapidly changing dynamic signals and thus is therefore only to be used for static loads. Care must be taken when changing conditions (speed, attitude) in the working section, that the balance is allowed to settle prior to taking data.

4.2.2 The half model balance

This is a smaller, 4 component mechanical balance which mounts directly onto the underside of the lower turntable. Half model wings connect, via a root block, directly onto the balance. This balance is not a permanent installation and is removed when other rigs are fitted in the tunnel. To assist with this a scissor-jack lift can raise the balance from the ground floor to just below the turntable. (This lift is also used to support the hydraulic power packs used by the rotary and oscillatory rigs.)

Like the overhead mechanical balance, it was intended that the half model balance should be a dual range device, with light and heavy weights for each of the weighbeams. At present, however, the balance has only one set of weights available, and these components ranges are given in Tables 3a and 3b. Whilst not unduly large, there are component interactions which are allowed for in the PRIME computer (off-line corrections).

Half models are mounted on a root block which, in turn, is mounted on two longitudinal slides on the live platform of the balance. Block adjustment of around 1.8 m is available using the slides, but the pitching moment datum must be updated to allow for this. A clearance (usually 6 mm) between the model underside and the tunnel floor is required to prevent fouling.

Model incidence is achieved by rotating the turntable, the limits being dictated by the model size. HP air pipework, on flexure coupling, allows HP air to be passed into the model without affecting the balance readings.

The half model balance uses the same displays and drives as the overhead balance, though obviously only 4 channels are used (Z, M, L, X).

4.3 The virtual centre balance

This is an experimental balance (Fig 15) and has not yet been commissioned for use in the tunnel, no instrumentation has been developed to connect it to the tunnel computer, nor does any software exist to retrieve the applied loads.

The balance was conceived as a replacement for the two existing mechanical balances. A principal feature of the balance is the deployment of 6 precision load cells placed in links between a 'live' model mounting platform and an earthed frame fixed to the lower turntable. The lines of action of 3 of these load cells intersect at a virtual centre which corresponds to the aerodynamic centre of whole models when strut mounted on the 'live' platform. In this way direct force and moment measurements are made for model related axes, thus reducing cross term errors following axis transposition.

At the time of writing tests were still being conducted on the balance load cells.

4.4 The dynamic balance

This balance (Fig 16) may be operated in conjunction with the half model balance (see section 4.2.2) and provide data on small dynamic loads in the presence of the larger steady forces. It has been used for several tunnel tests, but requires its own specialised instrumentation and Masscomp computer[5].

The balance takes the form of two rigid steel plates, that fit between the half model and the root block. Between the plates are four piezo-electric load cells (one in each corner). Each load cell is capable of measuring in the 3 orthogonal directions simultaneously. The computer package can combine these outputs to produce the 6 usual components. Forces up to 5000 N can be measured, within the dynamic range of 0-300 Hz. Steady state loads measured on both the dynamic and half model balances show good agreement.

4.5 In stream balance calibration

This mainly applies to strain gauge balances, as the mechanical balances have shown no significant sign of change since they were originally installed. The virtual centre and dynamic balances require different treatment and are still under development.

The balance is sting-mounted on its rig in the working section (no model) and set at zero pitch and yaw. The balance is connected to the sting at 180° to the model mounting position, so that dead weight loading gives rise to positive normal force. The balance is loaded over the full working range of each component in turn.

This is facilitated by use of a calibration adaptor which connects to the balance 'live' end. A longitudinal pitch arm and a traverse roll arm (both horizontal) provide points upon which weights can be hung using a weight hanger with a 'knife edge' attachment. Several loading points are provided on each arm to allow positive and negative loads to be applied.

A middle loading point on the pitch arm is directly under the balance centre and is used to apply pure normal force. To calibrate side force and yawing moment the balance is rolled 90° (clockwise looking downstream) and the calibration adaptor returned to the horizontal. The normal force and pitching moment procedure is repeated to give side force and yawing moment. Axial force is achieved by 'pulling' the calibration adapter with two equal loads on two horizontal strips (thin metal strips 10 mm wide) which are equally dispersed about the balance centre. The strips are mounted over pulley wheels and loaded by weights on the hangers.

Whilst performing these calibrations, the angular deflections (pitch, roll, yaw) are noted and the stiffness coefficients relating to the balance/sting assembly (force/moment divided by angular deflection in degrees) are determined. These are used in the off-line data reduction tasks.

5 PRESSURE MEASUREMENT

Pressure measurements provide information as to the airflow around the model, in more detail than the qualitative flow visualization techniques that are described in section 8.

5.1 Model surface pressures

A simple pressure transducer mounted in a multi-port scanning head (*eg* Scanivalve) is the most common form of pressure measurement technique. 48 way heads, either singular or modular (multiple heads per drive) are fitted inside the model to minimise the amount of pressure tubing required. The transducers are driven and scanned together under computer control, with a manual option to allow visual inspection of the outputs.

42 Ports are available for the users' measurements, the other 6 ports being required for calibration pressures (see Fig 17).

Ports	Pressure
1, 46	Settling chamber
2, 47	Working section - reference pressure
3, 48(0)	Calibration pressure

Note that the settling chamber and working section pressures refer to the spare pressure tappings, not the ones permanently connected to the tunnel speed controller. The spare tappings are adjacent to the main tapping, and for the working section, a choice of roof or wall tappings is available (depending on downwash considerations).

The settling chamber pressure (ports 1, 46) which is not used by the tunnel computer, can be used as a wind speed indicator during the off-line data reduction. The working section pressure (ports 2, 47) is also fed to the reference port of the transducer and is therefore a zero input. The calibration pressure (ports 3, 48(0)) is referenced to the working section pressure and tracks it by a fixed amount. This provides a gain input. Thus a gain factor (reading/pressure) for each transducer is calculated at each data point during data reduction, and any transducer or instrumentation drifts are neutralized.

The calibration pressure is produced by a differential precision pressure controller. It is referenced to the working section pressure and outputs the same pressure plus a user-selected offset.

$$P_{cal} = P_{ref} - P_{user}$$

P_{cal} = calibration pressure supplied to ports 3, 48(0);
P_{ref} = reference pressure from working section supplied to ports 2,47;
P_{user} = user-selected known offset (often full scale of the transducer).

P_{user} is variable from ±15 psi (103.47 kPa), but should not be less than 10% of the transducer range. The generator is a self contained unit and is situated adjacent to the working section.

The maximum configuration would be 8 transducers each monitoring 48 ports, providing a total of 384 pressures, 336 for user measurements. Transducer ranges available are 1 psi (6.89 kPa), 2½ psi (17.24 kPa), 5 psi (34.37 kPa) and 15 psi (103.42 kPa) (all ranges are differential). All the transducers are made by Druck, having a near linear relationship between output volts and pressure. Combined non-linearity and hysteresis is specified at ±0.04% of the Best Straight Line (BSL) fit.

Fig 18 shows some transducers and Scanivalves mounted in a model.

In the DRA 8ft × 8ft High Speed Tunnel, the mechanical pressure switching systems have been replaced with solid state electronic devices, which can be scanned at higher speeds. The 13ft × 9ft Tunnel will change over to solid state pressure measurements in the future, in order to maintain compatibility of equipment between the facilities, but at present, it will remain with the mechanically stepped pressure system which is sufficient to record the model pressures in the low speed environment.

5.2 Base pressure transducer

Two 1 psi (6.89 kPa) Druck transducers are permanently mounted in a corner fillet of the working section. Their reference ports are common and open to atmosphere at a point away from the air stream. Their input ports are connected via the hypodermic tubing to a point in close proximity to the sting and near the fuselage/sting mounting. This measurement is used in the off-line data reduction for drag corrections.

6 INSTRUMENTATION

In common with most wind tunnel facilities, specialised instrumentation is used to recover the signals from the model, using a variety of signal conditioning methods, and to pass the resultant values to a computer for recording and aerodynamic processing.

Some of the instrumentation operates standalone, whilst other parts are fully under computer control. For some models an external computer may be used to record additional information, which may be outside the capabilities of the tunnel's data acquisition system.

6.1 Observation room layout

The Observation Room, with its adjacent computer room, is the nerve centre of the facility. It is from here that the tunnel drive is controlled and the model signals recorded. It is located adjacent to the working section and so allows direct viewing of the model under test. Fig 19 shows the observation room.

A false floor is installed to allow cables and power to pass around the room. The power is split into: computing, instrumentation and raw; the first two are filtered to remove unwanted mains-borne interference. 24V ac, 110V ac and 3 phase power are also available. An insulated copper busbar runs from the observation room to an earth point external to the facility. This is the clean Earth and connections to this are strictly controlled to avoid noise entering the earth system.

A partition wall around the room provides one hour fire retention and reduces noise from the working section, especially during high pressure air testing, whilst the windows provide good visual access to the model under test. Cables exit/enter the room via flaps below the false floor. Four small air conditioning units located to the rear of the room can remove up to 7.5 kWh of excess heat generated by the instrumentation, but this is due to be replaced with a larger system, offering control of both temperature and humidity.

An open horseshoe-shaped console contains the majority of controls and displays required by the test supervisors (speed control, CCTV, model altitude, high pressure air, computer interface) whilst three racks to the rear of the room contain the signal conditioning units (force system, pressure system and housekeeping). The remaining space is taken by additional peripherals of the tunnel computer, or specialised instrumentation brought in specifically for the current test.

6.2 Force system (electronic)

Unlike the other DRA Bedford tunnels which use high speed analogue-to-digital converters (ADC), the 13ft × 9ft Tunnel uses panel meters to digitise the analogue signals from the model. 20 meters are available but several are pre-configured for specified tasks:

1 × balance strain gauge power supply monitor (V_{ex})
6 × balance strain gauges (6 components Z, M, Y, N, L, X)
2 × base pressure monitors (B_{p1}, B_{p2}).

The remainder can be used for monitoring auxiliary balance outputs, pressure transducers or other power supplies.

Power for the strain gauges is provided by precision power supplies, with remote sensing extending either into the model or as near as practical, depending on the model rig. These supplies are used as standard throughout the tunnels' facilities of DRA Bedford.

The meters operate under computer control, via a dedicated digital link. A calibration source is housed within the force system, to allow calibration values to be passed through the meters to check for drifts. This is also under computer control. The Electronic Services staff use the calibration signals manually to correct for offset prior to start of the day's testing.

Beldon low-level signal cabling is used between the model and the meters, with the power and signals travelling along separate cables. Provision is made for the signals to be inverted for sign changes. Correct earthing is important, and all the meter earths return to a 'star point' (to avoid earths at different potentials) before connection to the clean earth busbar.

6.3 Force system (mechanical)

The operation of the mechanical balances is described in section 4.2. The observation room contains a rack of up/down counters with associated displays. The counters can be zeroed or preset to chosen values. Movement of the jockey weight on the weighbeams causes a pulse-train (and directional signal) which is input to the counter. Buffered outputs from the counters pass the information to the data highway for transmission to the computer.

At the time of writing, a new set of counters and displays are being produced by the in-house staff, which will fit in the new console, thus allowing the old racks to be removed.

6.4 Pressure system

Pressure measurements in the 13ft × 9ft Wind Tunnel usually consist of mechanically stepped pressure switches (8 scanivalves) passing multiple pressures to a small number of discrete transducers, unlike the high speed tunnel facilities, which use electronically controlled multiple headed transducers, with each pressure being continually monitored by individual sensors.

Power to drive the mechanical switches (in parallel) is provided by constant current power supply, capable of delivery 48 V at 26 A (max), which can drive in excess of eight pressure switches. The switching is under computer control, with manual operation for observing specific channels during setting up.

Power for the transducers is provided by precision power supplies (as used in the strain gauge balances) and the signals are displayed on panel meters (similar to the force panel meters, but with a faster response time). Signals and power travel by similar Beldon cabling to the force system, with the same 'star point' earth arrangement to the clean earth. The computer controls and reads the meters by a second dedicated digital link.

6.5 Housekeeping

Other measurements from the test section, tunnel or external sensors are fed to the computer, via the data highway, by individual meters or signal conditioning units. This includes data from the high pressure air system, tunnel temperatures, model attitude, height and yaw.

Four Digiquartz pressure manometers communicate directly by a RS232 serial link and provide data relating to barometric pressure, tunnel speed and user pressures.

A four-channel large-screen display oscilloscope can be used to monitor analogue channels of interest (accelerometers, wing root strain) and a 14 track FM tape recorder capable of recording dynamic signals to intermediate band and wide band I (IRIG standard) is available for later off-line analysis. This can be remotely operated from the test supervisor position on the main console, and a voice track is included.

Two CCTV colour cameras (top and side view) monitor the model and these can be recorded, with a date/time display and the voice track, on to a VHS VCR. Both cameras are mounted on remotely operated pan and tilt units, with remote control of zoom, focus and iris. Two monitors show the live pictures, whilst a third shows the VCR playback picture. A fourth monitor displays the black and white output of a fixed security camera, which monitors the far side of the working section (see Appendix, A.1, on lasers and safety).

A handheld VHS camcorder is available for recording events in, or adjacent to, the working section, such as model assembly. The VHS tapes from this and the CCTV cameras can be edited, dubbed and titled by the photographic staff of the Site Services Department.

6.6 Data highway

As with all the wind tunnel facilities, a data bus is required to transfer information from all the various instrumentation sources to the computer. This usually takes the form of a parallel digital highway, though some dedicated serial links also exist.

The highway must be capable of transferring data of up to six decades (of BCD) in size, of data rates not less than 100 Kbit/second, if present performance of the system is not to be degraded. Accordingly, the highway is scheduled for replacement with an industry standard VME bus based system in early 1993.

7 COMPUTING AND DATA REDUCTION

As with most wind tunnels, data acquisition is computer controlled. At present a DEC PDP 11/44 machine performs the on-line data reduction. Its main purpose is to provide enough information for the test supervisor to detect areas of interest or faults on the model.

Off-line reduction is preformed by the central site PRIME 4050 computer which can compute the second-order balance interactions and process more detailed tunnel corrections. PRIME can provide tabular printouts and graphics for the users. Data transfer to the Prime is by magnetic tape. Fig 20 shows the PDP set-up.

By the end of 1993, a replacement computer, a Hewlett Packard 1000 series system comprising of an A990 main processor and an A900 front end processor, will be on-line. Communication between the main processor and the front end will be via dedicated IEEE 802.3 LAN. A second LAN line will provide communications with the PRIME 4050 and the HP computers in the other DRA Bedford tunnel facilities. The new HP system will have 8 MB of main memory and 900 MB of disk storage, with off-line storage using Digital Audio Tape (DAT) cassettes, each holding 1.3 GB of data. The front end processor is a memory based system of 6 MB.

The software packages, where possible, will be similar to those used in the other DRA Bedford tunnels' HP computers, though the reduction tasks will be based around the existing tasks developed in the PDP. This will provide the test supervisor with more calculations and on-line graphics. Fig 21 shows the HP1000 set-up.

Other computer systems which are used in the tunnel mainly revolve around the Masscomp series, used for more specialised dynamic analysis for models (see section 4.4). These can also exchange information using the LAN link.

7.1 On-line data reduction

On-line reduction enables the tunnel user to validate and assess test results during acquisition. Detailed corrections are omitted at this stage.

7.1.1 Strain gauge balances

Strain-gauge balance data is processed either by the sting rig/quadrant rig reduction task or the missile rig reduction task. For the former, model attitudes are conventional, but in the latter there can be a 90° offset, *ie* pitch may be horizontal and achieved by rotating the turntables.

A maximum of 16 channels (+ 2 balance powers + 2 base pressures) are available for recording. Information from up to 14 selected channels may be processed on-line in the form of non-dimensional coefficients in balance axes. The information from the first six channels may be processed further to obtain information in body axes, stability (wind) axes or resolved body axes (missile only).

For the balance calibration data constants, a 6 × 6 interaction matrix is used and second order interactions are omitted at this stage (see section 7.2). No corrections for tunnel constraint and blockage are included.

7.1.2 Mechanical balances

Mechanical balance data is processed either by the half model balance reduction task or the overhead balance reduction task. These are similar, but differ in that the overhead balance force measuring axes do not rotate with the model body axes.

The 4 or 6 channels of data may be processed on-line in the form of non-dimensionalised coefficients in balance axes, body axes and stability (wind) axes. Additionally for the overhead balance, allowance is made for the drag of the model support rig.

No account is made for balance interaction, and no corrections for tunnel constraint and blockage are included (see section 7.2).

7.1.3 Pressure data

Pressure coefficients based on a dynamic pressure, uncorrected for tunnel blockage, are produced. No tunnel corrections are performed on-line other than referencing the pressure coefficient to true freestream static pressure (*ie* that measured at the tunnel centre when the working section is empty) from the wall or roof reference pressure.

Calculation of zero and gain factors have been covered in section 5.1. Pressures are also available as dimensionalised units and corresponding coefficients.

7.2 Off-line reduction

Off-line reduction re-computes the on-line data, and includes such corrections as tunnel blockage and second order balance interactions, to produce the final results. These can not be calculated on-line, as to do so would exceed the PDP 11/44 available memory space.

The site central computer facility is based around a PRIME 4050 which currently receives the 13ft × 9ft data by magnetic tape. When the HP1000 computer is installed, data transfer will be via IEEE 802.3 LAN.

The PRIME can be accessed from office terminals throughout the Site. Many terminals have a graphics capability. Additionally a line printer connected to the PRIME is housed in the 13ft × 9ft. Thus the test supervisors can monitor the corrections and see the results without needing to leave the building.

8 FLOW VISUALISATION

The working section, with its ease of access and large window area, is ideal for flow visualisation experiments. Flow visualisation techniques range from tufts attached to the model, to laser beams scanning the airflow for vortex patterns. CCTV cameras can be mounted at the sides and above the tunnel, and in some instances inside the tunnel.

UV light (to fluoresce dyes) can be generated externally or internally, to aid viewing and a variety of oils and dyes are available.

8.1 Laser smoke screen

A large, high-quality glass window allows viewing of the model. This provides a useful place in which to pass a laser beam into and across the working section. By means of an optional pipe stack upstream of the model, smoke or fog may be introduced into the airflow at various heights. It is therefore possible to illuminate a cross-section of the smoke and observe effects caused by the air passage round the model, such as flow separations, or vortex effects.

The laser is a 2W argon ion beam (a class IV hazard, see Appendix, A.1, on safety) driven by a 3-phase supply and requiring water-cooling. It sits adjacent and parallel to the working section. The beam is deflected upwards via a fixed optical quality mirror and then sideways into the tunnel by an oscillating optical quality mirror. Both mirrors are moveable on a 'railway track', so the beam can enter the working section anywhere within the confines of the window (2.50 m × 1.08 m). The mirror oscillating frequency and the beam scan width are locally controlled by a signal generator adjacent to the laser table.

The smoke used is a water-soluble 'disco fog', which is non-toxic and allows breathing without choking. The smoke generator (basically a liquid tank, a pump and a hotplate) is mounted below the tunnel and is remotely controlled from the Observation room. The smoke generated is sucked up into the tunnel by venturi action through the pipe stack, which can be set to the required height. It is usually necessary to install bracing wires if the pipe stack extends more than 4ft into the airflow.

With the normal working section lights switched off, the flow surrounding the model can be laser illuminated and recorded by the CCTV system, with the best results occurring when the camera angle approaches 90° to the scan beam. A secondary reflection from the farside window of the working section can be beneficially used to illuminate the flow from two sources, but the window can be replaced with a blank if this is a problem. The model surfaces should be finished in matt black to avoid unwanted reflections off the model.

Operation and setting up of the laser is restricted to those staff who have been trained in its use. Regular operators are required to have additional medical checks to monitor for eye damage.

Fig 22 shows a typical laser smoke view.

8.2 Oil flows

To examine the flow over parts of a model, it is possible to coat the desired surface with an oil mixture consisting of paraffin or light oil with various amounts of Dayglo fluorescent powder (depending on the tunnel speed) prior to running. As the air passes over the model the flow causes patterns to appear in the oil, resulting from surface shear effects.

Ideally photographs should be taken, usually highlighted with UV light, during the wind on condition to avoid start/stop effects. The air flow can be stopped if necessary for more detailed examination of the patterns.

Protective clothing is required when handling the mixture (see Appendix, A.3, on safety), and metalwork downstream of the model should be protected by oil due to the corrosive effect of the mixture. This type of experiment is by its nature very messy, and the run-time is short compared to the analysis and photographic time.

Fig 23 shows a typical oil flow.

8.3 UV and micro-tufts

As an alternative to oil flows, the model surface can be covered in a grid of micro-filament luminous tufts[6], which will fluoresce in the presence of ultra-violet (UV) light to show the real-time flow patterns, whilst the wind is present. Recording by CCTV provides a permanent record.

The micro-filament tufts 0.5 mm thick and 10 mm long (other sizes are available as required) are stuck to the model surface (which is painted matt black) in a grid approximately 10 mm × 10 mm. The UV lighting is arranged around the model, either by replacing the standard lighting, or by installing an additional lighting frame inside the working section.

As the air passes over the model, the tufts will lie with the air stream and in the presence of the UV, visually appear much larger than their actual size, allowing the flow pattern to be observed and recorded by the CCTV cameras. Whilst this test takes longer to initially set up, it can be used continuously without need to stop the tunnel and recoat the model surfaces and does not produce the same mess and safety hazards as the oil flow experiments.

Fig 24 shows a micro-tuft view.

8.4 Liquid crystals

Liquid crystals have now been developed that are shear sensitive instead of temperature sensitive[7]. These are painted over the model and colour changes monitored in normal light. At present this is only an indicative experiment, as it is not yet possible to relate actual colour to known shear stress, but it is useful in showing the areas in which flow separation occurs. Recording by CCTV provides a permanent record.

9 HIGH PRESSURE AIR SUPPLIES

High pressure air (HP air) is used to simulate jet thrust in models of engine intakes or VSTOL ducts. Two supplies are available, the 660 psi (4.55 MPa) external line and the internal Howden compressor source (max 40 psi (275 kPa) continuous).

9.1 660 psi HP air line

The HP air supply, from pre-charged reservoir bottles on the site enters the tunnel building at 660 psi (4.55 MPa) into a 'Eltron' electric heater. The use of this is optional depending on ambient temperature and model test requirements. The heater can operate at 140 kW or 11.6 kW, selected by the user. The temperature sensor is monitored in the air pipe upstream of the model.

After the heater, the air passes through a filter (10 µm), then an orifice plate for the measurement of mass flow. Air passes through the main control valve (HP 43) or a smaller 'by-pass flow control valve' (HP 55) which runs parallel to it. These valves are used to vary the mass flow, and are themselves controlled by a PC based flow controller.

Air from the control valves will either proceed to the model, or to a blow off duct to atmosphere via a silencer. At various stages along the pipework control valves direct the flow and these are controllable from the console in the control room, along with pressure displays at different points in the pipework.

A second 'blow off' route is connected to a spring loaded relief valve to prevent over-pressure. Two pressure switches will also trip the blow off sequence if they detect over-pressure and a manual EMERGENCY STOP is provided for the user to likewise divert the flow safely.

Operation of the HP air supply is subject to several safety requirements. (See Appendix, A.4, on Safety).

At the time of writing, the external pipeline and valves had just been uprated to raise the supply delivery pressure to 1000 psi (6.89 MPa).

Fig 25 shows the layout of the HP air system.

9.2 Howden compressor - exhauster

A local pressure source is available to provide both suction and blowing, for small experiments, such as boundary layer control. Two Howden Lysholm compressor/ evacuators, each of 1300 HP, running off a 33 kV supply are located near to the main drive. The Howdens can run independently or in parallel and can provide a total flow of 12000 ft^3/min (340 m^3/min) free air.

The Howdens may be combined in five different ways (see Table 4). Changing the run sequence involves opening/closing hand valves and inserting/removing blanking plates.

Mass flow control is achieved via remotely controllable twin valve (large and small in parallel) arrangements, similar to the HP air control. Blow-off pressure relief valves and pressure trip switches are installed. At the time of writing, this system is to be replaced by a 350 psi (2.41 MPa) airline from the site facilities and the Howdens will eventually be removed.

10 TUNNEL SPEED CALIBRATION

The tunnel speed is routinely checked at the finish of the annual maintenance shutdown[8]. It is the calibration of dynamic pressure at the tunnel working section centreline (tunnel empty) against a precision gauge, which reads the pressure difference across the settling chamber and the working section. Since at present the reference pressure is determined by means of a gauge reading instrument, it is important that regular checks on the instrument's accuracy, e.g. for drift or calibration change, are made. In addition the cleanliness of the settling chamber screens will also influence the calibration. (Hence the cleaning of the screens - section 2.1.) Annual checks are required if the tunnel accuracy is to be maintained.

Measurement of the reference pressure difference is facilitated by the provision of static pressure holes in the surface of the settling chamber and working section, which are piped back to the speed control racks in the control room. Two working section tappings are available, the drive roof hole and the drive wall hole, both are located at the forward edge of the working section. Since the 1990 shutdown the drive roof hole has been adopted as the standard for tunnel speed calculations (see Fig 26).

Determination of dynamic pressure is by measurement of total and static pressure, the difference being uncorrected dynamic pressure. A standard calibration rig having a separate static probe and pitot probe is rigged at the tunnel centre. These are measured against the drive setting chamber wall hole, corrections for compressibility and the probe are applied. Further calibrations then included the spare holes, which are used in pressure data measurements (section 5.1).

The corrected values are used by the tunnel computer to calculate the air speed in the working section and a table of values (pressure *v* speed) are programmed into the engineering speed controller (section 2.2).

Fig 27 shows the calibration probe rigged in the working section.

11 THE 4ft × 3ft AUXILIARY TUNNEL

This is a small open ended test duct situated on the floor below the 13ft × 9ft working section (but not directly under it). It is driven by its own fan and motor generator set. Maximum speed is about 30 m/s.

It is not permanently instrumented, being more of a test duct in which users provide their own models and instruments. Windows allow flow visualisation experiments to be conducted and air supplies from the Howden compressor can be fed into the tunnel. Provision is made for a remote control to the Howden compressors.

A proposal has been made to re-locate the facility to the Main Drive building following the installation of the new speed control system control. (See section 3.2.)

Fig 28 shows the 4ft × 3ft Auxiliary Tunnel.

Appendix

SAFETY

Several of the rigs or techniques used in the tunnel can potentially present a hazard to life or cause damage to the tunnel if not correctly supervised. The Safety Officer (DRA Bedford) delegates authority through the Safety Officer (Aerodynamics) to the 13ft × 9ft Tunnel Manager and through the Safety Officer (Engineering) to the PTO (13ft × 9ft Wind Tunnel) for monitoring safe working conditions within the 13ft × 9ft Wind Tunnel.

NOTE this does not relieve individuals from their personal responsibility for safety.

Instructions for carrying out the Daily Inspection (DI) tasks and preparing the tunnel and rigs for use are given in the Engineering handbook 'RAE Bedford 13ft × 9ft Wind Tunnel operating instructions', a copy of which resides with the PTO (13ft × 9ft Wind Tunnel).

A.1 Lasers

Use of lasers is covered by JSP 309, (Military Laser Safety) and BS4803 Part 3. Class IV lasers are considered harmful and a protection system to prevent inadvertent or unauthorised access to the laser or the beam (direct or reflected) is mandatory.

A system of locks, detectors and hazard lights has been installed to warn of laser activity and prevent accidental exposure. Any attempt to breech the containment area will cause the laser beam to be blocked off. CCTV surveillance of remote areas within the laser enclosure is provided.

A.2 Rotary rig

A metal model, attached to a frame rotating at up to 500 rev/min, developing up to 80 g, presents a safety hazard should detachment occur.

Accordingly access is locked off, as for lasers, and the glass windows of the working section are replaced with metal armour. Key operation of the hydraulic power pack prevents any personnel approaching the rig while the power pack is live.

A.3 Chemicals

Use of chemicals is covered by the COSHH regulations, as some of the oil flow ingredients are harmful if swallowed.

All chemicals are kept in the locked chemical cupboard with safety notices posted. Protective clothing is provided in the cupboards for the safe handling of the substances. Washing facilities are provided adjacent.

A.4 HP air

Use of HP air is confined to suitably qualified tunnel staff. Engineering Department Permits to Work are required for any modifications, alteration or use of the HP air system.

Access to the working section area is locked off and the console is key-operated. Noise hazards apply adjacent to the valve gear and blow off exhausts. (See section A.6.)

A.5 Emergency lighting

In the event of power failure and a need for evacuation of the control room (*eg* Fire), a battery lighting system (3 hour charge) illuminates the route from the control room down to an external fire door.

A.6 Noise

There is no significant noise hazard in the office block or control room during normal tunnel operation, but access to the motor or MG rooms in the main drive building requires the use of ear-defenders.

When the HP air system is in operation, noise hazards exist on the middle floor under the tunnel (where the valve gear is located) and adjacent to the working section. Use of ear-defenders is required in these areas.

A.7 Airborne contamination

Any dust or debris which enters the airstream, becomes a potentially damaging missile, as it accelerates through the contraction towards the model under test. Accordingly the following procedures are in place to reduce and monitor the levels of debris within the air stream:

Sticky mats are fitted in the most common approaches to the tunnel, to pull dust off the footwear of staff entering the working section.

When the tunnel is at rest (during a model test) for any period greater than a few minutes, a carpet is laid between the access doors - this serves to both protect the paintwork and catch the dust.

The working section is swept after any model rigging or after the main model entry doors have been opened.

The grease band at the base of the contraction is renewed annually.

The catch-nets and screens are checked every morning (as part of the DI) for debris.

A one inch circular disk is periodically fitted into the working section, with a sticky surface facing the airstream. The disk is then photographed and the enlarged print checked for signs of airborne contamination (Fig 29).

These procedures ensure that the 13ft × 9ft Wind Tunnel maintains the cleanest airstream at DRA Bedford[9].

A.8 Tunnel operations

Operation of the tunnel is confined to suitable qualified tunnel staff. The tunnel may not run unattended, or in the sole charge of contract staff or external users. Instructions on operating the speed control system are contained in the Engineering Handbook 'RAE Bedford 13ft × 9ft Wind Tunnel operating instructions', a copy of which is located in the Observation Room.

Any model brought into the tunnel must first satisfy the DRA Bedford Design Office that meets the overload stress requirements (to prevent detachment).

The Tunnel Manager may suspend or halt any tests which he considers would endanger life or cause damage to the facility.

Table 1a (Imperial)

13ft × 9ft WIND TUNNEL STRAIN GAUGE BALANCES

	Z (lb)	M (lb/ft)	Y (lb)	N (lb/ft)	L (lb/ft)	X (lb)
L/2/C	700	250	250	85	85	100
L/2/D	700	250	250	85	85	150
2 ¼	1600	550	350	175	175	150
747	150	150	150	150	50	20
V20	350	1680	350	1680	140	250

Table 1b (Metric)

13ft × 9ft WIND TUNNEL STRAIN GAUGE BALANCES

	Z (N)	M (N m)	Y (N)	N (N m)	L (N m)	X (N)
L/2/C	3114	339	1112	115	115	445
L/2/D	3114	339	1112	115	115	667
2 ¼	7117	745	1557	237	237	667
747	667	203	667	203	68	89
V20	1557	2278	1557	2278	190	1112

Table 2a (Imperial)

13ft × 9ft WIND TUNNEL OVERHEAD MECHANICAL BALANCE

	Z (lb)	M (lb/ft)	Y (lb)	N* (lb/ft)	L* (lb/ft)	X (lb)
Light range	2000	±400	±400	±300	±300	400
Heavy range	5000	±1000	±1000	±750	±750	1000

$$* \text{ N.L. Scaling factor } = \frac{\text{pivot (lateral) distance}}{60.0 \text{ in}} .$$

Table 2b (Metric)

13ft × 9ft WIND TUNNEL OVERHEAD MECHANICAL BALANCE

	Z (N)	M (N m)	Y (N)	N** (N m)	L** (N m)	X (N)
Light range	8896	±542	±1779	±407	±407	1779
Heavy range	22240	±1356	±4448	±1017	±1017	4448

$$** \text{ N.L. Scaling factor } = \frac{\text{pivot (lateral) distance}}{1.524 \text{ m}} .$$

Table 3a (Imperial)

13ft × 9ft WIND TUNNEL HALF MODEL BALANCE

Z (lb)	M (lb/ft)	L (lb/ft)	X (lb)
±1500	±1500	±10000	±600

Table 3b (Metric)

13ft × 9ft WIND TUNNEL HALF MODEL BALANCE

Z (N)	M (N m)	L (N m)	X (N)
±6672	±2034	±13558	±2669

Table 4

13ft × 9ft WIND TUNNEL
HOWDEN COMPRESSOR EVACUATOR OPTIONS

Sequence	Compressor 1	Compressor 2
A	Suck	-
B	Suck	Suck
C	-	Blow
D	Suck	Blow
E	Blow	Blow

Compressor 1 rated at 480 hp. Suck ratio 5:1; Blow ratio 2:1

Compressor 2 rated at 850 hp. Suck ratio 5:1; Blow ratio 5:1

REFERENCES

No.	Author	Title, etc
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2	C.O. O'Leary	*Dynamic tests on a High Incidence Research Model (HIRM) in a low speed wind tunnel.* RAE Technical Report 84111 (1984)
3	C.O. O'Leary E.M. Rowthorne	*New rotary rig at RAE and experiments on HIRM.* RAE Technical Memorandum Aero 2039 (1985)
4	R.D. Law J.F.G. Warren	*The calibration of wind tunnel strain gauge balances using a precision automatic calibration machine.* DRA Technical Memorandum (in preparation)
5	B.L. Welsh C.R. Pyne	*A dynamic balance for the measurement of time-dependent aerodynamic forces on wind tunnel models.* RAE Technical Memorandum Aero 2182 (1990)
6	C.O. O'Leary W. Drew	*Flow visualisation on rolling models using minitufts.* RAE Technical Memorandum Aero 2083 (1986)
7	L. Gaudet T.G. Gell	*Use of liquid crystals for qualitative and quantitative 2D studies of transition and skin friction.* RAE Technical Memorandum Aero 2159 (1989)
8	D.W. Hyde	*Procedure for the speed calibration of the DRA 13ft × 9ft low speed wind tunnel.* DRA Technical Memorandum (in preparation)
9	B.L. Welsh	*A survey of airborne contamination in the DRA Bedford wind tunnels.* DRA Working Paper AP4(92)WP11 (1992)

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Fig 1

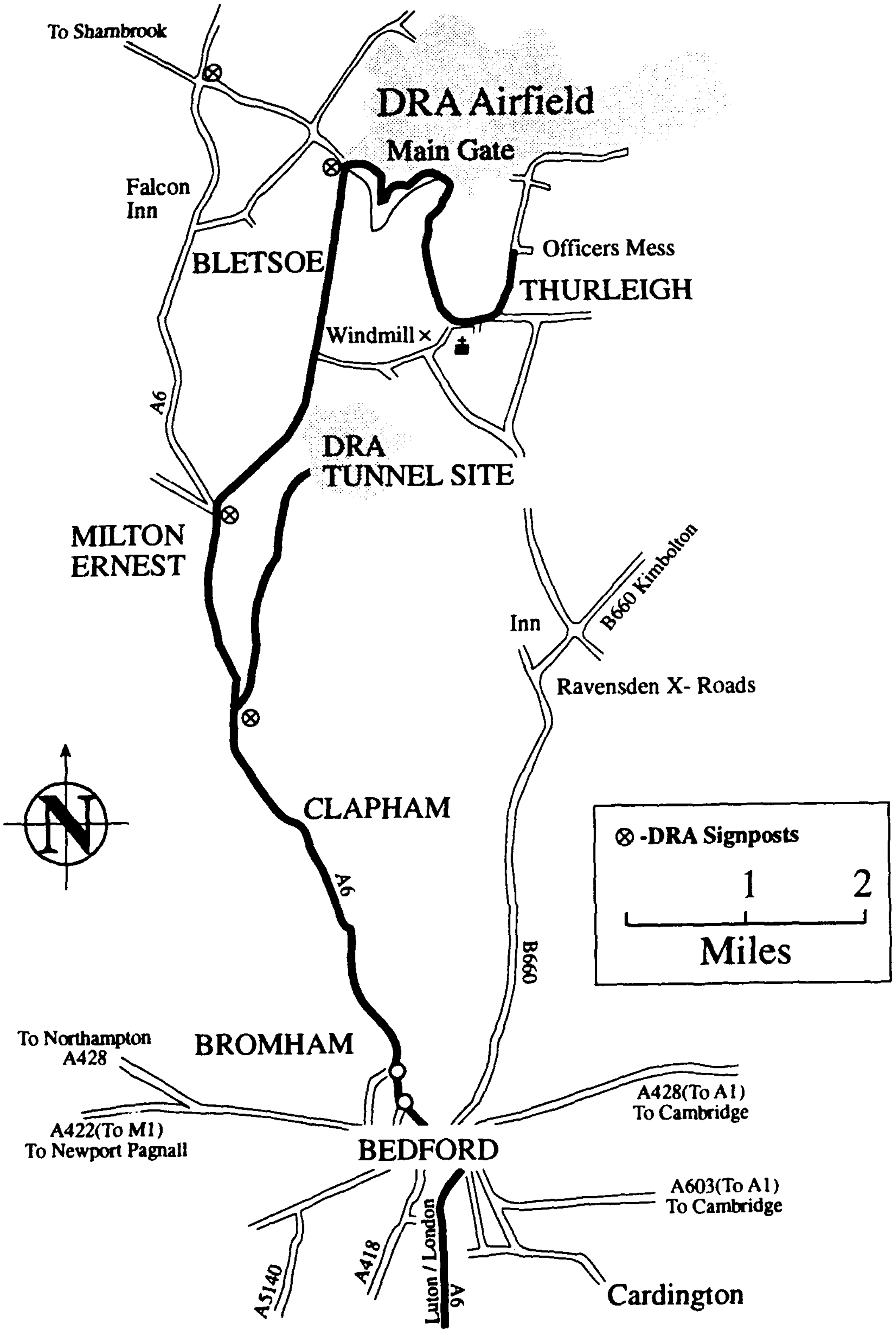

Fig 1 Map of North Bedfordshire

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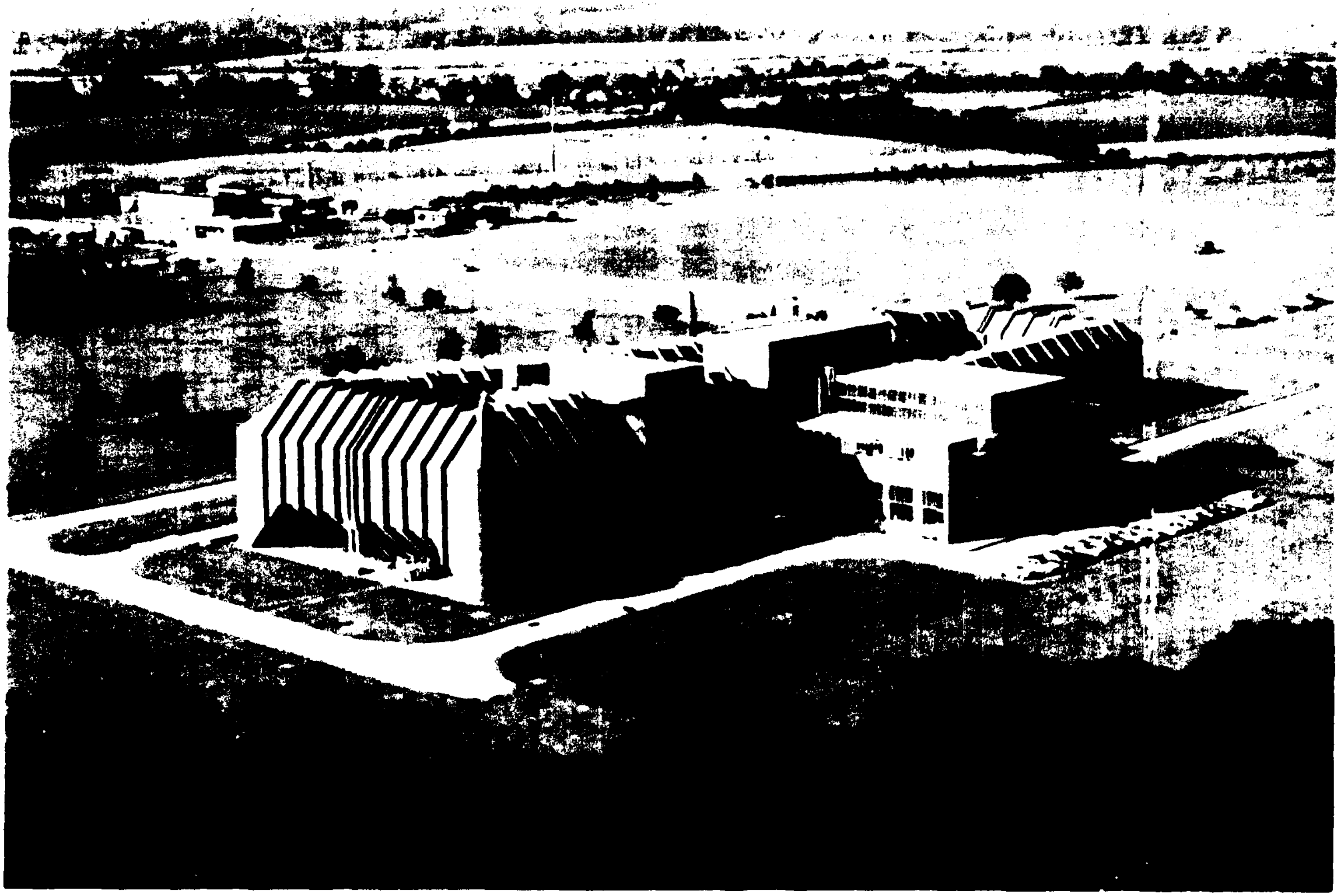

Fig 2 Tunnel exterior and office block

Fig 3

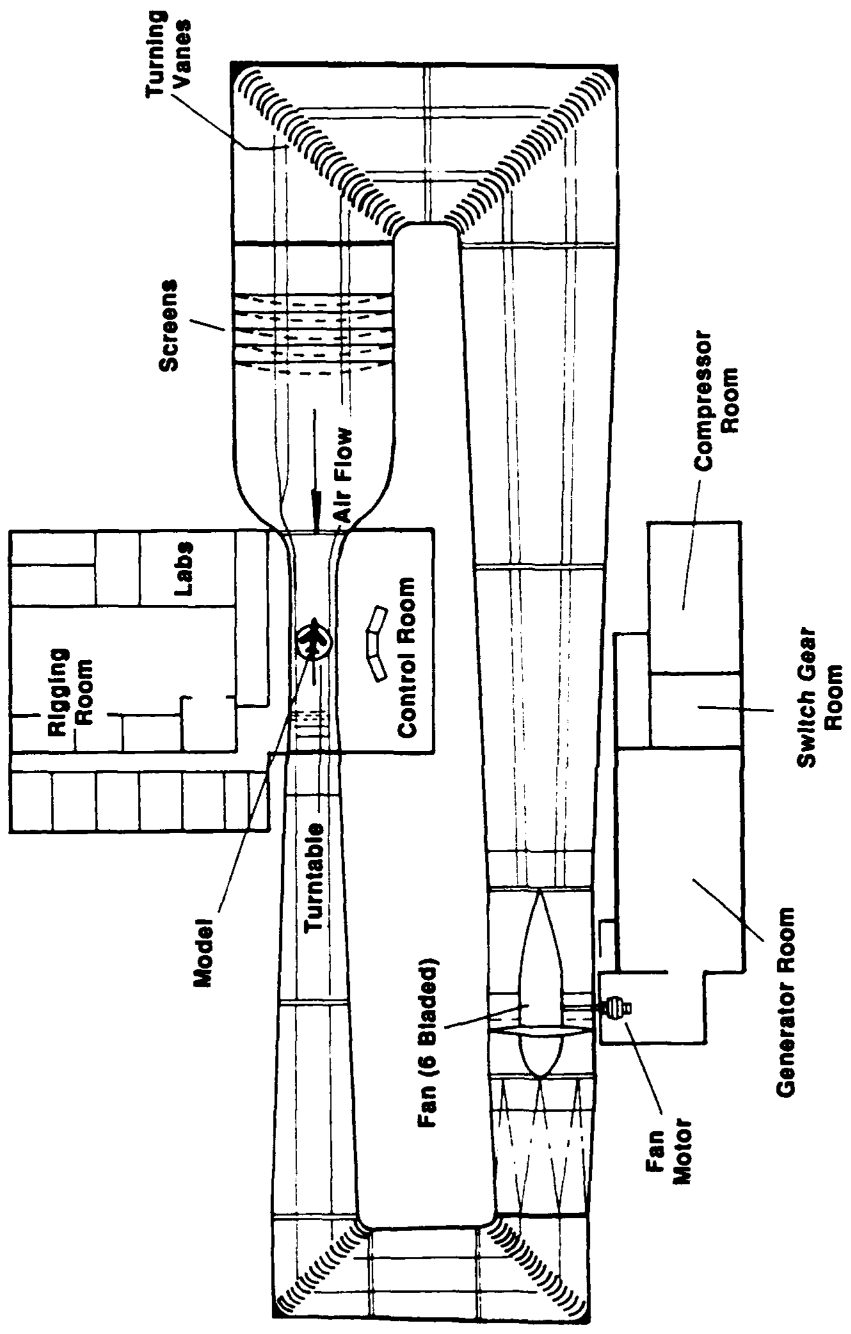

Fig 3 Sectional drawing of the 13ft. X 9ft. Wind Tunnel

Fig 4

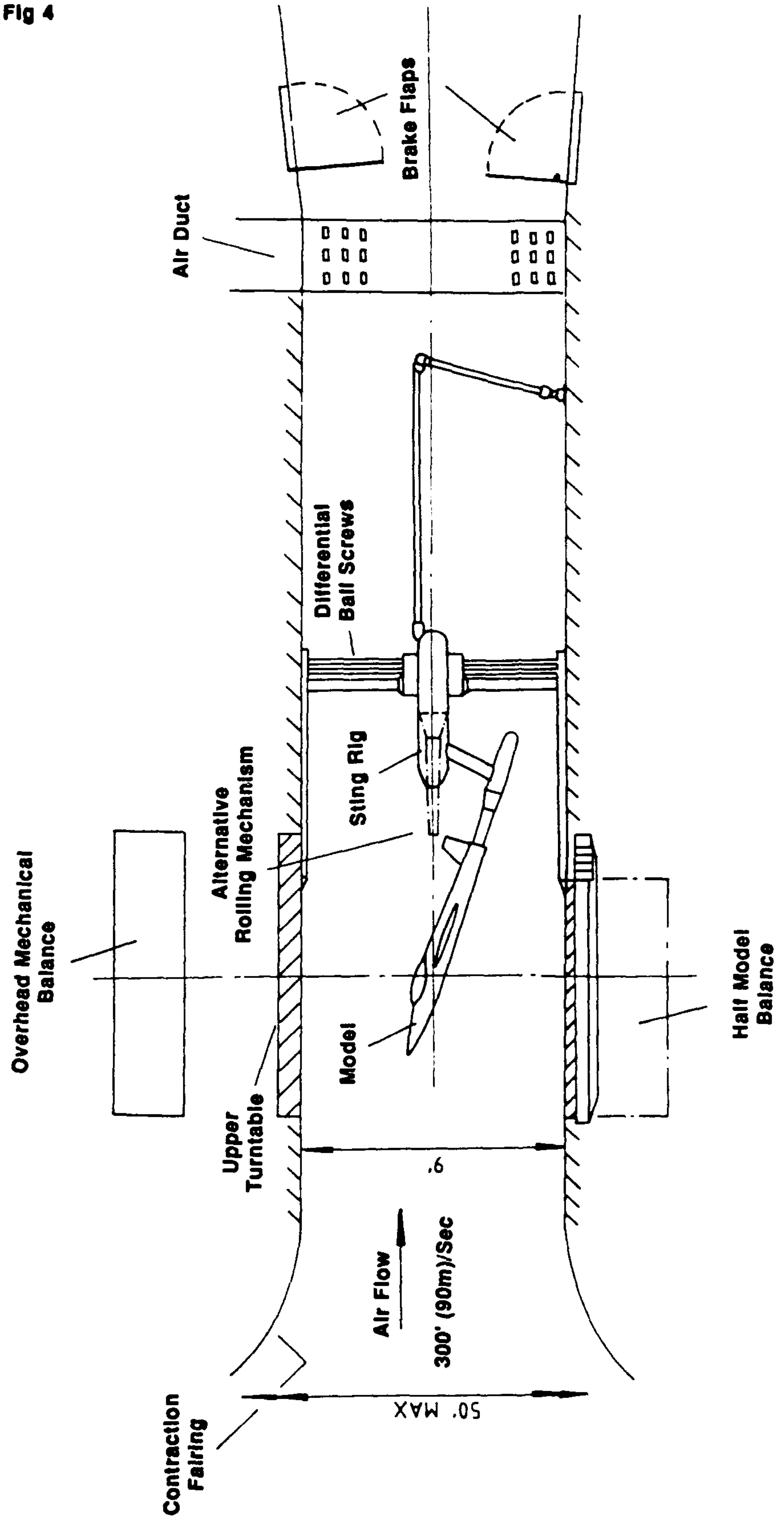

Fig 4 Sectional drawing of the working section

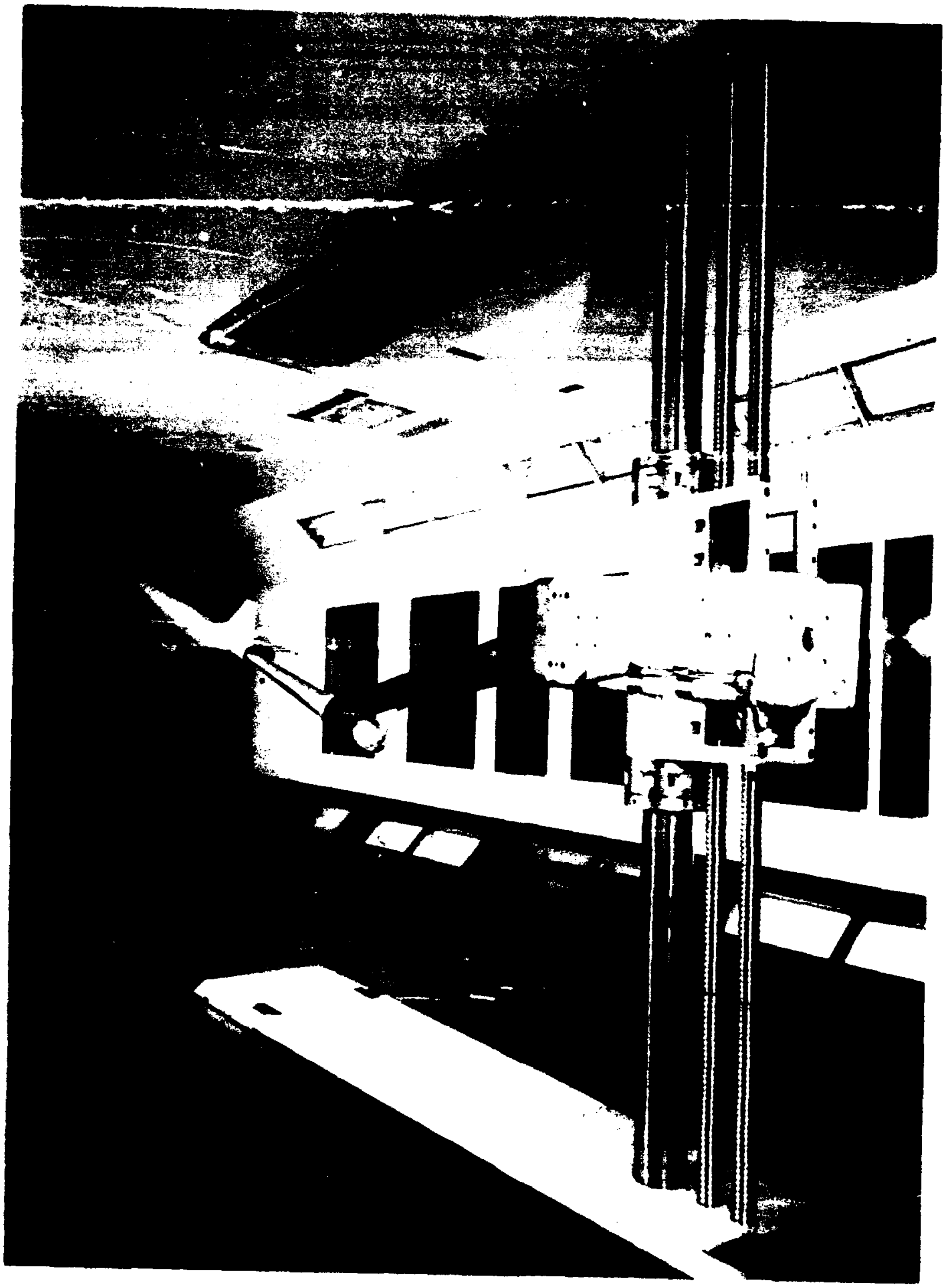

Fig 5 The sting rig

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Fig 6

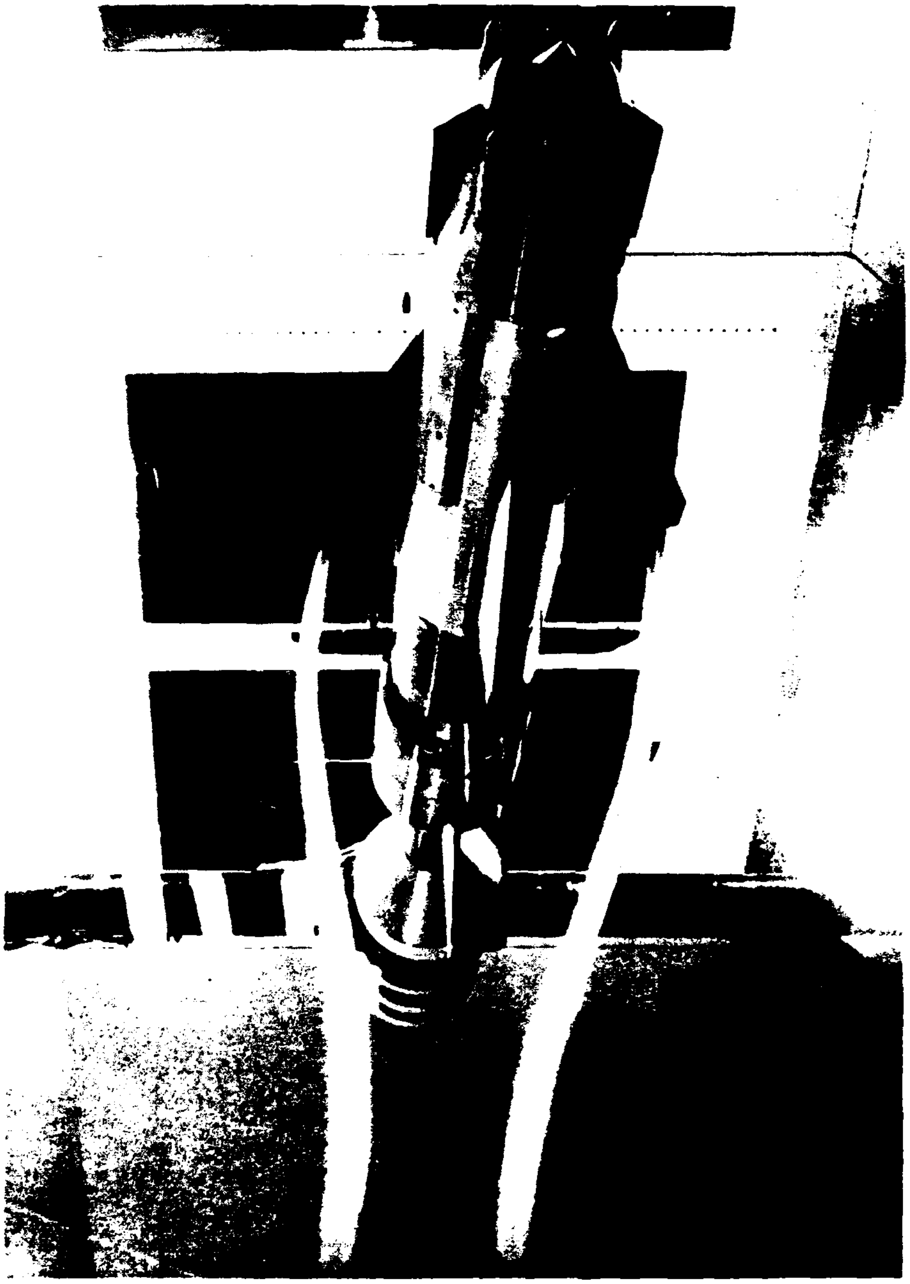

Fig 6 The missile rig

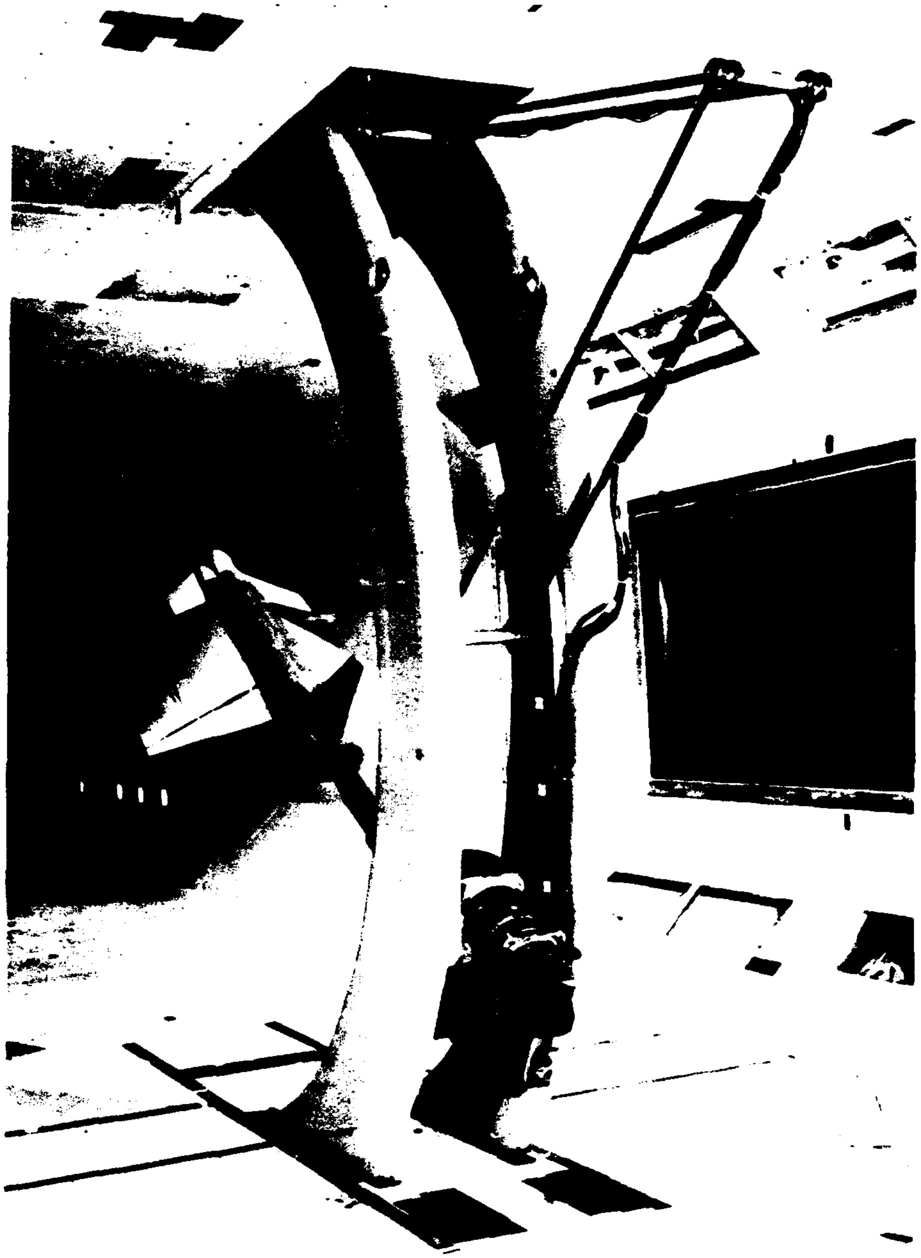

Fig 7 The high incidence rig

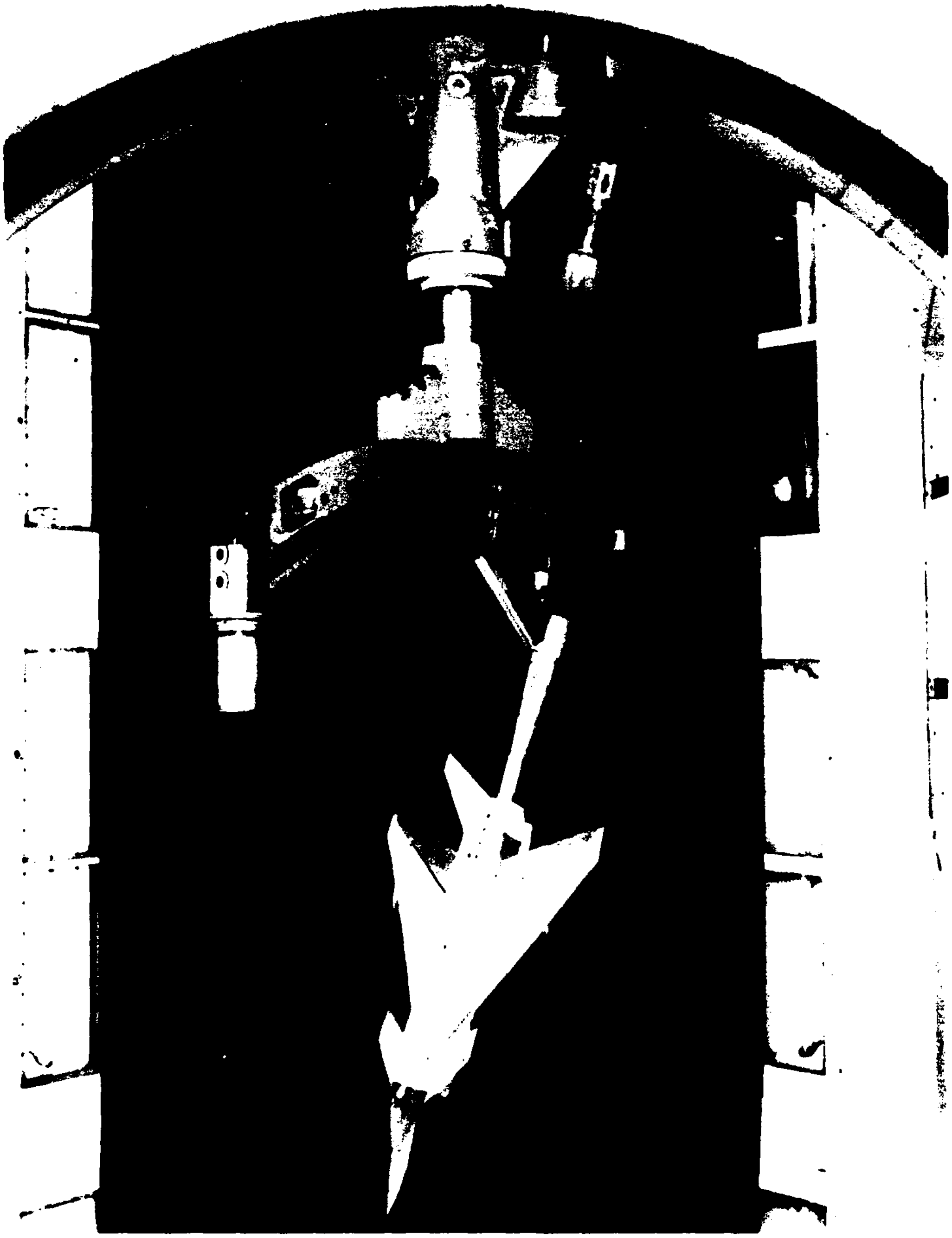

Fig 8 The rotary rig on the quadrant

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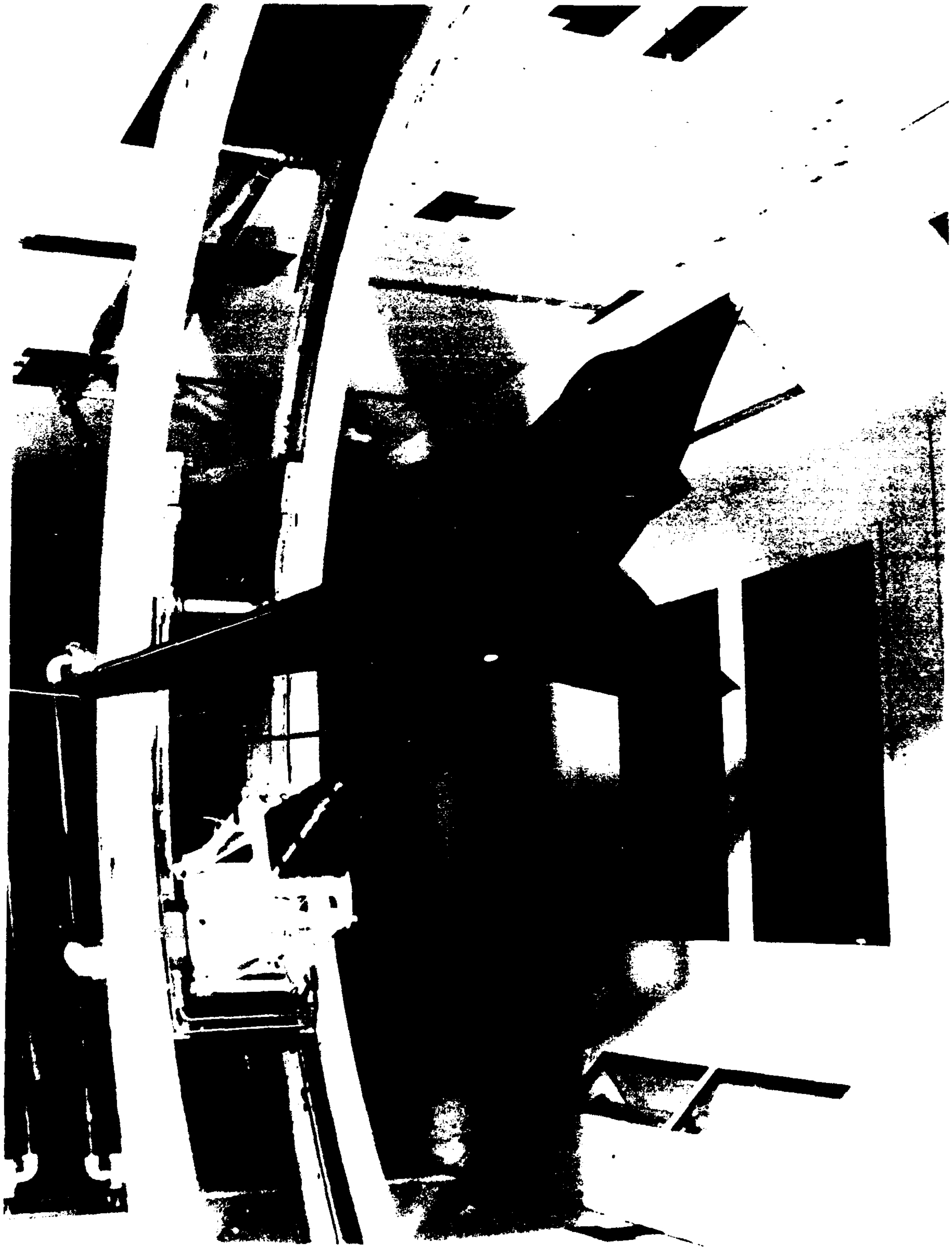

Fig 9 The oscillatory rig on the quadrant

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Fig 10

Fig 10 The free-to-yaw rig

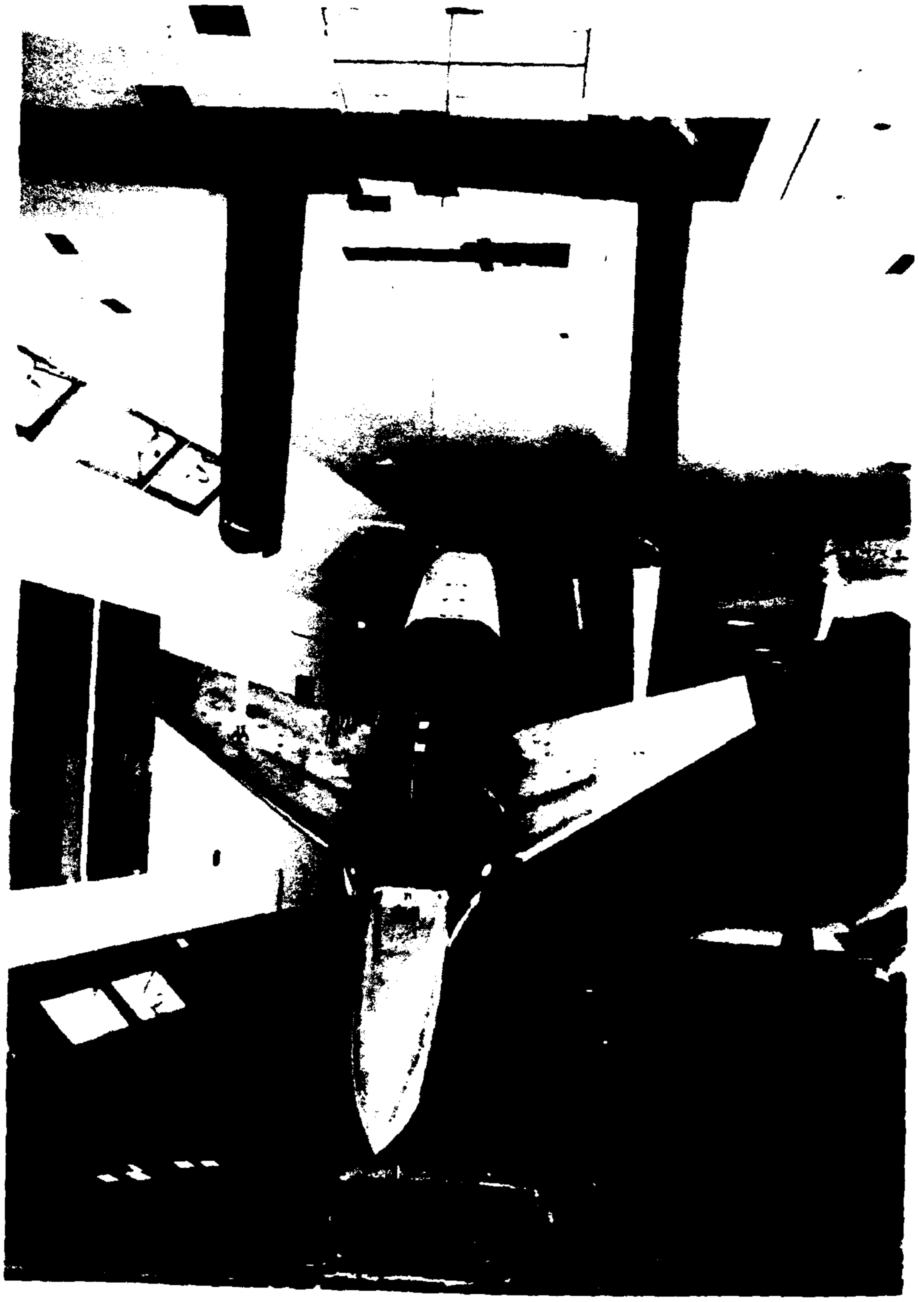

Fig 11 Model suspended from overhead balance

Fig 12 Half model in the working section

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Fig 13 The wake transverse gear

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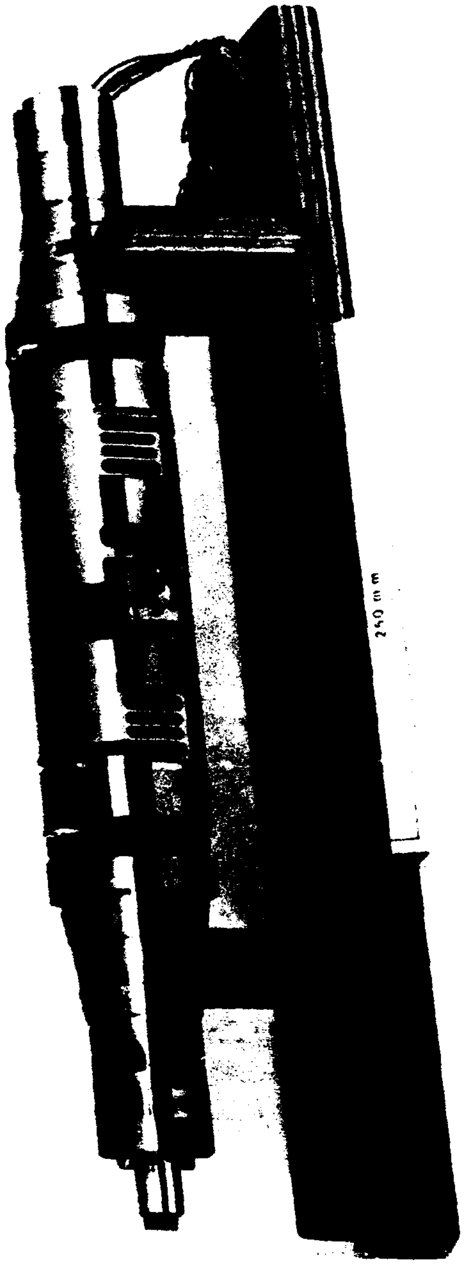
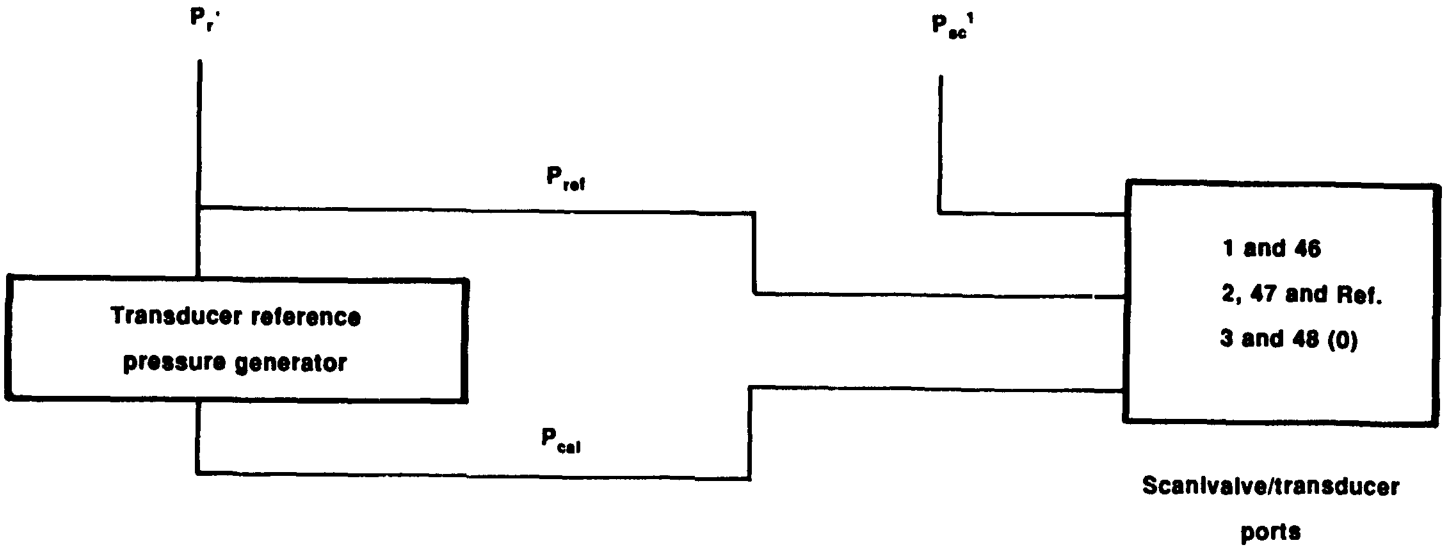


Fig 14 A strain gauge balance

Fig 15

Fig 15 The virtual centre balance

Fig 16 The dynamic balance



P_r^1	Working section roof tapping (spare)
P_{sc}^1	Settling chamber tapping (spare)
P_{ref}	Reference pressure applied to transducer
P_{cal}	Calibration pressure applied to transducer ($P_{cal} = P_{ref}$ - offset)

Reservoirs are not shown for clarity

Fig 17 Scanivalve/transducer calibration pressures

Fig 18 Transducers and scanivalves in a model

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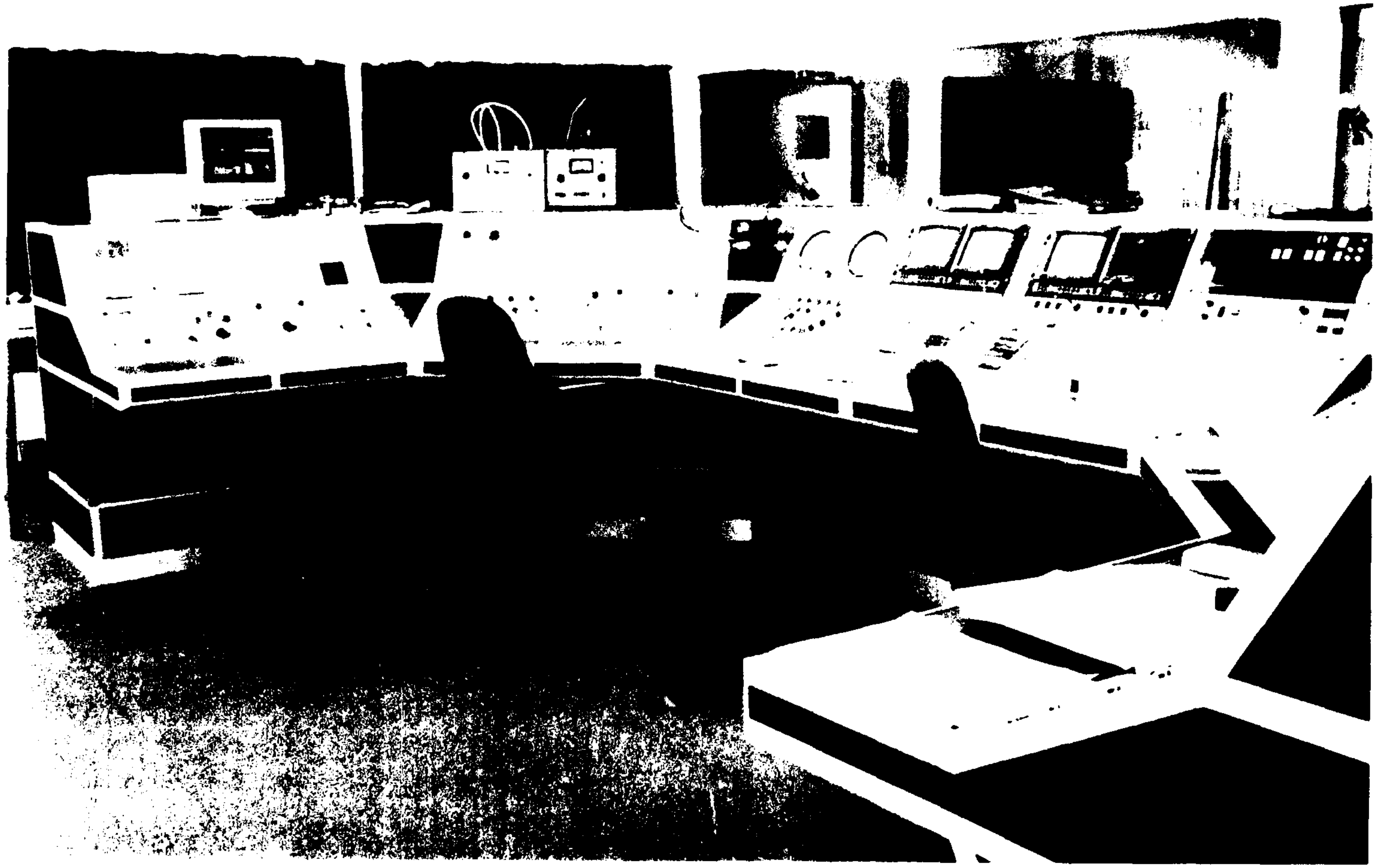

Fig 19 The Observation Room

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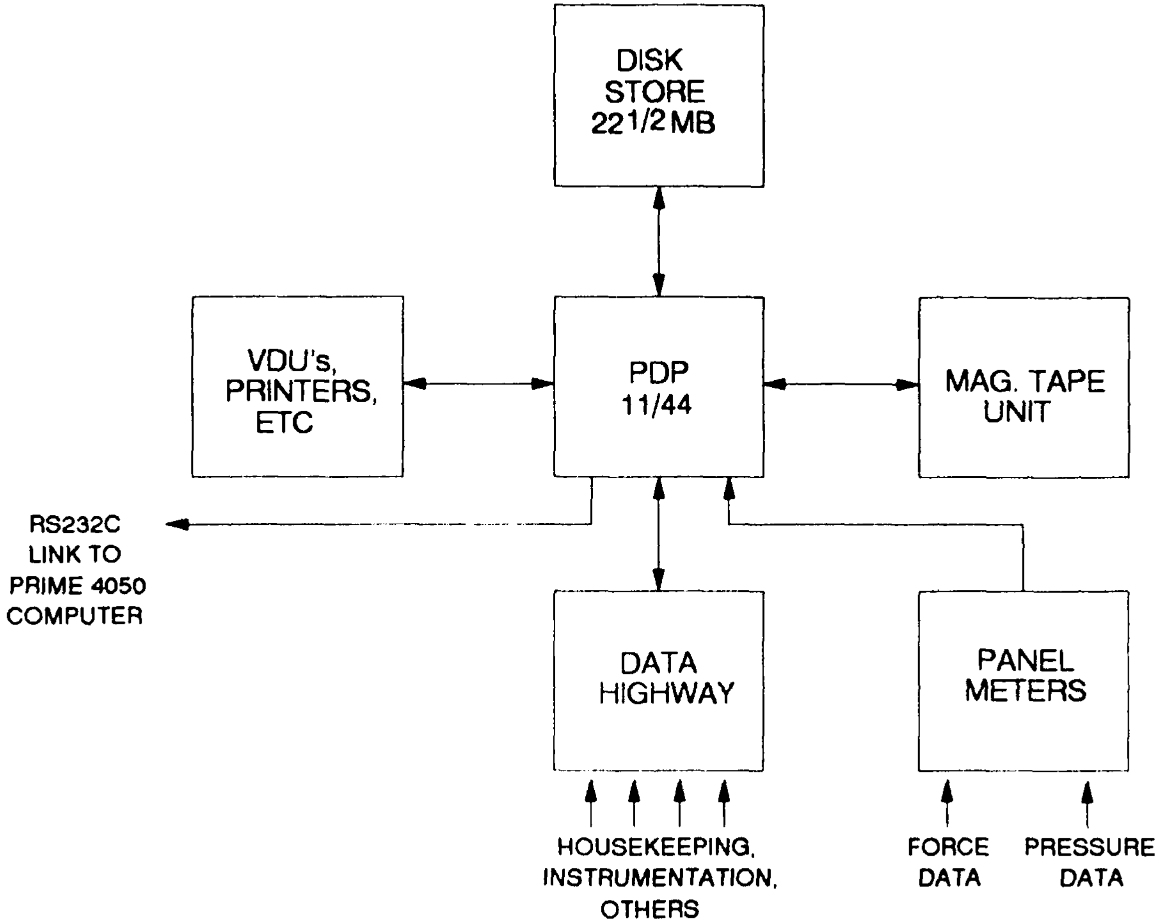

Fig 20 The PDP 11/44 layout

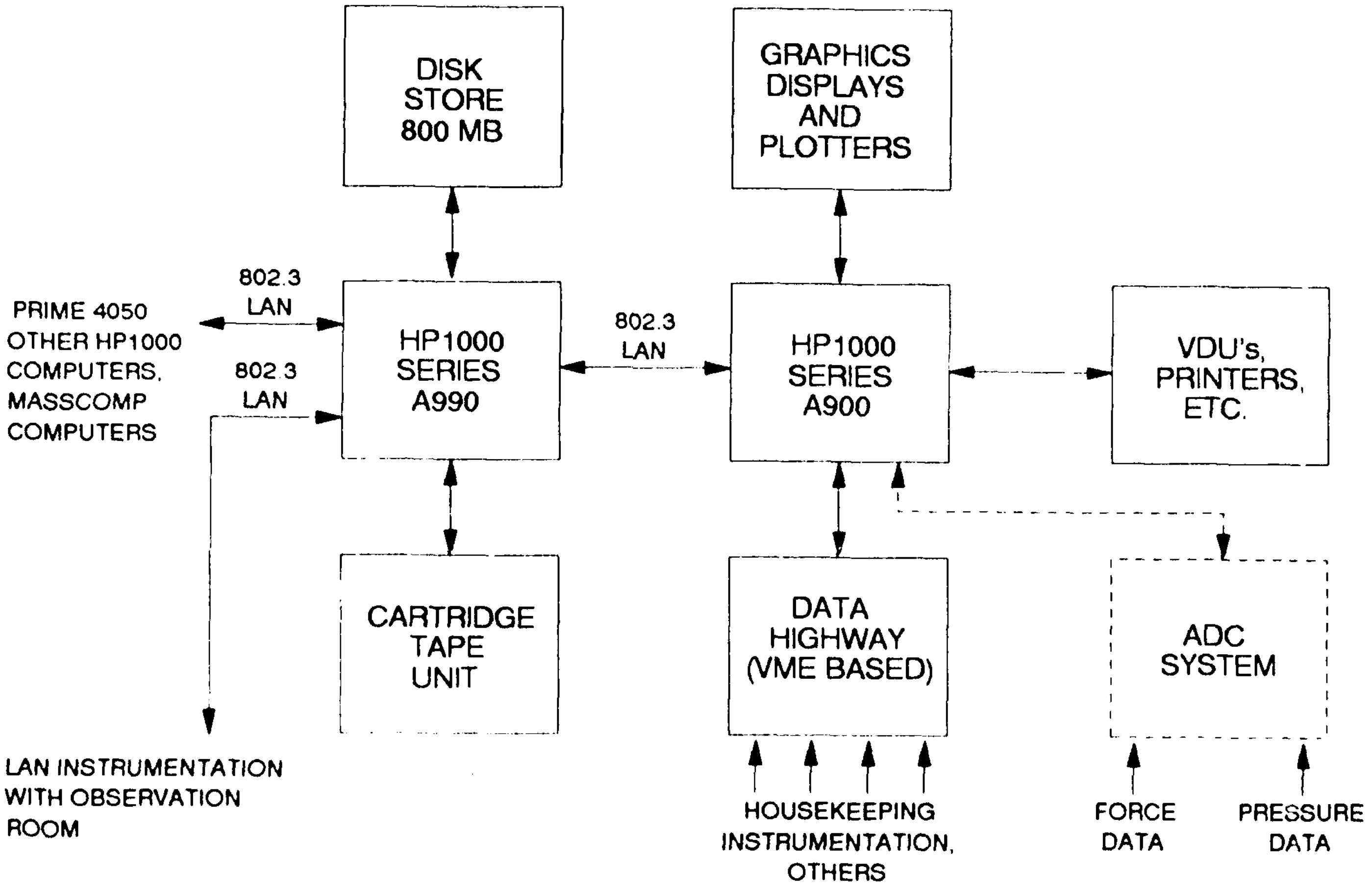

Fig 21 The HP 1000 layout

Fig 22 A laser-smoke screen view

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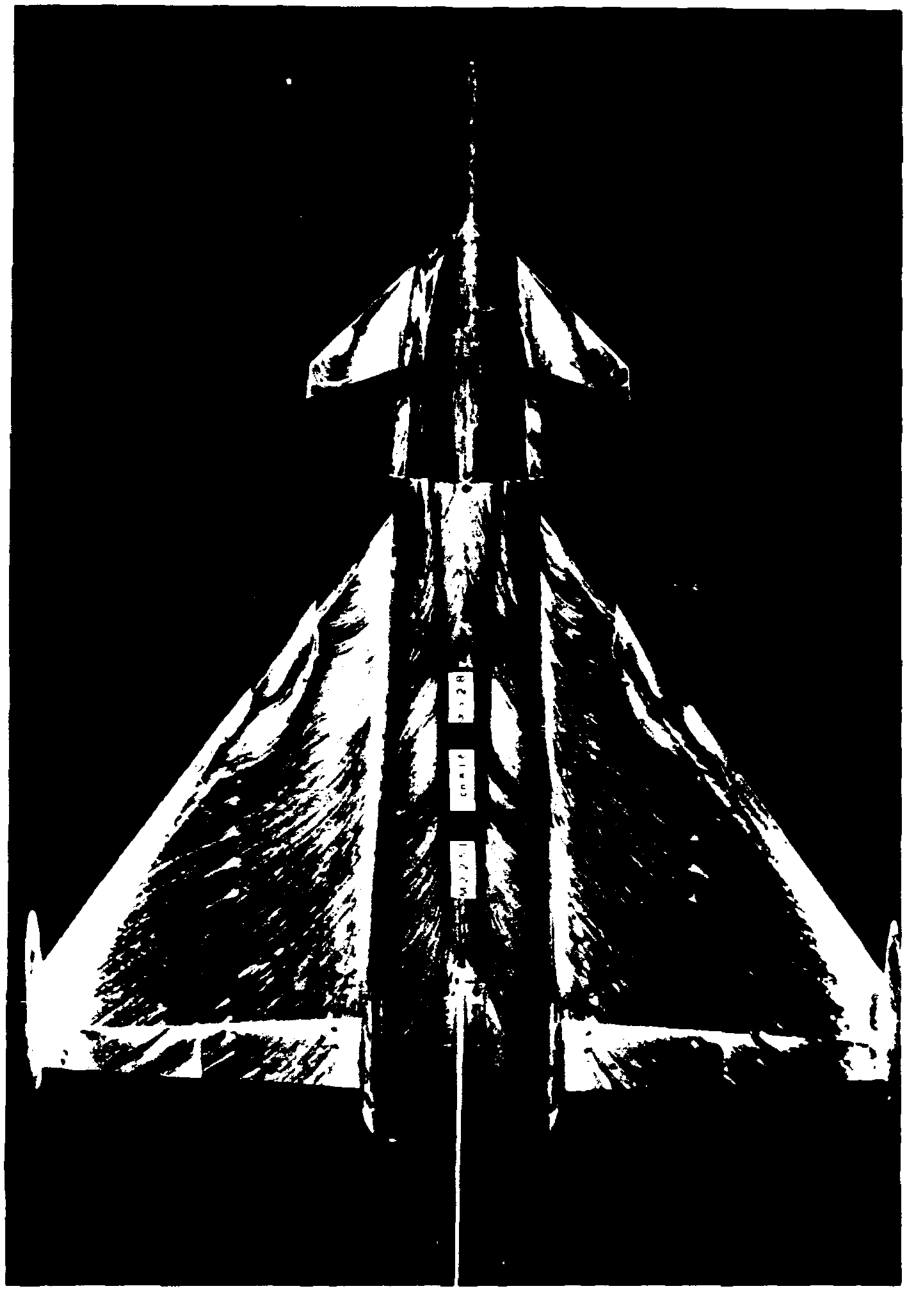


Fig 23 An oil flow view

Fig 24

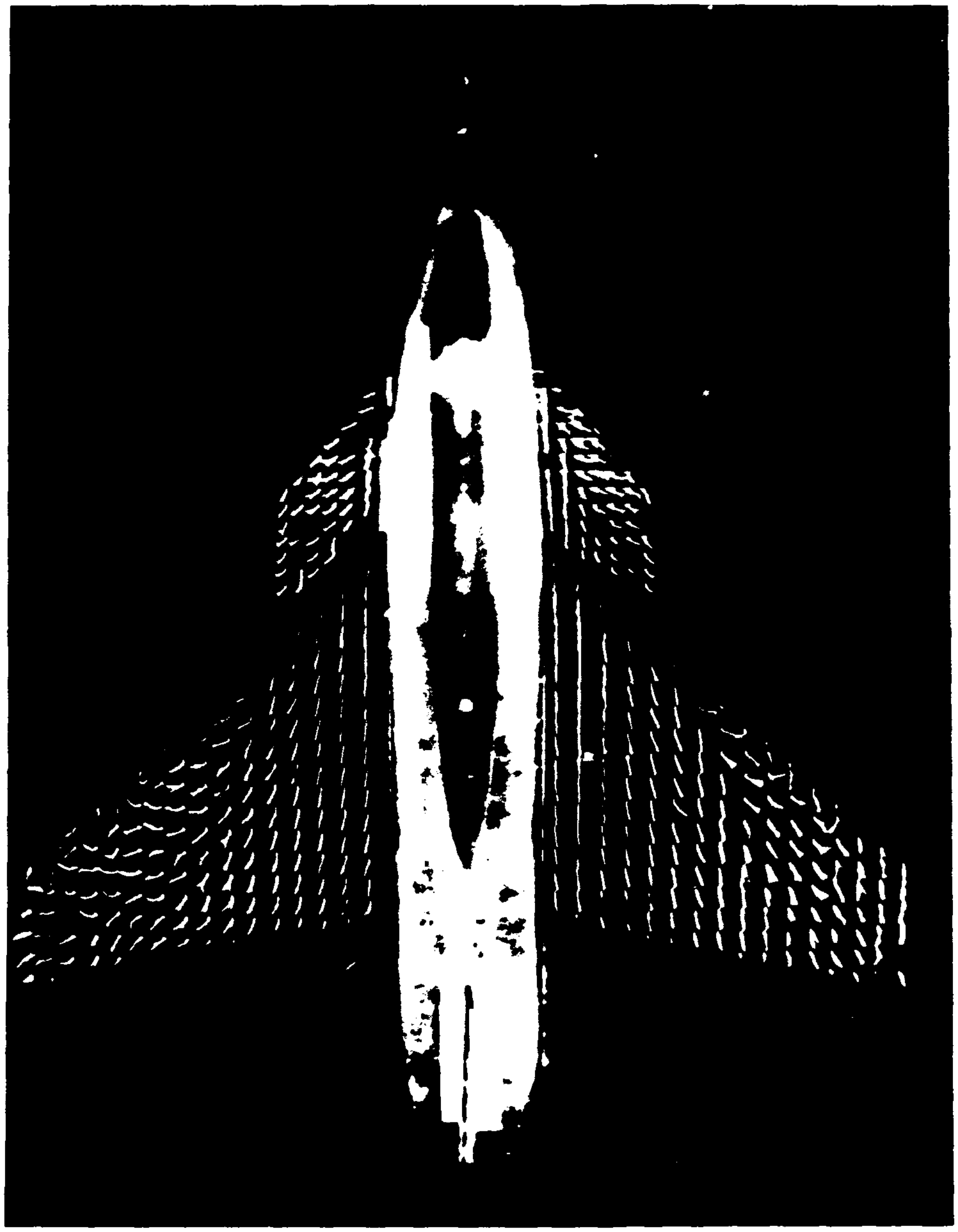
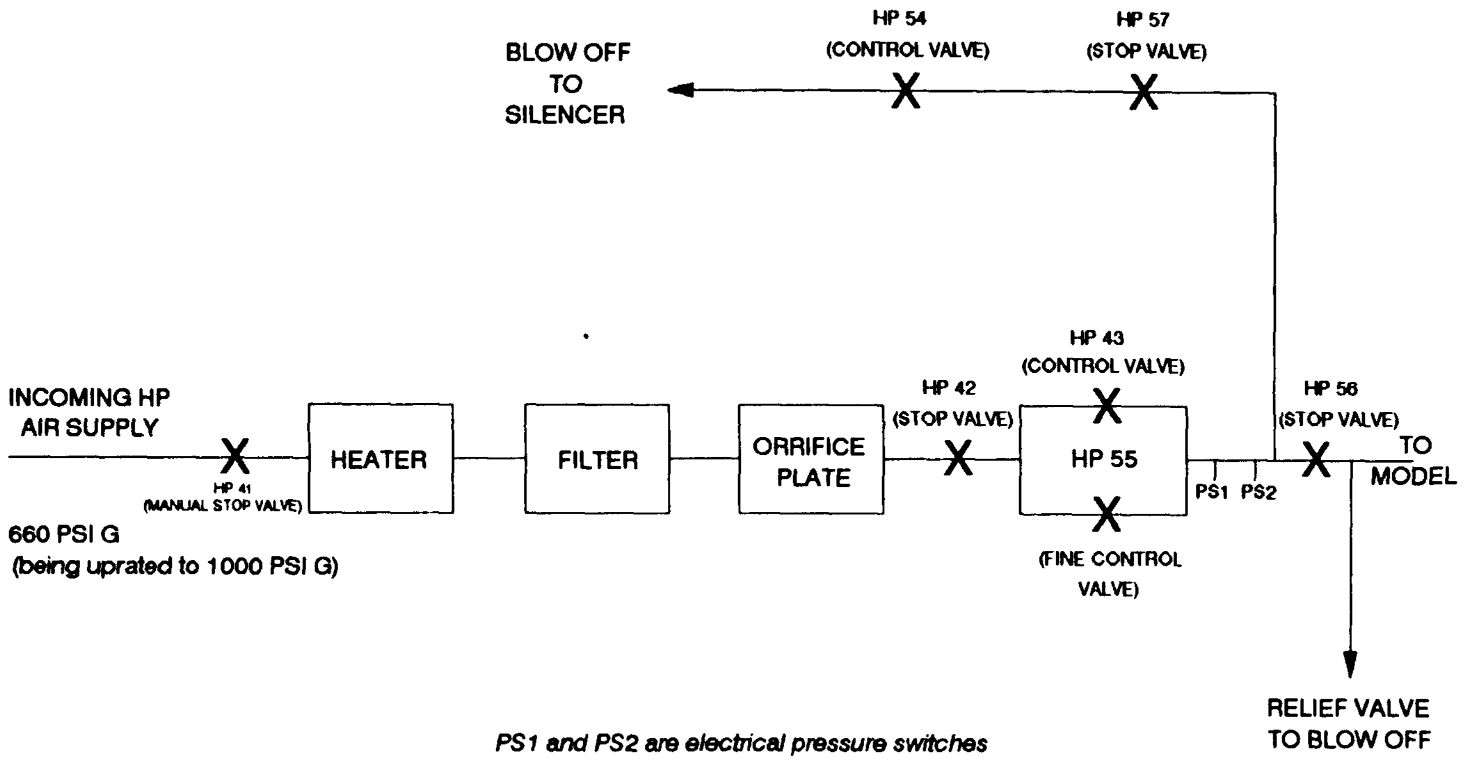
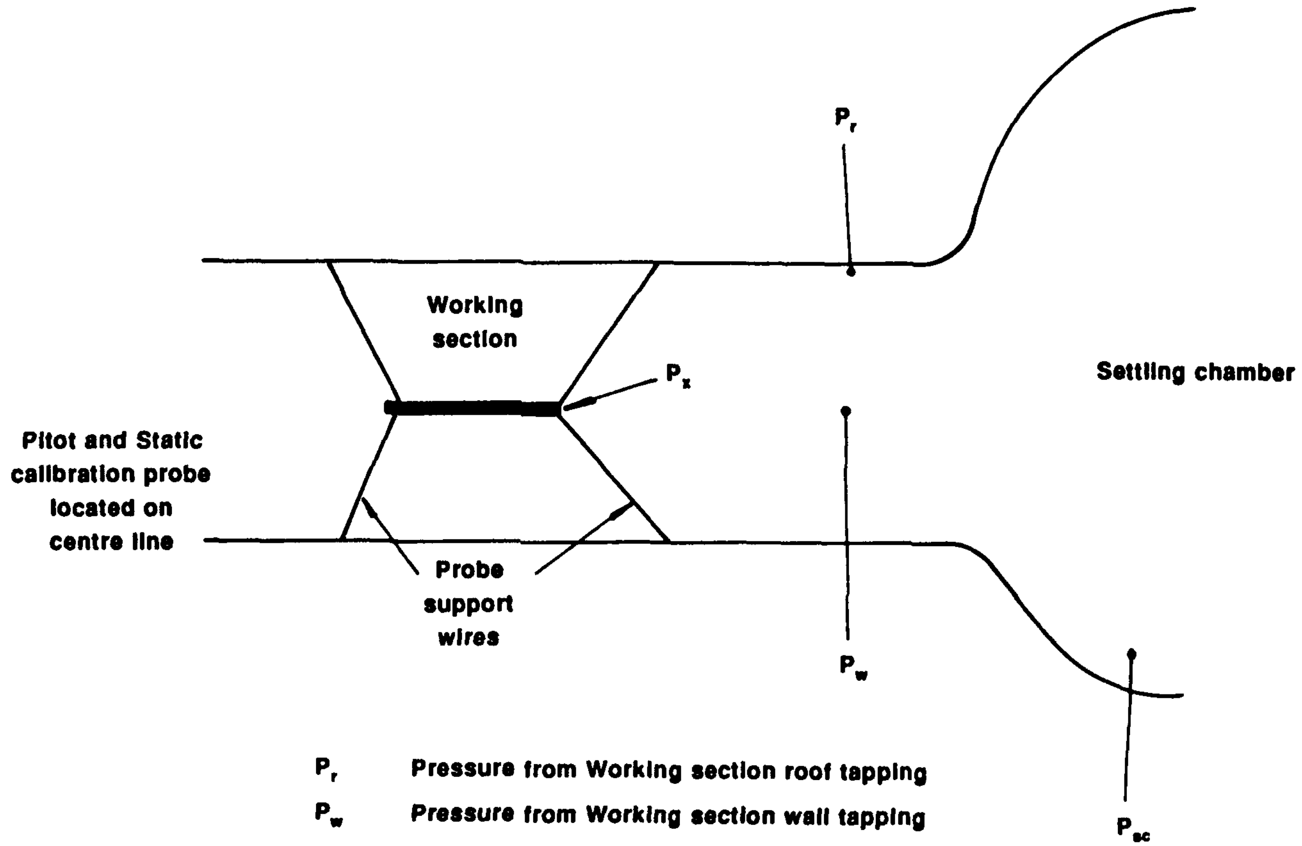


Fig 24 A micro-tuft view (under UV light)



PS1 and PS2 are electrical pressure switches

Fig 25 Layout of the HP Air system



P_r	Pressure from Working section roof tapping
P_w	Pressure from Working section wall tapping
P_{sc}	Pressure from Settling chamber
P_x	Pitot or Static pressure from centre line

Fig 26 Location of the pressure holes in the 13ft. X 9ft. Wind Tunnel

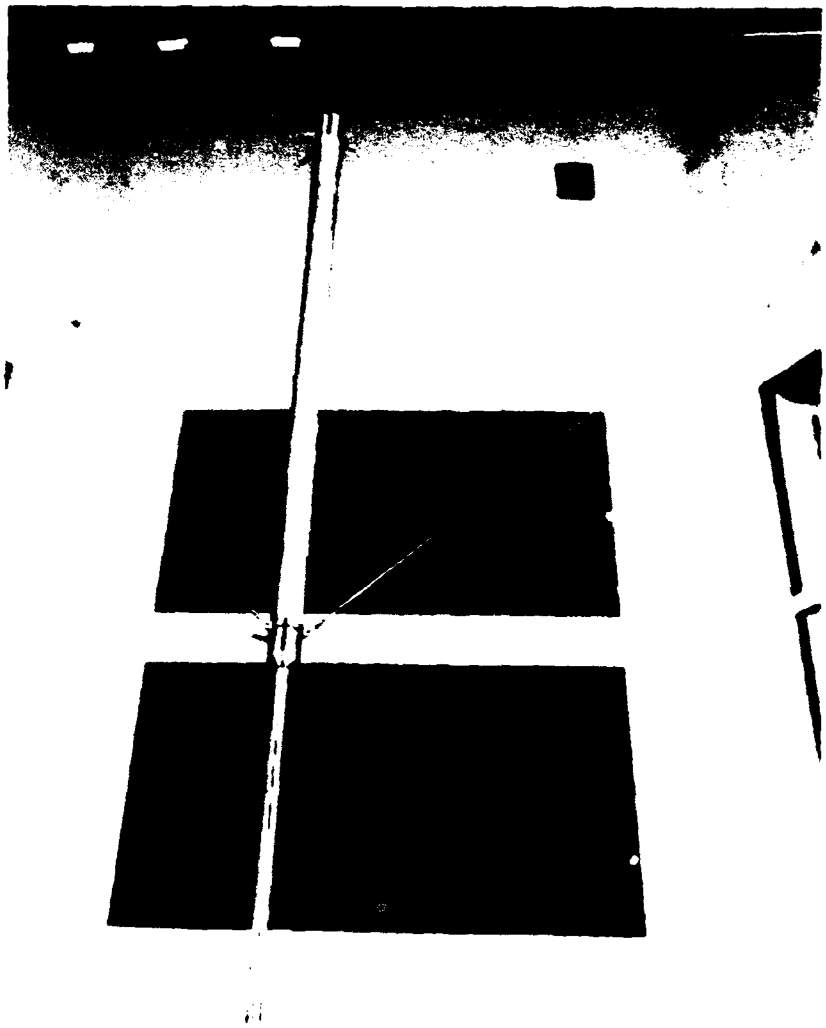


Fig 27 The tunnel speed calibration probe

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Fig 28

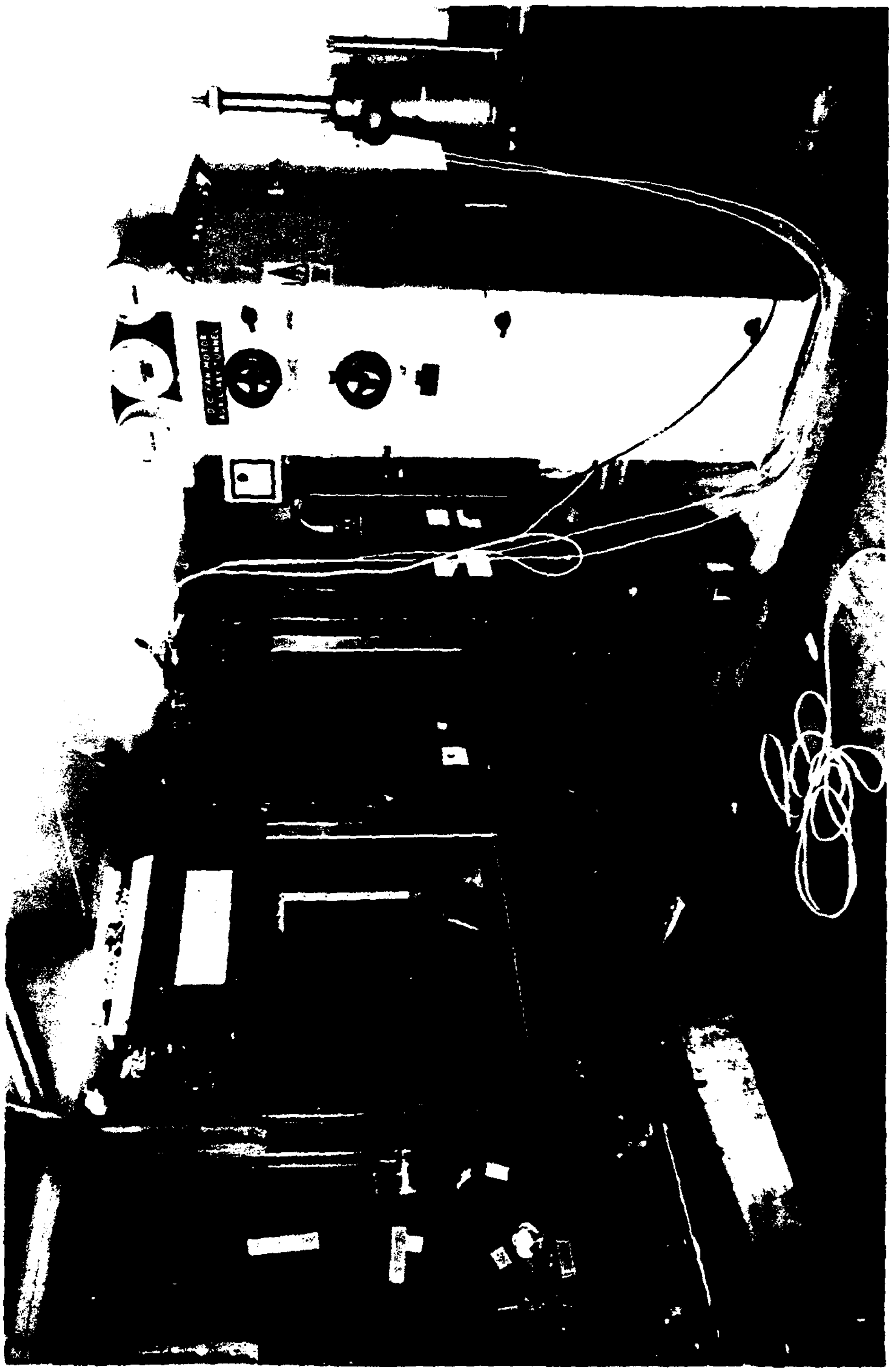

Fig 28 The 4ft. X 3ft. Auxiliary Tunnel

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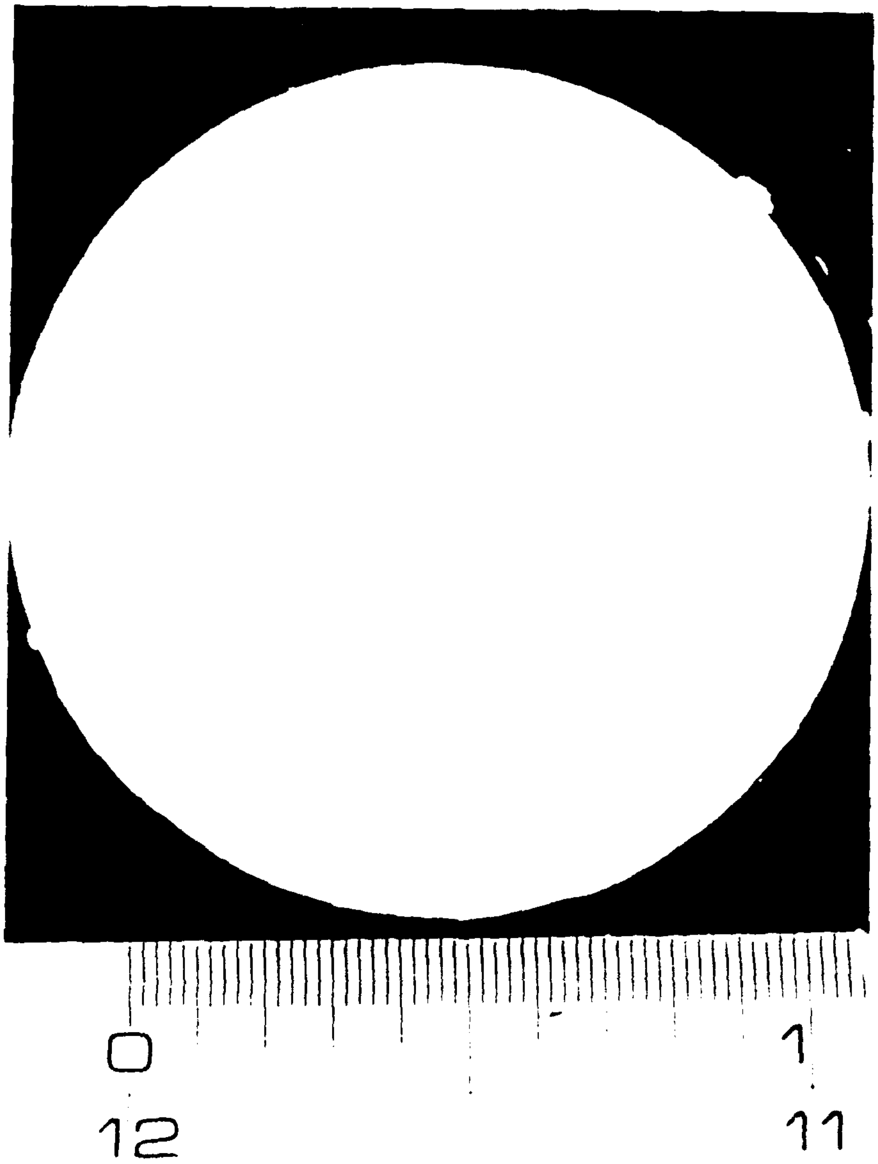

Fig 29 The air contamination disk (enlarged)

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REPORT DOCUMENTATION PAGE

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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

17. Abstract

This Technical Report is intended to provide a guide to the 13ft × 9ft Low Speed Wind Tunnel facility. It details the model support and balance assemblies, provides an insight to the instrumentation and computing capabilities and indicates the different flow visualisation techniques available. A description of the tunnel and local facilities is included, along with contact numbers for customers' use.

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DRA Form A143 (revised January 1992)