THE RAE 5 METRE PRESSURISED LOW SPEED WIND TUNNEL

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Abstract

This large, pressurised low speed wind tunnel has been built at RAE Farnborough to improve the accuracy and reliability achievable in wind tunnel tests on the low speed aerodynamics of modern aircraft and their complex high lift systems.

A description is given of the tunnel and its system for model support, model interchange, tunnel control and data handling. A brief survey is included of the results of commissioning and calibration.

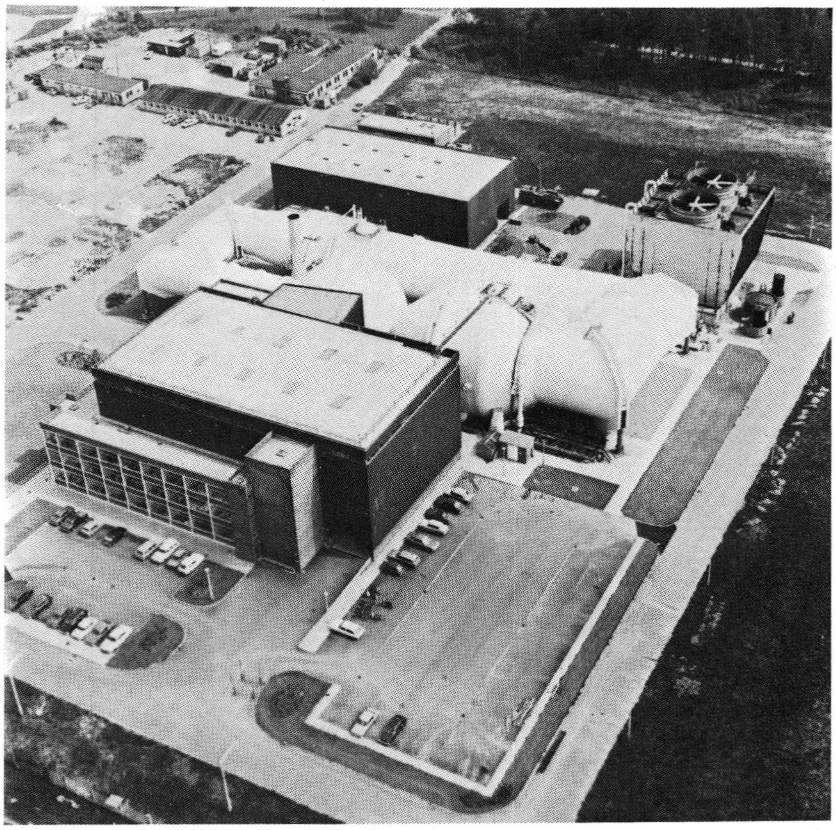

Figure 1. Aerial view of the tunnel

I. Introduction

The demand for good take-off and landing characteristics, in conjunction with the high wing loading required for high speed performance, has made it necessary for almost all conventional aircraft, both military and civil, to have complex systems of slats and slotted flaps and/or blowing in order to achieve the required lift coefficients. The rewards for achieving better lift-off capability for a given runway length, and also lower drag levels (with one engine failed) during climb-out from an airfield, are at least as significant as improvements in the high speed part of the flight envelope. The emphasis which is being given to ways of reducing noise in the vicinity of airports will, moreover, result in still greater attention being paid to the high lift, low speed behaviour of future designs.

Although the flight Mach number is low under these conditions, high local velocities, particularly near the wing leading edge, result in significant compressibility effects. Hence, it is important to conduct model tests at the correct Mach number. Also, the need to achieve acceptable Reynolds numbers on all the elements of a modern slotted high lift system, some of which may only be 10% of the basic chord, makes it more necessary to aim for high test Reynolds numbers than in the past. At the same time it is important to use large models so that slat and flap supports can be represented correctly. Extrapolation to full-scale performance can be made with reasonable confidence only if the effects of compressibility and scale can be separated out in the model results, and this demands a pressurised wind tunnel for such investigations.

For these reasons, a large pressurised low speed wind tunnel has been built at RAE Farnborough. Use of it in research and project development should lead to the design of aircraft with better low speed performance, with less development flying, and much reduced risk of expensive modifications being necessary at the flight test stage.

By virtue of the size of its working section (5 m wide by 4.2 m high), its pressure range (up to 3 atmospheres) and its drive power, this tunnel can be used to test models of small combat aircraft (such as BAe Hawk or GD-YF16) at full-scale values of Reynolds number. For models of transport aircraft of the size of the European Airbus (A300B), Reynolds numbers nearly a quarter of full-scale values can be achieved; the capability to test over a 3:1 range of Reynolds number at constant Mach number then enables the effects of scale and compressibility to be separated, and gives a firm base from which to extrapolate to full-scale conditions.

The tunnel (shown in an aerial view in Figure 1 and as a cut-away drawing on Figure 2) has been designed particularly with project development in mind, and has the following valuable features:

(i) the model size (typically up to 3.5 m span) is large enough to enable small but important details to be represented in high lift systems and in the excrescences associated with them;

(ii) high Reynolds numbers can be achieved for Mach number conditions covering not only landing and take-off, but also the climb-out and stalling tests at altitude;

(iii) interchangeable carts enable model rigging and preparation to be done outside the working section;

(iv) models can be mounted on struts from an underfloor mechanical balance of great sensitivity and accuracy, thus providing the means for confidently examining the effects of small changes;

(v) alternatively models can be mounted on strain gauge balances from a sting supported on a quadrant, thus providing a rig with low interference from which to deduce absolute values. Using the two support systems for the same model, together with suitable dummies, allows support interference to be assessed with confidence;

(vi) half models can be mounted on the mechanical balance using the floor of the tunnel as a reflection plane. The mechanical balance has adequate capacity to measure the large loads produced by such models at the highest kinetic pressure;

(vii) a versatile data acquisition system is available, which can provide corrected data online for commercial users of this tunnel;

(viii) RAE is immediately to hand to provide technical advice and workshop and computing facilities; models and personnel may be delivered to the airfield.

In this paper the main features of the design of the tunnel circuit, the access to the working section, the model mounting facilities, the instrumentation system and the tunnel control system are described in sections II to VI purely in terms of their design aims. Although the commissioning of the entire tunnel complex is almost complete at the time of writing this paper, in most cases there has been sufficient time to make only a preliminary assessment of how well these design aims have been achieved. Section VII describes the present state of this assessment; an up-to-date version will be presented at the Congress and issued as an Addendum to this paper.

II. Description of the Air Circuit, Main Drive Fan, and Auxiliaries

The general arrangement of the facility is shown in Figure 2. The tunnel circuit is of welded steel construction and aerodynamically is a conventional return circuit with 5½ degree diffusers, except for the more rapid expansion between the fourth corner and the cooler. The pressure shell is everywhere circular in cross-section, but liners are incorporated at the settling chamber, the contraction and the working section to make the air-swept surfaces rectangular (with corner fillets). From the settling chamber to the working section the shape of the cross-section is kept constant in order to reduce the possibility of secondary flows in the working section.

The cooler (13) is shown in Figure 3 and can dissipate the whole power input of the fan drive whilst maintaining an air temperature of 40°C or less. It is made from two rows of elliptic tubes with closely-spaced flat rectangular fins. Its pressure drop makes possible the use of the rapid expansion upstream, and the cooler acts as a fine-mesh honeycomb which strongly attenuates the turbulence of the incoming flow and generates small-scale turbulence with a high rate of decay. The combination of the cooler and the two 1.0 q screens (12) is designed to give a uniformity of kinetic pressure over practically the whole of the working section within the desired standard of ±0.1% and a turbulence level of 0.10 to 0.15% taking an average of all three components.

The main driving motors are housed inside a nacelle of 6.1 m diameter within the air circuit. The drive consists of an ac motor of 11000 kW continuous output (17) controlled by a liquid rheostat, together with a 1640 kW dc motor controlled by thyristors (16). These motors can be used separately or together, giving considerable flexibility in operation with good control extending down to low speeds. The aim is to maintain the kinetic pressure in the working section constant to within ±0.1% against the expected variations in electrical supply frequency and voltage.

The fan system is shown in Figure 4 and comprises 21 cambered and twisted prerotation vanes, a 10-bladed single stage rotor and nine symmetrical straightener vanes, some of which are used to admit and exhaust air to and from the circuit. The use of a fixed-pitch fan ensures a uniform velocity distribution to the main diffuser at all tunnel speeds.

The fan has an outside diameter of 10 m and each blade is 1.95 m long with a chord of 0.91 m; the thickness chord ratio varies from 10% at the tip to 20% at the root. The blades are made from glass fibre reinforced Araldite and are bonded in a special way[1] to steel root fittings. Strain gauges have been installed on three of the fan blades so that the dynamic loadings on the blade when the tunnel is running can be studied. With a composite structure such as this it is important to be able to detect the onset of delaminarisation in the glass fibre or an incipient failure in the bonding to the root fitting. Each blade has two hard points on it, into which an accelerometer can be screwed when the fan is stationary. The output of this accelerometer is recorded for each position when the blade is struck with a soft faced hammer. Seven distinct vibration modes have been identified from the output; for the three cleanest of these the frequency and damping is evaluated and recorded at regular inspection intervals; significant changes in these would indicate the need for further inspection and remedial action. So far, extremely consistent results have been obtained provided that account is taken of the temperature.

A system of compressors has been installed taking into account the need for pumping up the tunnel to 3 atmospheres in a reasonable time, the requirements for trimming air as part of pressure control during a test, and the provision of air for model blowing. A suction machine is also provided.

The compressors comprise:

(a) two identical machines, each providing 7.9 kg s^{-1} at 4.5 atmospheres;

(b) a third machine which can work in series with one of the above to give 7.9 kg s^{-1} at up to 22 atmospheres for model blowing; it can also work in parallel with the other compressors to give an extra 1.9 kg s^{-1} for pumping up the tunnel.

Cooling and water separation provide air of the required dryness. The compressors are designed to pump up the tunnel circuit to 3 atmospheres in 45 min and to repressurise the inner sphere in 3 min, (see section III). The suction machine can pump 4.2 m^3 s^{-1} at the machine inlet with an inlet pressure between 0.5 and 1.5 atmospheres. This fulfils the requirement for end-wall suction on two-dimensional aerofoils and easily suffices for boundary layer suction on models.

III. Access to Working Section

One of the main features of the design is the arrangement incorporated to ensure that ease of access to the working section is comparable to that in large low speed tunnels operating at atmospheric pressure. Two concentric spheres surround the working section. Parts of the working section walls at the upstream and downstream ends can be rotated, so that pressure doors (Item 2 on Figure 2) on the outside of the inner sphere can be swung across the air passage and closed on to the inner sphere. This can then be depressurised to give personnel access to the working section (Figure 5).

The model, together with all the instrumentation needed for the test, is mounted on a 'cart' which forms the floor of the working section. The working section can be rotated about the vertical axis of the spheres as shown on Figure 6, until it lines up with the main access tube (Item 4 on Figure 2) and then the complete cart can be driven electrically along a railway on to a turntable (Item 7 on Figure 2) and from thence parked in one of the four bays (Item 9 on Figure 2) as shown on Figure 7.

The main floor of the area around the rigging bays is about 1 m above the floor level of a cart parked in one of the bays (Figure 2). Temporary flooring can be easily placed across the rigging bay, level with the main floor area, to provide access to the model without the need to use steps and scaffolding.

It is estimated that a total of about 6 min is needed to stop the fan, get the pressure doors into position and obtain access to the model; a similar time will elapse from finishing a model change to being back in condition and ready to acquire data.

This part of the access system is controlled by a hard-wired sequencer which provides all the appropriate safety interlocks including counting personnel into, and out of, the working section. A separate system controls the rotation of the working section and the automatic movement of the carts between the working section and the bays in the rigging area.

IV. Model Mountings and Balances

Three mobile model carts are being provided initially, each providing a different type of model mounting. Additional carts may be introduced to the system by lifting them on the overhead travelling crane (shown on Figure 2) which has a lifting capability of 600 kN.

The Sting Support Cart

This enables models to be attached via a strain gauge balance and a sting to a circular arc quadrant as shown on Figure 8.

The Quadrant. This is designed to withstand a force of 82.5 kN in any direction normal to the roll axis of the quadrant, acting 380 mm ahead of the centre of rotation of the quadrant, together with a rearward force along the roll axis of 22 kN. The pitch range of the quadrant is $\pm 19^{\circ}$ about the horizontal position of the roll axis and this can be traversed from end to end in 30 s. The pitch drive is electrically powered through a rack and pinion.

The roll mechanism in the quadrant is designed to withstand a rolling moment of 20.3 kN m but only to drive against a rolling moment of 6.8 kN m. The maximum rolling moment figure corresponds to the sudden complete stall of one wing of a typical transport aircraft model producing a ΔC_L on that wing of -2.0 at maximum kinetic pressure.

The top part of the quadrant can be quickly detached at the joint line shown on Figure 8 to allow the cart to be removed from the tunnel.

The Sting. A straight sting and one with a 10° crank are at present available; a 17° cranked sting is being manufactured. The cranked stings are, of course, necessary in order to obtain a large enough maximum incidence to penetrate the stall, the 17°

cranked sting giving a maximum geometric incidence of 36°.

The stings are typically 5 m long with root and tip diameters of about 300 and 200 mm respectively; there is a hole down the middle of each sting of 100 mm diameter. The stings are made from high grade steel and standard gun barrel manufacturing techniques are used to produce the hole through the middle and the external taper over the length. The cranked stings are then bent, the male taper at the root end where it joins the quadrant and the female taper at the tip, being machined after bending. These tapers have to be cut in a special machine in which the cutting tool rotates and the sting remains stationary. The final finish on these tapers is obtained by the use of special laps.

The hole through the centre of the sting is used to carry electrical leads to the instrumentation in the model together with the flexible pipes supplying calibration pressures to the scanivalve units and the hydraulic pipes feeding the model roll unit (see below).

The Model Roll Unit. The combination of a cranked sting and two roll boxes (one in the quadrant, the other in the model) used in opposition allows the model to be yawed in the tunnel over small angles, without being rolled. This in turn avoids the difficulties associated with the calculation of tunnel constraint due to lift for a model rolled in a subsonic tunnel with a rectangular cross-section. Larger yaw angles (where the corrections would be of doubtful value anyway) are achieved by pitching and rolling the model in the usual way.

Two roll units have been manufactured. The first of these is hydraulically powered and allows the roll angle to be changed in steps of 0.1° whilst the tunnel is running. However it was not possible to manufacture a roll box of this type, within the space allowable, to carry the full load capability of the sting and quadrant, the maximum normal force being limited to 55.6 kN and the maximum rolling moment to 12.2 kN m whilst the maximum rolling moment against which the box will drive is 2.7 kN m.

The second roll unit was designed to take the full load capability of the sting and quadrant, but to achieve this the roll can only be adjusted manually, in steps of 5°, with the tunnel stopped.

Mechanical Balance Cart

Introduction. It is generally accepted that a well designed mechanical balance using weighbeam balancing can produce an accuracy approximately an order of magnitude better than a strain gauge balance. In a wind tunnel such as the 5m tunnel where the small difference in lift and drag between two settings of a given high lift system may be of interest right across the range of Mach and Reynolds number (and hence of kinetic pressure) a mechanical balance therefore has much to offer. The main disadvantages that can be put forward are:

(a) the aerodynamic interference of a typical underwing strut mounting may be comparatively large;

(b) the time taken to obtain a set of readings is rather long.

Neither of these are seen as sufficiently important to outweigh the major advantage of the increased accuracy, and

(a) the interference is probably not significant in strictly comparative testing and, in any case, can be minimised by using a single under-fuselage strut; for half-model testing there are no interference penalties arising from the use of a mechanical balance;

(b) with modern servo design, self-balancing weighbeams can produce results in a time very similar to that necessary to obtain suitably averaged results from a strain gauge balance.

Specification. The balance is a six component virtual centre type and is suspended from a large turn-table in the centre of the cart. The space between the cart and the access tube is uncomfortably small for a balance of this load-carrying capability and hence much design time has been expended in producing a particularly compact layout (Figure 9). It is designed to accept complete models mounted on either twin underwing struts or a single under-fuselage strut with a conventional tail (or nose) strut constraint in pitch. Yaw is obtained by rotating the turn-table so that all forces and moments yaw with the model.

The balance is also designed to accept large half-models and the side force and rolling moment load capabilities have been specially increased to cope with this mode of use (Table 1). In this case incidence is achieved by rotating the turn-table and the balance will record forces and moments in body axes.

Component	Range		Sensitivity	
	Heavy	Light	Heavy	Light
Lift	± 90 kN	-	3.5 N	-
Drag	± 22 kN	-	1.0 N	-
Side Force	±127 kN	-	5.3 N	-
Rolling Moment	±140 kN m	±20 kN m	8.0 N m	1.6 N m
Pitching Moment	± 15 kN m	± 3 kN m	1.2 N m	0.24 N m
Yawing Moment	± 40 kN m	± 8 kN m	3.2 N m	0.65 N m

Table 1 Mechanical balance load ranges

General Purpose Cart

This is a simple cart with a small electrically powered turn-table in the middle suitable for taking a model mounted on a single strut but having an internal strain gauge balance, or alternatively, mounted on a pole balance. It is also used for calibration of the empty tunnel but is intended to be modified, or added to, as necessary for a variety of tests which fall outside the capabilities of the other two carts.

Calibration Machine

It will be quite clear that the magnitude of the loadings that will be experienced on models in this tunnel is so great as to make it impossible to contemplate a deadweight calibration. Experiments with pneumatically-powered force generators[2] showed that it was possible to generate forces of the required magnitude with an accuracy within ±0.01%, assuming a linear calibration, and a repeatability to about 0.003%. A calibration machine[3] was built using these force generators, in which loads were applied to a strain gauge balance via a counterbalanced loading tree, the direction of the forces and moments being automatically compensated for balance deflections (Figure 10).

The desired combination and value of the loadings is set up by an operator on thumbwheel switches; these are translated into pressures to be applied to the force generators by a DEC PDP 11/40 computer acting through commercial quartz Bourdon tube gauges and their associated pressure controllers. The same computer also controls the movement of the jacks responsible for compensating for balance deflections and then records all the demanded forces, pressures, temperatures and balance outputs when the operator decides that conditions have adequately stabilised.

The software used by the computer is written in the same way as that for the instrumentation system (section V) to form a Calibration Machine Package (CMP) and has many routines that are common with the Mechanical Balance Package (MBP) and the Strain Gauge Balance Package (SBP).

For 5m tunnel use the deflection characteristics of a strain gauge balance are not needed because the instrumentation system measures the pitch, roll and yaw angles of the model directly, (see section V).

Calibration of the mechanical balance is more difficult since its basic accuracy will be of the same order as that of the calibration machine. For this reason an incremental and iterative scheme was planned which would also serve as a check calibration of the calibration machine. In this, deadweight loadings are applied up to say 20% of full range of the mechanical balance and basic interactions checked. Load can then be applied via the calibration machine to exactly reproduce the balance readings from the deadweight loading and another 20% deadweight loading increment be applied and so on up to full-scale, (see section VII).

V. Instrumentation and Data Handling

Overall Concept

The instrumentation and data handling system for the tunnel was conceived as a modular system based on multiple mini-computers arranged in a two-tier network[4]. Independent Front End Packages (FEP) are dedicated to particular wind tunnel tasks - force measurement, using either internal strain gauge balances or the mechanical balance, and pressure measurement.

The object has been to make available, at the time of the test, the results of an experiment in a recognisable form in order that the test can proceed in the most effective way. To do this, the package acquires and processes data as necessary to display selected results to the operator in real-time and in aerodynamic coefficient form. The structure of the three FEPs is similar; each is based on a PDP 11/40 mini-computer with 28K of core and each has the necessary control and display peripherals for its particular task. The fact that computers are being used is scarcely apparent to the user, all control being through an individual control panel which contains sufficient thumbwheels and push-buttons to establish the experimental conditions and then control the display of data. Only chosen data is committed to storage within the FEP by a definite action from the operator. This data is then available to the second level or Supervisory Package (SP) for further specialised data analysis and graph plotting.

The supervisory machine can communicate with the RAE central site computers which provide a database facility and all of the features of a large mainframe machine. Data is available from the supervisory computer on industry-compatible magnetic tape or, from FEPs, on standard discs. A PDP 11/45 is also available for off-line analysis. Although the software for the FEPs was frozen once their basic functions had been demonstrated, the SP provides a framework for user's specialised programs and a facility to adapt the complete system to cater for particular test schedules. In time a standard library of programs will become established within this framework which will then be made available to all tunnel users.

A second function for the SP is to control several FEPs individually during a multi-task experiment (although each can operate independently of the second-level computer in a 'Stand Alone' mode if required). To cope with this additional task, and to provide acceptable data handling capability, the supervisory computer contains 64K of core and is equipped with twin magnetic tape drives, twin exchangeable disc drives and a single fixed system disc. The arrangement of the complete system is shown as Figure 11, and the structure of a typical FEP as Figure 12. All of the computers within the instrumentation system communicate with the tunnel control computer (Figure 13); tunnel conditions can be set through the SP and the achieved conditions returned to the FEPs, together with the demands, for use in their calculations. The wind tunnel can therefore be under the direct control of the instrumentation system and this will be the usual way of conducting an experiment.

Communications between front end machines and their transducers is along a 32-bit data highway with interface 'crates' at either end. Transducers connect into the highway through Remote Device Crates, each having 'intelligence' as needed for that group of transducers. The highway is split into a single out-going cable and multiple returns, as shown in Figure 12. The design of this highway is complex because of the need to communicate with model instrumentation, no matter where the cart is located, as well as other instrumentation in fixed locations. Each remote device crate carries a group of addresses, each address initiating an action from the crate which may operate asynchronously to the front end computer and transfer data only on command. Software controls the operation of the highway system together with the basic tasks of scheduling, display, monitoring and calculation, with the package being controlled through the simple operator control panels. A large part of this software is common to all packages, individual routines being written for basic tasks such as reading from the data highway.

Front End Packages

Strain Gauge Balance Package (SBP)
Mechanical Balance Package (MBP). The basic functions of these two packages are the same; to accept data from force measuring transducers, apply a balance calibration to calculate actual forces and to control and set the model attitude. The remote crates associated with these packages provided an input to the computer which is an average of 4096 input signals (voltages from strain gauge bridges or jockey weight displacements) over a selected time period which may be reset during the test. The time periods are arranged in roughly geometric progression from 0.8 s (150 Hz) in 10 steps up to 22 min (0.1 Hz).

Allowance is made for model weight by an interpolation amongst a set of wind-off readings, and aerodynamic coefficients may be displayed in real-time with reference to either body or wind axes. The display is updated every three to four seconds; where the averaging period is longer than this the data will change only after the end of the averaging period. As with all of the packages, no data is recorded until a positive command (via a push button) is entered by the Test Controller. The balance matrix is established by calibrations using the Calibration Machine Package, (see section IV).

The second, and major, function of the two force packages is that of controlling model attitude. The high forces and moments cause significant deflections of the model support system and so the attitude of the model is measured directly using on-board transducers. Accelerometers provide attitude in pitch and roll, and measurements in yaw are made using a rotating fan of laser light. This sweeps over a row of three photodetectors which then provide pulses to interrogate the encoder to measure the angles between the beam origin and the three detectors. From this information, simple geometry leads to the actual yaw angle and, when used in conjunction with the mechanical balance, the rearward and sideways deflections of the model away from the balance virtual centre. The system is fast enough to cope with vibrations at the resonant frequency of the model support. The package then provides information to drive either the sting/quadrant or the turn-table/pitch strut assemblies to set the model at an accurate geometric attitude in the working section independent of support deflections.

Pressure Measurement Package (PMP). A hardware module, usually carried within the model, is used to control up to eight scanivalves and the package can cater for up to four such modules. The module also controls data transmission (in effect it is a remote device) and all communication out of the model to this package is in digital form. The package, as well as controlling the modules, accepts this data and displays results as pressure coefficients in two ways:

(a) as alphanumeric data, with up to eight channels being selected in addition to the basic tunnel information;

(b) as a graphic display in the form of a single bar chart.

Scanning speeds can be selected to give a complete pressure scan, of up to 1200 channels, in a minimum of 20 s. Again, only good data is committed to disc storage and a hard copy of the graphic display can be made without committing to store. At present the maximum speed of the system is being doubled to give a complete scan and display in about 10 s.

The pressure transducers are calibrated during each scan using a bank of air bottles carried on each cart. Pressures in these bottles can be set, by simple mechanical devices, to a known fraction of the tunnel total pressure and are then applied, together with a zero pressure differential to calibration ports on the scanivalve. Those same pressures are measured, with a precision pressure gauge controlled by another remote crate, and the information made available to the software. A linear or cubic fitting procedure is then used to calibrate the transducer during each scan. Note that the range of pressures is linked with the tunnel pressure level so the calibration is always made over the current operating range for the transducers.

It is normal practice to connect groups of pressure tubes having similar values of pressure coefficient to separate scanivalves and to install a pressure transducer of appropriate range in each. Because of the large range of kinetic pressure in this tunnel, this could imply the need to change pressure transducers at some stage in the experiment; to avoid this a programmable gain amplifier is provided for each transducer.

Further Additions. The network of mini-computers provides a simple means of expanding the system to cater for measurements other than straightforward applications to steady forces and pressures. Any of the front end machines can be switched to a different function by re-loading with new software (the necessary hardware being permanently on-line and only addressed when needed). This feature is in addition to other benefits of a distributed system[5] which are already recognised. These include an easing of the system development and, since only one force package is used in direct support of a tunnel test, a redundant machine which can be used for off-line calibration or as a spare in the event of machine failure. In addition, the extra machine might be used as the basis for the analogue input system which is under development. This currently provides for up to 20 channels of differential analogue information and will soon be extended to cater for about 50 such channels. The system will accept either steady or unsteady analogue signals with a capability for on-line analysis using FFT software. One of the first tasks with the analogue system will be to investigate the possibility of making force measurements from the strain gauge balance with the model moving.

VI. Tunnel and Plant Control System

An automatic, computer-based system has been provided to set and maintain the tunnel test conditions and to control and monitor the tunnel plant, (Figure 13). A separate, hard-wired system provides the interlocking and sequencing associated with access to the working section.

Control of Tunnel Test Conditions

The Test Controller can easily make changes to the setpoints of the three basic parameters - speed, pressure, temperature - with little knowledge of the workings of the control system, either through the Operator Control Interface (OCI) on the Supervisory Package (section V), or through a separate keyboard (Figures 13 and 14). Next to this keyboard are the displays from a closed circuit TV system used to monitor the model state and observe tufts etc. Recordings may be made from this system on a video recorder.

With regard to airspeed, normally he will set a desired ratio of kinetic pressure/total pressure, with the choice of a measured value or setpoint of total pressure being used in the control loop (effectively controlling Mach number or kinetic pressure respectively). Alternatively, the flexibility of the software is such that after a minor, 'on-line' modification, the Mach number itself may be inserted. The system controls to the appropriate setpoint by varying the speed of the fan.

The control of total pressure is achieved by admitting air to the charge/discharge manifold at steady rates, and controlling the blow off to atmosphere. The charge rate for a particular speed and pressure is set automatically so that an acceptable response is obtained to changes in model drag; other rates are used to provide adequate response to demanded speed and pressure changes. As with airspeed, the total pressure may be set indirectly by demanding a given value of the more fundamental 'Reynolds number/metre/unit Mach number'.

Temperature control also has two options; the total temperature may be controlled to a particular setpoint - but this is often, naturally, a lengthy process. Alternatively, since the prime requirement is to maintain low rates of change of temperature (thus enhancing pressure control), the setpoint is allowed to drift with the general trend of the measured temperature. This keeps the control valve in range, enabling it to respond rapidly to the disturbances.

Control and Monitoring of Tunnel Plant

Apart from the initial starting of a few auxiliaries, all of the plant associated with the tunnel may be operated from the Plant Control Desk in the Observation Room (see Figures 13 and 15). Airspeed, pressure and temperature can be controlled manually from this control desk if required.

The Plant Engineer can display and log information about the Tunnel Plant in a variety of ways on the CRT screen and keyboard at the left of the Plant Control Desk. Signals reaching alarm levels are indicated in a special position on the CRT Screen and an audible warning is produced simultaneously. When necessary the control system can be re-programmed 'on-line' from this position.

VII. Current Position in June 1978

General

In general terms the tunnel is now usable - it first ran in December 1977 and has been operated through its entire performance envelope satisfactorily without modifications being necessary to the air circuit. Preliminary measurements have been made of the velocity distribution and of the turbulence and noise levels. An exploratory test series with the 1/13 scale A300B model on the sting cart (Figure 20) has been successfully completed in which overall forces were measured as well as the pressure distributions at a number of spanwise stations, and the stall pattern was studied with tufts using closed circuit TV with remotely controlled cameras. The range of Reynolds and Mach numbers involved is shown in Figure 16.

Access Arrangements

The system for obtaining access to the working section for making small *in situ* model changes whilst retaining the remainder of the circuit under pressure, has very recently become fully operational and all the safety interlocks in the hard-wired sequencer have been checked.

The working section can be rotated under power but the 'stops' for obtaining precise alignment with the tunnel circuit at one end, and the model access tube at the other end, have not yet been fitted.

Carts can be driven under power in the rigging bay area but the automatic positioning and bay selection has not yet been implemented and the carts have to be controlled manually by a driver on a cart, (see Figure 6).

Apart from some unexpectedly large deflections on the turntable in the rigging area which necessitated additional stiffening, no problems have been experienced during commissioning. However, clearly the system is not yet in its final form and so no assessment has yet been made of whether the 30 min design time for cart interchange can be met.

Model Mountings and Balances

The pitch motion on the sting cart is now fully commissioned and the cart has been used for the early tests of A300B, but the drives to the two roll units are not yet complete, although the manufacture of the model roll box is complete and it has been satisfactorily bench tested under load. The A300B tests were performed with the manual roll unit fitted to the model, (see section IV).

The calibration machine was used to calibrate the strain gauge balance for the A300B test and the full calibration, sufficient to produce a second order interaction matrix, was completed in three days including the matrix inversion. The machine was also used to calibrate a strain gauge pole balance for use with the Anglo-French high lift research model, (see section VIII).

The mechanical balance is complete and has performed satisfactorily under calibration at the manufacturer's site. During this calibration the outputs from the balance were compared for the same nominal loadings achieved by deadweights and from the calibration machine. This level of loading sufficed to allow adjustments to be made to the virtual centre position and the interactions between components, and demonstrated the accuracy and repeatability of the calibration machine. This was so good that no further deadweight increments were used and the final calibration up to full load was performed using the calibration machine only.

Instrumentation and Data Handling

Parts of the instrumentation system have been coming into use since August 1977.

A modified version of the Pressure Measurement Package has been used for the initial calibration of the tunnel. An array of 16 pitot-static tubes was used to survey the flow and the package gave an on-line indication of the centre-line flow conditions, and of the relationship of the other 15 tubes to these centre-line values.

The full Pressure Measurement Package, together with the Strain Gauge Balance Package, have been used through the initial tests of the A300B model, although the model attitude system was not fully working. These tests have demonstrated that the packages are basically correct in concept and design, the results are being correctly calculated and displayed, and that the overall control tasks are functioning through the operator control panels. Reliability has been generally good for both software and hardware, and the initial response from the users has been very encouraging.

Work remaining to be done includes final completion of the Mechanical Balance Package for use with half-models, completion of the model attitude system and the analogue input system, and detailed definition of the Supervisory Package with its full graphics capability.

Tunnel and Plant Control System

This system is now fully commissioned and its ability to control tunnel conditions has been explored in some detail.

For control of tunnel speed with the model in a fixed attitude, it has been demonstrated that the ratio of kinetic pressure to total pressure (q/PT) is held to within ±0.1% of the setpoint for values from q/PT = 0.002 (M = 0.05) to q/PT = 0.074 (M = 0.34).

The accuracy of control of total pressure is limited by the accuracy of the measuring instrument which is quoted as ±0.015% of reading. However, the resolution of the instrument is considerably better than this and the control system has been demonstrated to hold the pressure steady to within ±0.005% of reading with the model in a fixed attitude and with a fixed value of (q/PT). This feature is considered to be particularly valuable in a low speed pressurised tunnel, allowing small differential pressures on the model to be measured accurately without the need for a high common mode rejection.

The steady state temperature has been shown to be controllable within ±0.2°C of the setpoint and, during disturbances, the rate of change of temperature is limited to 1°C/min.

The time to pressurise the complete circuit to 3 atmospheres is very close to the predicted 45 min.

Outline of Aerodynamic Performance

Performance Envelope. The operating envelope of the tunnel is shown in Figure 16. The lines show the calculated performance at the design stage, including allowances for the drag of a large model at the stall and for the efficiency of the fan. The points are a selection of those at which the tunnel has actually run. The circles represent the maximum Mach numbers achieved at various pressures with the tunnel empty during calibration. At the higher pressures it was not possible to run at full power due to the premature opening of the emergency pressure relief valve (which has since been reset) - hence the extrapolation of the estimated performance envelope with the tunnel empty. The triangles show the set of tunnel conditions over which the 1/13 scale A300B model was tested and its first spell in the tunnel.

Reynolds numbers in the diagram are based on 1/10 of the square root of the cross-sectional area of the working section (0.46 m); complete models of transport aircraft, of aspect ratio 7 say, will achieve values of Reynolds number about 10% greater than those shown; military aircraft models (aspect ratio about 3) some 80 to 90% higher. The use of half models can increase the Reynolds numbers by about 50% relative to corresponding complete models.

Flow Uniformity. At the time of writing, only a brief preliminary calibration of the flow has been possible. A typical distribution of total pressure in a cross-section of the working section at the centre of rotation of a model is shown in Figure 17. These results indicate that over a rectangular area at least 3.2 m × 2.0 m, the total pressure does not vary by more than ±0.15% of q from the mean value. In this initial test, there were difficulties in measuring the distribution of static pressure which were attributed to the movement of boundary layer transition past the slots of the pitot-static tubes. We expect to be able to report on static pressures and velocities when the paper is presented.

Turbulence Measurements. Again only preliminary measurements of the turbulence have been made, using a DISA miniature 'X'-probe hot wire. In early tests, as speed and pressure were increased the wires broke consistently at about 90 m/s at 1.6 bars, and this seemed to pose an upper limit to the conditions that could be explored. However, it was found that at pressures higher than 1.6 bars, the wires could be run up to full speed without breaking, so presumably some type of flutter condition is experienced by the probe at 1.6 bars and 90 m/s.

Based on tests of the flow through a sample of the cooler supplemented by calculations of the reduction in turbulence due to screens, contraction, and the decay length from the cooler to the working section, the turbulence level in the tunnel was predicted to lie between 0.1% and 0.15%, taking an average of all three components. The current measurements of longitudinal and lateral turbulence in the tunnel are shown in Figure 18. These exhibit the roughly 2:1 ratio between lateral and longitudinal turbulence that is usually measured, but unfortunately the levels are about 50% higher than had been expected. Although this set of measurements was very consistent in itself, some very early measurements at a different position near the side walls showed turbulence levels about 50% of the present ones. There is a slight suspicion that the present results may have been affected by the wakes from thermocouple instrumentation in the settling chamber, but clearly more work is necessary in order to establish with confidence the level of turbulence in the tunnel.

What Figure 18 and the spectra in Figure 19 show, which may be of more importance, is that the intensity and spectra are independent of Mach number at a given Reynolds number, and the variation of turbulence intensity is a very mild function of Reynolds number only. Thus tests in this tunnel are unlikely to show spurious scale and Mach number effects due to changes in flow quality with increasing pressurisation.

VIII. Planned Research Programme

A full research programme has been planned for this tunnel encompassing high lift systems on both civil and military aircraft. An important aspect of the initial programme will be the acquisition of data for comparison with flight test results to establish general confidence levels for the results from the tunnel.

The programme is spearheaded by three models which have been specially made to be tested over the full operating envelope of the tunnel and are already complete. The first of these is a 1/13 scale model of A300B which is intended to provide detailed information on the effects of Mach and Reynolds number on the flow around a typical modern transport in the landing, take-off and clean configurations. Detailed pressure distributions can be measured at a number of spanwise positions on each wing and these should help materially in the understanding of the overall behaviour of the model.

Since the model can be mounted either on the sting rig, as in Figure 20, or on twin underwing struts from the mechanical balance, tares and interferences can be obtained with a good degree of confidence hence minimising the unknowns in the flight/tunnel comparison that will be made for this model.

The second is a complete model of a typical low level strike fighter configuration designed to yield information on the design of slotted high lift systems on wings of low aspect ratio. Figure 21 shows half of this model undergoing a preliminary test on the underfloor balance in the 13ft × 9ft tunnel at RAE Bedford.

The third model is again a complete model but of Aspect Ratio 8 and 28° sweep, generating high lift through a simple jet flap. It will be tested in the RAE 5m tunnel, the F1 tunnel at Le Fauga and the S1 tunnel at Modane, providing information on tunnel constraint effects at high lift and contributing to the development of powered lift testing techniques in pressurized facilities.

Supplementing the work on these three models are several investigations using existing models, built originally for atmospheric tunnels, but strengthened sufficiently to be tested over a significant part of the operational envelope of the 5m tunnel. This will provide a useful extension of their results to higher Reynolds number and determine their sensitivity to changes in Mach and Reynolds numbers.

Future work, on which model design work is proceeding, will cover more advanced configurations both military and civil, and provide a broader range of tunnel/flight comparisons.

IX. Concluding Remarks

The RAE 5m tunnel improves the UK's experimental capability in low speed aerodynamics by an order of magnitude. Although at the time of writing, commissioning is not quite complete and only a start has been made on calibration, it is clear that the design aims have been achieved and that the new tunnel will be an important tool for the next few decades in both research and development on stalling and high lift devices, and will lead to the design of aircraft with better low speed performance and with less risk of expensive modification at the flight test stage.

The tunnel will be in full use towards the end of 1978.

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4	R.J. North D.W. Partridge E.C. Brown	A multi-computer instrumentation system for a new pressurised low speed wind tunnel. Fifth International Congress on Instrumentation in Aerospace Simulation Facilities 1973
5	R.J. North R.W. Jeffrey Mrs J.A. Dolman A.N. Tuck	Digital computer aspects of the instrumentation and control of the new RAE 5m low speed tunnel. AGARD Specialists Meeting, von Karman Institute Rhode-St Genese, Belgium June 1976. AGARD Conference Proceedings 210

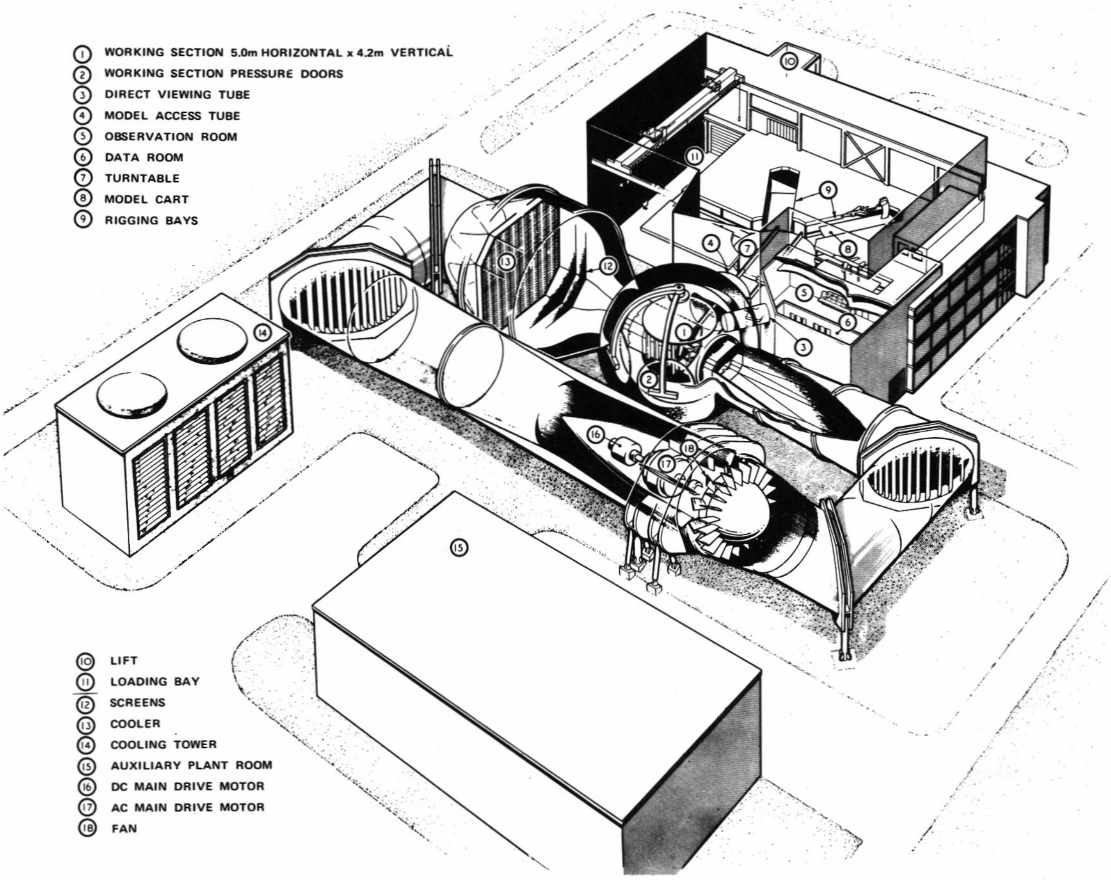


Fig 2 Cut away section

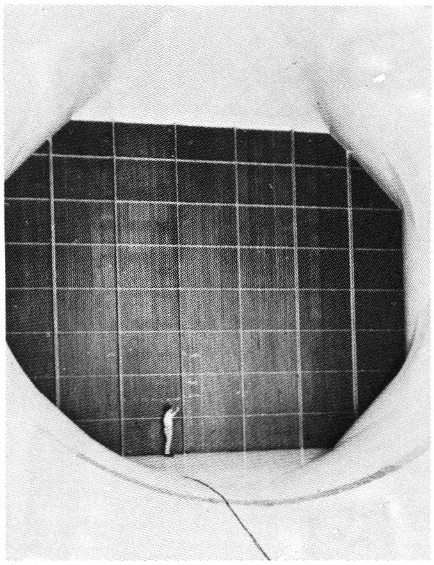


Fig 3 Cooler and rapid diffuser

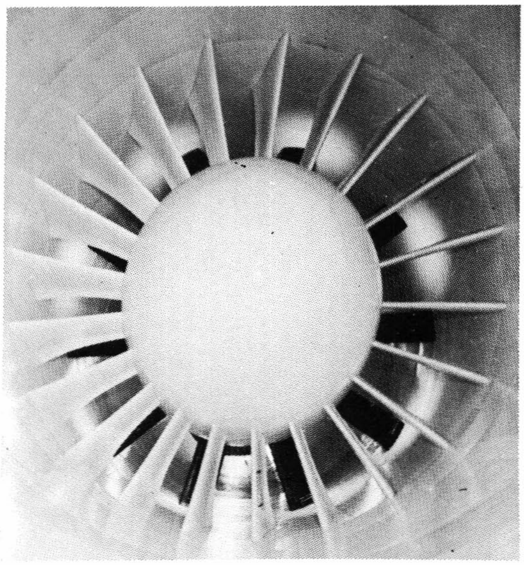


Fig 4 Fan and nacelle

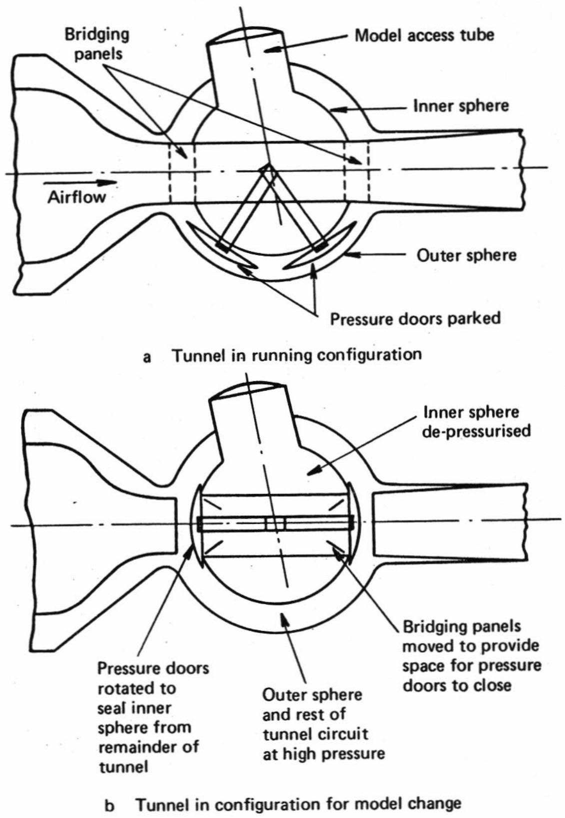


Fig 5 Schematic drawing of the operation of the model access system

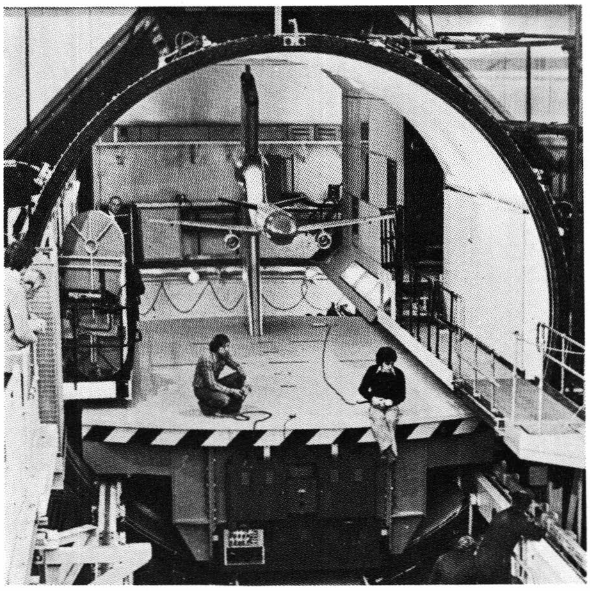


Fig 6 Working section rotated and cart emerging from access tube

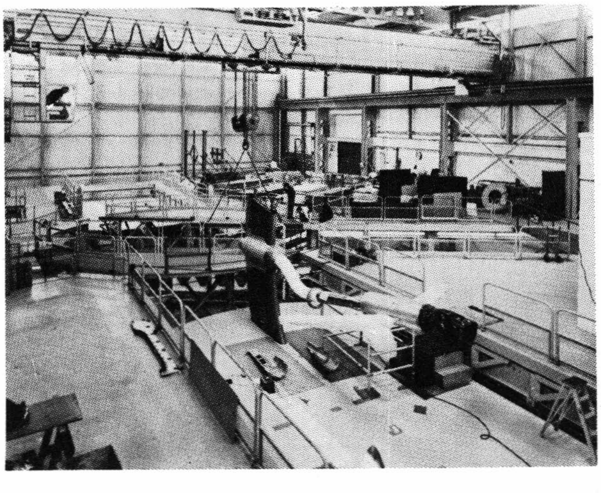


Fig 7 Rigging bay area with sting cart parked

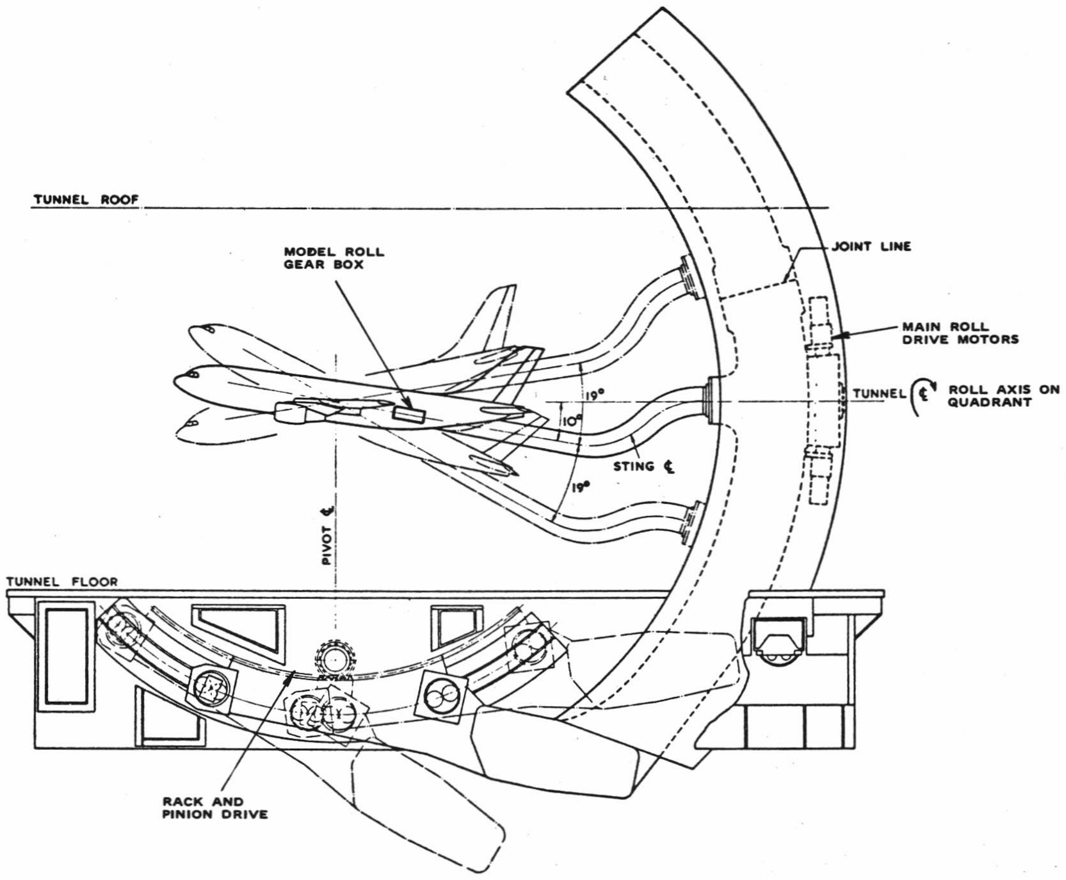


Fig 8 Diagram of sting rig

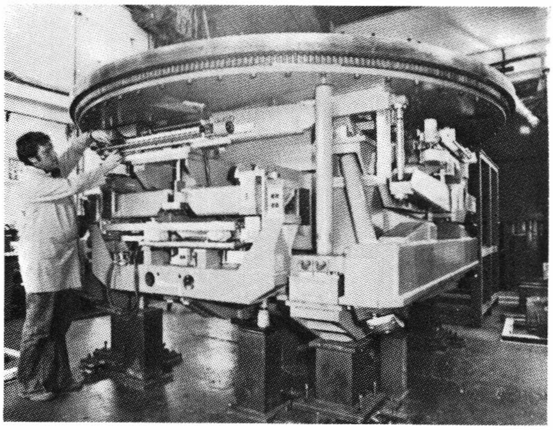


Fig 9 Mechanical balance

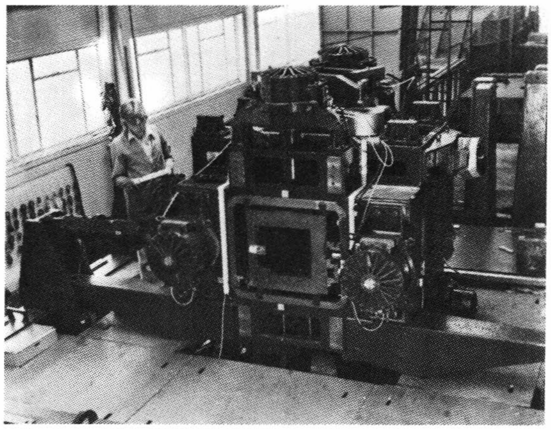


Fig 10 Calibration machine

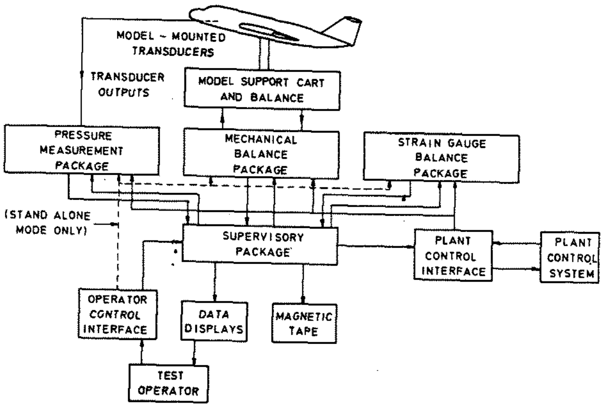


Fig 11 Data system block diagram

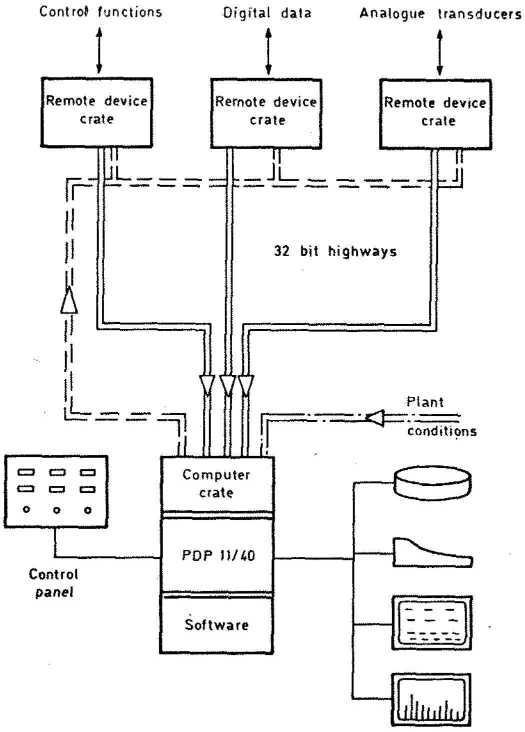


Fig 12 Typical front end package

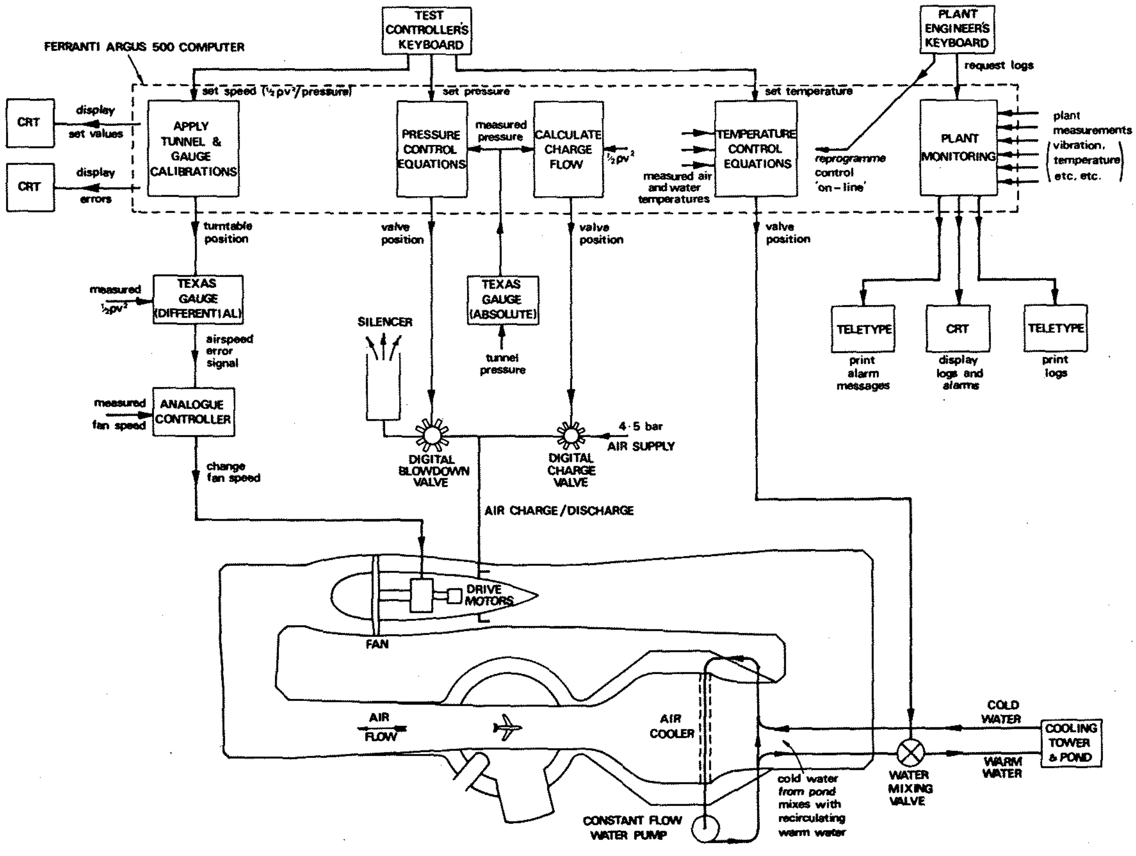


Fig 13 5m tunnel – control system schematic

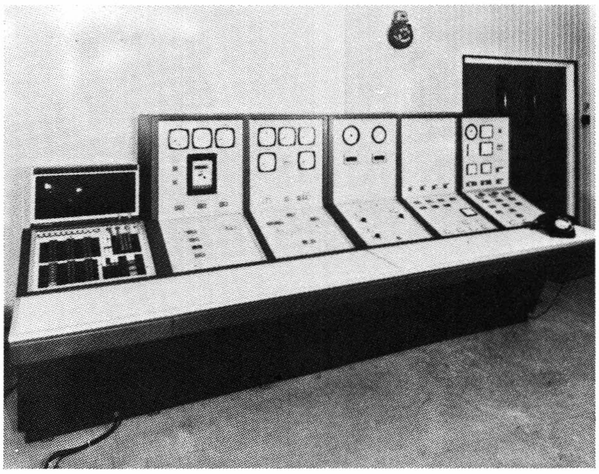


Fig 14 Tunnel operator's control desk

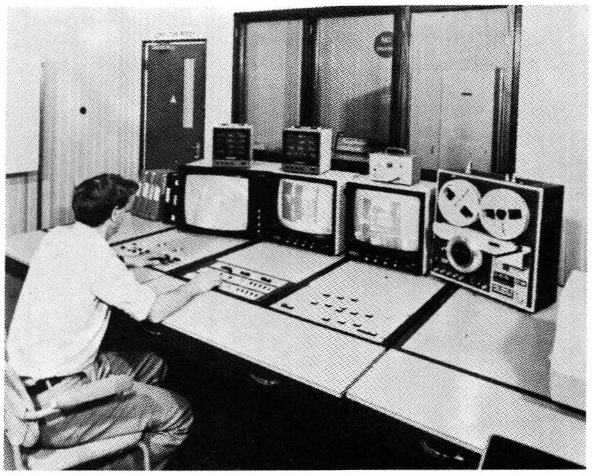


Fig 15 Test controller's keyboard and closed circuit TV

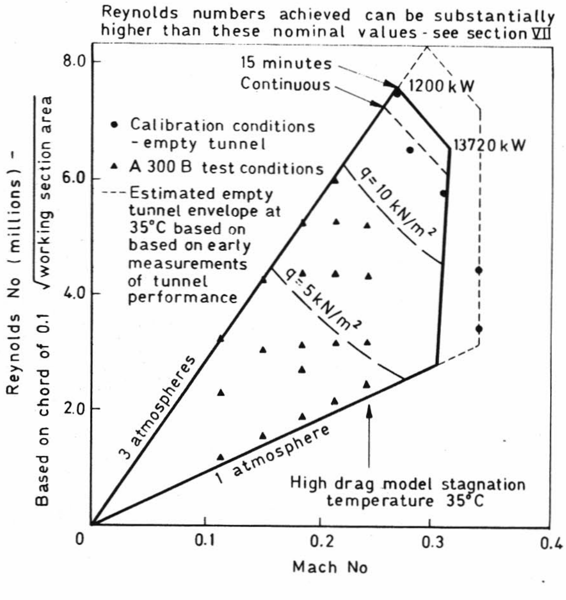
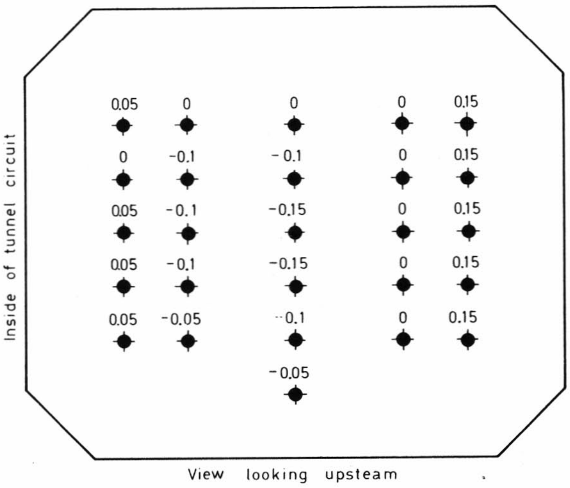


Fig 16 Performance envelope



Figures are deviations from mean of measured values of total pressure in tunnel working section expressed as percentages of dynamic pressure on tunnel axis

Fig 17 Total pressure distribution in working section. Mach number up to 0.34, P_T up to 290 kPa

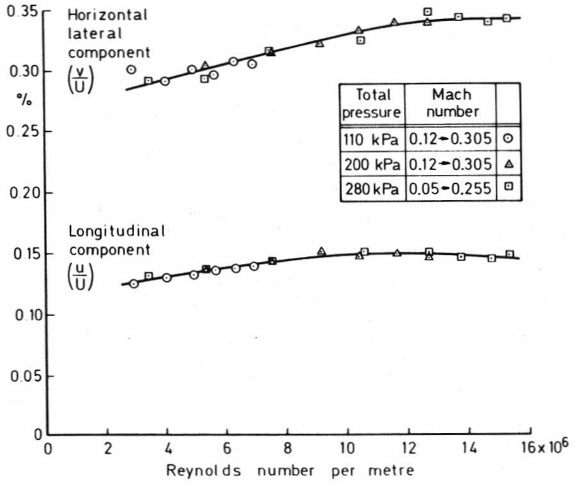


Fig 18 Rms turbulence components in RAE 5m wind tunnel. 0.5 m below centre line. Integrated 16 Hz $< f_{100} <$ 3150 Hz

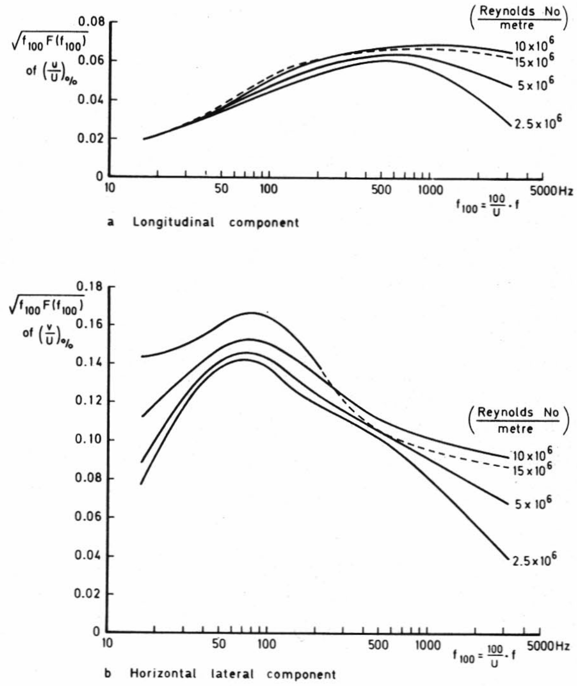


Fig 19a&b Typical turbulence spectra in RAE 5m wind tunnel. 0.5 m below centre line

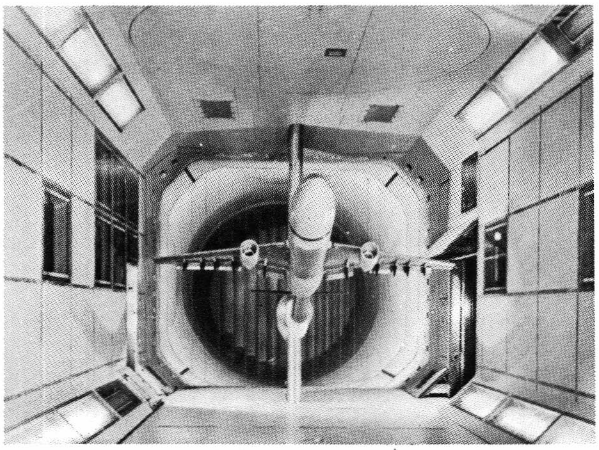


Fig 20 A300B model on sting rig in 5m tunnel

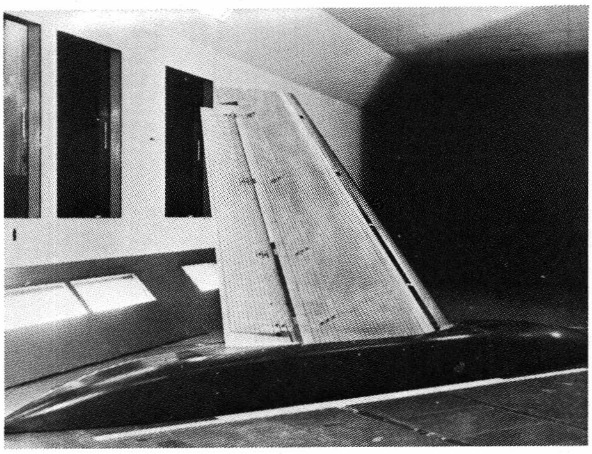


Fig 21 Half of strike fighter model in the 13ft x 9ft tunnel at Bedford