#No 2015

2015

AIC 1685

Journal of Industrial Aerodynamics, 1 (1975) 3—12
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

A BOUNDARY LAYER WIND TUNNEL FOR BUILDING AERODYNAMICS

N.J. COOK

Building Research Establishment, Building Research Station, Garston, Watford, Herts. WD2 7JR (Gt. Britain)

(Received August 2, 1974)

Summary

A wind tunnel of open-circuit configuration designed specifically for building aerodynamics is described and its performance is discussed. It has a working section 2 m wide × 1 m high × 8 m long with a maximum windspeed of 20 ms^{-1} under typical operating conditions. The overall length is 14 m. The tunnel has some special features to assist the simulation of the atmospheric boundary layer. At the upstream end of the working section is a region where various combinations of flow processing devices can be easily and quickly inserted. At the downstream end of the working section, a portion of the test area floor is removable and may be exchanged for a second floor unit. The test area is serviced by a 3-component traversing mechanism which allows the remote positioning of probes anywhere within the area.

The flow conditions in the working section are satisfactory for a wide range of building aerodynamics studies. The characteristics of the fan allow a wide variation of power factor without a significant loss in maximum velocity. Full-depth atmospheric boundary layer simulations up to 1/500 scale and part-depth simulations up to 1/200 scale are practical in this tunnel.

1. Introduction

The study of building aerodynamics in model scale requires that the atmospheric boundary layer appropriate to the environment of the building be simulated in a wind tunnel at a convenient scale. Early simulation methods employing graded blockage, grids of rods or slats etc., were developed for use in wind tunnels with short working sections, originally designed for aeronautical applications. These early methods have largely been superseded by more complete and accurate methods which achieve the accelerated growth of natural boundary layers over rough surfaces. This has resulted in a second generation of wind tunnels, designed for the one application and tailored to these simulation methods in terms of working section dimensions and power factor. In meeting the particular requirements of this application it is possible to evolve a more simple and economic design than for a versatile general purpose facility.

Copyright — Building Research Establishment, Department of the Environment, July 1974.

2. Choice of size and configuration

The site of the new wind tunnel for wind loading studies at the Building Research Establishment is across one end of a large high-roofed laboratory. Experience had shown that full-depth simulations up to 1/500 scale (Counihan [1]), and part-depth simulations up to 1/200 scale (Cook [2]), were practical in a working section 2 m wide × 1 m high × 4.5 m long (Cook [3]), but would be improved by additional length. Thus, a 2 m wide × 1 m high working section, 8 m in length, was stipulated for the BRE wind tunnel. There was sufficient width available across the laboratory (16 m) to allow an open-circuit configuration provided that the inlet was designed with care. As the range of power factor must inevitably be high due to the large losses through the hardware of the various simulation methods, the additional contribution of an open circuit was not significant, even with no attempt at diffusion before discharge. As the volume of the laboratory was large, the problem of air temperature rise often associated with closed-circuit configurations was avoided.

3. Description of the tunnel

3.1 Inlet

The configuration of the tunnel is shown as Fig.1. There is no conventional contraction at the inlet. Instead, a simple bellmouth inlet is surrounded by a large hardboard-clad rectangular box. The function of the box is to make the path of the air entering the inlet more symmetrical and to erase the "memory" of the return flow. Air enters the box through the side surrounding the bellmouth inlet, passing through a Terylene screen with a resistance coefficient $\Delta p_0/q$ nominally 2. The box thus forms a reflex contraction with a 7.6:1 area

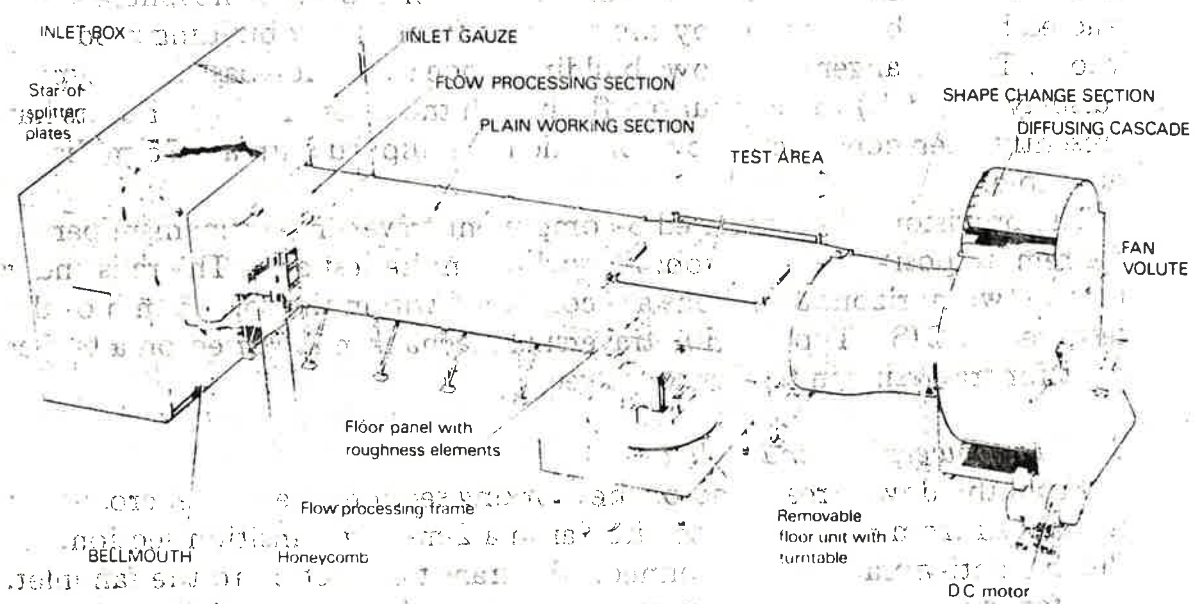


Fig.1. The BRE boundary layer wind tunnel.

ratio. It is necessary to stabilise the flow separating from the wall opposite the inlet and to locate the stagnation point at the centre-line of the tunnel. This is achieved by means of four triangular splitter-plates interlocked in the form of a conical star. After entering the inlet, the flow passes through a conventional honeycomb into the working section.

3.2 Working section

The first 1 m of the working section forms a "flow processing section", similar to that described by Barrett [4] in a wind tunnel at Bristol University. A number of rectangular frames of individual widths ranging from 100 mm to 400 mm may be inserted to a total width of 900 mm through a door on either side of the tunnel. Various combinations of flow processing devices such as gauzes, grids, barriers, etc., may be installed in the frames. Figure 2 shows a typical frame partially inserted. Downstream of the flow processing section is 4 m of plain working section into which panels of roughness elements may be inserted to give a rough floor surface. The flow processing section and the following plain working section were constructed entirely of wood and are supported at 1-m intervals by steel trestles.

The main test area is the last 3 m of the working section and takes the form of a free-standing steel frame clad with wood and glass. Access to this area is through a 2-m-wide door on either side of the tunnel. Both of these doors are glazed over the full height of the tunnel and there is also a 1-m-wide glazed panel along the centre-line of the roof for maximum visibility of the test area. A 2-m-square portion of the test area floor is removable as shown in Fig.3, and may be exchanged for alternative floor units. Each floor unit consists of a deep box on a wheeled trolley and a separate floor panel. The box forms a pressure seal against the working section; thus the loads due to the static pressure difference between the working section and the atmosphere are reacted by the box and not by the test area floor or any building model let into it. This arrangement allows building models on thick bases (*i.e.* typical "display" models) to be mounted flush with the floor. Two floor units have presently been constructed, one of which is equipped with a 1.75-m-diameter turntable.

The provision of a motorised 3-component traversing mechanism permits the remote positioning of probes anywhere in the test area. The rails and gantry for the two horizontal motions are contained within the top 65 mm of the test area. A DISA Type 55H01 traversing mechanism is carried on a telescopic strut for traversing in the vertical direction.

3.3 Fan, powerplant and outlet

From the downstream end of the working section, the tunnel cross-section is changed from rectangular to circular in a 2-m-long transition section. A flexible anti-vibration joint connects the transition section to the fan inlet. The fan is of the centrifugal type with backward-facing aerofoil-section blades. Four particular attributes of this type of fan were crucial to its choice.

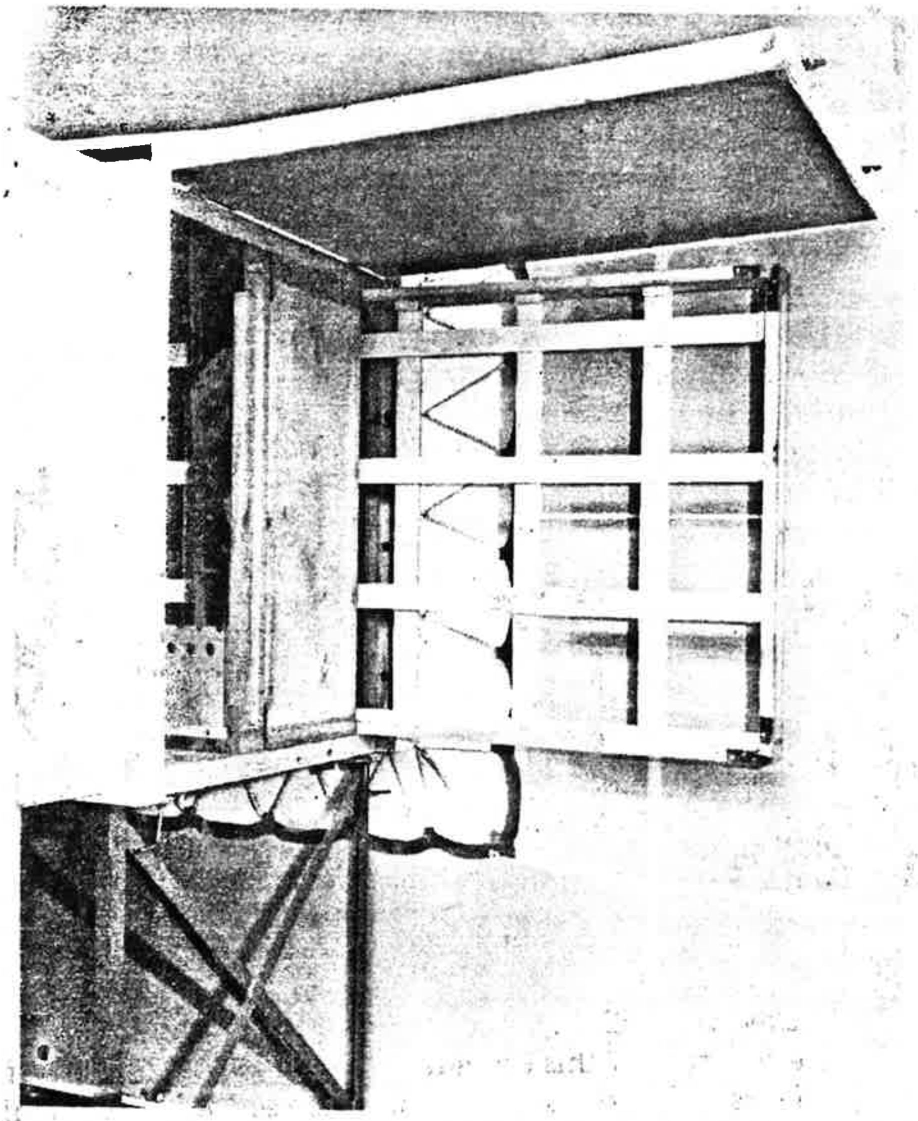


Fig.2. Flow processing section, showing perforated wall (inserted) and turbulence grid (partially inserted).

(1) It will operate over the wide range of power factor resulting from the use of the various simulation methods.

(2) It will accept inlet flow conditions with large velocity gradients and high turbulence intensities.

(3) It does not contaminate pressure signals with coherent periodic noise, unlike contra-rotating axial fans.

(4) It forms a 90° corner, thus allowing maximum utilisation of space. This type of fan has previously been used in blower tunnels (Bradshaw [5]), where the additional advantage of no swirl at outlet was exploited.

The fan is driven by a 56 kW d.c. electric motor through a multiple V-belt drive incorporating a 2:1 speed reduction. The motor speed is regulated by a closed-loop thyristor control system and is infinitely variable from 0 to 1500 rpm.

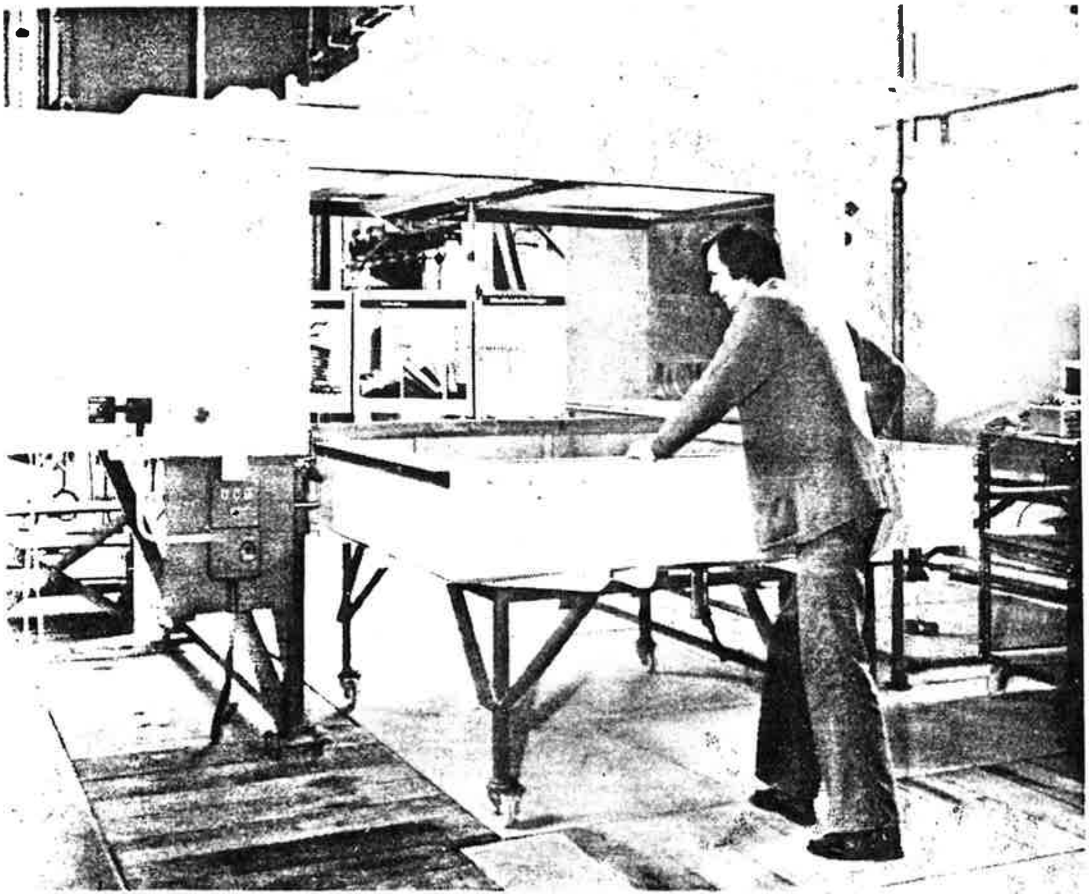


Fig.3. Insertion of floor unit into working section.

The flow is exhausted vertically upwards from the fan volute into a "diffusing cascade". The function of this cascade is to reduce the velocity of the return flow in the laboratory. No attempt is made to recover the dynamic pressure. Seven curved aerofoil blades on each side of a centre-line splitter turn the flow progressively through 11° increments to exhaust the flow radially over a 180° arc.

4. Performance

4.1 Flow through inlet box

A diagram of the flow is shown in Fig.4. The flow through the Terylene screen is faster next to the bellmouth (a) than around the periphery (b). Inside the box, the flow separates from the side walls, roof and floor (c), turns through 90° and re-attaches to the end wall (d), forming a rectangular vortex ring in the corner. The flow then converges towards the cone of splitter plates, separates again (e), turns through a further 90° and passes into the honeycomb. Eight vortices are formed, one between each pair of splitter plates, which collectively form a second vortex ring around the stagnation point on the centre-line of the tunnel. It is unusual to tolerate regions of separated flow in a wind

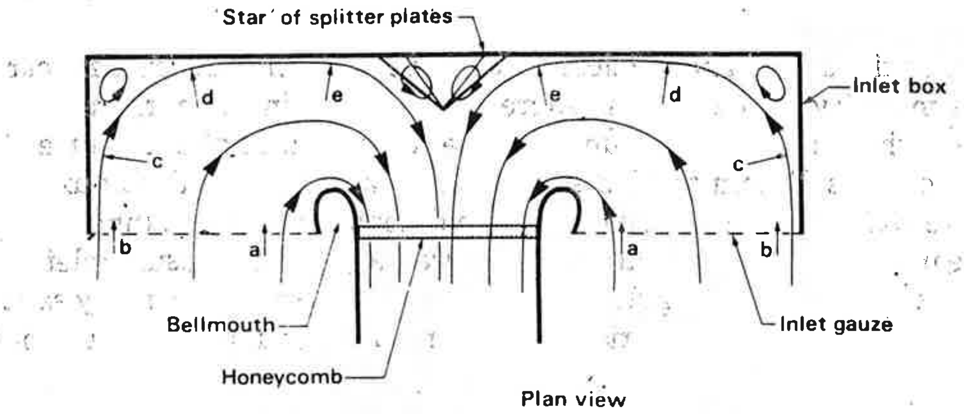


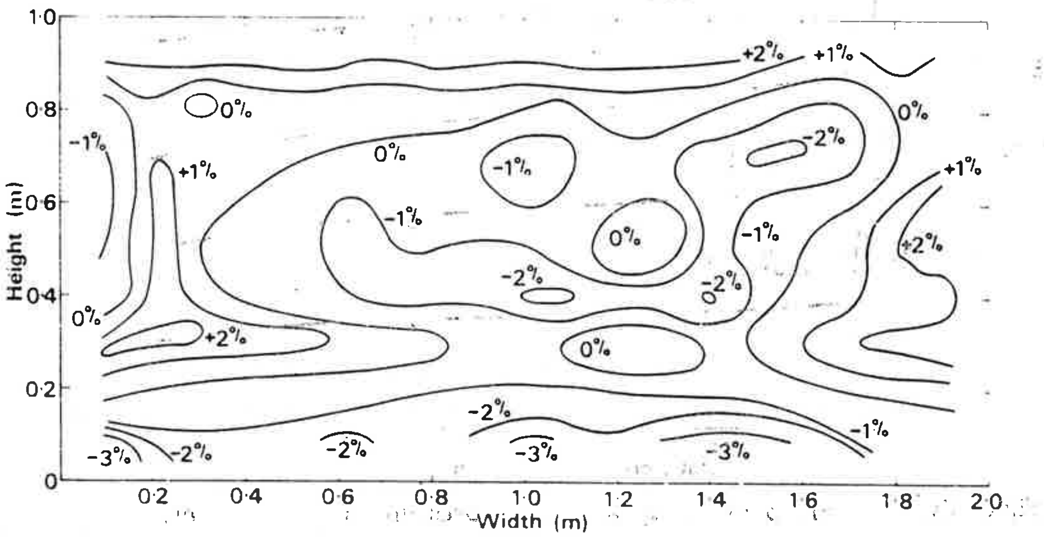
Fig.4. Flow through inlet box.

tunnel; however, both vortex rings are stable and perform a useful function in re-energising the boundary layers formed on the walls of the box. Flow enters the honeycomb at a velocity uniform to better than 5%.

4.2 Flow in the working section

Calibration of the flow in the working section was performed with a plain gauze of resistance coefficient $\Delta p_0/q = 1.6$ inserted into the flow processing section. Measurements were taken 5 m into the working section at the upstream end of the test area. The distribution of flow velocity, shown in Fig.5, gives a standard deviation of 1.7%. The distribution is approximately anti-symmetric about one diagonal, reflecting the location of the wind tunnel in the laboratory.

The intensity of the longitudinal turbulence component remains near 0.6% over the majority of the section, increasing to 1.4% in the corners. Similarly,



View upstream – with plain gauze, resistance coefficient 1·6
Mean velocity 11·13ms⁻¹
Standard deviation 0·19ms⁻¹

Fig.5. Velocity distribution in working section. Contours show deviation from mean.

the intensities of the lateral and vertical turbulence components remain near 0.4% over the majority of the section, increasing to 1.2% in the corners.

The depth of the smooth-wall boundary layer on the floor at the centre of the working section is 97 mm at 10 ms^{-1}. No residual effects of the boundary layers from the walls of the inlet box could be detected near the tunnel centre-line in the mean velocity and turbulence measurements. The unusual inlet performs well, since the resulting flow in the working section is entirely satisfactory as uniform flow for comparison with simulated boundary layer conditior

4.3 Speed control

The single-turn control potentiometer as supplied with the drive system was replaced by a calibrated ten-turn version with a clock-face type read-out. Repeatability was then obtained to better than 0.5%. An advantage of the particular drive system is that the control potentiometer may be pre-set before activating the drive, whereupon the tunnel will run up automatically to the selected speed.

The characteristics of the fan allow operation over a wide range of power factor with only a small loss in flow velocity. This is illustrated by Fig.6, which was obtained by inserting various combinations of uniform grids and gauzes into the flow processing section. This property is particularly desirable for the intended applications of this wind tunnel.

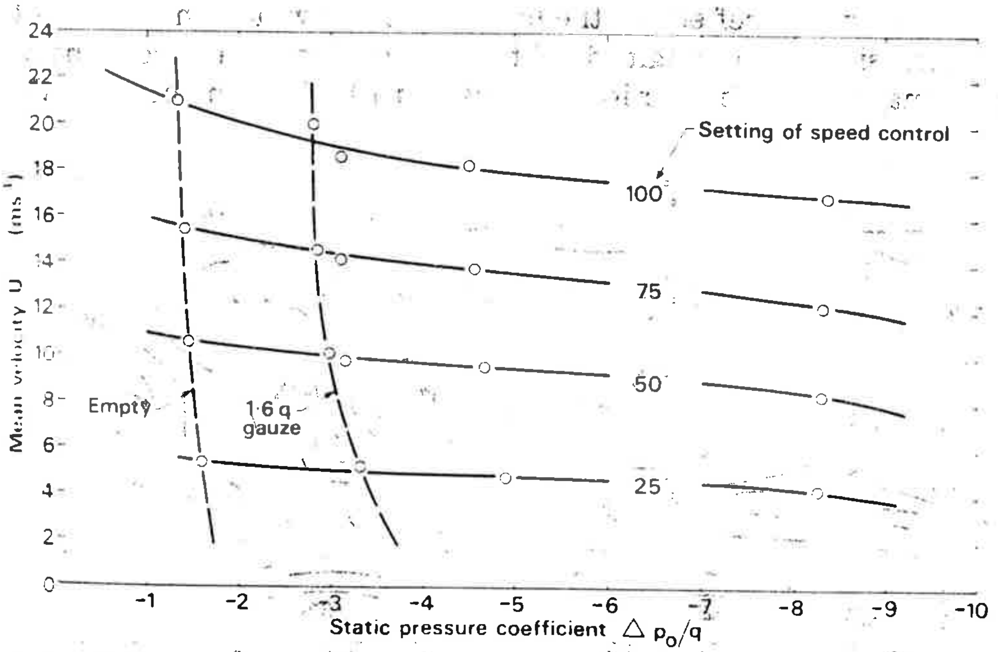


Fig.6. Variation of flow velocity with static pressure in working section.

4.4 Noise

Acoustic noise in the test area appears as an unwanted component in pressure signals. Measurements of the fluctuations on the pressure at the static tapping of a pitot-static tube were made in smooth flow. The direct contribution of the fan, *i.e.* fluctuations correlated to the rotational speed of the fan, was not found to be significant. However, a significant contribution does occur as narrow-band noise at frequencies which remain between 8 to 10 Hz independent of flow velocity and fan speed. This is due to resonance of the tunnel as an organ-pipe at the fundamental frequency. One major source of excitation was found to be panel vibration of the inlet box. Remedial measures are being taken to decouple the excitation, principally by adding mass to the rear wall of the inlet box.

In the meantime, the level of the acoustic noise is equivalent to an rms pressure coefficient of $p'/q = 0.16$; this is sufficiently large to present a problem when dynamic pressure measurements, especially correlations, are being made. Electronic filtering, *i.e.* band-rejection between 8 and 10 Hz, is not a satisfactory solution as the flow-induced fluctuations in the same frequency band are also lost. The only practical approach appears to be subtraction of the acoustic component from the measured pressure. Provided the acoustic pressures do not interact with the flow, three methods are applicable. The acoustic component may be subtracted:

(1) Mechanically; by using the fluctuating static pressure as the backing pressure on the transducer. As the tunnel is of the open return type and operates with the working section static pressure below atmospheric pressure, this would be done normally to make the reference static pressure independent of flow velocity. Unfortunately, not all transducers respond dynamically to backing pressure.

(2) Electronically; by acquiring the noise signal with another transducer and subtracting it from the signal to be measured using an analogue difference circuit.

(3) Mathematically; by acquiring the noise signal as in (2), but subtracting it from the signal to be measured during the analysis stage.

The second of the three methods is being used currently, with electronic difference circuits which are normally employed to separate the turbulence components from X-probe hot-wire signals. Providing no phase differences are induced, the coherent component of the acoustic noise signal is removed,

TABLE 1

Noise levels in laboratory, measured in dB(A)

Position in laboratory	Tunnel speed % of maximum			
	0%	33%	66%	100%
1 m from motor	77	78	82	90
window, motor side	69	71	79	89
flow processing section, motor side	68	70	78	88
flow processing section, other side	67	68	79	88
window, other side	65	68	78	89
1 m from fan	65	69	81	91

leaving only incoherent high-frequency components at a level of $p'/q = 0.06$.

The environmental noise levels in the laboratory were also measured around the tunnel and the results are presented in Table 1. There are two noise sources, the main fan and the auxiliary cooling fan on the motor. The latter is dominant at speeds below approximately 60% of maximum. The use of ear defenders is advisable at or near maximum speed. Compared with other wind tunnels, however, this tunnel is only an "average" noise source.

5. Data acquisition and analysis

Data from three types of measurement will be acquired in the wind tunnel. Velocity measurements will be made using linearised constant-temperature hot-wire anemometers. Pressure measurements will be made with miniature flush-diaphragm transducers mounted either directly in the walls of building models or multiplexed through pressure-scanning switches. A dynamic balance has been designed and is currently under construction which will allow the simultaneous measurement of loads in two mutually perpendicular horizontal directions and of moment about a vertical axis at frequencies in excess of 50 Hz.

Because of the high rate of data acquisition made possible by the contraction of the time scale in the simulation of the atmospheric boundary layer, it is intended to analyse the data from the tunnel in real time, using an on-line digital data processor. Analysis software will include amplitude probability, time correlation and frequency spectral analysis. Pre-programmed control of some of the mechanical functions of the tunnel is envisaged, such as scanning of pressure switches and operation of the traversing mechanism. The specification and performance of the data acquisition and analysis equipment will be reported in due course.

6. Reproduction of the facility

The fan and powerplant are readily available standard items; the fan is a 60-in. Airscrew—Weyroc HEBA/B and the powerplant is a Mawdsley Matador thyristor drive. With the exception of these and other small stock items, the detail design and all construction work were performed by staff of the Building Research Station using the Station's facilities. Working drawings will be available from Building Research Advisory Service on request.

Acknowledgments

The facility described has been designed and built as part of the research programme of the Building Research Establishment of the Department of the Environment, and this paper is published by permission of the Director.

Nomenclature

Δp_0	Change in static pressure
q	Dynamic pressure = $\frac{1}{2} \rho U^2$
U	Mean velocity in working section
p'	r.m.s. pressure fluctuation
ρ	Density of air

References

1 J. Counihan, Proc. Symp. on External Flows, University of Bristol, 1972, p.E1.
2 N.J. Cook, Atmos. Environment, 7 (1973) 691—705.
3 N.J. Cook, Atmos. Environment, 8 (1974) 85—87.
4 R.V. Barrett, Atmos. Environment, 6 (1972) 491—498.
5 P. Bradshaw, J.R. Aeronaut. Soc., 71 (1967) 132—134.