FOURTH AUSTRALASIAN CONFERENCE

on

HYDRAULICS AND FLUID MECHANICS

at

Monash University, Melbourne, Australia

1971 November 29 to December 3

TURBULENT PRESSURE FLUCTUATIONS ON THE FACE OF A LOW ASPECT RATIO, RECTANGULAR PRISMATIC BUILDING

by

J. D. Holmes

SUMMARY

Measurements of pressure fluctuations on the front face of a large, low aspect ratio, building were made during a strong wind. Corresponding measurements from a 1:600 scale wind tunnel model were also made. When plotted together non-dimensionally, the two sets of results compare favourably.

The strong horizontal cross-flow along the building face is shown to have an influence on the characteristics of the pressure fluctuations.

J. Holmes, Monash University.

1. Glossary of Terms

b	- breadth of building
h	- height of building
l	- downstream length of building
n	- frequency
p'	- fluctuating pressure
$\bar{P}$	- mean pressure
$R(\tau)$	- auto-correlation function
$R_{12}(\tau)$	- cross-correlation function
$R_{12}(n)$	- narrow-band cross-correlation (square root of coherence or normalised cross-spectral density)
$S_u(n)$	- power spectral density of velocity fluctuations
$S_p(n)$	- power spectral density of pressure fluctuations
u'	- fluctuating longitudinal velocity
$\bar{U}_{tbf}$	- mean longitudinal velocity at the height of the building in freestream
$\bar{U}_{c_t}$	- convection velocity of turbulence along building face
$\bar{U}_c(n)$	- convection velocity of the fluctuating pressure signal in a narrow frequency band centred on n
x, y, z	- cartesian co-ordinates (see Fig. 2.)
τ	- time delay

2. Introduction

To make any further progress towards the reliable and accurate prediction of the fluctuating response of tall buildings in strong winds, it is necessary to obtain information on the detailed characteristics of the turbulent pressure fluctuations on the faces of such buildings.

Measurements of these characteristics have been made on a low aspect ratio (= height/breadth) building in a suburban/light industrial environment with a strong wind normal to the building face. The actual dimensions of the building (the Robert Menzies School of Humanities Building) are:height 43m., length 13m., breadth 140m. (Fig. 1.). The main feature of the flow around this building is a strong horizontal cross-flow along the front face away from the stagnation area at the centre. Pressure fluctuation measurements have been made at four stations at the tenth floor level which is approximately the height of the stagnation point, as indicated by mean pressure measurements on the building (Fig. 2.).

Measurements on buildings with a range of aspect ratios is obviously a difficult and lengthy job. For this reason, an attempt has been made to model the flow around the Menzies Building in a wind tunnel where further measurements on other shapes can be made conveniently. A full graphical presentation of correlations and spectra for the four measurement stations is given in Figs. 4 - 10, the full and model scale results being plotted together non-dimensionally for comparison.

Discussion of these results is preceded by a description of the main features of the turbulent boundary layer flow in the wind tunnel.

3. Preliminary Wind Tunnel Measurements.

Pending the operation of a specially designed new large wind tunnel, attempts have been made to model the atmospheric boundary layer over the Monash campus in an all-purpose wind tunnel of $1m^2$ working section over a fetch length of 4.5m. The best result to date has been achieved by augmenting roughness elements (dimensions 3cm. x 2cm. x 2cm.; density 56/square metre) by 1m.high spire-shaped vortex generators of 5^0 apex angle at the start of the fetch length. Melbourne (1) has described this method in more detail.

The mean velocity profile through the boundary layer at the working section corresponds to a power-law exponent of 0.21 - a value appropriate for the terrain surrounding Monash.

Narrow-band correlations of the fluctuating longitudinal velocities measured by hot-wire probes separated horizontally and vertically from each other, indicated a lateral gust width in both directions of about 1/12 of the wavelength based on the mean velocity at the measurement height.[2]

The power spectral density of the velocity fluctuatons at two heights is shown in Fig.3. The scale of the tunnel boundary layer at the working section compared with full scale is 1:600 based on the boundary layer heights (gradient height in full scale). The universal curve for longitudinal velocity fluctuations in the atmospheric boundary layer during strong winds proposed by Harris [3] has also been plotted in Fig. 3. The curve proposed is based on a scale of turbulence (equal to $\sqrt{3}$ times the wavelength at the peak of the spectrum) of 1200m. at a reference height of 10m. In our wind-tunnel, this corresponds to a scale of 2m at a height of 1.67 cm. As clearly shown in Fig. 3., the peak of the velocity spectrum is shifted away from the scaled down Harris curve towards the high-frequency end. Looking at it another way, the scale of the longitudinal velocity fluctuations in the wind tunnel is apparently about two-thirds the value it should be. However, further discussion on this follows in the next section in the light of the building fluctuating pressure results.

In order to investigate the fundamental velocity/pressure relationship more fully, a stagnation pressure probe consisting of a small (25 mm diameter) brass cylinder containing a pressure transducer was inserted into the tunnel boundary layer at the same heights as the hot-wire probes had been placed previously. The power spectral density of these stagnation pressure fluctuations is also plotted in Fig. 3. There is a slight shift of the curve towards the high frequency end; the peaks are at about 15 Hz compared with 12.5 Hz for the velocity fluctuations. However, the same general form as the Harris curve is again exhibited. The mean velocity at the top of the boundary layer was the same for the measurements at both 5cm. and 10cm. and the variation in the peaks of both the velocity and the stagnation pressure spectra is negligible between the two heights.

Relevant turbulent intensities are also shown in Fig. 3. For small fluctuations, the intensity of the stagnation pressure fluctuations on the face of a probe smaller than the smallest length scale of the fluctuations is theoretically, twice that of the velocity fluctuations. This relationship is approximately true for the measured values, as may be seen.

4. Full scale and model building pressure fluctuations.

The recording and measurement system for the full-scale and model building face pressure fluctuations was described previously[2]. The full scale results were mainly processed using special analogue computer circuits [4].

On the Menzies Building itself, the reference mean velocity was taken from a pitot-static tube on top of a mast mounted on the 4.5m high blockhouse on top of the building; the total height was about 10m above the roof of the main building. In the wind tunnel, all mean velocities were measured at a standard reference height at the top of the boundary layer (70 cm.). These two mean velocities were corrected for position error and for profile variation to the mean velocity at the height of the building (or its model), $\overline{U}_{tbf}$, and this was used in the non-dimensional presentation of results given here.

Fig. 4. shows the auto-correlations of the pressure fluctuations at the four measurement points. In the case of the model, these show exponential decay form at all the points. This is also approximately true for the full scale results, except for station B10 which is close to the edge of the building. In general, the model curves lie above the full scale ones.

Sample time argument cross-correlations are shown in Fig. 5. The cross flow along the building face causes a convection of the turbulence pattern and, as a result, the peak of the cross-correlation appears at a positive time delay. Again the model results give smoother curves but the agreement between the two sets of results is good.

The relevant bandwidths for the curves of Fig. 4, 5 were : 0.005 to 15 Hz for the full scale and 0.32 to 2000 Hz for the model results.

The power spectral density of the pressure fluctuations at the four stations is shown in Fig 6. The Harris curve is also plotted for reference. Agreement between the full-scale and model points is good with the exception of the outer point B10. The greater scatter in the full-scale results for the inner point K10 is probably due to the fluctuation in mean wind direction and stagnation point. The fact that the full scale results do not lie on the Harris curve suggests that the proposed scale of 1200m at 10m height (originally suggested by Davenport) is not appropriate for the Monash site. The truth of this hypothesis will be confirmed or otherwise by the results of wind velocity measurements currently being made from towers on the site.

Unfortunately, the records of the full scale pressure fluctuations were not long enough to obtain any sort of accuracy at low frequencies below the spectral peak. However the plot of power spectral density for the point B10 appears to indicate a second peak at a higher frequency ($nh/\overline{U}_{tbf} \simeq 1$). The only explanations that are offered for this phenomenon are: (i) it is due to the vertical architectural features on the building face which were not modelled (see Fig. 1) or (ii) it is caused by vortex shedding in the separated flow at the corner of the building.

The power spectral density is of course directly related to the auto-correlations via the Fourier Transform, but, at this stage, no attempt has been made to verify this relationship for the results presented.

Narrow-band correlations are shown in Fig. 7. The main feature shown here is that, in the region between K10 and H10, which is closer to the stagnation area on the building face, there is noticeably less correlation than in the region between H10 and B10. The relative values of the lateral scale to wavelength ratios are approximately 1/10 and 1/6 respectively based on the mean velocity at the height of the building. In general, the full-scale points lie below the model points in Fig. 7.

In Fig. 8, the peaks of such cross-correlation curves as in Fig. 5 are plotted. This is therefore the plot of maximum total signal correlation. Again the full scale/model comparison is good although the model points again lie above the full scale ones. The exponential decay curve drawn in Fig. 8 corresponds to a full scale lateral scale of 26m.

The mean convection velocities of the total signal in the three regions are shown in Fig. 9. These were obtained from the time delays for maximum cross-correlation. The convection velocity clearly increases from the centre of the face towards the edge.

Narrow-band convection velocities, derived from the phase shifts in the narrow-band correlations are plotted in Fig. 10. Again the increase as y/b increases is clear. An increase in convection velocity occurs with increase in frequency.

5. Conclusions.

The results, despite some limitations, give new information on the airflow velocities past and pressure fluctuations on a large building.

The following conclusions are drawn:

(i) Except for the region near the edge of the building. the flow close to the building is modelled well in the wind tunnel.

(ii) An accelerating horizontal cross-flow is present along the face of the building at the height of measurement.

(iii) Narrow-band correlations are higher away from the stagnation area on the building face.

(iv) The power spectral density of the pressure fluctuations on the building appears to follow the form of the Harris curve for strong wind velocity fluctuations, but some doubt is thrown on the suggested scale length value of 1200m at 10m height for the Monash campus area.

The limitations of the work described here are:

(i) Pressure fluctuation records in full scale were not long enough to give accurate information at low frequencies.

(ii) Full information on the velocity characteristics of the airflow over the surrounding area has not yet been obtained.

(iii) Information on the intensity of the pressure fluctuations was not obtained.

All these deficiencies will be remedied in future work.

6. References

1. W. H. Melbourne "Comparison of Pressure Measurements made on a Large Isolated Building in Full and Model Scale." Proceedings, International Conference on Wind Effects on Buildings and Structures, Japan, September 1971.

2. J. D. Holmes "Full and Model Scale Cross-Spectral Density Measurements of Fluctuating Wind Pressures on the Face of a Large Building." Presented at the C.A.A.R.C. Symposium on Separated Flows and wakes University of Melbourne, 3 - 4 December, 1970.

3. R. I. Harris "Measurements of wind structure at heights up to 598 ft. above ground level." Proceedings, Symposium on Wind Effects on Buildings and Structures. Loughborough, 2 - 4 April 1968.

4. J. D. Holmes "Statistical Analysis of signals varying randomly with time using an Analogue Computer." Department of Mechanical Engineering, Monash University. Report MMEL 13, August 1971.

Fig. 1. MENZIES HUMANITIES BUILDING.

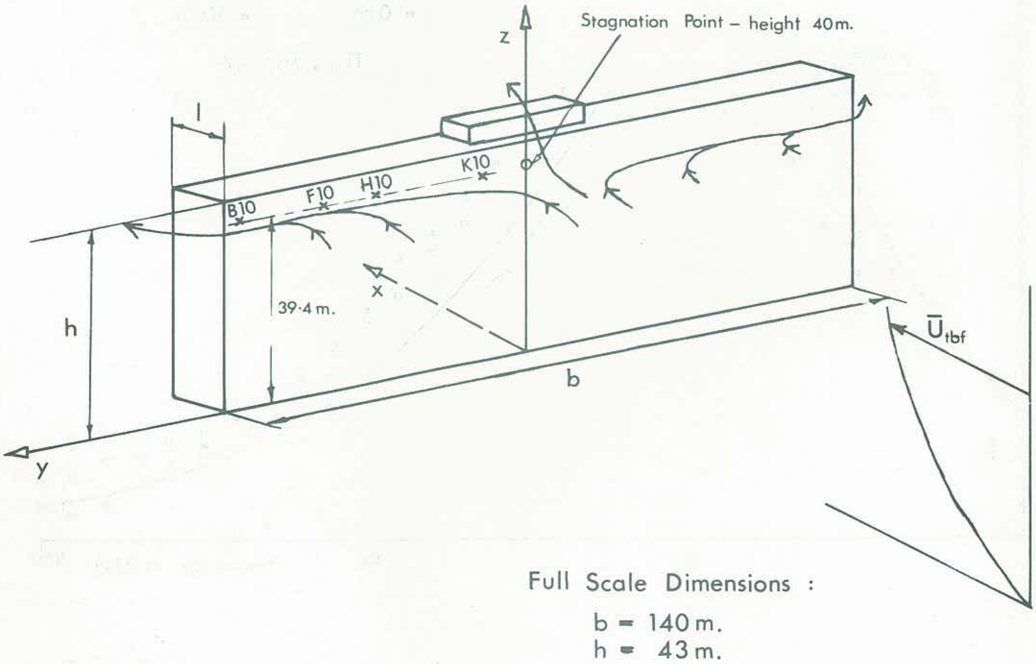
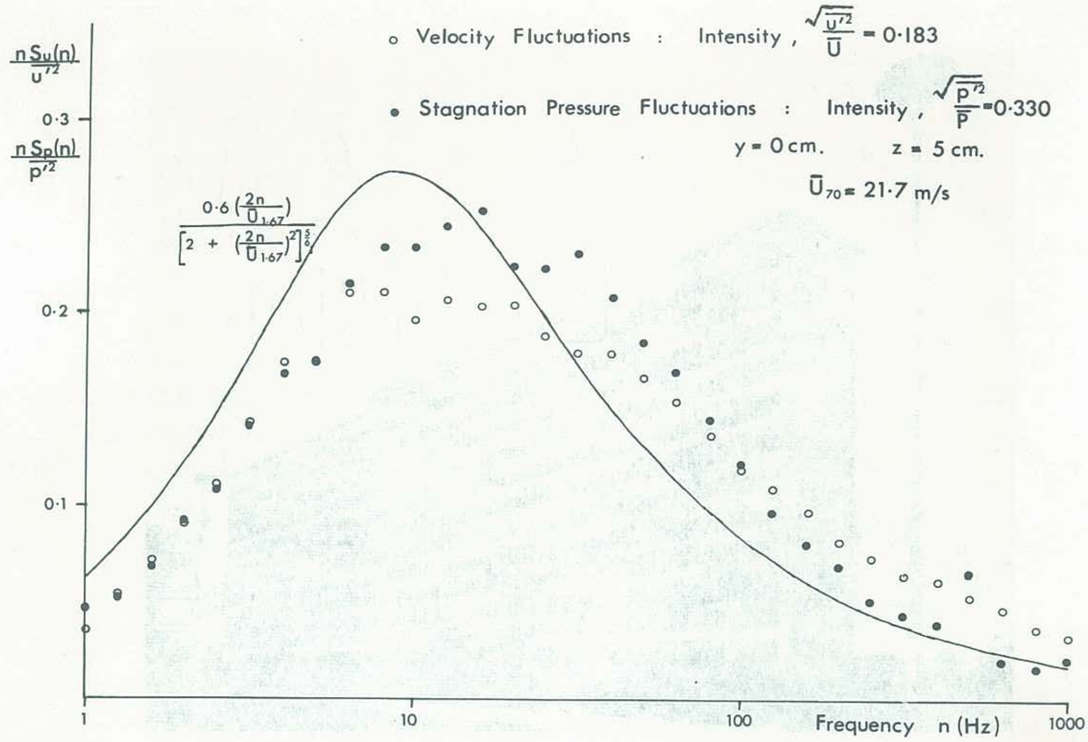


Fig. 2. MEAN FLOW AND MEASUREMENT POSITIONS.



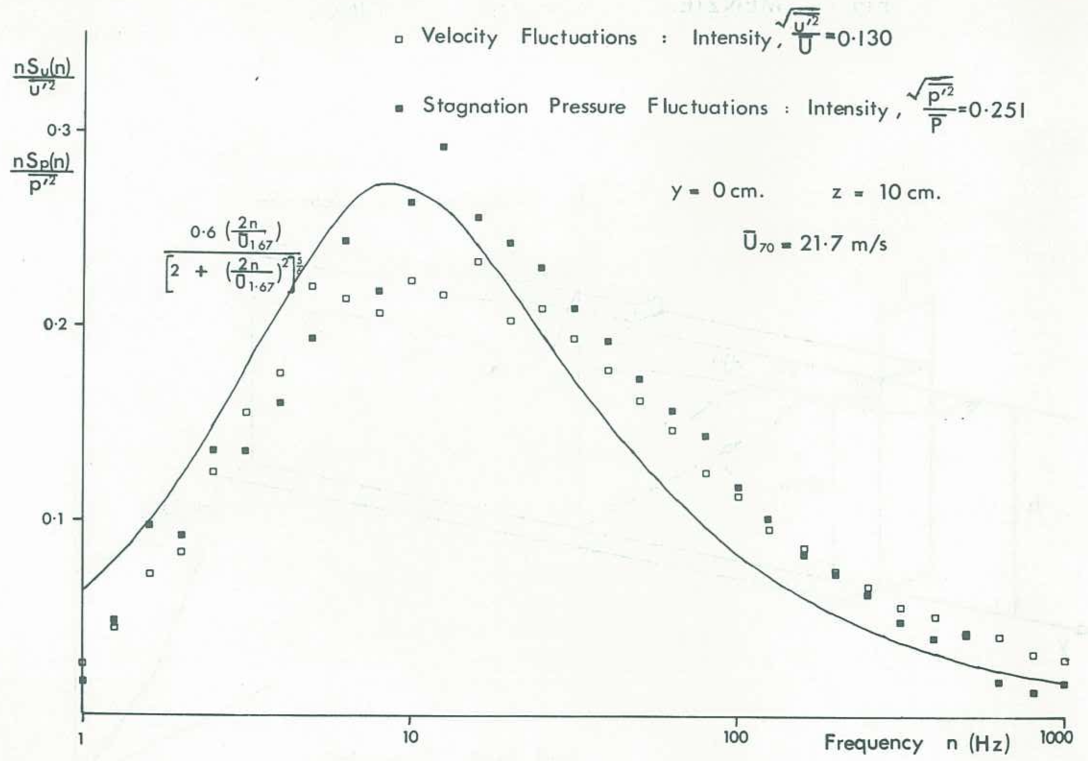
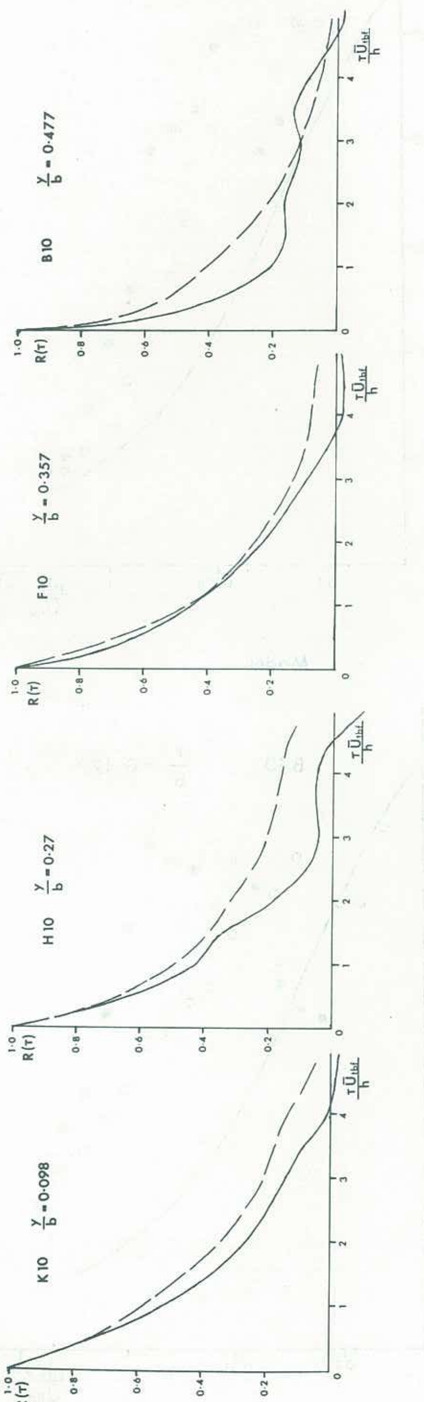
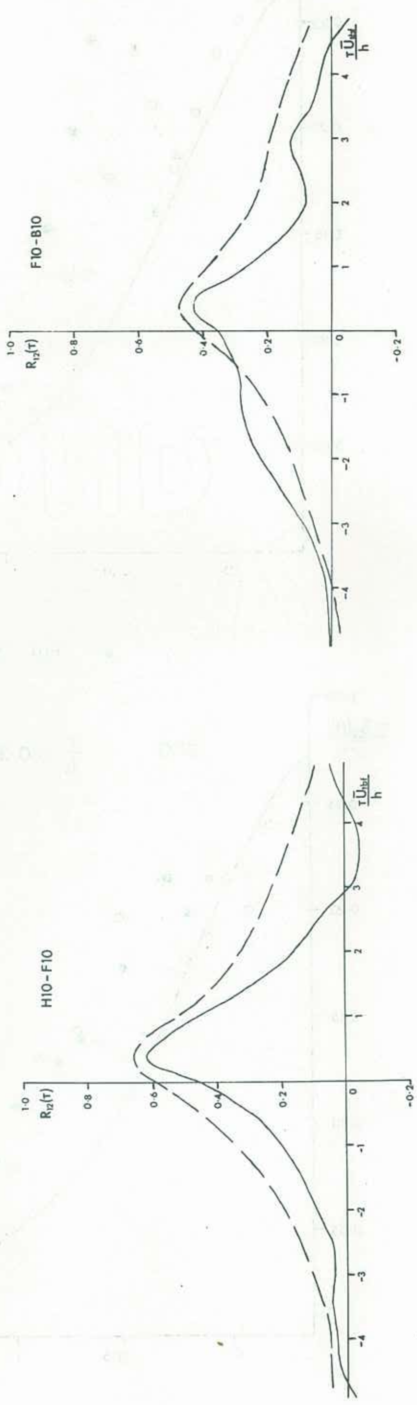


Fig. 3. POWER SPECTRAL DENSITY OF FLUCTUATIONS IN THE WIND TUNNEL.



—— Full Scale — — — Model.

Fig. 4. AUTO – CORRELATIONS



—— Full Scale — — — Model.

Fig. 5. CROSS – CORRELATIONS

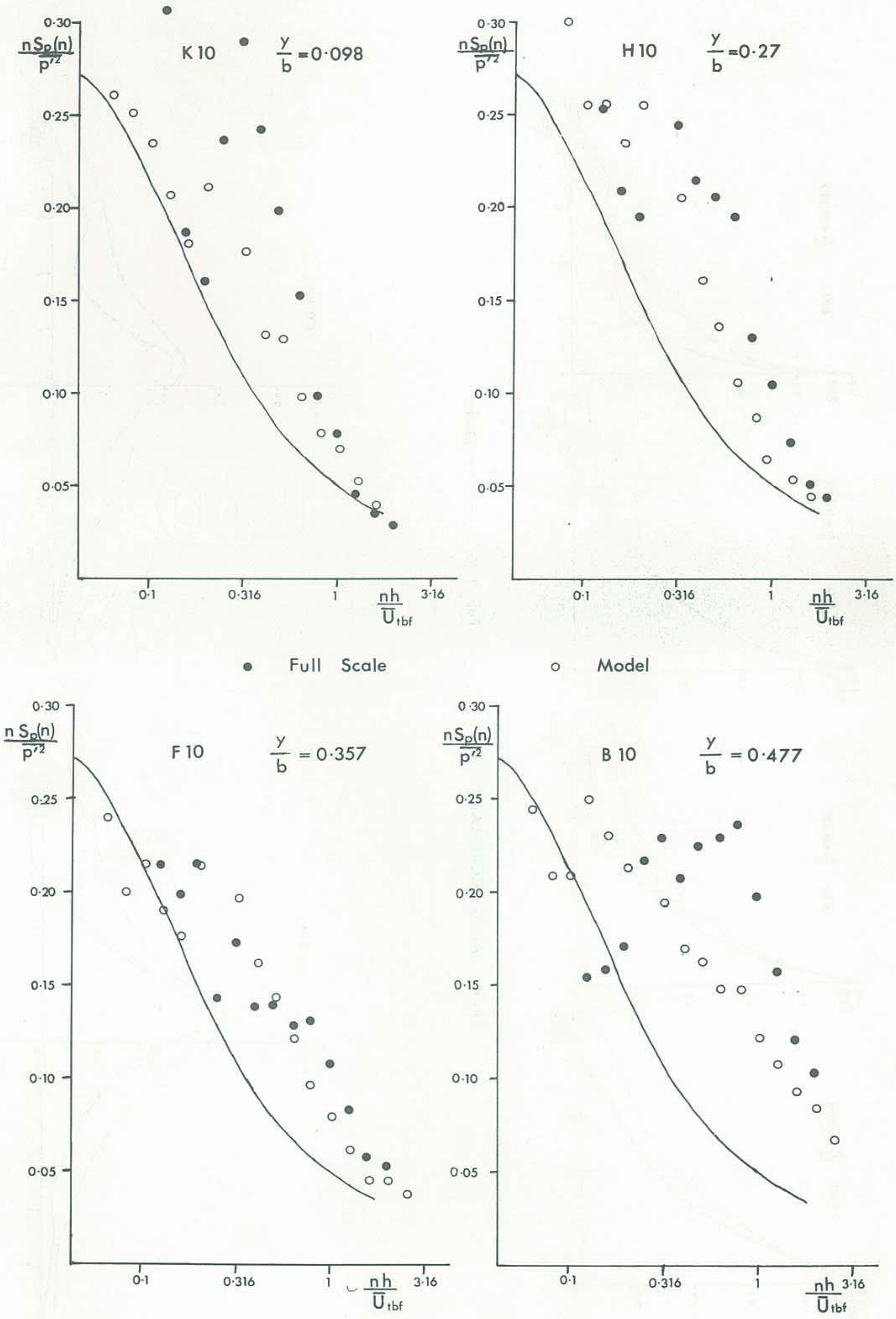


Fig. 6. POWER SPECTRAL DENSITY.

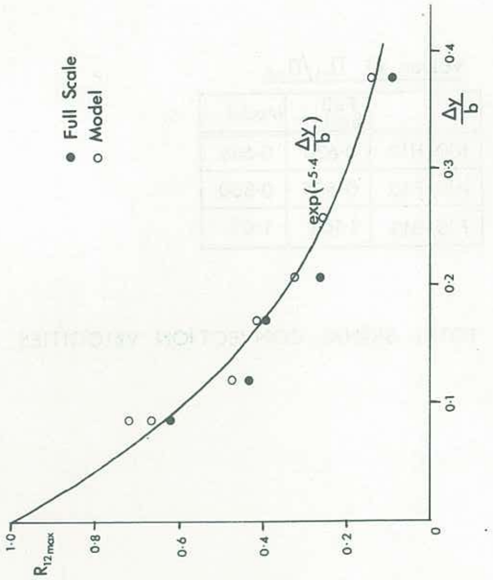


Fig. 8. TOTAL CORRELATIONS.

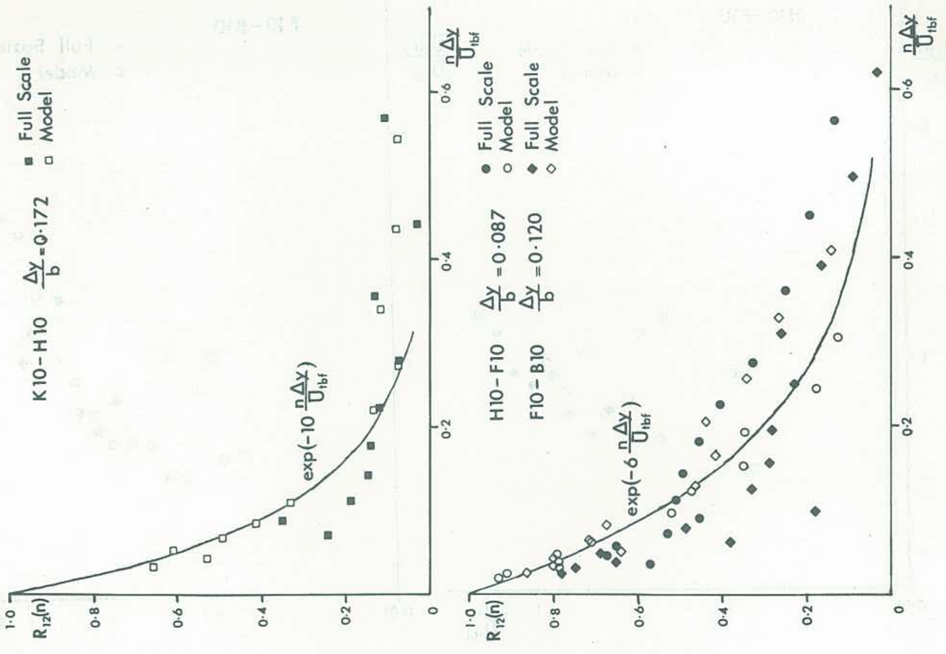


Fig. 7. NARROW BAND CORRELATIONS.

Values of $\bar{U}_{ct}/\bar{U}_{tbf}$

	Full Scale	Model
K10-H10	0·630	0·666
H10-F10	0·685	0·800
F10-B10	1·163	1·03

Fig. 9. TOTAL SIGNAL CONVECTION VELOCITIES.

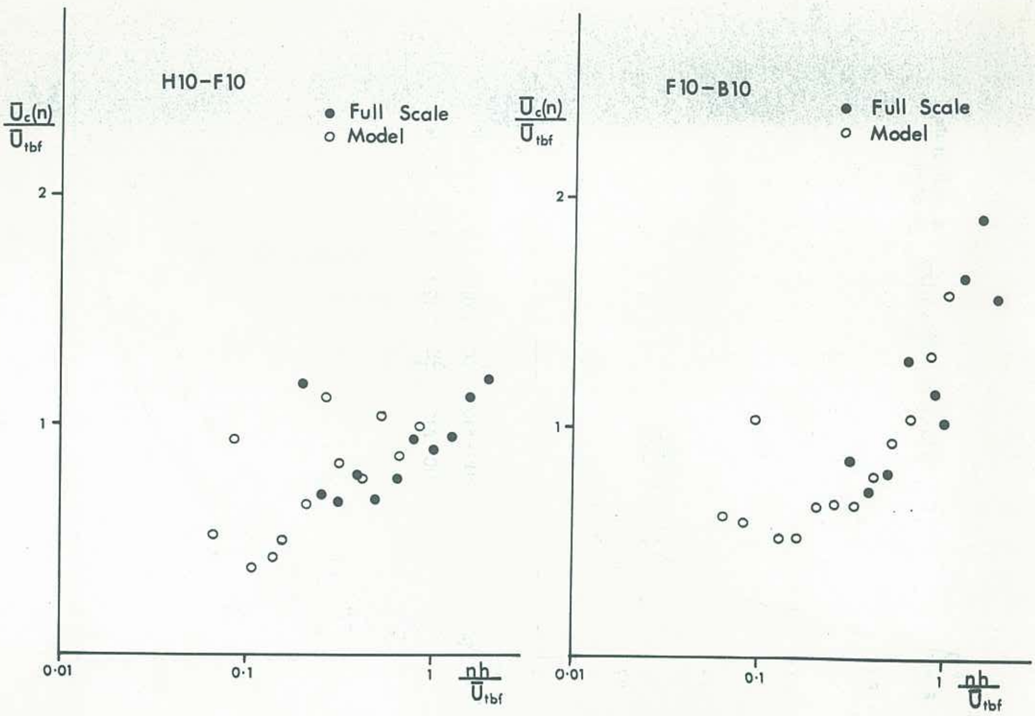


Fig. 10. NARROW BAND CONVECTION VELOCITIES.