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A probe for sensing static pressure in two-dimensional flow

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Abstract A probe has been developed for sensing static pressure in two-dimensional air flow. It was designed as a sensor for the measurement of static pressure acting on the surface of a building but the design also permits it to be used in free-stream flow. Details are given of the construction of the probe, the calibration procedure, the effects of Reynolds number and of the sensitivity of the probe to pitch.

1 Introduction

One of the problems of measuring wind loads on a full-scale building is that cladding profiles can give rise to sufficiently large local variations of the pressure field to preclude the use of simple pressure tapping holes in the surface as sensors, as found satisfactory in earlier research on glasshouse wind loads (Hoxey and Wells 1974). Large flat plates with central tapping holes to sense mean pressure can be mounted on the surface but these are difficult to fix and may influence local flow patterns. As an alternative, a probe has been developed which is small and therefore has minimal effect on surface flow and can be mounted sufficiently near to the surface to sense an integrated surface pressure. It was designed to be: (*a*) easily calibrated; (*b*) easily mounted on a building; (*c*) unaffected by rain or light falls of snow; (*d*) serviceable for a period of two years without maintenance; (*e*) inexpensive and easy to manufacture either singly or in small batches.

The probe is a development of a larger instrument for sensing atmospheric static pressure used at the Building Research Establishment, the Meteorological Office and the National Institute of Agricultural Engineering (Hoxey and Wells 1977).

2 Description of the probe

The probe (figure 1) is the result of empirical design which included a considerable amount of development work in a wind tunnel. The most important modification to the form of the larger instrument was the addition of a collar below the shroud. This provides a simple means of calibrating the probe by changing the shroud–collar gap and has the effect of reducing the sensitivity of the probe to pitch. The sensing head is an 8 mm diameter extension of the body with four small pressure-sensing holes equally spaced around the periphery.

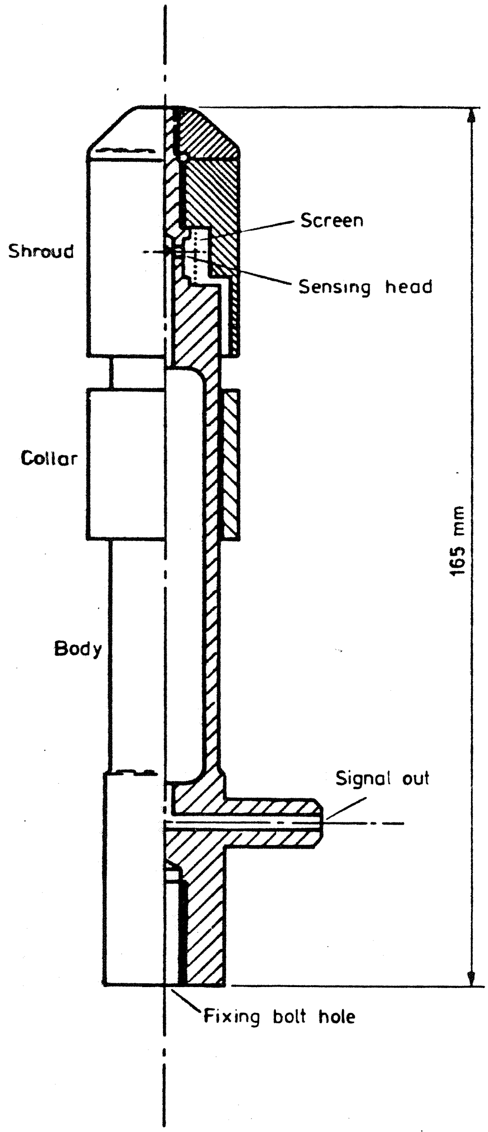

Figure 1 Sectional drawing of static pressure probe.

The air passage way to the sensing head and the gap between collar and shroud were designed to prevent water from forming a bridge which might affect the accuracy of the probe. The screen prevents insects from entering the sensing head. The collar is positioned at calibration so that static pressure is sensed; the nominal shroud–collar gap was chosen to be

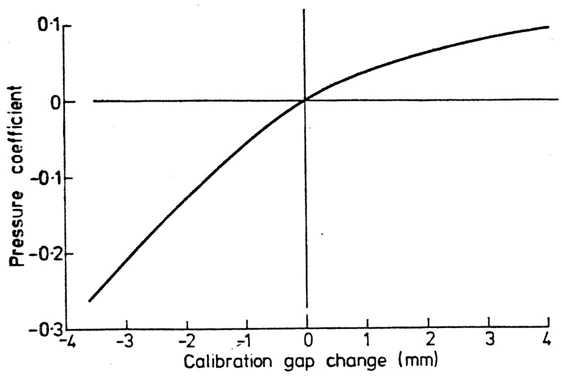

Figure 2 Effect on pressure coefficient of changing shroud–collar gap.

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5·5 mm but this can vary by up to 1·0 mm for individual probes. The sensitivity of the probe to gap change is shown in figure 2. The probe was made from H30WP aluminium alloy; this is light, easy to machine and relatively inexpensive and has good resistance to atmospheric corrosion.

3 Calibration

Experience with the probe used for sensing atmospheric static pressure has shown this type of instrument to be sensitive to turbulence in the air flow and it is necessary to calibrate in a flow with the appropriate turbulence intensity (Hoxey and Wells 1977). Since the probe being developed was to be used on full-scale buildings it was necessary to calibrate in natural wind.

The probe was mounted on a mast at a height of 3 m above a level site of cut grass which extended 150 m windward. Reference static pressure was provided from a perforated tank set flush into level ground, whilst total pressure was sensed by a directional Pitot tube also mounted on a mast at a height of 3 m. For the duration of this experiment the mean wind speed was 7 m s^{-1}.

Pressures from the probe and the directional Pitot tube were measured against reference static pressure by differential transducers and their electrical outputs recorded on an FM magnetic tape recorder. The output from the probe pressure transducer was also monitored by a computing voltmeter. A series of 4 min tape records was made for a range of shroud–collar gap settings on the probe. The computing voltmeter gave an indication of the point at which the pressure difference changed sign, but a more detailed computer analysis of the digitised data from the magnetic tape was used to establish the gap setting for zero pressure coefficient. The probe was then set to this gap.

The probe calibrated in this manner, however, gave a pressure coefficient of 0·07 in the smoother air flow of a small wind tunnel at the same mean wind speed. Three other probes, after being adjusted to 0·07 pressure coefficient in the tunnel, were found to have pressure coefficients of −0·01, −0·01 and −0·03 in natural wind. These errors were considered to be acceptably small compared with the experimental errors which can be expected when the probes are used to sense static pressure close to a building surface.

4 The effect of Reynolds number and sensitivity to inclination

The variation of pressure coefficient for wind speed from 6·5 to 20 m s^{-1} (dynamic wind pressures 25–245 Pa and Reynolds numbers 12000–37400) was investigated in the wind tunnel using a probe calibrated to give zero pressure coefficient under natural wind conditions at 7 m s^{-1}. The results (figure 3) show the pressure coefficient for the probe to be linearly related to the dynamic pressure of the wind.

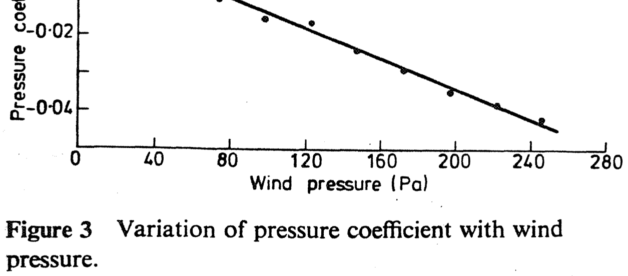

Figure 3 Variation of pressure coefficient with wind pressure.

The effect of pitching the probe into the flow was also evaluated in the wind tunnel. At a tunnel speed of 19 m s^{-1}, the variation of pressure coefficient at 1° intervals of probe inclination to flow direction up to 20° either side of normal was investigated for four probes with shroud–collar gaps of 4·5, 5·05, 5·2 and 5·8 mm. Pressure coefficients for the four probes did not exceed ±0·05. The variation of pressure coefficient for the probe with 5·05 mm gap is shown in figure 4.

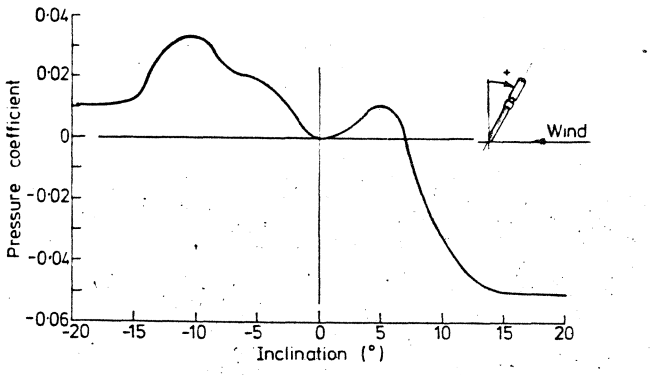

Figure 4 Variation of pressure coefficient with inclination to the direction of air flow.

5 Concluding remarks

A probe has been successfully developed to sense static pressure and can be used as a surface pressure sensor in full-scale wind load measurements on a building. The instrument was calibrated under natural wind conditions and from this a method of calibration in a wind tunnel was developed. A probe adjusted to have a zero pressure coefficient under natural wind gave a coefficient of 0·07 when calibrated in the wind tunnel at a wind speed of 7 m s^{-1}; this difference is considered to be an effect of the turbulence of the flow since the intensity of turbulence (2%) in the tunnel was an order less than in natural wind (approximately 20%). The instrument sensitivity to turbulence requires that it be calibrated for the conditions in which it will be used. Over the working range of conditions expected in full-scale experiments the probe was found to be insensitive to Reynolds number and to inclination (pitch) of flow.

Probes have been installed on four buildings and measurements of load have been made on many occasions. The installation of the probes has been straightforward and their operation to date satisfactory. When produced in batches of about fifty each probe costs £13 to produce, including materials (1978).

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