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Note on the effect of a nearby obstacle on turbulence intensity in a boundary layer

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It has been observed that the intensity of turbulence measured with a hot-wire anemometer close to the wall in a boundary layer can be substantially reduced by the presence of an obstacle nearby in a lateral direction. The obstacle in these experiments was another hot-wire probe. A brief survey was made of the positions of the two probes that could give a significant effect. However, the observation is reported mainly as an interesting phenomenon requiring further investigation. It is also of relevance to hot-wire anemometry; there may be a previously unsuspected and troublesome source of error due to a wire's own support.

This note describes what was essentially a passing observation during an experimental programme of correlation measurements in a turbulent boundary layer (Tritton 1967). It was noticed that, close to the wall, the intensity of turbulence as indicated by one hot-wire anemometer can be strongly influenced by the proximity of another probe, even when their locations are such that there would not be any wake effects.

The relative location of two probes in the boundary layer will be indicated by taking the x-direction as that of the mean flow, the y-direction normal to the wall, and the z-direction parallel to the wall and normal to the flow.

The basic observation is that the reading of turbulence intensity given by a hot-wire anemometer is reduced by an obstacle, such as another hot-wire probe, a small distance away in the z-direction. Reductions of up to 35 % in the mean square velocity fluctuation have been observed when the hot-wire was close to the wall. The observations were made on the reading of a U-wire, sensitive to longitudinal fluctuations, as an X-wire was traversed in its vicinity (see Tritton (1967) for details of the hot-wire procedure). My data contain some indication of a similar effect on the reading of an X-wire, but it is only for U-wires that the phenomenon has been carefully confirmed.

The construction of the X-wire probes is relevant as an indication of the type and size of the obstacle that produced the observed changes. The stem of each wire was approximately elliptical in section with axes of about 2 mm and 1 mm. Each stem was long enough ($\sim$ 10 cm) that the arrangement at the far end is of no concern. At the end carrying the hot wire, four leads emerged from or were soldered to the stem; these were typically about 0·5 mm in diameter and a little less than 1 cm in length with their ends very roughly at the corners of a square of side 5 mm with its centre in line with the stem. Since some of the observations were made with broken wires it was evidently the wire support, not the wire itself, that produced the effect.

During the experiments in which the phenomenon was investigated in a little more detail and from which figures 1–3 were obtained, the stem of the disturbing probe was aligned approximately in the z-direction and that of the U-wire giving the readings was in the y-direction. However the phenomenon was noticed for a variety of orientations of the disturbing probe, including a case in which its stem was inclined at less than 20° to the y-direction.

The observation occurred during $R_{12}(0,0,r_3)$ and $R_{13}(0,0,r_3)$ measurements (Tritton 1967) when the X-wire was traversed in the z-direction and the U-wire kept fixed. The reading from the U-wire alone changed as the other wire was traversed, being considerably reduced when the two wires were close. The possibility that this was a spurious observation, due to some movement of the U-wire as the other was traversed, was carefully eliminated. The distance of the U-wire from the wall was determined by my usual procedure—mean velocity measurements as it was traversed very close to the wall (Tritton 1967). This was done with the X-wire far away and then repeated with it in a position where it had a large effect on the intensity reading. Any differences were much too small to explain the effect. A second experiment to see whether it might be spurious consisted of a traverse of the type that produced the effect with the probe shifted so that the two wires did not come so close. Again the result was negative. There seems little doubt that a genuine alteration of the turbulence is brought about by the proximity of the second probe.

Clearly, one would want a simpler and more precisely defined geometrical arrangement for any detailed investigation of the effect. However, I ascertained a few broad features with the existing arrangement, to give some idea of when and to what extent the phenomenon might occur. The results are expressed by P, the percentage reduction in the signal. This is defined as

$$P = 100\,[(\overline{u^2})_a - (\overline{u^2})_b]/(\overline{u^2})_a,$$

where $(\overline{u^2})_a$ is the mean square longitudinal velocity fluctuation measured with the disturbing probe far away and $(\overline{u^2})_b$ is the corresponding measurement with the measuring probe unmoved and the disturbing probe brought up to the appropriate position. Values of P less than about 2 % are of no significance as the random error in a single reading is of this order.

The variables with respect to which variations in P have been briefly investigated are X and Z, the distances of the disturbing probe from the measuring wire in the x- and z-directions, and y, the distance of the measuring wire from the wall. No observations were made on the effect of an obstacle in the y-direction, as the measuring wire's own support was in that direction. Obviously, the variations with respect to Z and y are of most interest, as indicating the degree of proximity of the obstacle which produces the effect and the region of the boundary layer in which it occurs significantly.

Values of y are presented both dimensionally and non-dimensionalized as yu_τ/ν (where u_τ is the wall-stress velocity and ν is the kinematic viscosity) as this is presumably the most relevant representation of the position in the boundary layer. Values of X and Z are presented only in a dimensional form, as the most appropriate length-scale with which to compare them is presumably a characteristic dimension of the disturbing obstacle and it is not clear what this is. Also because the obstacle was not a simple shape, X and Z are not precisely defined. They are supposed to be the components of the distance from the middle of the hot-wire to a 'central point' of the plane of the four lead ends of the disturbing probe. The values taken are based on observations of the relative positions of the sensitive portions of the U- and X-wires together with an estimate of the amount the X-wire stood out from its leads. Hence, although differences in X and Z are rigorously measured quantities, there is not so much meaning to the exact position of their origins. No values of Y (separation in the y-direction) are recorded as this was never large compared with the distance between ends of different leads on the disturbing probe. A further comment about this is made below in connection with figure 3.

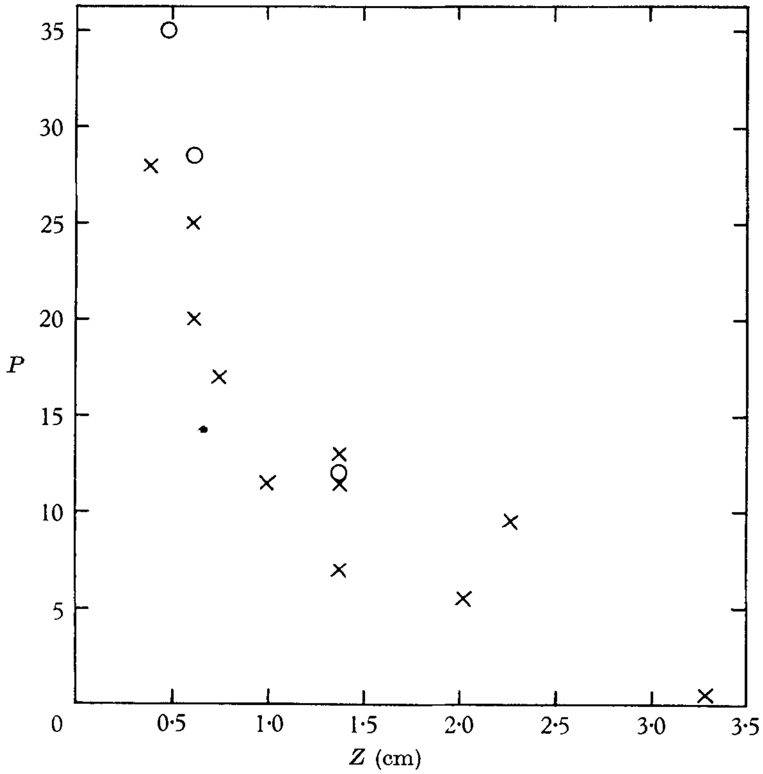

FIGURE 1. Variation of percentage reduction with lateral distance of disturbing obstacle. ×, y = 0·073 cm, X = 0; ○, y = 0·035 cm, X = 0.

Figure 1 shows how P varies with Z. This is a more detailed study of the type of observation that first revealed the phenomenon. The striking drop in the reading of the one anemometer as the other is brought up from a lateral direction is well shown by this figure. Although the results are presented dimensionally, comparison with the dimensions of the probe, as outlined above, indicates that a significant effect occurs even when the obstacle is a relatively large distance away.

The figure shows a full set of measurements for one value of y and a few points for a smaller value, the case in which the largest effect was observed.

To give a further indication of the zone in which the obstacle has an effect (apart from wake production), a few observations were made with displacements upstream and downstream. Figure 2 shows P plotted against X for two values of Z. The sign convention is that positive X corresponds to the obstacle being upstream of the measuring wire.

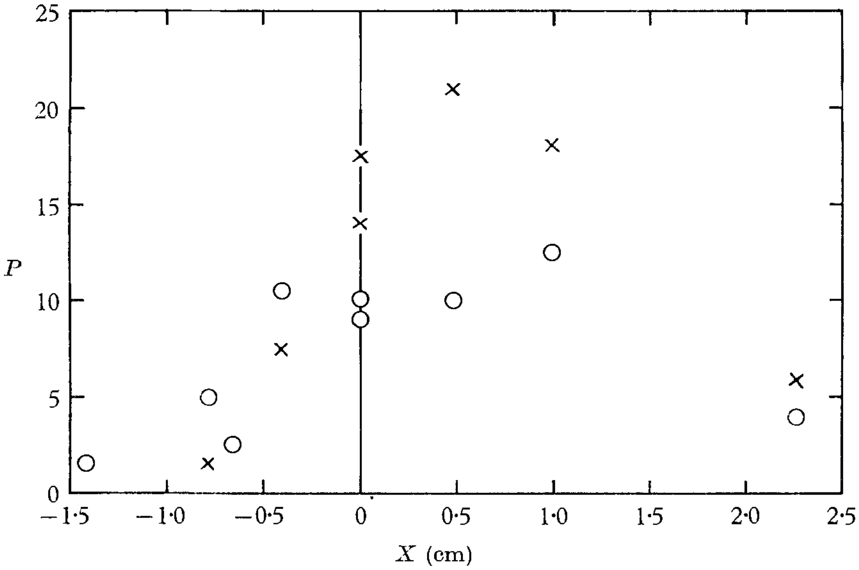

FIGURE 2. Variation of percentage reduction with longitudinal distance (superimposed on lateral separation) of disturbing obstacle. ×, y = 0·124 cm, Z = 0·61 cm; ○, y = 0·124 cm, Z = 1·37 cm.

It has already been remarked that the phenomenon occurs principally in the region close to the wall. Figure 3 shows the variation of P with y. Obviously, in a run like this, the question arises whether the obstacle, as well as the measuring wire, should be traversed in the y-direction. If it is not, the observations might be due to movements relative to the obstacle rather than relative to the wall. If the obstacle is traversed, this might be changing the pattern of the disturbance. The values of P in figure 3 are intended to be the maximum with respect to Y (for fixed y, X and Z). However, each maximization was based on only a few observations. (Each point is an actual result; there was no interpolation.) This may account for some of the irregularities in figure 3, but the trend with distance from the wall is clearly shown and would not be radically different if an alternative procedure had been adopted.

The mean velocity profile was unchanged, to within the accuracy of hot-wire measurements, when the obstacle was brought up. This is an aspect which would need further investigation in any detailed study. But there was certainly no change of the wall stress of an order necessary for the observations to be explained as a local equilibrium configuration with a changed u_τ.

Hence, the origin of the phenomenon remains a matter of speculation. It is, however, perhaps worth noting that the effect is most marked where the turbulence intensity varies rapidly in the y-direction. Although P is very different in different parts of the boundary layer, there is much less variation of the distance that one would have to traverse the hot-wire in the y-direction to bring about a change comparable with that produced by the obstacle. This distance is moreover of the same order as the displacement of the streamlines (based, for instance, on a cylinder in potential flow) produced by an obstacle of the size and distance of the disturbing probe. The chief discouragement to pursuing this line of thought is the following: it suggests that the approach of the obstacle should decrease the intensity in some places and increase it in others, whereas the observations always show a decrease.

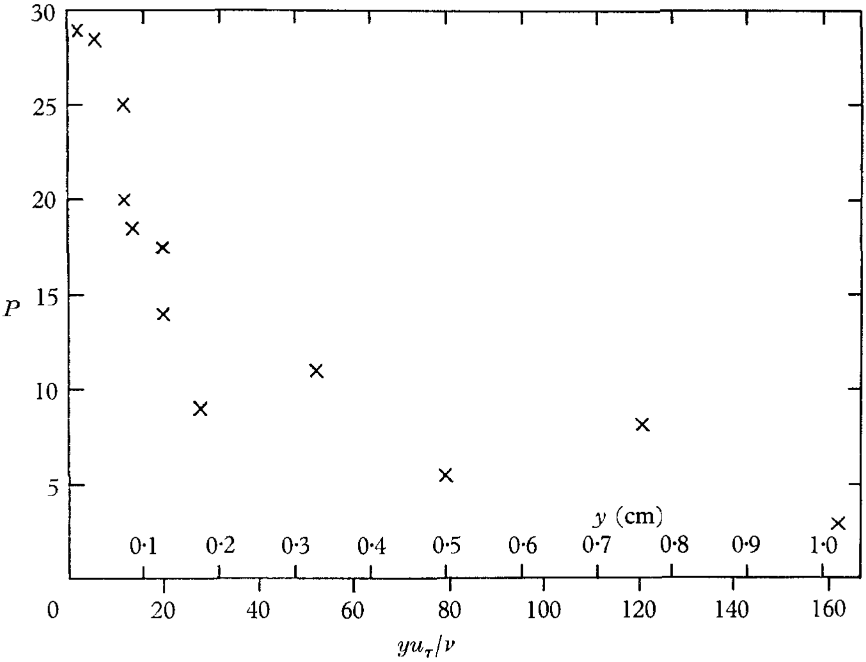

FIGURE 3. Variation of percentage reduction with distance from the wall. $X = 0$, $Z = 0{\cdot}61$ cm.

In addition to its intrinsic interest, the phenomenon is obviously of significance for hot-wire anemometry. It raises the rather perturbing question of the effect of a hot-wire's own stem. On the gloomiest possible view, all measurements, past and future, of turbulence close to a wall must be treated with some scepticism.

This work was done at the Department of Aeronautical Engineering, Indian Institute of Science, Bangalore, whilst I was holding a Rutherford Memorial Scholarship of the Royal Society. It is an offshoot of the work described in Tritton (1967), so thanks go again to all the people acknowledged there.

REFERENCE

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