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Summary.—When a pitot-tube is used in a pipe or boundary layer, the shear and the presence of the wall may cause the pressure in the tube to differ from the true total pressure on the axis of the tube. To investigate these effects, measurements were made in a pipe of circular section, with turbulent flow, using pitot-tubes of different external diameter D. Some supporting experiments were also made in a turbulent boundary layer on a flat plate with zero pressure gradient.

It was found that the effect of the shear alone could be conveniently expressed as a displacement δ_1 of the 'effective centre' of the tube towards the region of higher velocity. The value of δ_1/D was found to be $0 \cdot 15$, independent of Reynolds number and velocity gradient.

When the tube is near the wall, an additional correction must be applied. If this is expressed as a correction u to the measured velocity U, it is found that u/U is independent of Reynolds number within the accuracy of these experiments.

Alternatively, the effects of the wall and the shear together can be expressed as a total displacement δ of the effective centre, but δ/D then depends on Reynolds number and also on the ratio of distance from the wall to tube diameter.

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1. *Introduction*.—When a pitot-tube is used to measure the velocity distribution in a pipe or boundary layer, it is necessary to consider in some detail the various factors that may effect the pressure in the tube. For non-turbulent subsonic flow, the total pressure at any point may be defined as the pressure that is attained when the fluid passing through that point is brought to rest without any viscous dissipation. It is well known that in uniform non-turbulent flow the pressure in a pitot-tube is almost exactly equal to the true total pressure, provided the Reynolds number of the pitot-tube is not too small. When the Reynolds number of the pitot-tube is small, viscosity has an important effect; this has been investigated in several laboratories and the results have been summarised in an earlier paper by the author[1].

If the flow is turbulent, the pressure in the pitot-tube is not exactly equal to the total pressure in a non-turbulent stream with the same mean velocity and static pressure. The effect of turbulence on the pressure in a pitot-tube has been considered theoretically by Goldstein[2].

When the pitot-tube is used in a pipe or boundary layer, there are additional effects due to the shear and the presence of the wall, so that even if the flow is laminar and the tube Reynolds number is high, the pressure in the tube is in general not exactly equal to the true total pressure on the axis of the tube.

The present experiments were made in a pipe and in a boundary layer with zero pressure gradient, both with turbulent flow, to investigate the effects of shear and of the wall. The effects of turbulence and viscosity were not investigated in the present experiments ; these effects have been considered elsewhere for the case of zero shear.

Fig. 1 shows a portion of a velocity profile for a boundary layer or pipe. The apparent velocity U, as measured by a pitot-tube of external diameter D, is plotted against y, the distance of the geometric centre of the pitot-tube from the wall. The true velocity profile is also included in Fig. 1. It is clear that the discrepancy between the measured and true profiles can be considered either as an error in velocity ΔU, or as an error δ in y.

Young and Maas[3] showed that, in the absence of a wall, it was convenient to consider the discrepancy as an error in y, i.e., as a displacement δ of the ' effective centre ' of the pitot-tube from the geometric centre. Their results showed that, provided d/D was approximately constant and P could be considered to vary linearly across the mouth of the tube, δ/D was independent of D, P, and dP/dy. For $d/D = 0 \cdot 60$ they found that $\delta/D = 0 \cdot 18$ and, more generally, for any value of d/D, $\delta/D = 0 \cdot 13 + 0 \cdot 08\, d/D$.

All the present experiments were made with pitot-tubes having $d/D = 0 \cdot 60$, the value used by Young and Maas for most of their work. The object of the experiments was to determine the discrepancy between the measured and true velocity profiles (Fig. 1) in the presence of a wall, and to express this either as a displacement δ or as a correction to velocity. It was expected that, at large distances from the wall, δ/D would tend to a value near the one found by Young and Maas.

2. *Dimensional Analysis : Pitot-Tube in a Pipe.*—Consider the flow of an incompressible fluid in a smooth pipe, at a large distance from the entry, with the flow specified as either laminar or turbulent. The true mean velocity U_a at a distance y from the wall can only depend on the five variables ρ, μ, y, r, U_τ, where r is the radius of the pipe and U_τ is the ' friction velocity,' defined by the relation : shear stress at wall $= \tau_0 = \rho U_\tau^2$.

Thus if a pitot-tube of specified shape and external diameter D is placed at a distance y from the wall, the displacement δ of the effective centre can only depend on D, ρ, μ, y, r, U_τ.

Thus
$$\frac{\delta}{D} = f_1\left(\frac{y}{r}, \frac{y}{D}, \frac{U_\tau y}{\nu}\right), \qquad (1)$$
where $\nu = \mu/\rho$,

or alternatively
$$\frac{\delta}{D} = f_2\left(\frac{y}{r}, \frac{y}{D}, \frac{U_\tau D}{\nu}\right). \qquad (2)$$

Except near the centre of the pipe, the ratio U/U_τ should be almost a unique function of $U_\tau y/\nu$, so that y/r may be omitted from equations (1) and (2). It should be noted, however, that the omission of r as an independent variable is only permissible if curvature and blockage effects are negligible, *i.e.*, if D/r is small.

In analysing the experimental results it was found to be convenient to introduce the pipe Reynolds number $R_p = U_c r/\nu$. Since U_c/U_τ depends only on R_p, equation (1) may be re-written for this purpose as :
$$\frac{\delta}{D} = f_3\left(\frac{y}{r}, \frac{y}{D}, R_p\right). \qquad (3)$$
(Note that it is not possible to omit y/r from this equation.)

3. *Description of Apparatus.*—For the pipe experiments the apparatus was essentially the same as that used earlier by Preston[4]. The test section consisted of a piece of smooth brass pipe 7 ft 5 in. long, with an average internal diameter of 1·996 in. The pressure drop along the pipe was measured over a 6-ft length of the test section, and a static hole opposite the mouth of the pitot-tube was used to measure the static pressure p. Air was sucked through the pipe by four small centrifugal fans, arranged in parallel.

The entry to the test section consisted of 10 in. of roughened pipe and 14 ft 10 in. (89 diameters) of smooth pipe, all of 2-in. internal diameter. To make sure that fully developed turbulent flow had been attained in the test section, further measurements of velocity distribution were made at the traverse station, with the entry length increased from 89 to 133 pipe diameters. No change in velocity distribution could be detected for any Reynolds number within the available range.

Further experiments were made with various types of disturbance at the pipe entry, but none of these alterations had any effect on the velocity distribution at the traverse station. (These experiments, to confirm that fully developed turbulent flow had been attained at the test section, were important because the *local* shear stress at the wall was obtained by measuring the *average* pressure drop over a 6-ft length of pipe).

For the boundary-layer experiments a smooth flat Duralumin plate was used, spanning the working section of a wind tunnel. The plate was 6 ft long and 28 in. wide and was roughened near the leading edge to promote transition. The pitot-tubes were traversed along a line through the centre of the plate, at a distance of 30 in. from the leading edge. A static hole placed off the centre-line, at the same distance from the leading edge, measured the static pressure p.

In both the pipe and the boundary-layer experiments, the measurements of y were made by a traverse gear incorporating an ordinary micrometer screw, with springs to eliminate back-lash. The traverse gear was electrically insulated from the pipe or plate, so that an electrical contact method could be used to determine the reading of the micrometer when the pitot-tube was just touching the wall. The estimated error in y was no more than 2×10^{-4} in.

The pitot-tubes were the same as those used in an earlier investigation by Preston[4].

The tubes were all of circular section, with plane-faced ends and $d/D = 0 \cdot 600 \pm 0 \cdot 006$. The external diameters of the five tubes were 0·0239, 0·0292, 0·0544, 0·0907 and 0·1214 in. (These tubes will be referred to later as numbers 1, 2, 3, 4 and 5).

All the pressure measurements were made with manometers of the null-reading, inclined-tube type, with movable reservoirs. The sensitivity of each manometer could be altered by changing the slope of the inclined tube, as discussed in an earlier paper by the author[5]. The range of pressure differences measured was from about 0·02 to 3 in. alcohol, and the estimated error in an individual manometer reading within this range was always less than 1 per cent.

4. *Measurements and Analysis.*—Measurements in the pipe were made at three rates of flow, giving three nearly constant values of R_p. (Small variations of air temperature and pressure caused changes of ν and ρ, and hence of R_p for a given pressure drop. These variations of R_p were not large enough to have any significant effect). Values of the measured velocity U were corrected for the effect of compressibility and for the previously measured effect of the pitot-tube on the pressure at the static hole. The values of U were also corrected for the effect of viscosity on the pressure in the pitot-tube, at zero shear and in the absence of a wall, using the results obtained in earlier experiments by the author[1]. Thus the derived values of the displacement δ do not include the effects of viscosity, except in so far as these are altered by shear and the presence of a wall.

Values of U_τ were obtained from measurements of pressure drop along a 6-ft length of the test section, with a correction applied for the effect of the acceleration caused by compressibility. Since the highest air speed was only about 100 ft/sec, this correction was very small and it was sufficiently accurate to base it on the mean velocity across a section, using a one-dimensional theory. The temperature and pressure used in computing $U_\tau y/\nu$, for a given value of y, were the average values at the traverse station for each series of measurements.

A preliminary analysis of the pipe measurements was made by the following method, essentially similar to that used by Young and Maas[3]. It will be shown later that this method cannot be expected to give the correct value of δ near the wall (small y/D), but it can be used to determine the correction δ/D for large values of y/D. The true velocity profile can then be derived, for a considerable range of y, by applying this correction to the results obtained from all the pitot-tubes for large y/D.

Values of U/U_τ were found for each pitot-tube at a fixed value of y. The pressure drop in the test section was kept constant, so that $U_\tau y/\nu$ and R_p were nearly constant. (As already mentioned, variations of air temperature and pressure caused small changes of ν and ρ.) The values of U/U_τ obtained for this one value of y were then plotted against tube diameter D, and a straight line drawn through the points using the method of least squares. Fig. 2 shows the straight lines obtained in this way, for a range of values of y, at one value of R_p. Similar sets of straight lines were obtained at two lower values of R_p.

A second series of measurements was obtained using a slightly different procedure ; the pipe was traversed with each pitot-tube in turn, and values of U/U_τ at specified values of y were obtained by cross-plotting.

In Fig. 2, let U_0 be the value of U obtained by linear extrapolation to $D = 0$. If U/U_τ were strictly a linear function of D, then U_0 would be equal to the true velocity U_a. It can be shown, however, that this is not the case unless δ/D is independent of y/D. For if U/U_τ varies linearly with D, for constant y and U_τ, $U = U_0 + \beta D$, where β is independent of D. Putting $\Delta U = U - U_a = U - U_0$, Fig. 1 shows that $\Delta U/\delta = dU_a/dy$ (if ΔU is small), and this is independent of D. Thus $\delta/D = (\Delta U/D)(\delta/\Delta U) = \beta/(dU_a/dy)$, and this is also independent of D.

Thus if a linear relationship between U/U_τ and D is assumed in analysing the experimental results, no dependence of the apparent displacement δ_0 on y/D can be found. In regions where the true displacement is dependent on y/D it may be expected that the values obtained for δ_0 will be misleading.

Notwithstanding this difficulty, useful results were obtained from the linear extrapolation by proceeding as if the velocity U_0 were equal to the true velocity U_a. The values of U_0/U_τ, found by extrapolation to $D = 0$ for different values of y, were plotted against $U_\tau y/\nu$ at a constant value of R_p. Values of U/U_τ for an arbitrarily chosen value of y/D were then obtained from the straight lines as shown in Fig. 2, and plotted against $U_\tau y/\nu$ on the same graph as the U_0/U_τ curve. Regarding U_0 as the 'true' velocity, the apparent displacement δ_0 could be found from the distance between the two curves.

If the process had been repeated for another arbitrarily chosen value of y/D, the derived values of δ_0/D would have been exactly the same, because the method of analysis necessarily implies that δ_0/D is independent of y/D. This analysis was completed for the three values of R_p, and after smoothing the results and plotting δ_0/D against y/r the set of curves shown in Fig. 3 was obtained. In deriving these smooth curves, use was also made of the second series of measurements.

It is now necessary to consider the effect of the linear extrapolation, and the way in which the apparent displacement δ_0 may differ from the true displacement δ. The experiments of Young and Maas suggest that in the absence of a wall δ/D should be constant, *i.e.*, independent of y/r, y/D, and Reynolds number. It is reasonable to assume that this is also true for a pipe or boundary layer, provided y/D is sufficiently large. Accepting this assumption, let δ_1/D be the constant value to which δ/D tends at large values of y/D. δ_1 may then be described as the displacement of the effective centre of the pitot-tube due to the effect of shear alone, *i.e.*, in the absence of a wall. At any smaller value of y/D, let the displacement be $\delta = \delta_1 + \delta_2$, where δ_2 is the displacement due to the effect of the wall, to be added to the displacement due to shear δ_1. Although δ_1/D is constant, δ_2/D may be expected to depend on y/D and $U_\tau y/\nu$ (or on y/D and $U_\tau D/\nu$), as given by equation (1) or (2) with y/r omitted. For sufficiently large values of y/D (say $y/D > K$), $\delta_2 = 0$ and $\delta = \delta_1$.

In the light of these assumptions, the straight lines drawn in Fig. 2 may be reconsidered. The simplest case is that for which y is so large that $y/D > K$ for all the pitot-tubes used. Then $\delta/D = \delta_1/D =$ constant; the linear extrapolation is justified, and the apparent displacement δ_0 is equal to the true displacement δ.

The case where $y/D < K$ for some of the pitot-tubes is represented by the points A in Fig. 4. The points do not lie exactly on a straight line because, for the smaller values of y/D, δ_2 is not zero and will depend on y/D. The wall effect is unimportant towards the left of the diagram, where y/D is large, and becomes more important towards the right, where y/D is smaller. The points B represent the values of U/U_τ that would have been obtained if δ_2 had been zero for all the values of y/D. (It will be shown later that the sign of the wall effect is as shown, tending to reduce the measured values of U/U_τ, e.g., from B_5 to A_5.)

The broken line in Fig. 4 represents the best straight line through the A points. The slope of this line, β/U_τ, is smaller than that of the straight line through the points B, so that the wall effect, or δ_2 term, decreases the slope.

It is easily shown that, for a given value of $d(U/U_\tau)/dy$, the ratio δ_0/D is directly proportional to the slope β/U_τ. Thus the wall effect makes δ_0 less than δ.

In Fig. 2, if y is sufficiently large, y/D will be so large for all the pitot-tubes that the wall effect will be zero. Thus in Fig. 3, δ_0 should tend to δ_1 for large y/r. This suggests that δ_1/D is about $0 \cdot 15$, the value shown in Fig. 3 for δ_0/D at large y/r.

It is concluded that the only useful information to be obtained directly from Fig. 3 is that δ_1/D is about $0 \cdot 15$. The rather large variation of δ_0/D with Reynolds number, for small y/r, is surprising, and it seems likely that this is caused mainly by the variation of δ_2/D with y/D.

Fig. 3 shows that δ_0/D has the constant value of $0 \cdot 15$ for all values of y/r greater than about $0 \cdot 24$. Thus for $y/r = 0 \cdot 24$, $y/D \geqslant K$ for all the tubes. Since the limiting case ($y/D = K$) occurs for the largest tube ($D/r = 0 \cdot 12$), this result gives $K = 2$. Thus it may be concluded that for $y/D > 2$ the wall has no appreciable effect on any of the tubes, so that $\delta_2 = 0$ and $\delta = \delta_1 = 0 \cdot 15D$.

If these results are correct, it should be possible to obtain values of the true velocity U_a, by considering only those results for which $y/D > 2$ and applying a displacement correction $\delta/D = 0 \cdot 15$. The results obtained from the traverses of the pipe were corrected in this way, and U_a/U_τ was plotted against $U_\tau y/\nu$ for each value of R_p (Fig. 5). For the whole range of the measurements the points for each Reynolds number were within $0 \cdot 3$ per cent of the mean curve, thus confirming that (provided $y/D > 2$) the correction $\delta/D = 0 \cdot 15$ reduces the results obtained with different pitot-tubes to a single true curve.

At the lowest Reynolds number, results were obtained for $y/D > 2$ over a wide range of $U_\tau y/\nu$, but for the two higher Reynolds numbers results were only obtained for $y/D > 2$ at the higher values of $U_\tau y/\nu$. To extend the lower range of $U_\tau y/\nu$ for these two Reynolds numbers it was assumed that, at sufficiently small values of y/r, U/U_τ would be strictly a unique function of $U_\tau y/\nu$, independent of R_p. The broken lines in Fig. 5 show how the curves for the two higher Reynolds numbers were extrapolated to low values of $U_\tau y/\nu$, making use of this assumption. It was found that, for a given value of $U_\tau y/\nu$, U_a/U_τ became sensibly independent of R_p for values of y/r below about $0 \cdot 07$.

By making use of the true velocity profiles shown in Fig. 5, the effect of the wall at low values of y/D could be determined. The measured values of U/U_τ for each pitot-tube at each Reynolds number were corrected for shear (using $\delta_1/D = 0 \cdot 15$), and then plotted against $U_\tau y/\nu$ on the same graph as the true curve of U_a/U_τ. Fig. 6 shows a portion of the curves for pitot-tube No. 5 at $R_p = 2 \cdot 7 \times 10^4$. The displacement δ_2 can be found as the change of y necessary to make the two curves coincide.

Although the wall effect can be expressed as a displacement δ_2, and this can be added to the known value of δ_1 to find the total displacement δ, it was found convenient to express the wall effect as a velocity correction of the form u/U, where u is to be added to the measured velocity U. The correction can be obtained in this form directly from curves such as those shown in Fig. 6.

Equation (1) shows that δ_2/D, or u/U, may depend on y/r, y/D, and $U_\tau y/\nu$. At sufficiently small values of y/r, as already mentioned, U/U_τ depends only on $U_\tau y/\nu$, and δ_2/D or u/U should then be independent of y/r. It has already been shown that the wall effect only becomes appreciable, even with the largest pitot-tube, for $y/r < 0 \cdot 24$. This value of y/r is small enough for U/U_τ to be approximately a unique function of $U_\tau y/\nu$, so that the dependence of the wall correction (δ_2/D or u/U) on y/r should be negligible.

For each value of y/D, the derived values of the wall correction u/U were plotted against $U_\tau y/\nu$, as in Fig. 7. The accuracy of the results was not sufficient to determine the dependence of u/U on $U_\tau y/\nu$. An average value of u/U was therefore taken for each value of y/D, and it was assumed that u/U was independent of $U_\tau y/\nu$. This is probably not strictly correct, since for small y/D the velocity profile across the mouth of the pitot-tube must depend on $U_\tau y/\nu$, but the experimental results suggest that the variation of u/U with $U_\tau y/\nu$ is small enough to be neglected in most practical cases.

The scatter of the points shown in Fig. 7 is typical of the results obtained. It may be noted that in this case 6 of the 9 points lie within $0 \cdot 0025$ of the horizontal straight line drawn through the arithmetic mean. Thus the scatter of these 6 points represents an error of only $\frac{1}{4}$ per cent of the measured velocity.

Fig. 8 shows u/U plotted against y/D. This curve can be used, in conjunction with the shear correction ($\delta_1/D = 0 \cdot 15$) to find the total correction to be applied to a measured velocity profile. It is recommended, however, that these corrections should only be applied over the range of $U_\tau y/\nu$ (from about 30 to 230) covered by these experiments.

An alternative presentation is given in Fig. 9, in which the ratio δ/D of total displacement to tube diameter is plotted against D/y, for various values of $U_\tau D/\nu$. The use of the reciprocal D/y, instead of y/D, allows the total possible range, from $y/D = \frac{1}{2}$ to $y/D = \infty$, to be covered on the diagram. Since u is a correction to be added to the measured velocity, the corresponding displacement δ_2 is negative, so that δ/D is less than $0 \cdot 15$ for small y/D.

The unbroken lines in Fig. 9, for $U_\tau D/\nu = 50$, 100 and 200, cover approximately the range for which δ/D has been determined in the present experiments. The broken lines, for $U_\tau D/\nu = 25$, 500 and 1,000, were derived by assuming that Fig. 8 is correct at all Reynolds numbers. Thus these curves should be used with caution, although it seems unlikely that there can be any large errors for the high values of $U_\tau D/\nu$.

With the form of presentation used in Fig. 9, it is possible to include in the displacement δ the effect of viscosity at zero shear. This makes no appreciable difference to the curves for $U_\tau D/\nu = 50$ or more, but for $U_\tau D/\nu = 25$ the effect is quite important. At this low Reynolds number, δ/D becomes greater than $0 \cdot 15$ for large y/D, when the effect of viscosity at zero shear is included. The interpretation of the viscous effect as a displacement depends on the velocity profile. Thus the curve given in Fig. 9 for $U_\tau D/\nu = 25$, with the viscous effect included, is only applicable in cases where the functional relationship between U/U_τ and $U_\tau y/\nu$ is similar to that obtained in these experiments.

The results of the measurements in the turbulent boundary layer on the flat plate were analysed by a method similar to that already described. The dimensional analysis for this case is similar to that already given for the pipe, but with the pipe radius r replaced by the boundary-layer thickness Δ. The measurements were made at two values of the boundary-layer Reynolds number R_Δ, equal to the two lower values of R_p used in the pipe experiments. The boundary layer was traversed with each of the five pitot-tubes at each Reynolds number, and for each tube $(U/U_1)^2$ was plotted against y/Δ. $(U/U_1)^2$ was then plotted against D, for constant values of y/Δ. Using the method of least squares, straight lines were drawn through the points and extrapolated to $D = 0$ to obtain $(U_0/U_1)^2$. Values of the apparent displacement δ_0 were then obtained, using the same method as in the pipe experiments. When δ_0/D was plotted against y/Δ, curves resembling those in Fig. 3 were obtained, with δ_0/D tending to an upper limit of about $0 \cdot 15$ at large values of y/Δ. As in the pipe experiments, it was found that the wall effect became negligible for $y/D > 2$.

The true velocity U_a was obtained by applying the correction $\delta/D = 0 \cdot 15$ to the results for $y/D > 2$, and U_a/U_τ was then plotted against $U_\tau y/\nu$. An attempt was made to find the correction for wall effect u/U, as before. Unfortunately, this could not be done satisfactorily because the number of observations was not large enough, but the few results obtained were in fairly good agreement with the earlier results obtained from the pipe experiments.

5. *Experimental Errors.*—After careful consideration of all the sources of experimental error, it was estimated that the possible error in the correction for shear effect ($\delta/D = 0 \cdot 15$) was about $\pm\, 0 \cdot 01$. The possible error in the correction for wall effect u/U was estimated to be about $\pm\, 0 \cdot 004$. This error in u/U may lead to an error in δ_2/D of as much as $0 \cdot 02$, so that the total error in δ/D (as shown in Fig. 9) may be as large as $0 \cdot 03$ in some cases.

6. *Conclusions.*—The experiments have shown that for $y/D > 2$ the total correction may be expressed as a displacement given by $\delta/D = 0 \cdot 15 \pm 0 \cdot 01$, where the effective centre is displaced from the geometric centre towards the region of higher velocity. Provided $y/D > 2$, δ/D is independent of y/D, y/r (or y/Δ), and Reynolds number.

When $y/D < 2$, an additional correction must be applied for the effect of the wall. This can be expressed as a correction u, to be added to the measured velocity U. Within the limits of accuracy of these experiments, u/U is found to depend only on y/D, as shown in Fig. 8, and is independent of $U_\tau D/\nu$.

Alternatively, the corrections for the effects of shear and of the wall can be combined and expressed as a single displacement δ. The ratio δ/D is conveniently expressed as a function of D/y and of $U_\tau D/\nu$, as shown in Fig. 9.

These results may require modification at Reynolds numbers outside the range of the present experiments (*see* Fig. 9). Additional corrections may also be required to allow for effects of turbulence and of viscosity at zero shear.

The experiments were made in turbulent shear flow for which U/U_τ was very nearly a unique function of $U_\tau y/\nu$. In considering the application of the results to more general flows, it may be expected that the correction for shear (δ_1/D) would apply to any shear flow, whether laminar or turbulent, for sufficiently large values of y/D. It should be noted, however, that the way in which the correction for wall effect (δ_2/D) varies with y/D and $U_\tau D/\nu$ will in general depend on the velocity profile, defined by the relation between U/U_τ and $U_\tau y/\nu$. Moreover, the limiting value of y/D, above which the wall effect becomes negligible, may also depend on the velocity profile.

It is known, however, that the velocity profile near the wall in any turbulent boundary layer, except near separation, is similar to that found in a pipe. Thus the corrections found in these experiments may be applied to measurements made in any turbulent boundary layer, provided the pitot-tube diameter D is small compared with the boundary-layer thickness, so that y/D is only less than 2 for those regions in which the unique velocity profile is obtained.

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NOTATION

d		Internal diameter of pitot-tube
D		External diameter of pitot-tube
p		Static pressure, at position of pitot-tube
P		Pressure in pitot-tube
r		Radius of pipe
R_p	=	$U_c r/\nu$ Reynolds number of pipe
R_Δ	=	$U_1 \Delta/\nu$ Reynolds number of flat plate
u		Correction for wall effect, to be added to measured velocity U
U	=	$\left[\frac{2(P-p)}{\rho}\right]^{1/2}$ Measured velocity
U_0		Velocity obtained by linear extrapolation to $(D = 0)$
U_a		True mean velocity at position of centre of pitot-tube
U_1		Velocity at edge of boundary layer on flat plate
U_c		Velocity at centre of pipe
U_τ	=	$(\tau_0/\rho)^{1/2}$ 'Friction velocity'
ΔU	=	$U - U_a$
y		Distance from wall to centre of pitot-tube
δ_0		Apparent displacement of effective centre of pitot-tube, obtained by linear extrapolation to $(D = 0)$
δ_1		Displacement of effective centre of pitot-tube due to effect of shear alone
δ_2		Displacement of effective centre of pitot-tube due to effect of the wall
δ	=	$\delta_1 + \delta_2$ Total displacement of effective centre
Δ		Thickness of boundary layer on flat plate
β	=	$(U - U_0)/D$
μ		Viscosity of air
ν		Kinematic viscosity of air
ρ		Density of air
τ_0		Shear stress at wall

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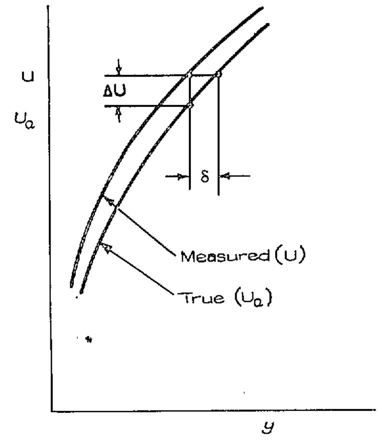

FIG. 1. Portion of velocity profile, showing displacement δ of effective centre of pitot-tube.

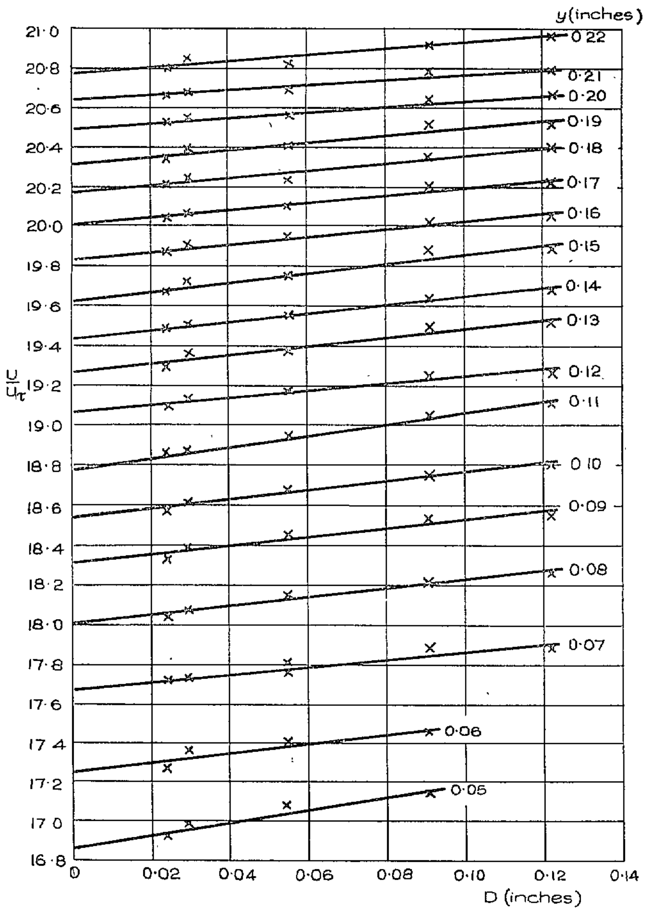

FIG. 2. Measured values of U/U_τ plotted against pitot-tube diameter, showing linear extrapolation to $D = 0$. ($R_p = 5{\cdot}9 \times 10^4$).

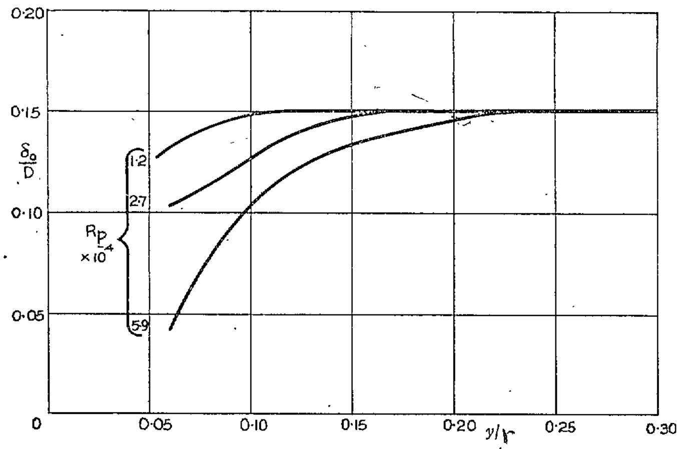

FIG. 3. Apparent displacement δ_0 as obtained by linear extrapolation in Fig. 2.

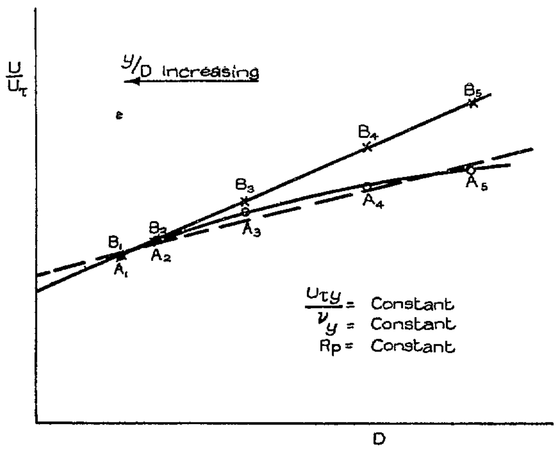

FIG. 4. Schematic representation of effects of shear and wall on measured values of U/U_τ.

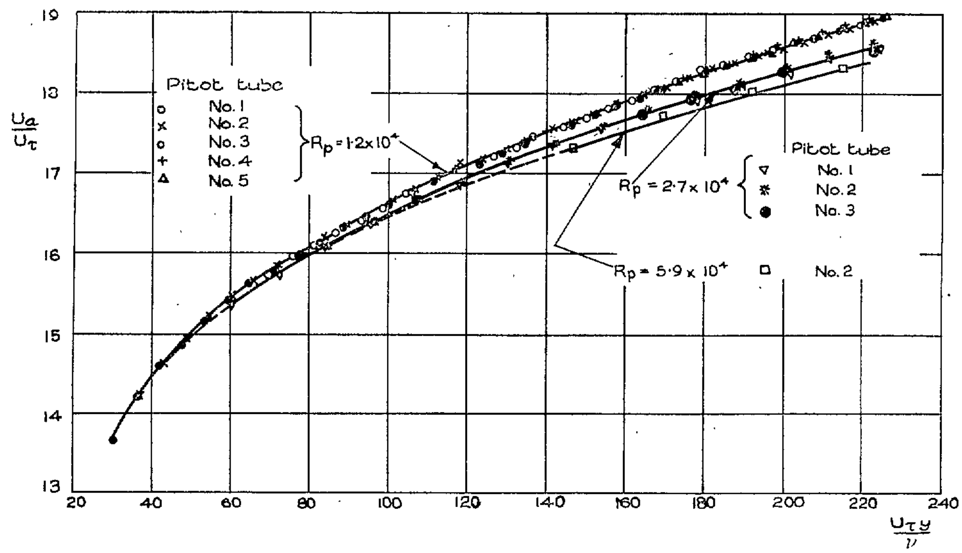

FIG. 5. True velocity profiles.

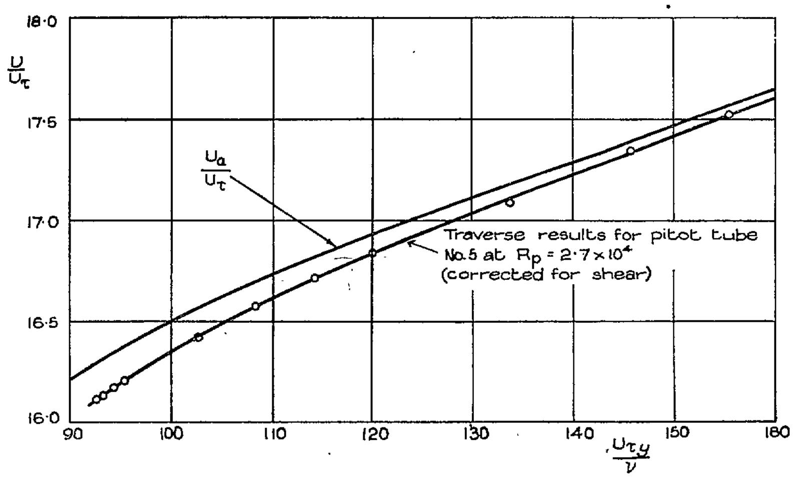

FIG. 6. A portion of a velocity profile, illustrating the wall effect.

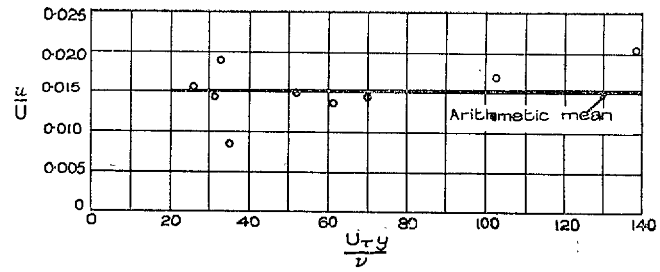

FIG. 7. The wall effect expressed as a function of $U_\tau y/\nu$ $(y/D = 0 \cdot 5)$.

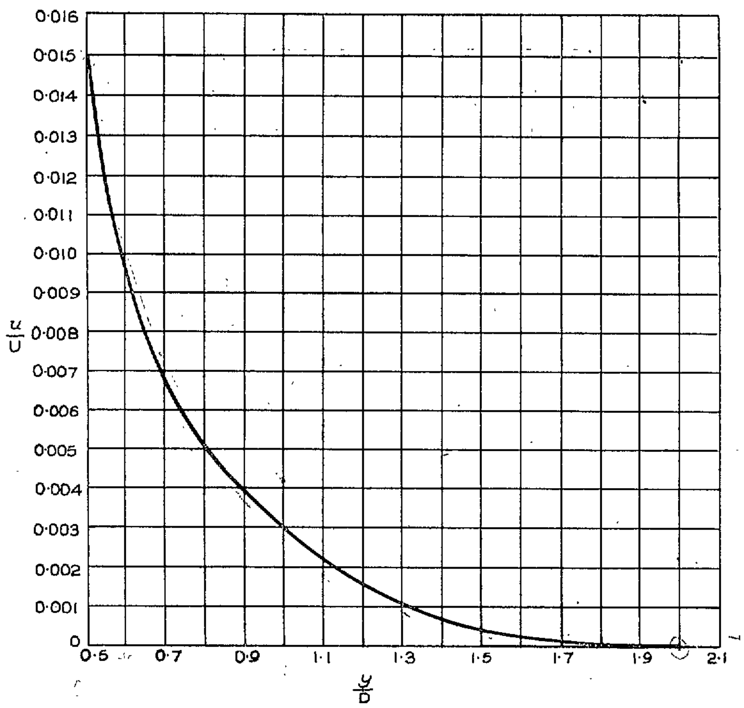

FIG. 8. The wall effect expressed as a function of y/D.

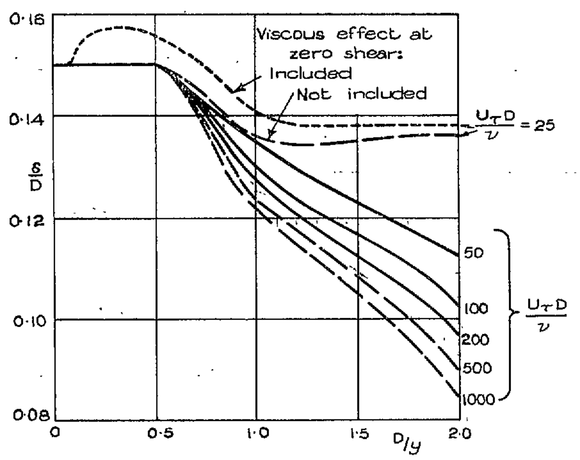

FIG. 9. Total displacement effect.

(Note: curves for $U_\tau D/\nu = 25$, 500 and 1,000 are obtained by extrapolation beyond the range of the present experiments)

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