INFLUENCE OF THE DISTRIBUTION OF SUCTION ON THE STRUCTURE OF THE TURBULENT BOUNDARY LAYER

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In this paper we present the results of an investigation of the influence of distributed suction on the structure of a turbulent boundary layer in an aqueous medium. It is shown that with increasing suction rate, the completeness of the profile increases while the pulsation intensity of the longitudinal velocity component decreases.

The influence of distributed suction on the structure of an air boundary layer has been extensively studied [1] in a low-turbulence wind tunnel.

In this paper we investigate the influence of distributed suction on the structure of a turbulent boundary layer in water. The distributions of the mean velocity and pulsation intensity of the longitudinal velocity component over the boundary layer thickness are determined by a photoelectric turbulence measuring method proposed in [2]. With the aid of this method, the velocity probability distribution curve can be obtained at the measurement point in the flow.

NOTATION

u – longitudinal mean-velocity component
U – rate of oncoming flow
y – instantaneous coordinate along the normal to the surface
δ – boundary layer thickness
a – mathematical expectation
σ – rms value of pulsations
p – velocity probability density distribution
c_q – suction rate
v_0 – rate of seepage through the porous surface
δ^* – displacement thickness
δ^{**} – momentum thickness
H – parameter
u' – pulsations of the longitudinal velocity component in the boundary layer

Tests were performed in a hydrodynamic channel, at one of the walls of the usable length. A 100-mm-long impermeable portion of the wall was followed by a 500-mm-long porous surface. The chamber (of the same dimensions as the surface studied) was covered with a rigid plate containing a large number of small-diameter holes. The plate was covered with three layers of $0.16 \cdot 0.16$-mm mesh wire, topped by a $0.04 \cdot 0.04$-mm mesh wire. The usable surface thus obtained was used for boundary layer studies. The test flow rates ranged from 1.3 to 2.3 m/sec. At high turbulence levels in the channel, a turbulent boundary layer formed at the test surface at distances somewhat above 200 mm from the beginning of the usable length. The experimental mean velocity profiles measured over the boundary layer thickness in the absence of suction correlated well with profiles computed on the basis of the 1/7 law. As an example, the points in Fig. 1 show the results of several velocity measurements at a distance of 350-mm from the beginning of the plate for an oncoming-flow rate of 2.3 m/sec.

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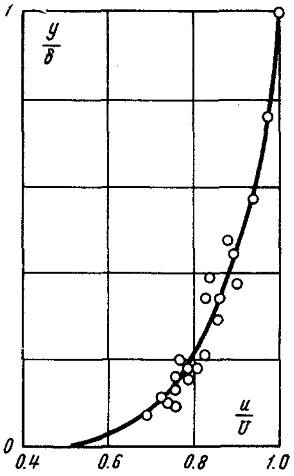

Fig. 1

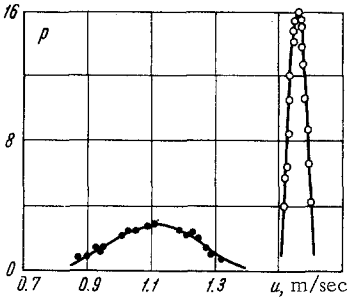

Fig. 2

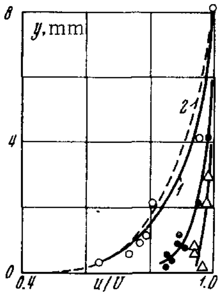

Fig. 3

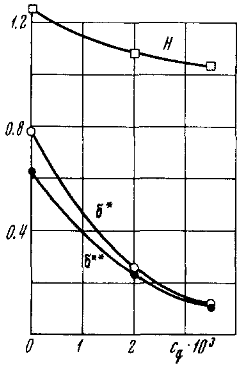

Fig. 4

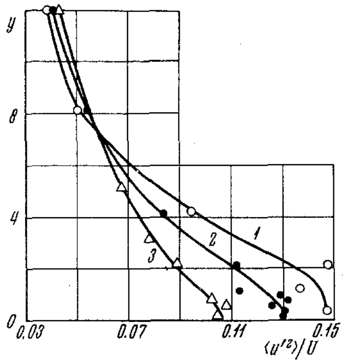

Fig. 5

The solid curve corresponds to the 1/7 law

$$u / V = (y / \delta)^{1/7} \qquad (1)$$

We see that, with a spread of 5%, the experimental points coincide with the analytical curve.

Figure 2 shows two velocity probability density distributions at distances of 1.1 (black points) and 12 mm (circles) from the surface for an oncoming-flow rate of 1.6 m/sec. These velocity distributions, obtained by a photoelectric technique, clearly reveal the accuracy with which mean velocities are recorded, and the magnitudes of the deviation between the rms values of the velocity fluctuations within and beyond the boundary layer. The solid lines are plotted for velocity probability distributions calculated from the formula

$$p = \frac{1}{\sqrt{2\pi}\sigma} \exp \frac{-(u-a)^2}{2\sigma^2} \qquad (2)$$

Here, a = 1.11 m/sec and σ = 0.14 m/sec for a distance of 1.1 mm from the surface, and a = 1.558 m/sec and σ = 0.025 m/sec for a distance of 12 mm from the surface. Within the boundary layer, there is a certain deviation of the velocity probability distribution from the normal distribution law; it increases as the surface is approached, while in the flow core, there is agreement within experimental uncertainty.

The investigation of turbulent boundary layers in water showed that in the presence of suction the mean velocity profile becomes more complete, the completeness of the profile increasing with an increase in the suction rate. Figure 3 shows mean velocity profiles measured over the boundary layer thickness at a distance of 350 mm from the beginning of the porous surface for a flow rate of 1.6 m/sec in the channel. The first velocity profile refers to flow conditions without suction (circles); it is in satisfactory agreement with the profile calculated on the basis of the 1/7 law [curve 2, plotted from formula (1)]. The remaining two profiles characterize the velocity distribution over the turbulent boundary layer thickness in the presence of uniformly distributed suction over the entire surface for the mean suction rates $c_q = v_0/U = 2 \cdot 10^{-3}$ (black points in the figure) and $c_q = 3.5 \cdot 10^{-3}$ (triangles).

From the experimental profiles of the longitudinal velocity component, one can calculate the displacement thickness δ^*, the momentum thickness δ^{**}, and the parameter $H = \delta^*/\delta^{**}$ as a function of the suction rate. Results of computations (in mm) are shown in Fig. 4. It can be seen that δ^*, δ^{**}, and H decrease with increasing suction rate.

Unfortunately, the technique employed made it possible to record only the longitudinal component of the velocity fluctuations under the influence of distributed suction in the turbulent boundary layer. Figure 5 shows the behavior of the rms values of the velocity fluctuations $\langle u'^2 \rangle /u$ over the boundary layer thickness (in mm). The curves are plotted for the same conditions as the mean velocity profiles: curves 1, 2, and 3 correspond to $c_q = 0$; $2 \cdot 10^{-3}$; and $3.5 \cdot 10^{-3}$, respectively. It can be seen quite clearly that distributed suction tends to decrease the fluctuation intensity of the longitudinal velocity component, particularly near the surface.

A quantitative comparison cannot be made, since both the tests in water and for a turbulent air boundary layer with suction [1] were carried out at various turbulence levels of the oncoming flow. Only a qualitative agreement between the relations for the variation of the mean velocity over the boundary layer thickness and for the fluctuation intensity of the longitudinal velocity component in the presence of suction has been established.

LITERATURE CITED

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