

BOUNDARY LAYER INVESTIGATION
BY MEANS OF A LASER

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The measurement of velocity in boundary layers by means of an optical Doppler velocity measurer is considered.

The results obtained for boundary-layer flows rotating in plane vortex chambers are presented.

Velocity measurements in boundary layers usually involve considerable errors. This is due to the fact that the dimensions of the velocity probes introduced into the boundary layer are often comparable with the transverse dimensions of the layer. According to [1], the error in measuring average velocities in the region of the viscous sublayer, made with a thermoanemometer with a filament diameter of 4μ , reaches 30%.

The use of an optical Doppler velocity measurer, employed as a source of laser radiation, which has already been used to study the distribution of average velocities [2, 3], seems very promising. Such a system introduces no distortions into the flow, and requires no calibration.

The use of an optical Doppler velocity measurer to investigate thin boundary layers requires a further increase in the spatial resolving power and accurate determination of the coordinates of the measurement point.

The minimum linear dimensions a in the direction of the velocity being measured in the region investigated, from which reliable information can be obtained, must satisfy the condition

$$a > \frac{\lambda}{2 \sin^{1/2} \alpha}$$

where λ is the wavelength of the laser radiation, and α is the angle between the incident light beams. For example, for the usual values $\lambda = 0.63 \mu$, and $\alpha = 30^\circ$, the value of a is 10μ .

The dimensions of the measurement region in other directions are limited by the quality and depth of field of the objective, and can be of the order of 1μ .

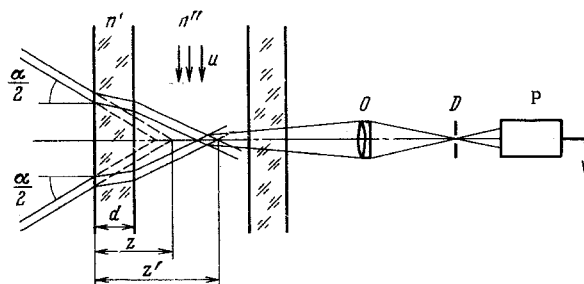


Fig. 1

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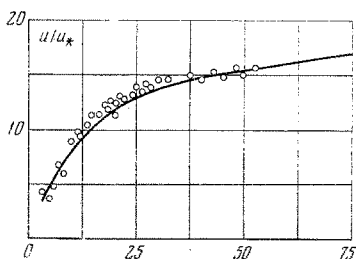


Fig. 2

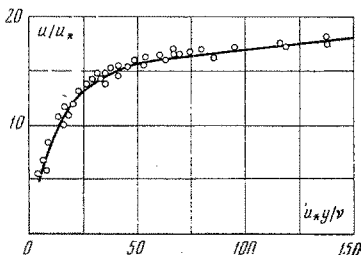


Fig. 3

In this investigation the optical Doppler measurer, the arrangement of which is described in [3], was employed to investigate the velocity distribution in boundary layers on the walls of plane vortex chambers. To obtain the necessary spatial resolution, the angle between the incident beams was chosen to be 60° , and short-focus lenses were used. The scattered light was collected by a high-quality objective O and focused onto the photoreceiver P, in front of which there was an iris D. The signal from the photoreceiver was fed to a spectrum analyzer.

The development of methods for the aerodynamic design of such chambers requires a study of the distribution of average velocities to estimate the tangential stresses which act from the side of the walls on the rotating flows in the chamber.

The experiments were made with a plane vortex chamber of diameter $D = 6.0$ cm and height $H = 1.0$ cm, which had a tangential inlet for the flow through a rectangular channel of width $b = 0.8$ cm and height H . The exit opening of diameter $d_e = 0.8$ cm was in the center of the chamber in one of its end walls. Tap water was used as the working material. The flow rate was varied in the experiments in such a way that the Reynolds number, computed from the hydraulic diameter of the tangential channel, lay within the limits $3000 < R_b < 11,000$, so that the flow which entered the chamber was turbulent. When investigating the boundary layer on the cylindrical surface of the chamber, the measurements were made in the plane of symmetry of the chamber. The results obtained are shown in the graph of Fig. 2 in dimensionless coordinates

$$\frac{u_\varphi}{u_*} = f\left(\frac{u_*y}{\nu}\right)$$

where u_φ is the peripheral velocity at a distance y from the wall, u_* is the dynamic velocity, and ν is the kinematic viscosity.

The dynamic velocity $u_* = (\tau_w/\rho)^{1/2}$ was found from the theoretical formula for the frictional force τ_w on the wall and the density of the liquid ρ [5] [Eq. (21.5)], in which we substituted the experimentally measured values of the layer thickness and the velocity at the boundary.

When investigating the boundary layers which arise on the end walls of the chamber, measurements were made in each case at three points, situated at different distances from the axis of the chamber. The peripheral velocities u_φ were measured, the values of which are almost the same as the moduli of the absolute velocities. The experimental data are shown in Fig. 3.

In Figs. 2 and 3 the continuous lines represent the experimental data obtained for the boundary layer of the turbulent flow in smooth circular tubes and smooth two-dimensional channels [1, 4]. As can be seen, these curves are in good agreement with the experimental data on the velocity distribution both on the cylindrical walls (Fig. 2) and on the end walls (Fig. 3) of the vortex chamber.

For the given place at which the local velocity is to be measured, it is necessary to take into account the defocusing of the beams when passing into a medium with another refractive index. In the case of a flow bounded by two transparent walls with refractive index n' (Fig. 1), the ratio between the true position of the intersection of the beams z' and the position of the beams z in air has the form: $z' = Az + Bd$, where A and B are constants which depend on the refractive index and the angle between the two incident beams, and d is the thickness of the wall.

If the region in question is shifted by an amount Δz toward the beams, the point of intersection of the beams is shifted by an amount $\Delta z'$, where

$$\Delta z' = A \Delta z \quad (1)$$

If the bisector of the angle α is perpendicular to the surface, the coefficient A , as can be easily shown by geometrical optics, has the form

$$A = n'' \left(1 - \frac{1}{n''} \sin^2 \frac{1}{2} \alpha\right)^{1/2} \left(1 - \sin^2 \frac{1}{2} \alpha\right)^{-1/2}$$

The coefficient A can also be easily determined by experiment from relation (1).

Hence, it can be stated that when considering turbulent flow curling around in a vortex chamber, the distribution of peripheral velocities in the boundary layers can be assumed to be the same as in uniform turbulent flow in the region of a smooth surface.

Note that besides measurements of peripheral velocities, the optical Doppler velocity measurer can be used to measure velocities in unsteady flows and, in particular, turbulent velocity pulsations [5].

LITERATURE CITED

1. G. Conte-Belleau, Turbulent Flow in a Channel with Parallel Walls [Russian translation], Mir (1968).
2. B. S. Rinkevichyus, "Use of a laser to determine the velocity of particles in the two-phase jet by the heterodyne method," Radiotekh. i Elektron., 14, 10 (1969).
3. I. V. Lebedev, B. S. Rinkevichyus, and E. V. Yastrebova, "Measurement of local velocities of very small-scale flows by means of a laser," Zh. Prikl. Mekh. Tekh. Fiz., 5, 125 (1969).
4. H. Schlichting, Boundary Layer Theory, McGraw-Hill (1968).
5. R. I. Goldstein and W. F. Hagen, "Turbulent flow measurements utilizing the Doppler shift of scattered laser radiation," Phys. Fluids, 10, 6 (1967).