ROTATION OF A CYLINDER AT THE BOUNDARY OF A JET

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As is well known, when a rotating body moves in a stream of liquid or gas, it is acted upon by the transverse Magnus force. One of the factors causing rotation of the body is inhomogeneity of the flow velocity profile. In order to discover the dependence of the angular velocity of rotation of the body on the parameters characterizing the inhomogeneity of the flow, we set up the following experiment. A cylinder capable of rotating freely about a fixed axis was introduced into a jet of air, or more precisely, into the region bounding this jet. The result of the experiment was wholly unexpected. In a certain position relative to the boundary of the jet, the cylinder rotated in a direction opposite to the circulation of the velocity of the main flow. To study this phenomenon, we conducted experiments with cylinders having diameters of 3.5, 7, and 10 mm. These experiments involved jets which were axisymmetric with initial diameters of 10, 30, and 60 mm, also plane jets with dimensions 10 × 50, 20 × × 152, and 152 × 250 mm.

The Reynolds numbers for jets of air were within limits of $R = 10^4$ to $R = 4 \cdot 10^5$, and for jets of water $R = 1.5 \cdot 10^3$ to $R = 5 \cdot 10^4$.

The Reynolds numbers for the cylinders were $R = 10^3$ to $R = 4 \cdot 10^4$ in air and $R = 10^3$ to $R = 3 \cdot 10^4$ in water.

Figure 1 shows a velocity diagram in the vicinity of the boundary of a plane jet with width h = 152 mm. The distance y in millimeters from the boundary of the jet is plotted on the axis of ordinates and the flow velocity (m/sec) on the axis of abscissas.

The cylinder employed in the experiments was placed at a distance of 5 mm from the discharge nozzle exit section, that is, in the initial section of the jet; however, the effect was also observed when the cylinder was placed in the main section. The cylinder was moved across the jet with the aid of a coordinate device. The velocity of rotation of the cylinder was determined by a stroboscopic method. The cylinders were made of hard rubber. One half was painted white. The rotating cylinder was illuminated by a neon lamp whose frequency was regulated by a tone generator.

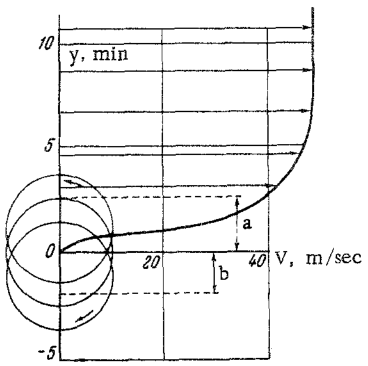

Fig. 1

When the cylinder was moved from the periphery to the axis of the jet (upward in Fig. 1), the following picture was observed. When it reached the jet, the cylinder began to rotate clockwise. As the cylinder was displaced into the depths of the jet, its velocity increased to a certain maximum, then dropped to zero when the axis of the cylinder coincided with the jet boundary (y = 0). When the cylinder was displaced deeper into the jet, the direction of rotation was reversed, a maximum velocity was reached again, and finally, the cylinder stopped rotating. Figure 1 shows the direction of rotation of the cylinder depending on its position in the jet; if the axis of the cylinder lay in zone b, the rotation was clockwise, if in zone a, counterclockwise.

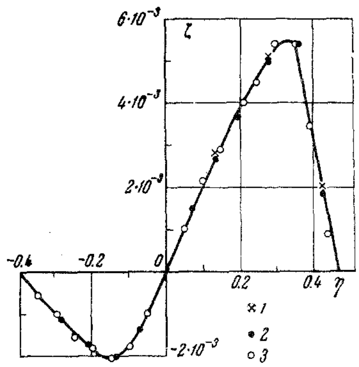

Fig. 2

In order to determine whether this phenomenon was of a local nature relative to the jet or was the consequence of the interaction of the entire jet with the cylinder, the width of the jet h was varied within limits of 10 to 152 mm, but in practice it could be considered semi-infinite. It was found that the "opposite" motion of the cylinder is a local phenomenon occurring on the boundary of any jet whose dimensions exceed the radius of the cylinder. It was also found that the discovered effect of change of direction takes place not only for a cylinder, but also for a sphere, on the boundary of both plane jets and axisymmetric ones, in streams of air and of water.

The dependence of the rpm of the cylinder on the discharge velocity in the jet turned out to be practically linear. However, rotation did not begin at an infinitesimally small velocity, but only when the velocity reached some value V_0. This was due to the presence of a constant moment of friction of the cylinder shaft in its bearings. In the experiments we conducted, the cylinder was installed on a watch shaft rotating in bearings (ruby watch jewels were used for this purpose). Under these conditions, the moment of friction was very small so that the magnitude of V_0 did not exceed 1 m/sec, but it turned out to be different for different positions of the cylinder.

The experimental data in the coordinates

$$\zeta = \frac{\omega r}{V - V_0}, \qquad \eta = \frac{y}{d}$$

are presented in Fig. 2, where ωr (in m/sec) is the circumferential velocity of rotation of the cylinder, V (in m/sec) is the velocity of the liquid or gas on the axis of the jet, d (in mm) is the diameter of the cylinder; points 1, 2, and 3 correspond to cylinders having diameters d = 3.5, 7, and 10 mm.

The distance from the point at which the direction of rotation reversed (when the cylinder passed through this point) was taken as the quantity y.

The results from processing the experiments lie close to a single curve. As yet, no theoretical explanation has been given for the phenomenon described.

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