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AERODYNAMIC CHARACTERISTICS OF A ROTATING CYLINDER IN THE FORM OF A TRUNCATED CONE

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Results of experimental investigations into the aerodynamic characteristics of a rotating cylinder in the form of a truncated cone with a smooth surface and a rough surface have been given. It has been established that the variability of the cross section of the rotating cylinder in an air flow in the range of variation in the parameter of conicity 0.25–0.35 ensures a decrease in the drag coefficient with the values of the lift coefficient being preserved. The results have shown that the presence of the rough surface of the rotating cylinder leads to an increase of 25–30% in the lift. Conditions under which the Magnus effect contributes to the maximum increase in the lift and accordingly the increase in the efficiency of rotation of the cylinder in the form of a truncated cone have been determined experimentally.

Keywords: *rotating cylinder, smooth and rough surfaces, drag, lift, Magnus effect.*

Introduction. Investigating the aerodynamics and establishing the regularities of flow past cylinders of finite length with various shapes of the ends in a free unbounded air flow in the case of longitudinal and lateral flows in a wide range of geometric and regime parameters are fragmentary in character and do not cover a wide range of variation in these parameters [1–6]. In calculations, use is usually made of dependences that have been obtained for infinitely long cylinders, but the record shows that taking account of the ratio of the length of the cylinder to its diameter is a must in practical calculations. Establishing the dependences for short cylinders with a varying geometry of the ends with account taken of the change in the relative length is necessary for many engineering calculations.

Indeed, near the ends of a cylinder of finite length, there is a significant departure from the pattern of plane flow, since it is spatial flow that dominates. This in turn affects the entire aerodynamics of the body in flow. A substantial influence on the drag coefficients of a cylinder of unbounded length has been shown in [7, 8] where cylinders with plane ends were investigated. At the relative length $L/D = 40$, the value of this coefficient differs by 18% from the data for an infinite cylinder [9, 10].

The present work seeks to analyze the obtained results of experimental investigations into the aerodynamic characteristics of a rotating cylinder in the form of a truncated cone (frustum).

Experimental Procedure. Experimental investigations were conducted at the Laboratory of Aerodynamic Measurements. The mock-up was installed in the working (test) section of a T-1-M wind tunnel fastened with thin metal taut bands to the frame of a three-component aerodynamic balance which permitted measuring the drag force and the lift with a sufficiently high degree of accuracy.

To calculate the lift C_{lift} and drag C_{dr} coefficients and in the course of the work, we used the following formulas:

$$C_{\text{lift}} = \frac{F_{\text{lift}}}{\rho \frac{u^2}{2} S} \quad \text{or } C_{\text{lift}} = \frac{2F_{\text{lift}}}{\rho u^2 S}\,; \tag{1}$$

$$C_{\text{dr}} = \frac{F_{\text{dr}}}{\rho \frac{u^2}{2} S} \quad \text{or } C_{\text{dr}} = \frac{2F_{\text{dr}}}{\rho u^2 S}\,. \tag{2}$$

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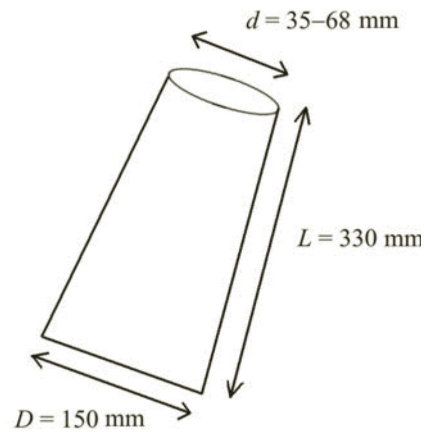

Fig. 1. Geometric parameters of a truncated cone.

Fig. 2. Experimental setup with the cylinder in the form of a truncated cone with a rough surface.

To obtain universal dimensionless dependences, in the experiments we use, as the dimensionless velocity, the Reynolds number Re

$$\mathrm{Re} = \frac{u d_{\mathrm{av}}}{\nu}, \tag{3}$$

where d_{av} is the averaged diameter of the cylinder in the form of a truncated cone in m. Under experimental conditions, the values of the air density and viscosity are equal to respectively $\rho = 1.21$ kg/m^3 and $\nu = 1.49 \cdot 10^{-5}$ m^2/s.

Testing was carried out with rotating cylinders in the form of a truncated cone (of variable cross section) with smooth and rough surfaces. The velocity of the air flow varied from 5 to 15 m/s; the parameters of a cylinder were $D = 150$ mm and $d = 35$–68 mm, and the cylinder length, $L = 330$ m. To the cylinder were attached discs which rotated together with it. The discs were necessary for decreasing the separation of a swirling air flow from the cylinder′s end and for increasing the lift. Geometric parameters of the disks were as follows: $D_{\mathrm{d}} = 200$ mm and $d_{\mathrm{d}} = 200$ mm.

Figure 1 shows the geometric parameters of the truncated cone.

Figure 2 gives the photograph of an experimental setup with the cylinder in the form of a truncated cone in the wind-tunnel′s working section.

The parameter of conicity is determined from the expression

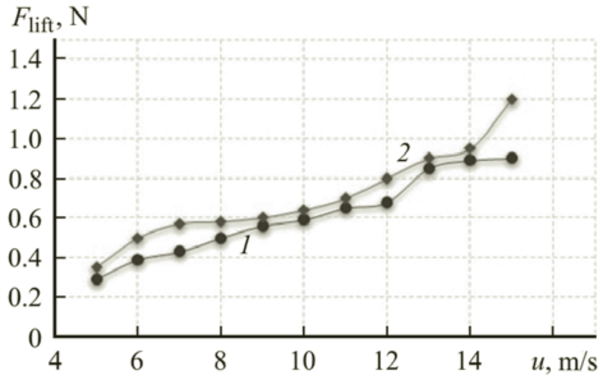

Fig. 3. Lift vs. air-flow velocity for smooth (1) and rough (2) cones with rotation.

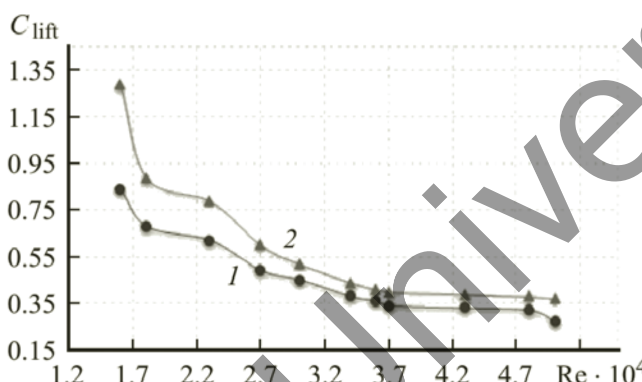

Fig. 4. Lift coefficients vs. Reynolds number for smooth (1) and rough (2) cones with rotation.

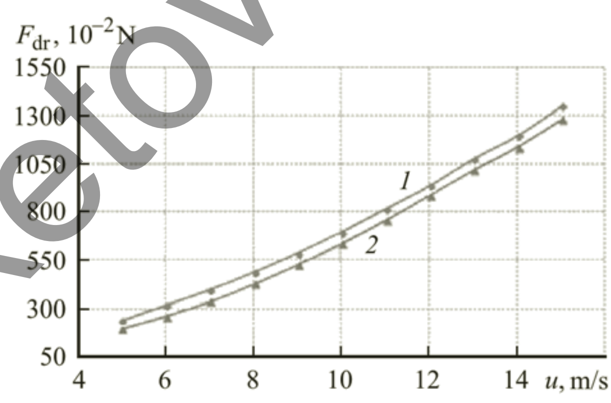

Fig. 5. Drag force vs. air-flow velocity for the cone with rotation at different values of the parameter of conicity: 1) C_{con} = 0.35 and 2) 0.25.

$$C_{con} = (D - d)/L \,. \tag{4}$$

Investigation Results. Figure 3 gives results of experimental investigations into the dependence of the lift on the air-flow velocity for smooth and rough rotating cones. The rotational velocity of the cone ranged within 700–1000 rpm and was measured with an AT-8 noncontact digital phototachometer. The parameter of conicity ranged within 0.25–0.35. It can be seen from Fig. 3 that the lift grows with incident-flow velocity, with the roughness of the surface in flow enhancing the effect of increase in the maximum lift [9, 10].

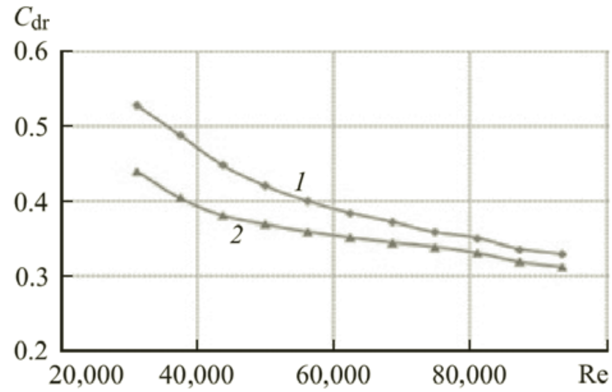

Fig. 6. Drag coefficient vs. Reynolds number for the cone with rotation at different values of the parameter of conicity: 1) 1) C_{con} = 0.35 and 2) 0.25.

Surface roughness is a set of surface asperities with a relatively small spacing on the basic length. The spacing of an asperity is very small and is measured in μm. The relative thickness of asperities is comparable with the boundary-value thickness. In the present experimental investigation, the surface roughness was within 150–180 μm.

Figure 4 shows the lift coefficients versus the Reynolds number of rotating cylinder in the form of truncated cones with a smooth surface and a rough surface. Physically, the obtained data (Fig. 4) are similar qualitatively. There are differences in numerical values of the maximum lift coefficient. Its value is much higher for the cone with a rough surface.

Figure 5 and 6 demonstrate the drag force versus the air flow velocity and the drag coefficient versus the Reynolds number for the cone with rotation and with account taken of the parameters of conicity C_{con}.

From the obtained experimental results (Figs. 5 and 6), we have established that the variability of the cross section of the rotating cylinder in the air flow in the range of variation of the parameter of conicity 0.25–0.35 ensures a decrease in the drag coefficient with the values of lift coefficients, being preserved, which is attained due to the optimum geometric shape.

Conclusions. Analyzing the results of the experiments and of studying the dependences of the lift on the velocity of the air flow onto the surface of a rotating cylinder in the form of a cone, we arrive at the conclusion that the lift grows with air-flow velocity and with truncated-cone surface roughness.

Thus, the presence of the roughness of the rotating-cylinder surface leads to an increase of 25–30% in the lift. This positive effect is associated with additional flow turbulization due to both the rough surface of the rotating cylinder and the arising Magnus force.

This phenomenon is used by us in developing a mock-up of a multiblade wind turbine with load-bearing elements in the form of rotating cylinders of variable cross section.

NOTATION

C_{con}, parameter of conicity; C_{lift}, lift coefficient; C_{dr}, drag coefficient; D, cylinder′s large base diameter, m; d, cylinder′s small base diameter, m; F_{dr}, drag force, N; F_{lift}, lift force, N; L, cylinder length, m; Re, Reynolds number; S, midsection area, m^2; u, air-flow velocity, m/s; ρ, air density, kg/m^3; ν kinematic air viscosity, m^2/s.

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