Reduction Drag of Circular Cylinder Due to Installation of Four Flat Plates

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Abstract. The paper presents theoretical and experimental studies on the reducing drag of a circular cylinder. The reduction drag is achieved by installing near a circular cylinder four flat plates. Flat plates installed under the meridional angle relative to the cylinder and at an angle of attack. Flat plates are symmetrically relative to the cylinder. There is a flat injection channel of constant width between the plates and the cylinder. We examine this situation of flat plates due to which the drag coefficient of the total combination reaches the smallest value. The study of reducing the drag of the cylinder was carried out in the package hydrodynamic analysis of Flow Simulation, as well as in the wind tunnel of Samara University. It has been shown that that the location of plates near the cylinder at certain angles, allows us to achieve reduction drag approximately before 40% compared with an isolated cylinder.

1. Introduction
This paper is devoted to the reduced drag of a circular cylinder. The study of the reduction drag may be performed by different active and passive methods. The problem of the reducing drag of a circular cylinder is the subject of numerous works that include: drag reduction due to injection or suction of the gas [1-3], the moving wall of the body surface [4], the cooling or rise of the temperature of the wall [5, 6], the acoustic excitation [7], the generation of an electric discharge plasma [8, 9] and other methods that require energy supply. The main drawback of the active method is the need to use extra energy. The effect of reducing drag can be estimated taking into account the energy spent by any active method. Passive methods do not require energy supply and include the placement of additional devices: plates [10], wires [11] or round cylinders [12]. An overview of a wide range of passive techniques that help to reduce the drag of a circular cylinder, presented in [11]. Comparison of all known results showed that short dividing plates with a length less the diameter of the cylinder can reduce drag, but at the same time lead to the formation of additional vortices. Long dividing plates does not lead to the formation of additional vortices, however, the drag coefficient of the cylinder is not reduced below the value of 0.8 [11]. A systematic study on the effect of extra body on the drag of the circular cylinder is given in [13]. As additional bodies located near to the circular cylinder flat plates were selected. The combination of their location, in this case, was as follows: the plates were attached to the main body or were located on the axis of the aerodynamic trail behind the body. In [13] focused on the suppression of vortices behind the body and reduce the Strouhal Number. In [14] attempted to reduce drag by two plates installed on opposite sides of the cylinder, parallel to the longitudinal axis of the cylinder. Between cylinder and plates, there was a gap. The minimum value of
the drag coefficient that was achieved was equal to 0.83. Based on the result, the wafers were replaced by curved guide blades. The best result in the drag reduction obtained for this method is the drag coefficient was reduced to values of 0.51 [14]. In addition to the plates [13, 14] and the vanes [14] near the cylinder were investigated the location circular cylinders of smaller diameter. In [12] presented such a method with a variation in the number of additional cylinders, the width of the slot between the main cylinder and additional cylinders, as well as the ratio of the diameters of the cylinders themselves. Experimental data revealed that for the case of four cylinders, arranged around the body, under equal conditions there is drag reduction to 0.75 [12].

Previously, the authors of the study investigated the decrease of the drag of a circular cylinder due to the installation of flat plates. The decrease of the drag due to one plate with different variants of its location is given in [15-18]. In this paper, we study the drag of a combination of a circular cylinder and four plates located around this cylinder. The research object is a cylinder with a diameter $d=62.5$ mm that shown in Fig. 1.

![Figure 1. – Geometry the location four flat plates near the cylinder](image-url)

Near the cylinder were mounted four flat plates with the following characteristics: $t=2$ mm is the plate thickness, $c=c/d=0.5$ is the relative chord of the plates. The plate was located in relation to the cylinder at the meridional angles: $\theta_1$ is the meridional angle of the location front plate, measured from the front critical point $A$, deg; $\theta_2$ is the meridional angle of the deflection backplate, measured from the front point $A$ deg; $\delta_1$ is the angle of attack of front plates, deg; $\delta_2$ is the angle of attack of backplates, deg. This paper proposes the following scheme for front plates: $\theta_1=40$ deg, $\delta_1=-20$ deg for the backplates the meridional angles changed in the range $\theta_2=[90; 140]$ deg and angles of attack varied in the range $\delta_2=[20; 30]$ deg. The upper and lower plates were located symmetrically relative to the cylinder. The flat plates were mounted so that the boundary layer of the airflow in contact with the surface of the cylinder is accelerated by narrowing the ejection channel. The ejected flow from the ejection channel continued to move along the outer wall of the circular cylinder and displaced the separation point of flow to the trailing point of the body $B$. The gap needed to accelerate the flow was $h=0.1d$. The calculation of the flow for combinations of cylinder-plate was made at the Reynolds number $Re=u_\infty d/\nu=10^5$ where $u_\infty$ is the velocity at infinity, $m/s$; $\nu$ is the coefficient of the kinematic viscosity, $m^2/s$. The degree of turbulence for all calculations was taken to be equal to $\varepsilon=0.8\%$.

2. Mathematical simulation

The study was carried out in gas-dynamic package FlowSimulation which is an add-on SolidWorks [19]. The integration of the Navier-Stokes equations (1) was conducted in the inpatient setting.

\[
\frac{\partial u}{\partial x} + u \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right), \quad \frac{\partial v}{\partial x} + u \frac{\partial v}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right), \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}
\]
where \( u \) is the longitudinal component of the velocity, \( m/s \); \( \upsilon \) is the transverse component of the velocity, \( m/s \); \( p \) is the pressure, \( Pa \). The integration of the system of equations was produced by the finite volume method.

Fig. 2 show the example of numerical calculations. We can see velocity isolines of the flow around combinations of cylinder and plate.

![Figure 2. – Velocity isolines of the flow around the combination of the cylinder-4 plates](image)

For obtaining the drag coefficient of a system of bodies was making integration with respect to the velocity profile in the section of the wake. For this purpose, we used the formula (2) [20]

\[
C_D = \frac{\rho}{q} \int_{y=-\infty}^{y=\infty} u_1 (u - u_1) dy
\]

(2)

where \( q \) is the dynamic pressure, \( Pa \); \( u_1 \) is the velocity in the cross-section of the wake behind the cylinder at the distance of the \( 20d \) from the back point \( B \) of the cylinder.

3. Experimental study

The experimental study consisted of flow around the combination of cylinder-plates in the wind tunnel of Samara University. Fig. 3 shows the cylinder with four flat plates in the work part of the wind tunnel.

![Figure 3. – The equipment for experimental study flow around the combination of the cylinder with four plates](image)

Behind the cylinder have sets of the comb of Pitot tubes (Fig. 4).

![Figure 4. – The comb of Pitot tubes](image)
The comb of Pitot tubes is a set of 32 tubes, 4 of which are receivers of static pressure; the other tubes are receivers of the dynamic pressure. The step between the tubes is 3 mm. In order to fully capture the aerodynamic wake after each purge, the comb of Pitot tubes shifted along the vertical axis.

4. The results of theoretical and experimental studies
Theoretical calculations the drag coefficient for the cylinder in the presence of four flat plates shown in Fig. 5. Values $\theta = 40$ deg, $\delta = -20$ deg was remained unchanged. We investigated the dependence of drag coefficient $C_D$ on the angle of attack of the back-plates $\delta$ at various meridional angles $\theta$.

![Figure 5](image)

**Figure 5.** – The drag coefficient $C_D$ vs angle of attack $\delta$ of the plates for various values of the meridional angle $\theta$.

![Figure 6](image)

**Figure 6.** – The drag coefficient $C_D$ vs angle of attack of the plates $\delta$ at the value of the meridional angle $\theta = 140$ deg

As can see from Fig. 5, the smallest values of drag coefficient reach at values of the meridional angle $\theta = 140$ deg and at the range of angles of attack for the rear plates $\delta = [20; 30]$. For the verification, this result was carried out experimental studies at selected meridional angle $\theta = 140$ deg. The calculation and experimental data presented in Fig. 6. Table 1 shows a comparison of the smallest values of the drag coefficient $C_D$ obtained from the results of the simulation and experiment for the configuration cylinder-4 flat plates.

| Research method | $\theta$, deg | $\theta$, deg | $\theta$, deg | $\theta$, deg | $\theta$, deg |
|-----------------|---------------|---------------|---------------|---------------|---------------|
| Calculation     | 40            | 40            | 40            | 40            | 40            |
| Experiment      | 40            | -20           | 140           | 21            | 0.620         |

5. Conclusion
According to the data obtained and known experimental results for an isolated cylinder [16, 21], we can say that the location of plates near the cylinder at certain angles allows achieving the reduction of drag approximately before 40% compared with an isolated cylinder.

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