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Comparative Studies of Cylinder's Aerodynamic Features Depending on Propagation Direction for the Non-Arching Surface Discharge in Subsonic Flow

A.V. Ivchenko, O.A. Zhuravliov, V.G. Shakhov

Samara State Aerospace University (SSAU), Samara, Russia

Regulating the aerodynamic features of bluff bodies by using surface discharges depends on the feasibility of energy acting directly on the outer layer, leading to changes of medium viscosity and formation of directed jet flows without additional supply of gas masses [1,2]. Various effects that can be observed in this case depend mainly on the spatial orientation of jet flows generated by the discharge. Their characteristics are defined by the electric field distribution (i.e. electrode system configuration) [3]. The necessity of considering the electrophysical, thermal, and gas-dynamic characteristics of surface discharges [4] during interaction of bluff structural elements with the stream leads to the setup of an aerodynamic experiment with a cross-flow past a round cylinder [5]. The use of cylindrical bodies makes possibility to simplify the analyses of observed processes and extrapolate the conclusions to a broad class of bluff bodies [5,6].

The article [7] presents an overview of the results of experiments connected with the study of surface discharge influence on cross-flow past cylindrical bodies in subsonic gas flows. Artana G. et al. (2003) and Thomas F. O. et. al. (2006) have shown that the effect of a surface discharge (at $Re \leq 54k$) can modify turbulent wakes behind the cylinder, thus influencing its aerodynamic drag. The researchers concentrated their attention on the processes occurring in asymmetrical electrode systems used to form gas jets directed tangentially to the cylinder surface [7]. At the same time, it is well known that surface discharge generation in like-charged electrode systems can lead to formation of gas jets oriented normally to the surface [8,9]. Such jets can extend beyond the boundary layer, thus influencing not only the near-wall gas streams structure but also the main flow characteristics.

Characteristics of interaction of the flow and jets that are formed in areas near curved surfaces can be defined only by additional experimental research that makes possibility to define the connection between the geometric parameters of the surface discharge electrode system and the bluff body's aerodynamic features.

These experiments were conducted in the subsonic wind tunnel T-3 (SSAU) with the open test section (600x400 mm) using a pressure orifice model of cylinder (60 mm in diameter, 150 mm long) [10].

Non-complete Surface Discharge (NSD) was generated in the electrode system situated on the cylinder's conducting generatrix; the system consisted of consecutively deposed high-resistance dielectric film layer 1 and discharge electrode 2 (Fig.1). The deposed on cylinder surface a cover film 1 has barrier dielectric coefficient ε=7 and its thickness is h=80-320 μm. The discharge electrode made of foil (thickness of 50-100μm) consisted of several interconnected linear or ring elements (Fig.1 a,b). The surface discharge appeared on the cylinder's generatrix under alternating current with ($dU/dt<10^9$ V/s) at a frequency of f=9 kHz and amplitude $2 < |U_p| < 5$ kV, and its burn mode was controlled then by oscilloscope [11]. Depending on how the discharge electrode segments were arranged (in a linear or ring way), the propagation pattern of the NSD plasma layer changed (along or across the incoming flow), which facilitated to obtain the effect of electrode system geometry on the model's aerodynamic features.

The methodology of the aerodynamic experiment consisted of measuring the distribution of static pressure on the aerodynamic model's surface, which allowed indirectly defining its drag value.

Testing the cylinder's aerodynamic features with ring and linear configurations of the discharge electrode segments was performed at a flow speed varying from 8 to 35 m/s, and the discharge power varying from 0.1 to 1 Watt/cm^2. According to [5], this range of speeds corresponds to $Re=(0.4\text{-}1.2)\times10^5$ and satisfies the requirements for pre-critical flow past a cylinder

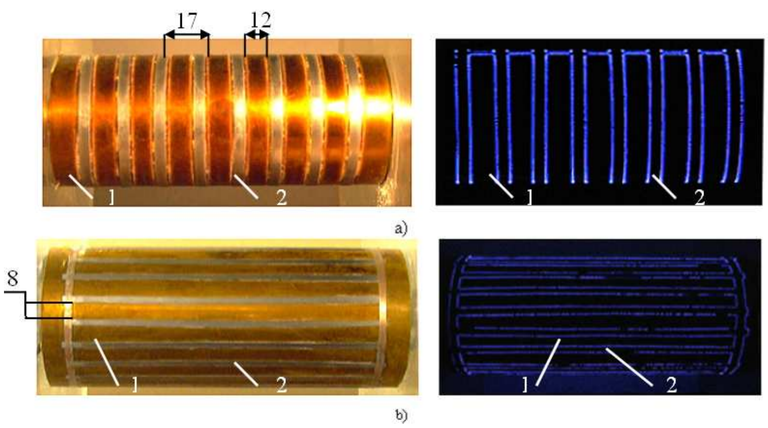
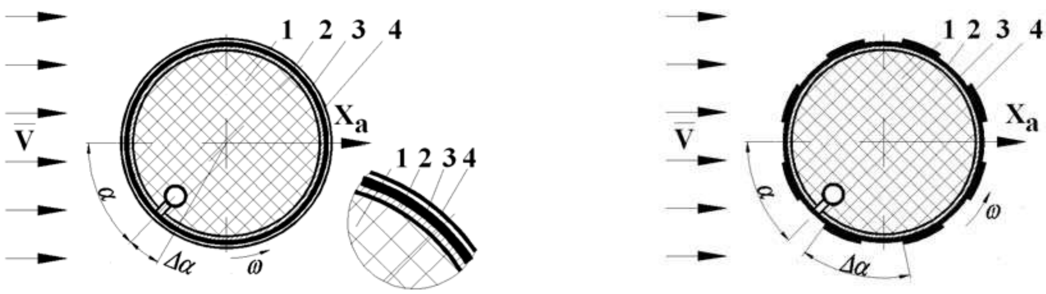


Fig.1. Front view of cylinder with electrode system on the generetrix and phosphorescence of non-arcing surface discharge: (a) ring configuration of discharge electrode; (b) linear configuration of discharge electrode. 1 - dielectric film barrier; 2 - discharge electrode

The static pressure diagrams for each configuration of the discharge electrode were investigated in three stages. In the first stage, the pressure distribution on the surface of smooth cylinder covered with film dielectric barrier was recorded. The second stage was performed due to the necessity of investigating how the cylinder's aerodynamic features can be influenced by the foil element (uncharged) situated on the dielectric barrier's surface, whose segments (100 μm thick) could expand beyond the viscous sub-layer's borders and interact with the flow as ribletts [12]. In the third stage of the experiments, the pressure was recorded during the discharge burning that could be excited at different levels of energy input.



a) b)

Fig.2. The scheme of experiment at the different types of discharge electrode: a) ring configuration; b)- linear configuration. 1 - Cylinder model; 2 - conductive screen: 3 - dielectric film barrier; 4 - discharge electrode. V - vector of flow velocity; α .- angle of the tumbling of the pressure orifice axis; $\Delta\alpha$ - the angle step of turning; ω - direction of tumbling angle change; X_a - the aerodynamic drag force

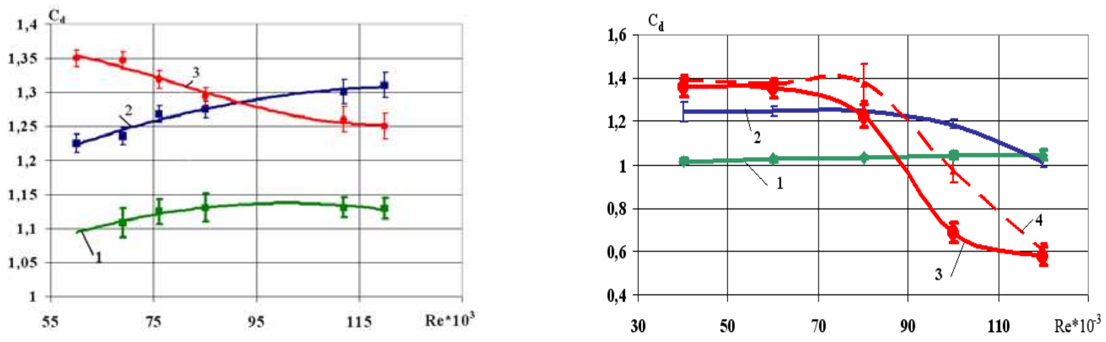
The drain orifice in the central part of the model aided in the determination of the static pressure P(α) on the cylinder's surface using the differential transmitter DUXL 10D (±2.5 kPa), instrumental error no more than 0.5%. Its readings were recorded on a computer using the information collection card LCard 761. During the recording process for the P=P(α) diagram, the model took on during the test various angular displacements α (see Fig. 2). The model was rotated in the range of α from 0° to 180° with the step of $\Delta\alpha$. The α value was chosen according to the state of the cylinder's aerodynamic surface. For a smooth cylinder and the model with the ring-type discharge electrode, $\Delta\alpha$ was chosen as 5°, while for the discharge electrode with linear elements, the pitch value was chosen to correspond to their angular positions and was 18°.

Another specific feature of recording the P=P(α) distribution lay in considering the effect of heating the model. To make this effect negligible, the experiments were started 20 minutes after the discharge appeared.

On the basis of P(α) relationships described in [1], elementary components of the main force vector X_a, as well as the model's aerodynamic drag coefficient C_d were defined.

Fig. 3 shows that excitation of NSD at Re<80-100k increases the drag of the model, while at Re>100k it reduces it. This effect is particularly significant when the discharge propagates along the flow (when discharge electrode segments are situated along the generatrix line), when the drag coefficient C_x decreased from 1.2 to 0.8-0.6, thus becoming less than that of a smooth cylinder (fig.3, b).

Sharp decrease in the value of aerodynamic drag at Re < Re_c (critical Reynolds Number) permits one to advance a suggestion regarding the commencement of the development of critical phenomena in the flow, and shift of the critical Reynolds number to the region of lower flow speed.



a) b)

Fig.3. The drag coefficient dependency C_d from Reynolds Numbers for cylinder at the different types of discharge electrode: (a) ring segment configuration (h=80 μm); (b) linear segment configuration (h=320 μm) 1 - smooth cylinder; 2 - cylinder with discharge electrode; 3 - cylinder at discharge excitation with W_a=0.78 Watt/cm^2; 4 - W_a=0.28 Watt/cm^2

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