The Study of the Non-Arching Surface Discharge Influence on Gas-Dynamic Processes near Cylinder in Sub-critical Flow

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It is known that processes occurring in boundary layers largely define the structure and character of subsonic gas flow and can lead to phase effects associated with its turbulence [1]. The transition of the flow to a turbulent state is defined by the critical Reynolds number, but can occur due to surface discharge generation [2]. According to [3-4], a Non-Arching surface discharge (NSD) can create directed micro-stream flows (Fig. 1) thus altering the object's aerodynamic properties. From the energy point of view [3], the NSD-use can turn out to be efficient in precritical flow around cylindrical body [5] due to aerodynamic drag reduction [6]. One of the reasons for such reduction of aerodynamic losses may be premature turbulence of the boundary layer (Fig. 2) that changes the critical Reynolds number [7]. The possibility of using NSD to manage the laminar-to-turbulent transition determines the necessity to investigate the characteristic features of gas-dynamic processes in cross-flow of cylindrical bodies.

The flow features investigation was produced by two independent methods, including measurement of the static pressure distribution on cylinder surfaces and PIV-registration of velocities and vorticity fields in the near-wake. The work was executed in the subsonic wind tunnel T-3 (SSAU) when models with ring-type and linear-type electrode configurations were used and experiment conditions corresponded to the article [6]. Three stages of experiments have been conducted, associated with sequential changes of a flow around a streamlined surface (smooth cylinder, cylinder with an electrode system applied over the surface, cylinder at discharge generation).

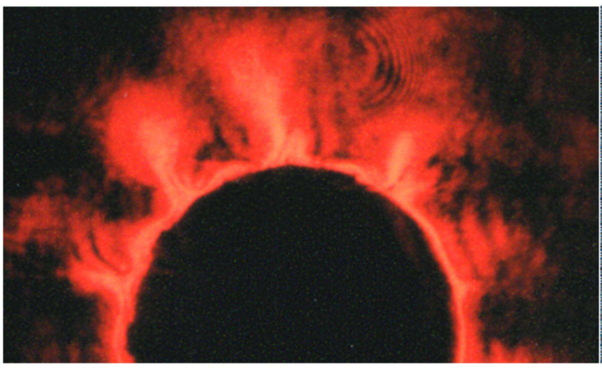


Fig.1. Schlieren-photography of gas heat jets generated by Non-Arcing Surface Discharge in quiescent atmosphere

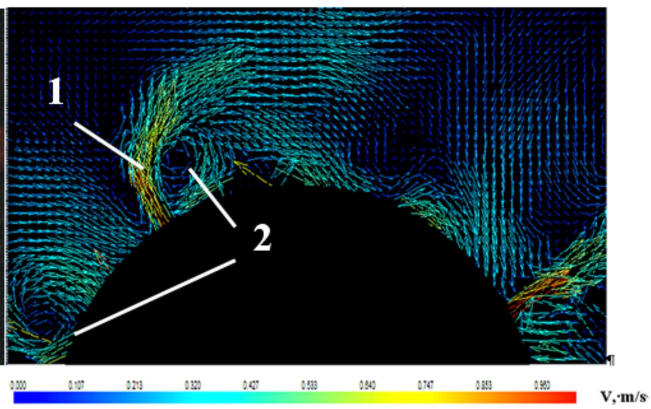
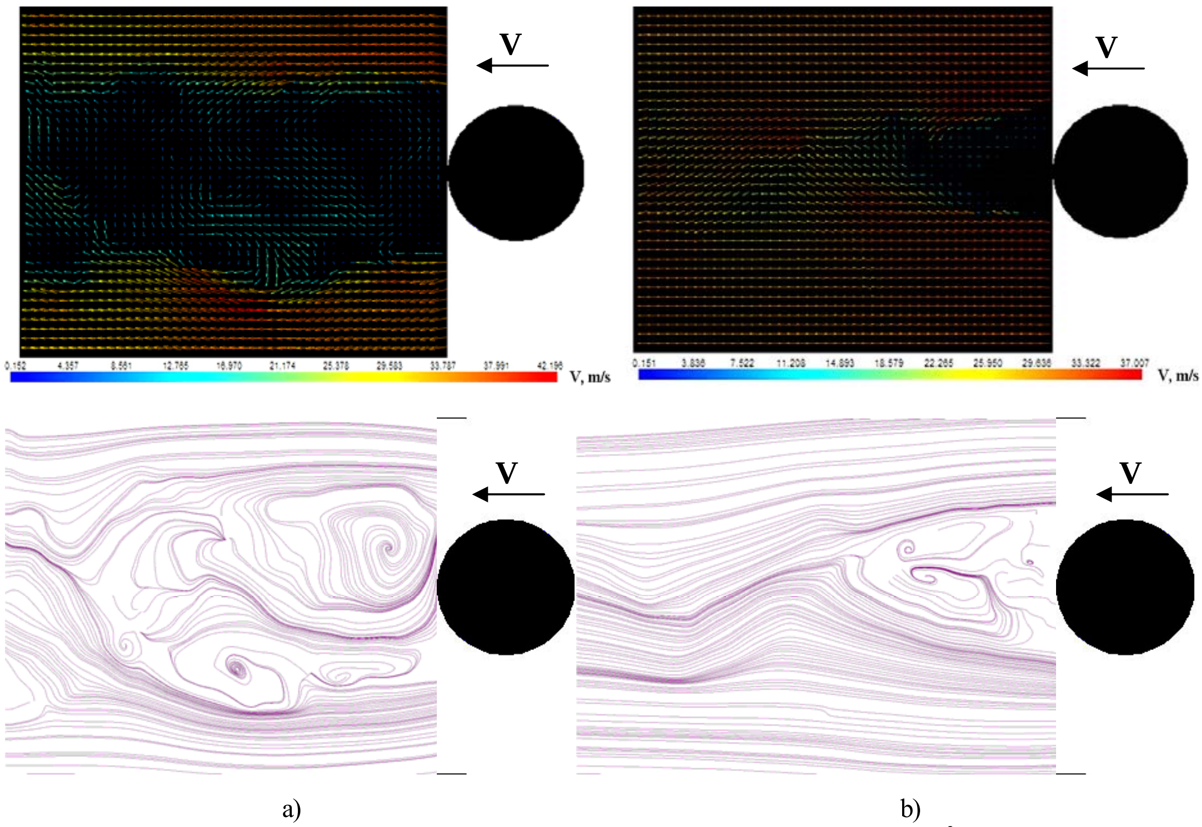


Fig.2 Flow velocity distribution near cylindrical body with Non-Arcing Surface Discharge in quiescent atmosphere (PIV-data): 1- gas jet; 2-vortexes

NSD initiation at the surface of a cylindrical body with frequency f=9 kHz and amplitude $|U|\leq$4 kV led to formation of radial jet flows with flow speed on the order of 0.5-1 m/s (Fig. 2). This process was accompanied by development of near-wall turbulent structures, the spatial orientation of which was dependent upon the configuration of discharge electrode segments.

The presence of longitudinal or transverse turbulence in the boundary layer caused significant effect on gas flow processes in the model's near wake, altering its aerodynamic characteristics. Likewise [6], it was shown that the model's drag in the presence of NSD generation increases by 15-20% for Re<80k and then decreases for Re>80k. The degree of decrease of the aerodynamic drag coefficient C_d for Re>80k depends upon the discharge electrode configuration. For a model employing ring segments, C_d changed by no more than 5%, but when a discharge was initiated at a surface with electrode system elements arranged linearly, C_d decrease reached 40-60%.

A laser PIV-unit manufactured by DantecDynamics was used for optical measurement of the spatial characteristics of the flow. The flow was filled with light-diffusing oil particles of d_p=2 μm in diameter and was visualized by a laser light stripe 5 mm wide. Flow images were recorded by a



Fig, 3 Weak modification by Non-Arching Surface Discharge excitation at $W_a/S \cong 0.275$ Watt/cm^2 with liner-type discharge electrode at Reynolds number Re =124×10^3 (flow velocity maps and stream lines): a)- smooth cylinder; b) – cylinder with discharge

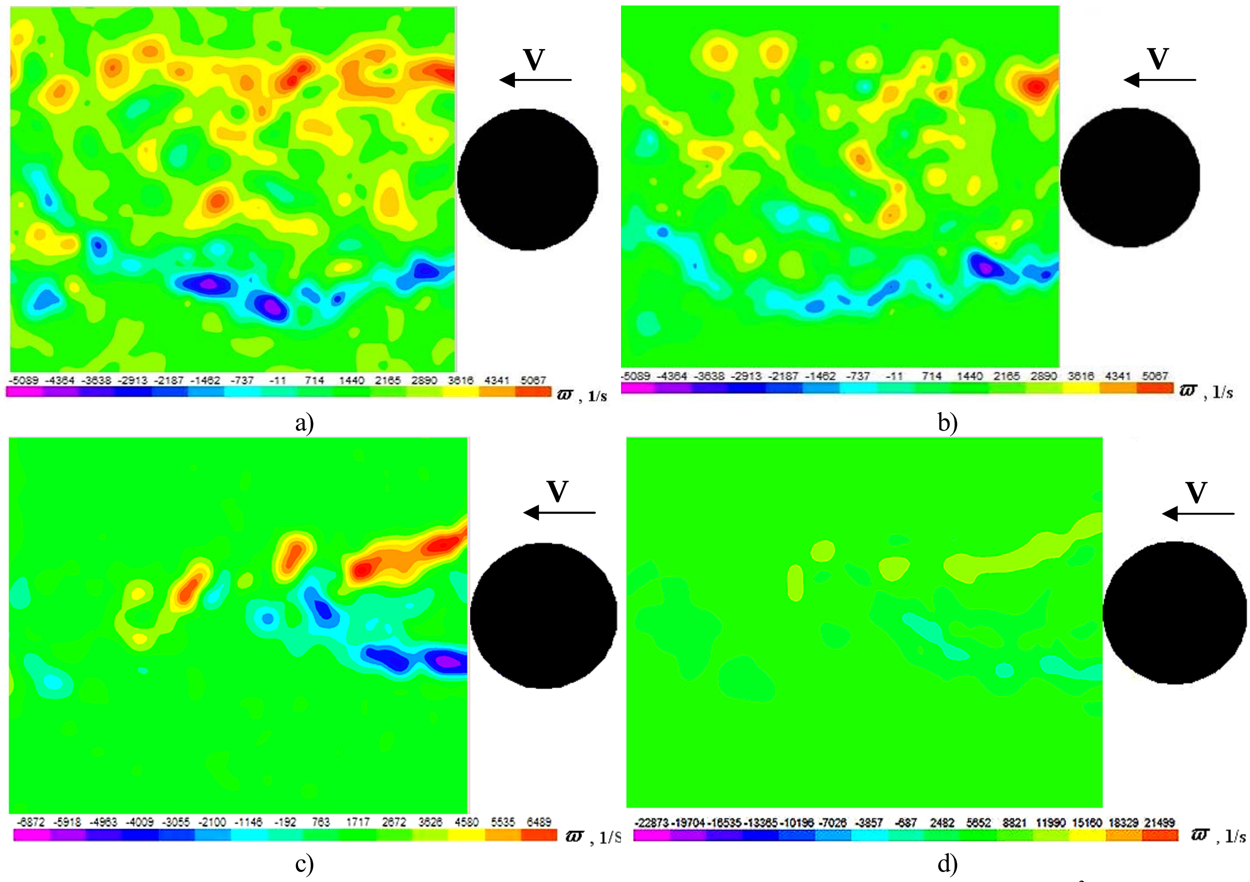


Fig.4. Vorticity flow distribution for different aerodynamic model at Reynolds number Re $=124\times10^3$: a)-smooth cylinder; b)- cylinder with ring-type discharge electrode at $W_a/S \cong 0.775$ Watt/cm^2 ; c) cylinder with and linear-type discharge electrode at $W_a/S \cong 0.275$ Watt/cm^2; d)-cylinder with and linear-type discharge electrode at $W_a/S \cong 0.775$ Watt/cm^2

Flow Sens–2M camera with frame frequency f_{fr}=8 Hz and laser irradiation impulse energy W_{im} =30 mJ (λ=532 nm). A series of images of 50 frames each were recorded during model flow. Later, the series that were obtained were processed using an adaptive correlative algorithm with sampling window size of 32*64 pixels and 50% overlap [8]. This procedure allowed deriving information on the velocity and Vorticity fields.

The comparative PIV-measurements evaluation has shown that at Re<80k NSD-generation has the weak influence on the flow, regardless from electrodes configuration type, bat provides the vorticity incensement up to 15-30%.

The essential flow modification in near-wake under the discharge action was occurred only with linear-type discharge electrode at Re>80-100k (Fig.3). The NSD- excitation led to the narrow wake formation and large-scale eddy disappearance while flow vorticity increased in two times (Fig.4).

Comparative patterns of gas flow in the near wake at NSD initiation at the generatix that were presented in the work provide evidence of global flow change in the recirculation zone which may be caused by premature laminar-to-turbulent transition. This last assertion can be proven by the simultaneous occurrence of three following factors:

1. Significant decrease of the model's aerodynamic drag in pre-critical region of Reynolds numbers;
2. Formation of a linked wake structure directly behind the cylinder;
3. Increase of recirculation zone turbulence level with the shrinking or disappearance of large-scale turbulent structures.

The detected characteristics of cylinder cross-flow with surface discharge at the generatix shows effectiveness of the action of the NSD on near-wall gas layers. This can be used to modify flows in the proximity of other bluff bodies.

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