Active Riblets

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Gas-dynamic processes in the boundary layer can significantly influence on features of near-wall flows and determine parameters for majority of flying machines at subsonic flight regimes [1]. Under these conditions, external disturbances are able to initiate flow instabilities in the boundary layer (Tollmien-Schlichting waves etc.) leading to the laminar-turbulent transition [2]. The turbulent state of the boundary layer is accompanied by a substantial increase in the aerodynamic drag associated with the friction between gas and surface of the moving body [3].

One way to control the laminar-turbulent transition is associated with the formation of spatially-periodic flows by means riblets [4]. Riblets stabilize disturbances of near-wall gas layer and help reduce the body drag (about 6-15%) compared with a smooth surface due to the periodic surface structure [5]. Depending on conditions, the riblets step λ (see Fig.1) may be about 0.05-15 mm while a height h overtops the thickness of the shear layer. Thus the riblets effectiveness has limitation and requires optimization of their geometry for specific flow conditions [2].

Interaction between riblets and boundary layer is accompanied by the formation of stable vorticity filaments (into riblets grooves) which called as "vortex cells". Therefore, by influencing the processes in vortex cells you can modify the boundary layer essentially.

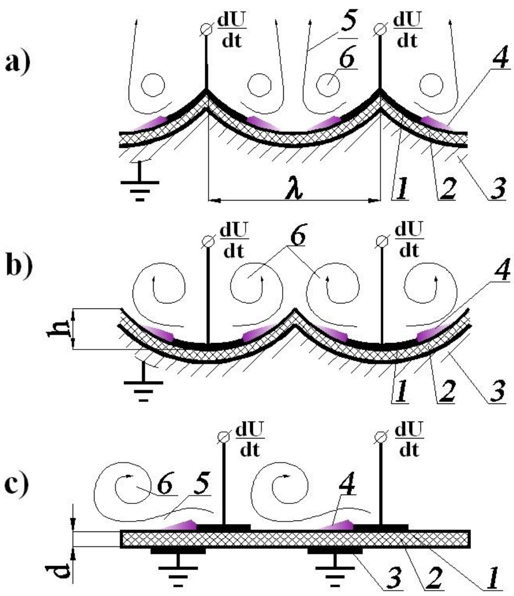


Fig.1. Schemes of active riblets with electrode sets:
a) – electrode system with discharge electrodes disposed on the ribs
b)- electrode system with discharge electrodes disposed in grooves
c)-plasma actuator for the virtual riblets formation
1-discharge electrode,2-dielectric layer, 3-graund electrode,
4-surface discharge, 5-microjet, 6-vortex
λ-riblets step, h-deep of groove, d-thickness of dielectric layer

The vortex flow modification near the riblets surface can be implemented by using of plasma actuators based on surface discharges [6,7]. According to paper [8], surface discharges can neutralize perturbations in the boundary layer. On the other hand, a short time of plasma excitation (10^{-7}-10^{-5}s) extends the capabilities of any control system due to the use of reliable (long-time) algorithms. Fig. 1 shows the variants of discharge devices producing vortex-jet modification of the boundary layer near the riblets surface. Here discharge electrodes can be mounted on ribs, into grooves as well as on the smooth surface.

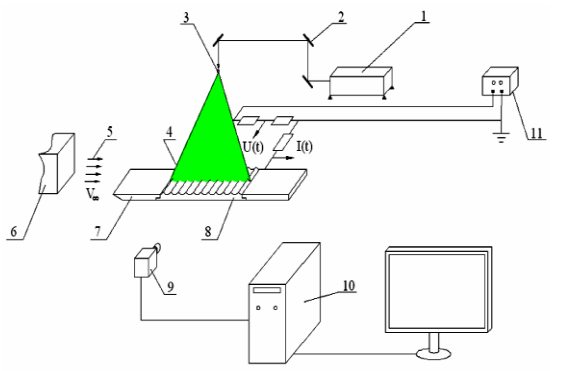


Fig 2. Experimental setup: 1-Laser Solo-120XT-15H2, 2-optical waveguide, 3-lens, 4-light sheet, 5-direction of gas flow, 6-subsonic wind tunnel T-4, 7- air cowl, 8-active riblets, 9- camera FlowSence-2M, 10-computer 11- high-voltage source.

a)

b)

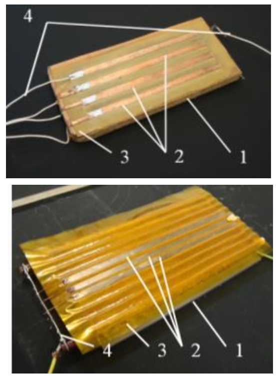


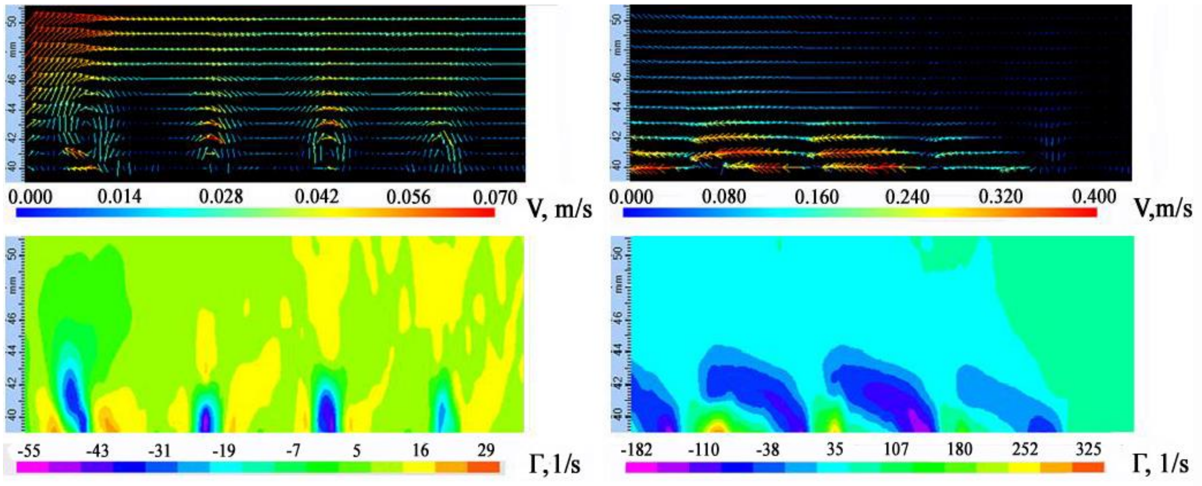
Fig 3 – Multi-electrode sets on flat plate (a) and on the plate with "U"-shaped riblets (b): 1-plate, 2 –discharge electrode, 3-dielectric layer, 4-electrical terminals

Electrode sets in Fig 1 a) and Fig 1 b) are able to generate colliding surface discharges [9-10] wich can be used for changing the flow in vortex cell due to micro-jet formation in vicinity of dielectric surface. On the other hand the asymmetric electrode set (see Fig.1 c) can also create vortices system by acting like virtual riblets.

This study presents the results of the active riblets action for electrode configuration shown in Fig.1 b) and Fig.1 c). For this aim the experimental setup was used (see Fig.2). The smog visualization method was used for registration of flow patterns. The quantitative determination of vector velocity fields (V) and scalar fields vorticity (Γ) was produced by PIV-method [12]. The method of the discharge registration corresponded to paper [9]. If necessary, the external air flow created in one-pass subsonic wind tunnel (V<30 м/с) with test section 200*200*500 mm.

In our case the surface discharge excited by the alternating high voltage with |U|<6.5 kV and f=9 kHz. The plasma formation was performed on the flat plate surface as well as "U"-shape riblets with λ= 10 mm and h = 5 mm (Fig. 3). Both of them had a working surface area about 200 * 100 mm. However dielectric layer for each system was different. For example, in the system (see Fig.3a) fiber-glass plastic (d=0.8 mm) was used while the riblets surface (see Fig.3b) was covered by kapton film (d=0.32 mm,). This electrode set contained three discharge actuators though flat plate had four discharge electrodes.

An investigation of the active riblets interaction with the surrounding space was performed in two stages. In the first stage, the observation of interaction between surface discharges and still air was carried out. It allows you to analyze the flows which were induced by plasma. After that, the registration process of active riblets interaction with transverse external flow (V<2-3 m/s) was executed. It allowed to observe the generated vortices at the sufficient spatial resolution, as well as to investigate the interaction of active riblets with flow separation [2]. PIV-recordings were performed by means of video camera FlowSence-2M with frame frequency f_{fr}=4 Hz and laser irradiation impulse energy W_p =45 mJ. The recorded images (200 frames in each series) were processed using a cross-correlative algorithm with sampling window of size 16*16 pixels and 50% overlap [12].

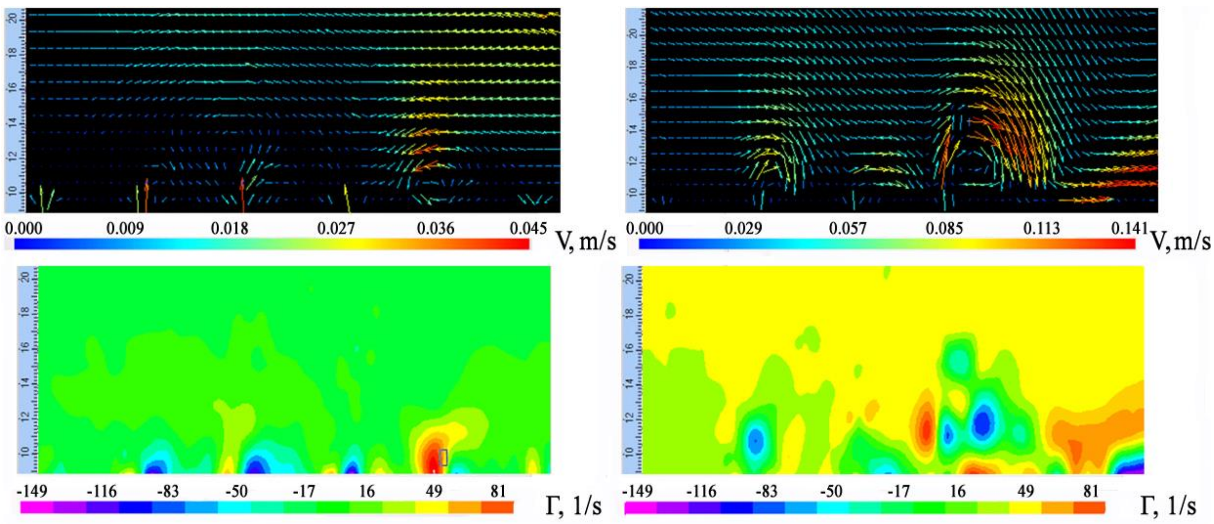


a) b)

Fig.4. Fields of velocity (V) and vorticity (Γ) generated due to the action of virtual riblets in quiescent flow: a)-|U|<2.5 kV; b)-|U|<4 kV

Examples of arising gas flows under the surface discharge action in the quiescent air are presented in Fig.4 and Fig.5. Plasma generation on the flat plate (see Fig.3a) enables the vortex structure formation in vicinity of discharge electrodes (Fig.4) though the operating mode of virtual riblets is not stable. Any external flow can blow the vortices along the smooth surface, by leading to unsteady flow in the boundary layer. Moreover voltage growth causes a transition from the vortex systems to jets which are directed along the streamlined surface (see Fig.4b).

On the other hand vortex cells located above the active riblets surface (Fig. 5) are more stable. Under these conditions, vortex structures are localized in the space (Fig.6) and they are increased in size when voltage increases (Fig. 5b). In the flow, active riblets can improve features of velocity profiles in boundary layer (see Fig.7). It enables to control the flow near the wall efficiently as well as prevent separation flow phenomena.



a) b)

Fig.5. Fields of velocity (V) and vorticity (Γ) formed by plasma enhanced riblets in quiescent flow: a)-|U|<2.5 kV; b)-|U|<4 kV

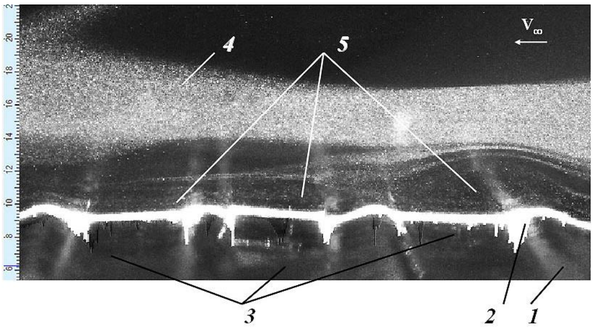


Fig.6. Flow pattern ($V_\infty \cong 1$ м/с) near surface of "U"-shaped active riblets during discharge generation: 1 – riblets vertex; 2 – light sheet; 3-groove containing discharge electrodes; 4-aerosol; 5-vortexes.

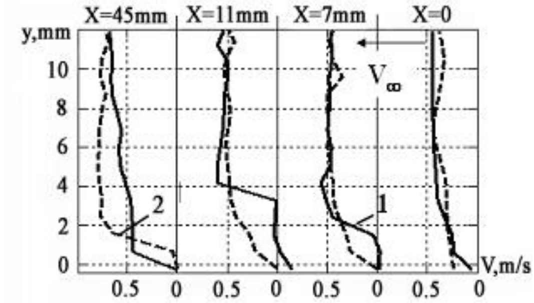


Fig.7 Distribution of tangential velocity component in boundary layer (along flow direction) over the riblets surface: 1-plasma ON; 2-plasma OFF. Coordinate (y=0) correspond to the level of riblets vertexes

In contrast to [8], the presented results demonstrate the ability of effective use of active riblets for flow control in the boundary layer at λ >> 1mm. It extends the capabilities of the presented plasma technology and pays attention to the interaction process research between surface discharges and vortex cells.

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References

[1] Schlichting, H., Gersten, K. Boundary layer theory - Berlin et al.: Springer. 2003.

[2] Physical basis of the transition to turbulence in non-isolated flows / A.V. Boiko, G. R. Grek et al. - Moskow at al.: Publisher of Computer Science. 2006. [In Russian]

[3] Savill A.M. Drag reduction by passive devices – a review of some recent developments // Structure of Turbulence and Drag Reduction / Ed. by A. Gyr –IUTAM Symposium - Berlin: Springer-Verlag, 1990.-P.429-465.

[4] Grek G. R., Kozlov V.V., Titarenko S. V. An experimental study on the influence of riblets on transition // J. Fluid Mech. – 1996.-Vol. 315. – P. 31-49.

[5] Viswanath P.R. Aircraft viscous drag reduction using riblets // Progress in Aerospace Science. – 2002. – V. 38. – P. 571-600.

[6] Moreau E. Airflow control by non-thermal plasma actuators // J. Phys. D: Appl. Phys. -2007 - V.40. - P.605–636.

[7] Grundmann S., Tropea C. Experimental damping of boundary-layer oscillations using DBD plasma actuators // International Journal of Heat and Fluid Flow – 2009. - V.30. - P.394–402.

[8] Patent US № 8,220,754 International Class: B64C 21/00 Plasma enhanced riblet // McClure et al. Filed: 03 06.2009.

[9] The Properties of Colliding Surface Discharges in Air/ Ivchenko, P.E. Timchenko, V.P. Zakharov, et al // Europhysics Conference Abstracts - 2012.- V. 36F-4p.

[10] Ivchenko A.V. Gas-Dynamic Features of Jets Generated by Colliding Surface Discharges // Europhysics Conference Abstracts - 2013.- V. 37D-4p.

[11] Corke T.C., Post M.L., Orlov D.M. SDBD plasma enhanced aerodynamics: concepts, optimization and applications // Progress in Aerospace since, 2007, V.43. – P.193-217.

[12] Raffel M., Willert C., Kompenhans J. Particle Image Velocimetry: a practical guide – Berlin: Springer, 1998.