ARTIFICIAL TURBULIZATION OF THE SUPERSONIC BOUNDARY LAYER BY DIELECTRIC BARRIER DISCHARGE

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Abstract The most evident way to decrease drag and pollution of transonic airplanes is extensive using of laminar flow wherever it is possible. Unfortunately the laminar flows are difficult to implement in presence of adverse pressure gradients caused by the shock wave / boundary layer interaction. Undesirable flow separation may eliminate all advantages of the laminar flow. Therefore it is necessary to design a technique of fast and reliable turbulization of the boundary layer right upstream of the interaction zone to reduce the separation. The paper is devoted to experimental and numerical study of plasma application for turbulization of the boundary layers at $M=1.5 \div 2$. The experiments demonstrated the possibility of the supersonic boundary layer turbulization by the dielectric barrier discharge. Parametric study of this effect was performed by CFD to find the mechanisms of the turbulization and optimize plasma discharge parameters.

INTRODUCTION

Ecological demands and increasing price of fuel cause an intensive study of laminar flow wing problem. It is generally acknowledged that transonic and supersonic commercial airplanes of the next generations will be equipped with a laminar wing [1] to decrease the viscous drag. Unfortunately the laminar boundary layer has weak resistance to adverse pressure gradients especially ones produced by shock waves. The shock waves are the native feature of the transonic and supersonic flow around complex bodies and their interaction with the boundary layer is of great importance. It is well known (see, for example [2]) that the separation of the laminar boundary layer on the transonic airfoil has bigger extent in comparison with turbulent separation resulting in the total drag increasing. Elimination of this negative effect with keeping all advantages of the laminar flow is possible if the laminar-turbulent transition is forced right upstream of the shock wave. The shock waves usually move due to variation of the flow parameters, angle of attack and etc. therefore the point of turbulization has to move correspondingly. The traditional turbulators such as roughness and vanes are fixed to the wing surface therefore some controllable devices are needed [3]. One of such kind of devices is a plasma actuator based on the dielectric barrier discharge (DBD). This actuator has a complex influence on the flow by the ionic wind and discharge streamers and allows to turbulize the flow. The main advantage of DBD is low energy consumption that allows to use it during the whole flight. At the moment there is a great interest to application of DBD and the main part of study was done for subsonic speeds. This paper deals with application of DBD for turbulization of supersonic boundary layers.

EXPERIMENTAL AND NUMERICAL RESULTS

The main part of experiments has been performed in wind tunnel T-325 for Mach number $M_\infty = 2$, and freestream unit Reynolds number $Re_1=10.5\cdot 10^6$ m^{-1}. The experimental model was a flat plate with sharp leading edge. The plasma actuator was installed in the replaceable nose section (Figure 1). DBD consisted from two electrodes separated by thin layer of dielectric. The first electrode was exposed to surrounding gas and the second one was encapsulated. Asymmetric design allowed to actuate the flow in definite direction. When AC voltage of sufficient frequency and amplitude was applied the plasma region originated above the encapsulated electrode.

The plasma region of DBD for the conditions of the experiment consists from great number of short duration filaments or streamer channels arising with high frequency. The local energy deposition in streamer heats the air and produces shock waves. These shock waves interact with the flow and cause the boundary layer turbulization. DBD also induces the unsteady ionic wind directed upstream in this particular case. The sandpaper turbulator was placed 70 mm downstream of the plasma actuator to obtain the turbulent boundary on the model if plasma is off. Figure 1 shows the effect of plasma on the boundary layer profiles measured by hot-wire anemometer. Activation of plasma results in growing of the boundary layer associated with upstream shifting the transition location. It can be seen that pulsation distribution across the boundary layer remains similar.

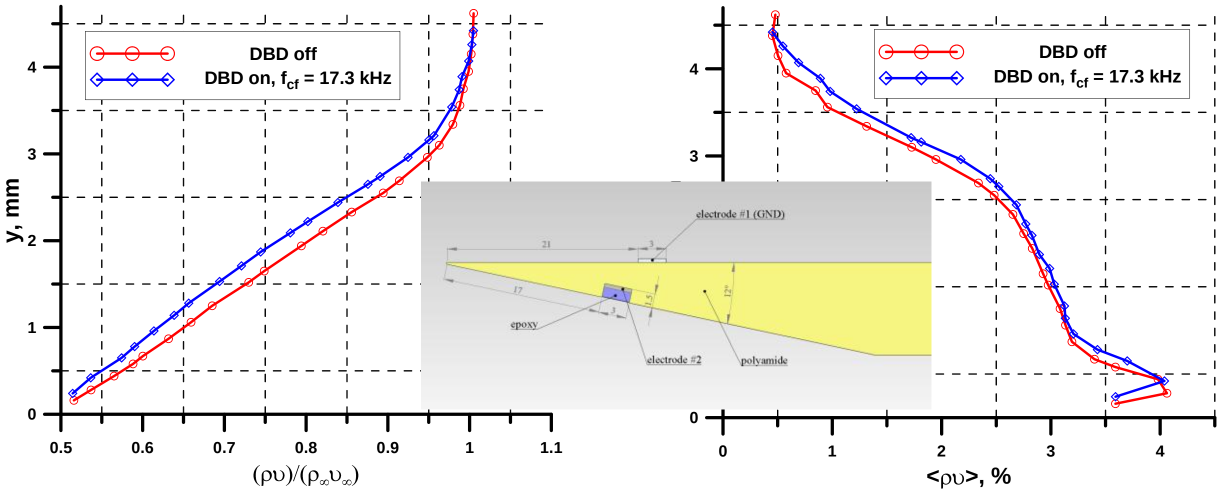

Figure 1. Vertical profiles of mass flow and mass flow pulsations (RMS values)
in the turbulent boundary layer (x = 260 mm)

The experiments revealed the possibility of using plasma discharge for turbulization of supersonic boundary layers but mechanisms of turbulization remained unclear. The detailed study of DBD effect on the laminar boundary layer was performed by numerical simulation.

DBD plasma excites significant disturbances in the flow therefore the process of boundary layer transition was simulated by LES approach with Smagorinsky subgrid model. The computation domain was meshed to provide $\Delta y^+ \approx 2$, $\Delta x^+ \approx 17$, $\Delta z^+ \approx 11$. The advantage of CFD simulation is a possibility to separate DBD actions on the flow and to compare their effects. Two influence mechanisms were considered: 1) The single streamer was modeled by local energy deposition into cylindrical region near the wall; 2) The ionic wind was modeled by addition of periodic volume force in the near-wall region. The parametric study of energy deposition, shape of the streamer, their frequency, boundary layer thickness and etc. was performed. The discharge parameters in CFD simulation corresponded to experimental ones. The effect of plasma discharge on the flow was compared with effect of the roughness turbulator (figure 2). The data obtained allow to evaluate the capacity of DBD for the supersonic boundary layer turbulization.

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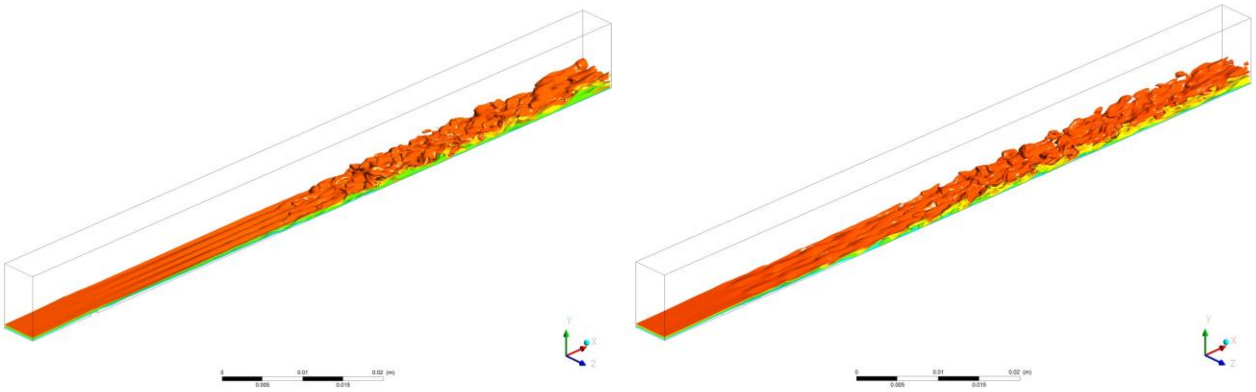

(a) (b)

Figure 2. Iso-surface of velocity (a – fixed turbulator, b – DBD).

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