Turbulence generation by DBD plasma actuators

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Turbulence generation by plasma actuator is one of the key barrier for the application of these devices as a virtual DRE in boundary layer transition control. To study this process, spectra of the velocity pulsations, generated by the actuator in a 2D subsonic boundary layer were analyzed. It has been shown that low-frequency velocity pulsations correlate with the microdischarges dynamics in DBD. Effect of supply voltage parameters and electrode material on the intensity of the pulsation was studied.

Novel methods of the transition control, utilizing the strategy of boundary layer forcing from the leading edge by plasma actuators, strongly increase the requirements to the discharge parameters control. In recent studies of swept wing transition control by plasma "virtual roughness" elements, unwanted broadband excitation of the boundary layer by the actuator was obtained. This excitation takes place in the receptivity band of the unsteady travelling crossflow waves, leading to the unexpected upwards shift of the transition point. This result was independently obtained by several groups [1], [2], with different construction of the actuators. As an obvious precaution, in all these cases the frequency of voltage powering the discharge was chosen to be far above than the receptivity band of the travelling waves in the transition experiment. Therefore, one of the key problems of the transition control by plasma actuators from the leading edge is the following: how the dielectric barrier discharge can initiate the turbulence at the frequencies many orders below the supply frequency; what mechanisms lie behind this process and how the amplitude of the low-frequency spectra can be decreased.

Dielectric barrier discharge at atmospheric pressures exists as a set of microdischarges (MDs), formed at the edge of the exposed electrode several times in a period. Microdischarges position and breakdown phase is controlled by a number of volume and surface processes sometimes referred as "discharge memory" [3]. Each MD individually creates a hydrodynamic effect on the flow, and both the EHD force field and heat release are three-dimensional [4]–[6]. Would the breakdown take place each half-period at the same phase, and the discharge structure be conservative in time, the spectra of generated disturbances would lie to the right of the supply voltage frequency. Therefore, the low frequency spectra of the discharge should be controlled by the stochastic processes of the MD formation in DBD.

This paper is devoted to the study of the turbulence spectra generated by the dielectric barrier discharge. The actuator was manufactured of alumina ceramics (ε=10), with copper or aluminium foils used as an exposed electrode, and powered by 60kHz 2.6-4kV sinuous voltage. Discharge-induced turbulence spectra was measured in a Blasius boundary layer at U=20-40 m/s with the actuator located at the position 200mm from leading edge with a co-flow direction of the plasma induced velocity(fig.1a). Velocity pulsations were measured by a hotwire at various distances from the actuator (15-60 mm). Typical velocity spectra at various voltage amplitudes are shown in fig.1b. It can be seen that the actuator generates a broadband spectra in all the frequency range available for a given experimental conditions. Plasma-induces disturbances are damped in the boundary layer, with the amplitude decrease first affecting high frequency part of the spectra. The total RMS of the added pulsations can be estimated by extrapolation of data to the electrode as 0.2-0.6% U.

To prove the role of the MD dynamics in the turbulence generation, cross-correlation method was used. The correlation was calculated between the hotwire signal and light emissions of the discharge, the latter measured by PMT from the narrow section on the electrode. The typical spanwise distribution of the correlation for various distances from the actuator are shown in fig.1d. It is shown that disturbances are convected in a boundary layer as an embedded vorticity with a local velocity at the position of correlation maximum. The transverse spreading of the disturbances from the given part of the electrode occurs in the angle of 14^o.

Effect of the exposed electrode material, frequency and amplitude of operating voltage is studies. It is shown that increase of the voltage amplitude linearly increase the pulsations RMS. Change of the electrode material from aluminium to copper was shown to have a significant effect on the MD dynamics and flow structure, with the level of pulsations remaining relatively high.

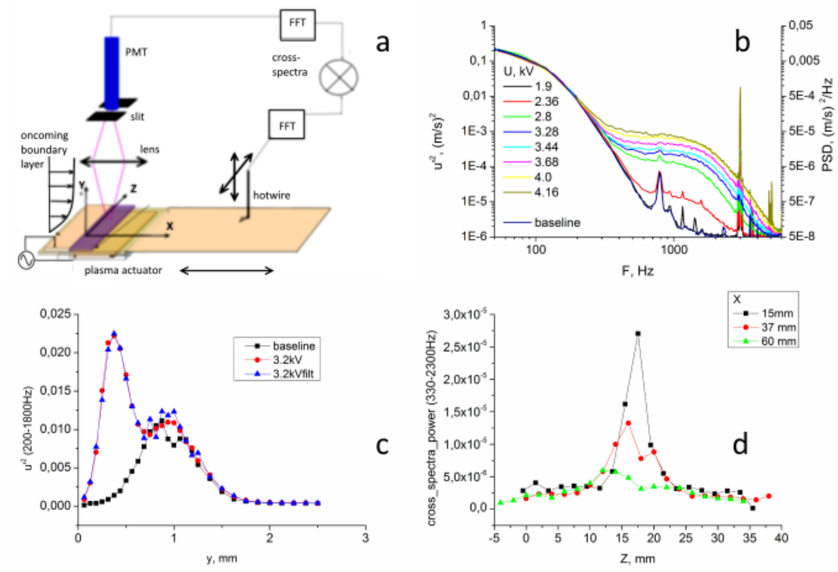

Figure 1: a)Plasma actuator and experiment scheme, b)Spectra of the velocity pulsations at X=15mm for various voltage amplitudes, c)Vertical pulsation profiles in the boundary layer. d)Transverse profile of the PMT-hotwire cross-correlation magnitude

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