Suppression of stationary cross-flow vortices on the swept wing by dielectric barrier discharge

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Laminarization of the lifting surfaces is currently being considered as one of main opportunities for reducing the aerodynamic drag of aircraft. For a swept wing, widely used in modern aviation, the mechanism dominating the transition is development of cross-flow instability. In flight or low-turbulent experimental conditions, the transition is governed by stationary disturbances.

The technique of most unstable modes suppression by modification of the boundary layer structure by a less amplified mode (so called “killer mode”) was proposed and successfully tested by Saric [1–2]. The extension of this idea is using of dielectric barrier discharge (DBD) for creation of “killer mode”.

The study of the flow control by DBD was carried out in the low turbulent wind tunnel T-124 of Central Aerohydrodynamic Institute (TsAGI). 3D boundary layer was organized on a swept flat plate with curvilinear upper and side walls, imitating pressure gradient present on a swept wing. The model with sweep angle 35°, 998 mm span, 2100 mm chord, 20 mm thickness was made of plexiglas. Leading edge of the model is ellipse shaped with a semi-major axis 80 mm. X distance is normal to the leading edge and counted from it.

Experiments were carried at oncoming velocity U_{fs} = 30 m/s. The investigation of the boundary layer structure was carried out by hot-wire. DBD actuator, designed to create separate localized groups of microdischarges (detailed description and study is given in [3]) with a total span 390 mm was placed parallel to the leading edge 110 mm from it. According to preliminary calculation of boundary layer stability the pitch of microdischarge groups was chosen 5 mm on position X = 125 mm to create “killer mode”. Actuator was powered by sinuous voltage with amplitude of 2.5 kV and frequency 65 kHz.

To excite the most unstable stationary mode (“target”) with a wavelength of 7.62 mm the set of cylindrical roughness elements 20 μm×1 mm was placed on the leading edge at position X = 75 mm.

Analysis of hot-wire measurements in several X-positions showed efficiency of DBD for “killer mode” creation (see Figure 1). The amplitude of the mode in the region of maximal amplitude can be varied in a wide range: 0.02–0.15U_{fs}. The amplitude of the wave is mainly determined by the operation envelope of the actuator-inception voltage for low voltages and discharge structure stability at high ones. Simultaneous development of the “killer” and “target” modes was studied in the region X = 400–650 mm. It was shown (Figure 2) that a “killer mode” with an amplitude of 3% suppress the development of “target mode” in the region X = 400–550 mm. Downstream from this region the amplitude of “target mode” for regime with DBD is nearly equals to the natural regime without DBD.

However, analysis of velocity pulsations in the boundary layer has shown the increase of the total RMS value in all measurement positions in the "actuator on" case in comparison to the "actuator off" regime. Spectral analysis has revealed that pulsations increase occurs due to the excitation of travelling cross-flow instability by the actuator in the range 100–600 Hz. As a final result, the actuator operation leads to the acceleration of transition process at far positions from the leading edge, which is illustrated by the increase in high frequency parts of measured spectra (see Figure 3).

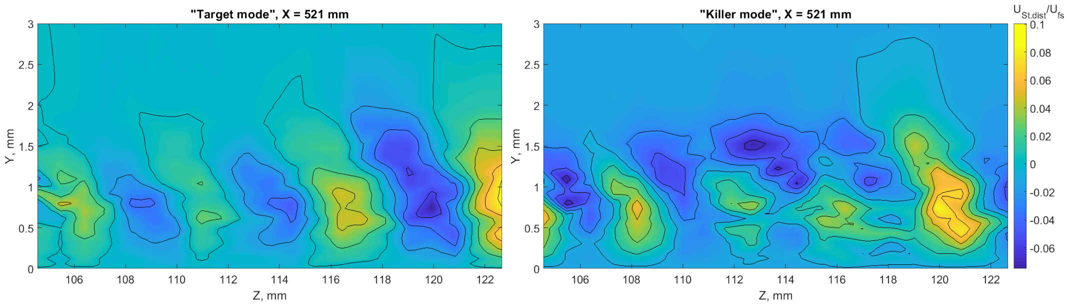

Figure 1: Distribution of stationary disturbance of velocity in position $X = 521$ mm: “target mode” relative undisturbed flow (left subfigure); “killer mode” relative disturbed by “target mode” flow (right subfigure).

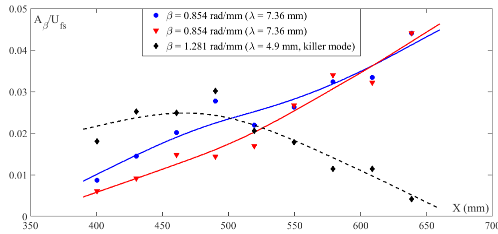

Figure 2: Development of stationary modes along the flow:
“target mode” with DBD (red); “target mode” without DBD (blue); “killer mode” (black).

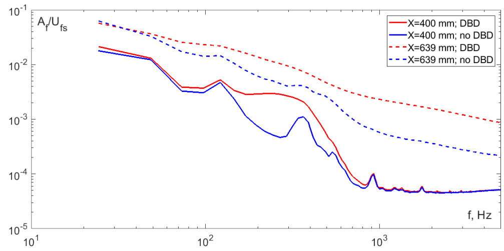

Figure 3: Spanwise-averaged amplitude spectra for regimes with DBD (red) and without (blue) in two X-positions: 400 mm (solid line); 639 mm (dashed line).

Experiments discovered the potential for using DBD to control the laminar-turbulent transition from the leading edge. Still, the key problem to be solved for further development is cross-flow travelling instability modes generation by the actuator.

References

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