Flow control by distributed suction behind three-dimensional roughness element on the straight wing model

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Abstract. The paper is devoted to the close investigation of the flow over perforated suction section in the presence of the three-dimensional roughness element. Measurements were conducted over the surface of the straight wing with and without suction. It was shown that distributed suction allows diminishing the intensity of longitudinal structure. Also the boundaries of the effective suction usage were found.

1. Introduction
Nowadays the problem of laminar-turbulent transition control is one of the main problems in the aerohydrodynamics field. The key task for airfoil flowing is a possibility of full elimination or maximal shift towards the rear edge of the wing of the transition point [1, 2]. It is known that there are a lot of methods to fulfill this task but one of the most effective is suction of the boundary layer. This method allows suppression of the Tollmien-Schlichting waves and shifting downstream laminar-turbulent transition. Dislocation of the transition results in reducing of drag friction.

In [3] it was shown that suction of the flow can be effectively used for cross-flow instability control in three-dimensional boundary layer. It was confirmed that traveling waves disappear faster than the stationary ones.

The process of initially sinusoidal disturbance development in laminar boundary layer using narrow slot suction was investigated in [4]. It was shown that amplitude of disturbances in the flow decreases across the boundary layer in the region of the slot. Also it was detected that efficiency of the suction relates to the stage of the laminar-turbulent transition and does not depend on the intensity of the pulsation within the boundary layer.

In [5] the possibility of the active secondary instability control for longitudinal structures using localized suction in a three-dimensional boundary layer was investigated. Experimental results show that intensity of the secondary instability can be diminished by suction. The degree of the impact is based on the location of the suction section relative to the core of the vortex structure. Maximal effect is achieved by suction directly under the vortex and this leads to the development of the secondary instability.

This work is a continuation of research of the roughness element influence on the different types of wings [6, 7].
2. **Experimental setup**

The experiment was carried out in the working part of the subsonic wind tunnel T-324 ITAM SB RAS. The wind tunnel had low-level of turbulence less than 0.04%. Free-stream velocity $U_{\infty} = 10.8$ m/s and was controlled by Pitot-Prandtl nozzle connected to micro manometer. Favourable pressure gradient over the surface investigated was obtained by placing the wing model at the angle of attack $\alpha = -6.5^\circ$. The model was a rectangular wing with symmetrical airfoil NACA 0012 (figure 1).

Chord was 500 mm, wing span was 930 mm, and maximal thickness was 60 mm. Distributed suction was achieved through a perforated hydraulically smooth section. Use was made of three-dimensional roughness element for excitation of the stationary disturbances. This cylindrical roughness element was 1.7 mm in height and 1.8 mm in diameter and was placed at the distance of 215 mm from leading edge of the wing. All measurements were carried out by hot-wire anemometry.

3. **Results**

In the beginning of the investigation the mean velocity distribution was measured over the wing at the distance of 25 mm away from the surface of the wing (figure 2). In the presence of the three-dimensional roughness element two measurements were conducted: without suction (blue line) and with suction on (red line). It can be seen that roughness element is placed in the favourable pressure gradient region ($X = 215$ mm). Turning on the suction of the boundary layer leads to the impact on the incoming flow (increase in the velocity) before perforated section ($X = 290$ mm) therefore suction has impact not only downstream but upstream as well.

![Figure 1. The model of the straight wing (1), perforated suction section (2), three-dimensional roughness element (3).](image1)

![Figure 2. Mean velocity distribution over wing surface in the presence of the roughness element.](image2)
Figure 3. Isolines of mean velocity deviation (a) and integral velocity pulsation (b) for X = 320 mm without suction.

Figure 3 and figure 4 shows isolines of mean velocity and integral velocity pulsation over suction section when suction is off and on, respectively. It can be seen that the three-dimensional roughness element leads to the appearance of the longitudinal structure but in case when suction is turned on intensity of the velocity pulsation becomes smaller.

Figure 4. Isolines of mean velocity deviation (a) and integral velocity pulsation (b) for X = 320 mm with suction.
Measurements of the stream wise distribution of the velocity pulsation behind the roughness element were carried out within the boundary layer (figure 5). Right before the beginning of the suction section there is the disturbance but suction allows full elimination of this disturbance. There are no pulsation after suction section (X = 370 mm). Span wise measurements of the velocity pulsation also show that the disturbance disappears after going over the perforated suction section (figure 6).
Conclusions
The experimental investigation of the flow over the perforated suction section has been carried out. This work is a continuation of research of the roughness element influence on the different types of wings and shows how flow behind roughness element can be impacted by suction. Hot-wire anemometry allowed obtaining new quantitative data. Distributions of the velocity pulsation within and over the boundary layer show that over the suction section the distributed suction is implemented and the disturbance behind roughness element is eliminated. This disturbance does not grow downstream. It allows us to make the relaminarization of the flow behind three-dimensional roughness element.

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