Visualization of the flow behind a two-dimensional roughness element and its role in the laminar-turbulent transition on the swept wing model

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Abstract The paper given is devoted to the investigation of two-dimensional roughness behavior and its influence on the laminar-transition on the swept wing model. The excitation of the stationary disturbances was conducted by three-dimensional roughness element with height 0.8 mm and diameter 1.6 mm. The two-dimensional roughness element was used to investigate its influence on the stationary structure behind three-dimensional one. Hot-wire anemometry helped to obtain visualization pictures of processes taken place near the leading edge of the wing model. The multiplication of longitudinal structures was detected. That multiplication amplified when adding acoustic influence 500 Hz. The majority of the modern planes civil or military aviation have swing wings which suit best for the transonic regimes.
Keywords: laminar-turbulent transition, swept wing, two-dimensional roughness element, cross-flow instability.
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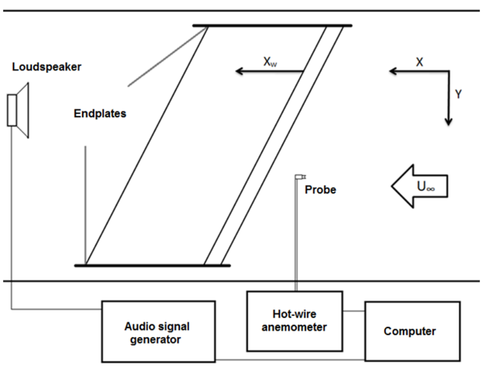
1 Introduction

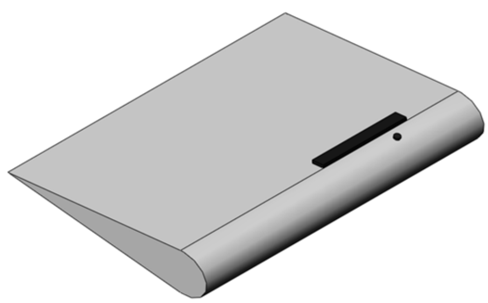
Swept wings are widely used for aircrafts but there are some features. One of them is appearing of the cross-flow instability due to the sweep of the wings. It is also main cause of laminar-turbulent transition of the leading edge. An additional point is that cross-flow instability is highly sensitive to surface roughness. Thus in the experiment given attention was paid to two-dimensional roughness element placed on the leading edge of the swept wing and its influence on the flow behind three-dimensional roughness element.

2 Experimental setup

The experiment was carried out in the low-turbulent wind tunnel T–324 in the Institute of Theoretical and Applied Mechanics SB RAS. The cross section of the working area is 1000x1000 mm with length is 4000 mm. The level of the flow turbulence didn't exceed 0.03%. The Pitot-Prandtl tube connected to electronic manometer was used to monitor the free stream velocity. During the first experimental session freestream velocity was set to U_∞ = 10.9 m/s. On the second experimental session it was set to U_∞ = 9.2 m/s. The air temperature was in interval 296–300° K. The sweep angle of the wing model was 45°. The profile of the wing was formed by cylinder with radius is 40 mm and two converging planes with chord of the wing is 400 mm. The angle of attack was -12.3° to prevent separation on the upper side of model. Set of 15 mm height cones was used to deal with separation on the down side of the model.



(a)



(b)

Fig.1. Experimantal setup (a) and swept wing model with two- and three-dimensioanl roughness elements on its surface (b)

Carrying out the experiment stationary disturbances were excited by three-dimensional roughness element with height is 0.8 mm and diameter is 1.6 mm. Use was made of two-dimensional roughness element to investigate the interaction between two types of roughnesses. Width of the two-dimensional roughness element is 15 mm, length is 200 mm. This kind of roughness was multilayer with thickness of one layer is 0.13 mm. Thus the total thickness could be varied from 0 to 1.6 mm. Excitation of high-frequency disturbances was realized by using loudspeaker placed in diffuser of the wind tunnel.

3 Results

In the absence of two-dimensional roughness element (h_{2D} = 0 mm) the stationary structure forming behind three-dimensional roughness element consists of high and low speed area (Fig. 2). Reaching h_{2D} = 0.52 mm two-dimensional roughness leads to the appearance of stationary vortices itself. Further increasing of the height amplifies this effect. Beside that two-dimensional roughness element has destabilizing influence on longitudinal structure formed by three-dimensional one. The amplitude of additional structures increases but meanwhile the amplitude of the structure behind three-dimensional roughness element fades downstream.

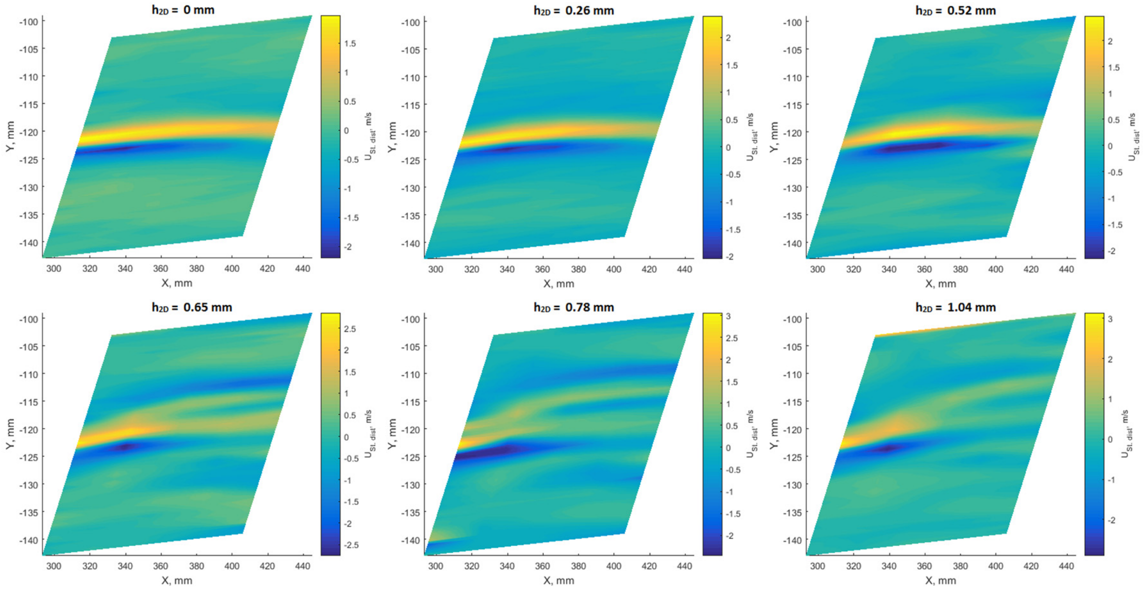


Fig.2 Influence of the two-dimensional roughness height on the flow

Application of 500 Hz acoustic field causes multiplication and intensification of longitudinal structures (Fig.3). Mechanism of multiple modes appearance has an influence on the development of secondary disturbances in downstream region. This take place upon condition of amplitude being high enough (more than 1.5% of free-stream velocity). Eventually the flow becomes turbulent leading to reduction in stationary disturbance amplitude.

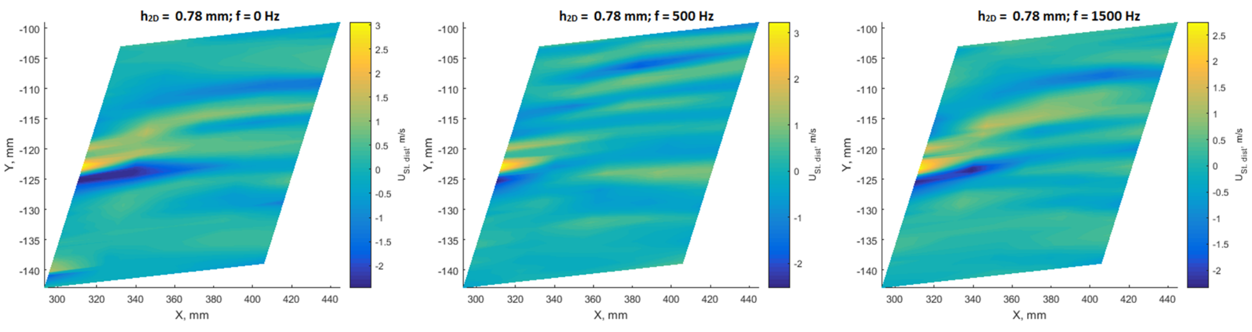


Fig.3 Influence of the acoustic field (f = 500 Hz) on the flow behind two-dimensional roughness element