ON THE ARTIFICIAL DISTURBANCE EVOLUTION IN 2D/3D SPANWISE MODULATED BOUNDARY LAYERS AT MACH 2 AND 2.5

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Abstract The paper presented the results on the generation and development of the wave train in spanwise modulated supersonic boundary layer at Mach 2 and 2.5 which obtained experimentally in the same conditions of controlled experiment. In experiments on the flat plate with roughness it was obtained that at the Mach number M = 2.5 both a subharmonic and fundamental wave packet develops almost linearly, whereas at the Mach number M = 2.0 there is competition between the two mechanisms of unstable waves interaction. It was obtained that in the boundary layer on swept wing the roughness presence can leads to the stabilization of the wave packet development at fundamental and subharmonic frequency in the downstream direction.

EXPERIMENTAL EQUIPMENT AND DATA PROCESSING

The experiments were conducted in T-325 supersonic wind tunnel of ITAM SB RAS at Mach 2 and 2.5. The model of a swept wing with a slightly blunted leading edge and the model of a flat steel plate with a sharp leading edge were used. The experiments were carried out at unit Reynolds number $Re_1 = 5\times10^6$ m^{-1} for Mach 2 and then at $Re_1 = 5\times10^6$ and 8.5×10^6 m^{-1} for Mach 2.5 in order to get the same Reynolds number for first case and the same static pressure value for second case in comparison with Mach 2. Constant temperature anemometer (CTA) was used for mean and pulsating flow quantities measurements. Artificial disturbance sources based on high frequency glow discharge in chamber [1] were built into the models. Controlled pulsations are delivered into the boundary layers through the surface aperture of 0.5 mm in diameter. The pulsation measurements were synchronized with glow discharge which was ignited with fundamental frequency of 20 kHz. The spanwise measurements were made at the fixed normal distance from the model surface and at $y/\delta \approx$ const for each position at the perturbation maximum in the boundary layer. The square stickers from a scotch tape were applied to induce the spanwise modulation of mean flow in the boundary layer. The sizes of labels for the flat plate were 4 mm × 4 mm, and sizes of labels for the swept wing were 3 mm × 3 mm, the height in both case was 60 microns. The frequency-wave spectra of controlled disturbances were obtained from two-dimensional Fourier transform in time t and the transverse coordinate [2]. The mean flow distortion was determined using the ratio between the relative change of the average mass flow and relative change of mean voltage output from the anemometer [3].

RESULTS

The method of controlled disturbances, which is used in this study allowed us to determine the basic mechanisms of transition in supersonic boundary layer on a flat plate [4]. These results are concerned to the smooth surface of the flat plate. According to the calculations [5], one of the competing transition mechanisms of two-dimensional supersonic boundary layer is the so-called oblique breakdown. Earlier it was experimentally revealed that subharmonic resonance is playing a leading role in the process of transition in supersonic boundary layer, and the mechanism of oblique breakdown significantly behind in competition with subharmonic type of transition. It was found that the role of these mechanisms may change in the transverse-modulated boundary layers [2]. Most our previous studies of disturbance development in modulated boundary layer were conducted at Mach 2. Let us consider the results of studies of perturbations in the transverse-modulated supersonic boundary layer at M=2.0 and 2.5 in comparable conditions of controlled experiments. It was found out that the wave train development downstream in the boundary layer on flat plate essentially depends on the Mach number. It was obtained that at the Mach number M = 2.5 both a subharmonic and fundamental wave packet develops almost linearly, whereas at the Mach number M = 2.0 there is competition between the two mechanisms of unstable waves interaction (subharmonic resonance and the oblique breakdown mechanism). A comparison of the amplitude wave spectra over β' at fundamental frequency for smooth flat plate and flat plate with roughness in the initial and chosen section at M=2.0 and 2.5 are presented in Fig. 1. It was obtained that the efficiency of disturbance sources decreased in the case of flat plate with roughness at Mach 2.0 and 2.5 and $Re_1=5\times10^6$ m^{-1}. In the case of of flat plate with roughness at Mach 2.5 and $Re_1=8.5\times10^6$ m^{-1} the efficiency of disturbance sources increased.

Comparing the results for the smooth model and for the model with roughness elements we can obtain the data on the effect of roughness on the evolution of perturbations in the boundary layer. However these results for the case of M = 2.5 and $Re_1=8.7\times10^6$ m^{-1} on the model of swept wind is not given since in both cases at chosen electrical power of discharge does not allowed to observe the wave packet evolution. A comparison of the amplitude wave spectra over β’ at fundamental frequency for smooth swept wing and wing with roughness in the initial and chosen section at M=2.0 and 2.5 and $Re_1=5.2\times10^6$ $m^{-1}$are presented in Fig. 2. It was found out that the roughness presence leads to a decrease of the disturbance source efficiency at Mach 2. However, the growth rate of perturbations is the same as for the smooth wing and wing with roughness elements. For the case M=2.5 and $Re_1=5.2\times10^6$ m^{-1} there is the stabilization of the wave packet development in the downstream direction. The same results were obtained for wave packet at subharmonic frequency.

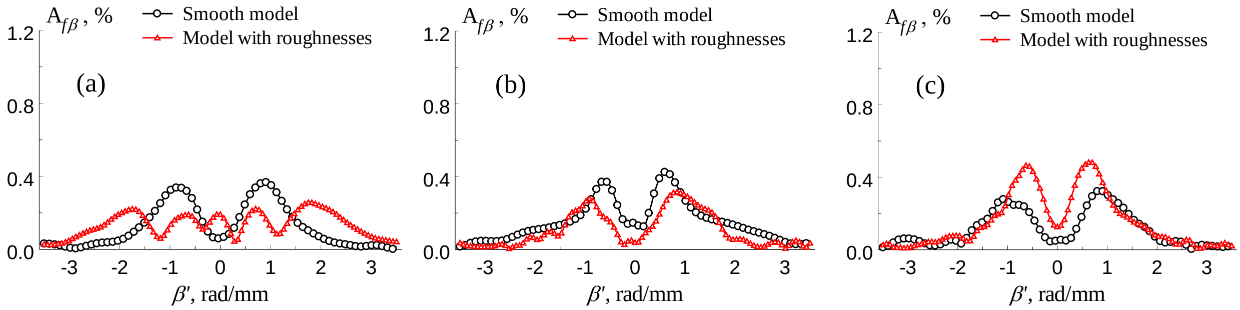

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Figure 1. Comparison of the amplitude wave spectra over β’ for smooth flat plate and flat plate with roughness in the chosen section (a) at M=2.0, $Re_1 = 5\times10^6$ m^{-1} , (b) M=2.5, $Re_1 = 5\times10^6$ m^{-1} , (c) M=2.5, $Re_1 = 8.5\times10^6$ m^{-1}.

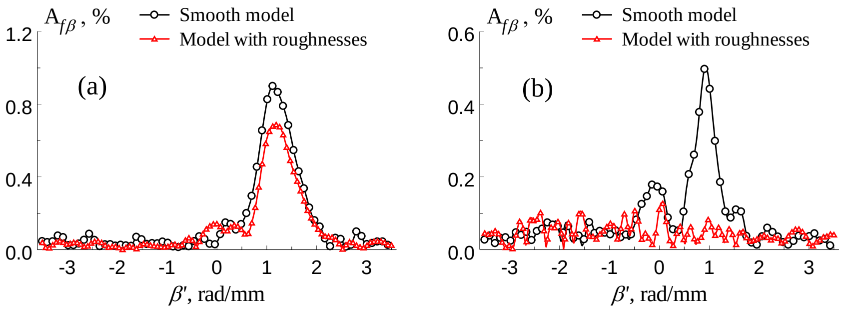

Figure 2. Comparison of the amplitude wave spectra over β’ for smooth swept wing and wing with roughness in the chosen section (a) at M=2.0 and (b) M=2.5.

CONCLUSION

For the first time the results on the generation and development of the wave train in spanwise modulated supersonic boundary layer at Mach 2 and 2.5 were obtained experimentally in the same conditions of controlled experiment. In experiments on the flat plate and swept wing it was found out that the roughness have the same effect on the mean flow for M = 2.0 and 2.5 at fixed static pressure. With a decrease in static pressure amplitude distortion mean flow decreases. In experiments on the flat plate with roughness it was obtained that at the Mach number M = 2.5 both a subharmonic and fundamental wave packet develops almost linearly, whereas at the Mach number M = 2.0 there is competition between the two mechanisms of unstable waves interaction (subharmonic resonance and the oblique breakdown mechanism). It was obtained that in the boundary layer on swept wing the roughness presence leads to a decrease of the disturbance source efficiency of the perturbation source at Mach 2. However, the growth rate of perturbations is the same as for the smooth wing and wing with roughness elements. For the case M=2.5 and $Re_1=5.2\times10^6$ m^{-1} there is the stabilization of the wave packet development at fundamental and subharmonic frequency in the downstream direction.

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