EXPERIMENTS ON THE WAVE TRAIN DEVELOPMENT IN SPANWISE MODULATED 2D BOUNDARY LAYER AT MACH 2 AND 2.5

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Abstract A comparative experimental study of the evolution of controlled fluctuations in the spanwise modulated boundary layer on flat plate at a fixed electrical power of disturbance source for Mach 2.0 and 2.5 are presented. It was found out that at Mach number M = 2.5 both subharmonic and fundamental wave train developed almost linearly, whereas at Mach number M = 2.0 there is a real competition between subharmonic resonance and oblique breakdown mechanism.

Usage of the controlled disturbance technique to study the nonlinear interaction mechanisms of unstable waves in a supersonic boundary layer is a preferable method. By this method the subharmonic and oblique breakdown mechanisms were experimentally detected [1]. However, up to now our experiments on the development of the wave train in a supersonic boundary layer were mostly made at Mach number M = 2.0 [1, 2]. The paper is devoted to investigation of wave train generation and development in the spanwise modulated flow of the supersonic boundary layer at Mach 2.0 and 2.5. The investigation is continuing the series of experiments that were conducted before by us [3].

EXPERIMENTAL SETUP

The experiments were conducted in T-325 low noise supersonic wind tunnel of ITAM SB RAS at Mach 2 and 2.5. Two roughness elements were placed on the model surface in order to get spanwise modulation of mean flow in the boundary layer. Fig. 1 presents the installation the symmetric square elements that named so in [4]. Constant temperature hot-wire anemometer was used for mean and pulsation flow characteristic measurements. Hot-wire probe from tungsten wire of 10 micron in diameter and 1.6 mm in length was used. The model of a flat steel plate with a sharp leading edge was used. Source of artificial disturbances was built in the model and it is driven by the high frequency glow discharge in chamber that is similar to presented in [2]. Controlled pulsations have been introduced into boundary layer through the aperture in the model surface of 0.5 mm in diameter. The pulsation measurements were synchronized with glow discharge which was ignited with fundamental frequency of 20 kHz. AC and DC signals from CTA were written to the PC by using of 12-bit ADC with sampling rate 750 kHz and by DC voltmeter correspondingly. Four time traces of 65536 points in length were measured and written to file in each space position of hot-wire. Mean and pulsation characteristics of the flow were obtained after data processing using a standard technique. The spanwise measurements (over Z, at X = const) were made at the fixed normal distance from the model surface and at $y/\delta \approx$ const for each X position at the maximum perturbation across of the boundary layer. The experiments were conducted at unit Reynolds number $Re_1 = 5\times10^6$ m^{-1} for Mach 2 and at unit Reynolds number $Re_1 = 5\times10^6$ and 8.4×10^6 m^{-1} for Mach 2.5 in order to get the same Reynolds number for first case or the same static pressure value for second case in comparison with Mach 2.

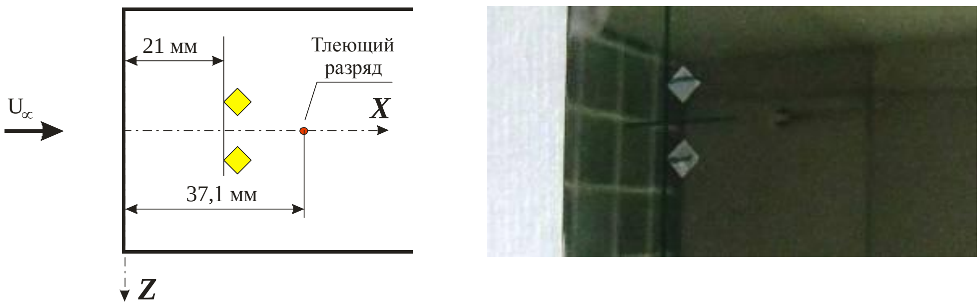

Figure 1. Experimental set-up.

RESULTS

Here we will consider only results for fundamental (20 kHz) and subharmonic (10 kHz) frequency pulsations. As it is shown in Fig. 2, the symmetric square elements have been generated the spanwise flow distortion about 5% (pick-to-pick) at Mach 2 as well as at Mach 2.5 and $Re_1 = 8.4\times10^6$ m^{-1}. In the case of M = 2.5 and $Re_1 = 5\times10^6$ m^{-1} spanwise flow distortion was slightly low. The measurements of wave train development were made at X = 60, 70, 80 and 90 mm from the leading edge. Fig. 3 shows a comparison of the amplitude of the wave spectra over β at X = 90 mm for subharmonic (left) and fundamental (right) wave train. It was found out that at Mach number M = 2.5 and $Re_1 = 5\times10^6$ m^{-1} both subharmonic and fundamental wave trains are developed almost linearly. In the case of M = 2.5 and $Re_1 = 8.4\times10^6$ m^{-1} the exciting of fundamental frequency pulsations are mainly observed. Subharmonic disturbances at frequency of 10 kHz are excited with relatively small amplitude and they are developed almost linearly downstream. However, at the Mach number M = 2.0 there is competition between subharmonic resonance and the oblique breakdown mechanism. Thus, at the first time the results for the periodic wave train development at Mach 2 and 2.5 in the spanwise modulated supersonic boundary layer was experimentally obtained at the same conditions of controlled experiments. The results allow seeing the effect of the Mach and unit Reynolds numbers to the wave train generation and its development in spanwise modulated supersonic boundary layer.

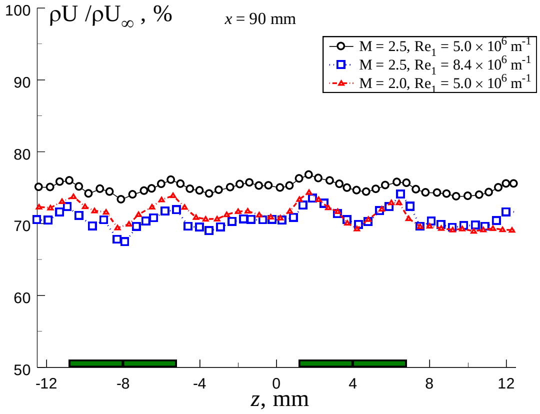

Figure 2. Comparison of mean flow distortion at X = 90 mm for M = 2.0 and 2.5.

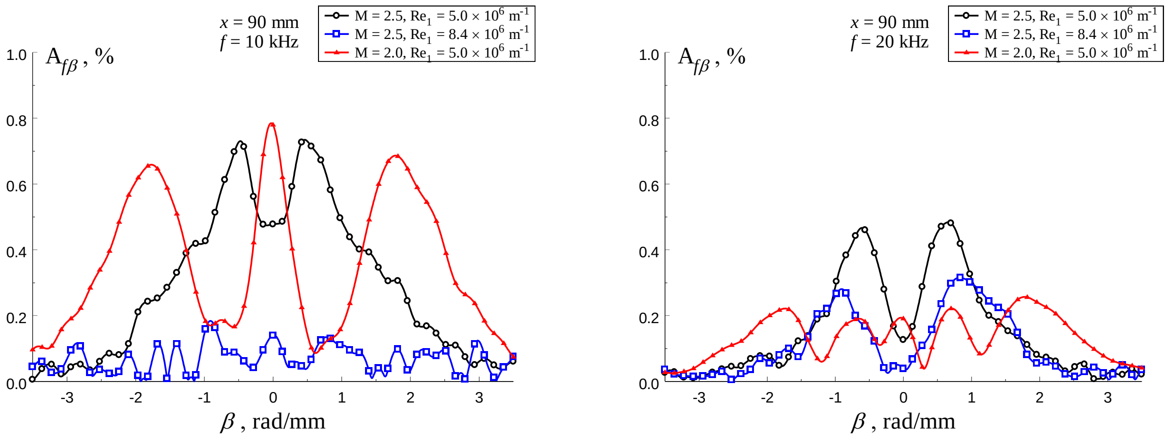

Figure 3. Comparison of amplitude wave spectra over β at X = 90 mm
for subharmonic wave train (f = 10 kHz - left) and fundamental wave train (f = 20 kHz - right)

References

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