INFLUENCE OF EXTERNAL DISTURBANCES ON NONLINEAR PROCESSES OF THREE-DIMENSIONAL SUPERSONIC BOUNDARY LAYER

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The problem of turbulence beginning in 3-D boundary layers is very interesting for the practical applications (similar boundary layers are observed in the flow around a swept wing of an airplane), and, on the other hand is very complicated. It is well-known [1] that high-amplitude crossflow waves are subject to a high-frequency secondary instability preceding breakdown to turbulence in swept wing boundary layers. Currently, the secondary instability is investigated experimentally (only for subsonic flows) and theoretically (and for the compressible too) in different countries. Compare results of supersonic stability experiments on swept wing [2] with subsonic case, note, that so excitation and fast growth of high-frequency disturbances with a frequency one order higher than the fundamental disturbance in our supersonic experiments was not observed.

The experiments were made in a supersonic wind tunnel T-325 of the ITAM with test section dimension 200×200×600 mm at Mach numbers M=2 and 2.5 at unit Reynolds numbers $Re_1=5\times10^6$ m^{-1}. Model was a symmetrical wing with a 45° sweep angle, a 3-percent-thick circular-arc airfoil. The model length was 0.4 m, its width was 0.2 m, and the maximum thickness was 12 mm. The disturbances were measured by constant temperature hot-wire anemometer. The frequency spectra of disturbances were determined by the discrete Fourier transformation. To determine the nonlinear interaction of perturbations used well-known fact, that the Gaussian signal indicate a linear process (linear independence of the harmonic components of the signal), and any significant deviation from the normal distribution is the nonlinearity of the process. Evaluation for normality of probability density distribution was carried out according [3]. The estimates of “skewness” and “kurtosis” of the measured pulsation signals were made. Was designed and tested source of external disturbances (such sources are used at subsonic speeds). Vortex perturbations produced by a wire of various diameters, stretched in front of nozzle inserts. The experiments used a wire with a diameter d = 0.63 mm, 0.95 mm, 1.9 mm and 3 mm.

Evolution of pulsations in supersonic boundary layer of swept wing was investigated in detail for the cases with the source of external disturbances or without it. Oscillograms, amplitude-frequency spectra, mean velocity profiles, pulsation profiles and statistical diagrams were obtained for the all cases.

Up to the values of the longitudinal coordinate x = 140 mm ($Re_x=0.7\times10^6$) estimation of “skewness” and “kurtosis” were close to zero in the case without the source of disturbances. At first the significant deviations of “skewness” and “kurtosis” below the critical layer were observed at x = 140 mm. Further downstream ($Re_x=0.9\times10^6$), these deviations increased and were observed above and below the critical layer, and near the surface of the model. Comparing the results of statistical analysis and analysis of amplitude-frequency spectra was performed. Fluctuations grow at the frequency range from 8 to 35 kHz in the region of linear evolution of disturbances at M=2. It can be assumed that the growth of high-frequency part of the spectra (f > 35 kHz) is caused by the mechanism of secondary instability at supersonic speeds for M = 2. Similar analysis, but no so detailed was performed for the experimental data obtained at M = 2.5. Fluctuations grow at the frequency range from 8 to 45 kHz in the region of linear evolution of disturbances at M=2.5, and high-frequency part of the spectra (f > 45 kHz) increase in nonlinear region of disturbances evolution.

It was found that in the presence of the source of disturbances, weakly nonlinear processes with d = 0,95 mm and strongly nonlinear processes with d = 3 mm was observed in the initial section x = 50 mm. Nonlinear processes in three-dimensional boundary layer on a swept wing (where cross flow lead to distortion of mean flow) can cause the mechanism of secondary instability and lead to early transition.

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