EXPERIMENTAL STUDY OF LOCALIZED DISTURBANCES AT STRAIGHT WING BOUNDARY LAYER

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Summary Turbulence production processes in boundary layer at high level of free-stream turbulence have been studied experimentally. The longitudinal localized disturbances arising in the boundary layer under the action of free-stream turbulence were artificially modeled from the incoming flow using a blowing-suction technique. Wave packets, or forerunners, produced in the boundary layer, in the region preceding the abrupt local change of flow velocity near the longitudinal disturbance fronts, were examined.

INTRODUCTION

Laminar-turbulent transition is observed in various shear flows, such as boundary layer flows, jet flows, and channel flows. Interest expressed by workers in studying the transition process is due to the applied aspect, including drag and noise reduction for aircraft, and also due to the desire to gain new fundamental data capable of clarifying the presently available physical picture of the phenomenon. In recent years, much attention has been given to the study of longitudinal localized disturbances, or structures, developing in boundary layer under the action of high free-stream turbulence. Such structures create conditions for the development of high-frequency wave disturbances (secondary instability, forerunners) that can subsequently transform into turbulent spots; as a result, the boundary-layer flow changes its state from laminar into turbulent [1,2]. Experiments under natural conditions fail to give exhaustive answers to posed questions because the emergence of boundary-layer disturbances is a stochastic process, and in most cases it is almost impossible to trace the origin and subsequent evolution of a particular disturbance. For a detailed study, longitudinal structures, or localized disturbances, are to be artificially modeled in boundary layer. The present work was aimed at an experimental study of wave packets, or forerunners, formed in boundary layers, in regions preceding the abrupt local change of flow velocity inside boundary layer (local-disturbance fronts).

EXPERIMENTAL TECHNIQUE

The experiments were carried out at the MT-324, subsonic wind tunnel of ITAM SB RAS, whose test section had dimensions 200×200×800 mm. The free-stream velocity was U_∞= 3.2 m/s, free-stream turbulence level Tu = 0.18 % U_∞. The study was performed on model of straight wing with chord C_1 = 290 mm. The model was installed in the middle of the test section under angle of attack α = -1.2°. The local disturbances were introduced from the incoming flow into the boundary layer by air blowing from thin pipe, located at 3 mm upstream of the model nose (see Fig. 1).

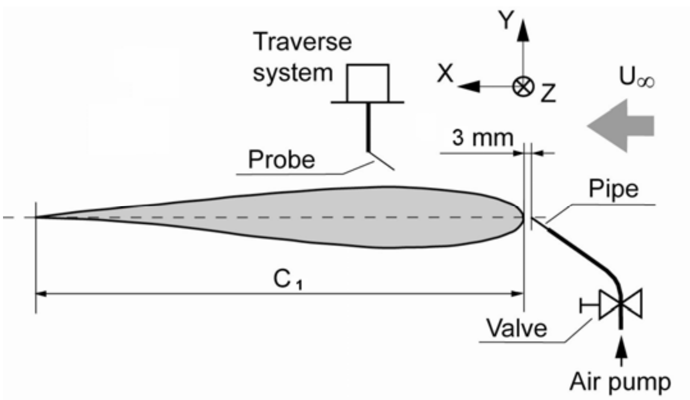

Fig. 1. Experimental geometry. C_1 = 290.

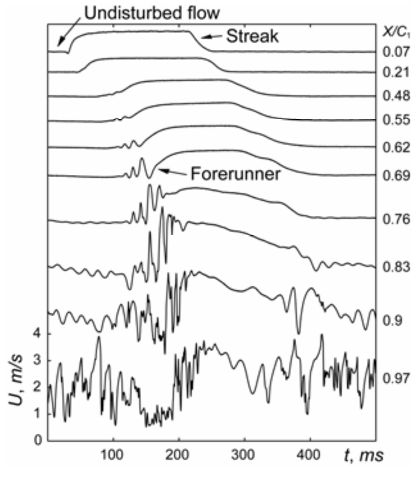

Fig. 2. Time traces of the hot-wire signal inside the boundary layer at Z=0 mm. $Y=Yu_{max}$.

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The blowing pulse length was regulated by a fast solenoid-controlled valve synchronized with the signal recording system. Measurements were performed with a single-wire sensor, with the help of a Dantec constant-temperature hot-wire anemometer (model 54T30). Measured quantities were the mean (U) and fluctuation (u) components of the longitudinal flow velocity. The analog signal from the hot-wire anemometer synchronized with the moment at which artificial disturbances were introduced into the boundary layer was converted into digital form by an L-Card E14-440 analog-to-digital converter, to be subsequently recorded as a file in PC memory. The sensor was positioned in the flow with the help of an automanual traversing gear, the positioning accuracy of the probe along the X, Y, and Z coordinates being 0.5, 0.005, and 0.5 mm, respectively.

EXPERIMENTAL RESULTS

The measurement flow field over the profile show that the area of $0 < X/C_1 < 0.35$ represent a flow with favorable pressure gradient, and $0.35 < X/C_1 < 1$ is area with unfavorable pressure gradient. Air pulse from the pipe comes into the boundary layer and result in streak (longitudinal localized disturbance) appearing. The time traces (see Fig. 2) represents a downstream evolution along the chord of the streak and forerunner, which is a high frequency wave packet, appearing near the fronts of streak. Wave packet (forerunner) start to extremely grow at the area with unfavorable pressure gradient. Near the $X/C_1 \approx 0.8$-0.9 we see a signal, typical for the turbulent spot. The natural turbulence starts later, after $X/C_1 \approx 0.9$. It should be noted, that in [3] the natural wave packets at the flat plate boundary layer at weak turbulence level are also observed. Those wave packets becomes a Λ-structure if its frequency reach the unstable area of the neutral stability curve. Next, we examined the flow fields in the planes $Z/\delta - t$ and $Y/\delta - t$ inside the boundary layer. In the vicinity of the leading front of the streak, a high-frequency wave packet, or forerunner, is generated (Fig. 3). Presented here are contour lines of fluctuation velocity over the wing span in the downstream region of the disturbance source at $X/C_1 = 0.9$ represent a spatial geometry and certain features of their development.

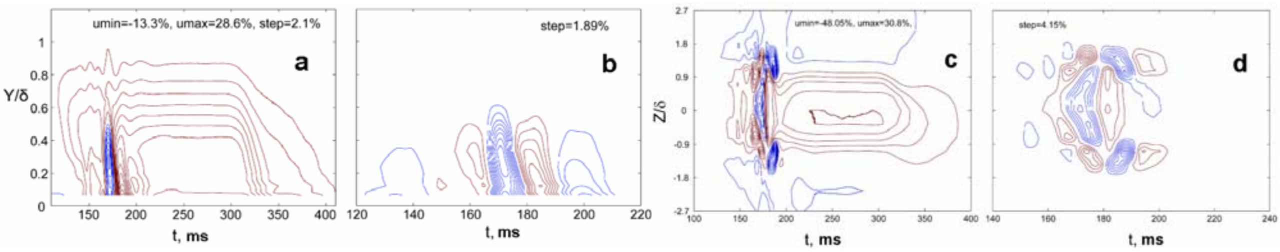

Fig. 3. Hot -wire visualization of boundary layer disturbances. Contour lines of velocity fluctuations in the $Y/\delta - t$ plane at Y = Yumax, Z=0, (a, b) and $Z/\delta - t$ plane (c, d) at $X/C_1 = 0.9$; (b, d) – filtered signal.

As was shown in [2], the forerunners of localized disturbance fronts normally emerge as packets of Tollmien - Schlichting (TS) waves. In fact, a forerunner is a result of the action of the rectangular pulse (unsteady blowing) on the boundary-layer flow. Owing to dispersion, the leading and trailing edges of the rectangular pulse grow separated over frequencies, of which most unstable ones undergo amplification in the boundary-layer flow. The forerunners, as they evolve in the boundary layer, were found to transform in the downstream region into Λ−structures (Fig. 3, d), thus leading to turbulence production via the formation of a turbulent spot.

CONCLUSIONS

The results of the study make reason to consider the forerunners as wave packets of 3D instability (T-S) waves. It was observed that the forerunners are strongly amplified in the adverse pressure gradient flow being much influenced by local velocity gradients. It was found that at downstream development of the forerunners they transform into so - called Λ-structures.

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