EXPERIMENTAL INVESTIGATION OF THE STABILITY OF A SUPERSONIC BOUNDARY LAYER ON A PLATE WITH BLUNTING OF THE LEADING EDGE

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In an aerodynamic tube, an experimental investigation of the development of small natural perturbations in a laminar boundary layer on a plate was made. The measurements were made using a thermoanemometric method with a Mach number $M_\infty = 2$ and a unit Reynolds number $Re_1 = 3.1 \times 10^6$ m$^{-1}$. An investigation of the effect of blunting of the leading edge of the plate on the development of the perturbations was made. It is shown that blunting decreases the range of unstable frequencies and the region of instability and increases the critical Reynolds number of the loss of stability. In the initial section of the plate there is a rise in the perturbations of all frequencies up to a maximal value, whose coordinate is inversely proportional to the frequency. The development of perturbations in this region is insensitive to the state of the boundary layer. The position of the maximum does not change with blunting of the leading edge.

INTRODUCTION

The carrying out of experiments on the study of the initial stage of the transition of a supersonic laminar boundary layer to a turbulent boundary layer is subject to great difficulties. Very rigid requirements are imposed on the aerodynamic tubes, the mechanical equipment, and the electronic apparatus. This obviously explains the fact that investigations [1-3], carried out at the California Institute of Technology, exhaust practically all the known experimental works on the development of perturbations in a laminar boundary layer with supersonic velocities.

In these works, the principal conclusions of the theory of hydrodynamic instability were confirmed. The further study of the initial stage in the development of the perturbations can clarify the effect on the transition of a laminar boundary layer into a turbulent one of factors which have been brought out in a great number of experiments [4].

Thus, a small degree of blunting of the leading edge of the model leads to a considerable shift of the transitional zone and to an increase in the Reynolds number of the transition [4-6]. In [6] it is noted that the sources of such a behavior of the transitional zone may lie in a change in the characteristics of the stability of the laminar boundary layer. An experimental verification of this postulation has obviously not been given.

§ 1. In the present work, an experimental investigation of the development of small perturbations in a laminar boundary layer with a Mach number of the oncoming flow $M_\infty = 2$ for a plate with a sharp leading edge $b=0$ (it is difficult to monitor the thickness of the leading edge as $b \rightarrow 0$; therefore, in actuality, a plate with $b \geq 0.02$ mm was used), as well as for plates with bluntings $b = 0.2-0.4$ mm was made. Such bluntings have the most considerable effect on the position of the transitional zone, shifting the transition by more than a factor of two in comparison with a sharp edge [5].

The experiments were made in a T-325 aerodynamic tube at the Institute for Theoretical and Applied Mechanics of the Siberian Branch of the Academy of Sciences of the USSR [7]; the dimensions of the working part were $200 \times 200$ mm and the experiments were made for a unit Reynolds number, calculated for a length of 1 m, of $Re_1 = 3.1 \times 10^6$. The turbulence in the oncoming flow was determined by the level of the noise radiated by the boundary layer at the walls of the nozzle and the working part, and, for pulsations of the pressure, was $\sim 0.3-0.4\%$. The parameters of the flow were determined using standard measuring instruments of class 0.5, with which the unit was equipped [7]. The mean-square error in the determination of $Re_1$ did not exceed $\pm 2\%$.

The measurements were made on a model of a steel plate (thickness 10 mm) of trapezoidal form in a plan view, with bases of 170 and 60 mm and a length of 220 mm. The edges of the plate were sharpened at an orientation...
angle of 14°30'. The plate was rigidly attached to the side wall of the working part of the aerodynamic tube using a pylon and was mounted at a zero angle of attack in the central plane of the large base of the trapezoid.

Along one of the side walls of the plate, at a distance of 20 mm from the edge, there were drainage openings with a diameter of 0.3 mm for measuring the distribution of the static pressure, which was recorded using a GRM-2. The absolute error in measurement of the distribution of the pressure was 10 mm water column.

Examples of the distribution of the coefficient of the pressure $k = \Delta P / q_\infty$ along the plate are shown in Fig. 1 (here and in what follows, the numbers 1-3 relate to bluntings $b = 0, 0.2$, and 0.4 mm, respectively); $q_\infty$ is the velocity head, determined from the parameters of the oncoming flow; $\Delta P = P - P_\infty$; $P_\infty$ is the static pressure in the oncoming flow; $\Delta x = x - x_0$; $x$ is a longitudinal coordinate, reckoned from the leading edge; and $x_0$ is the coordinate of the first drainage point, equal to 8.6, 7.8, and 7.0 mm for bluntings of $b = 0, 0.2$, and 0.4 mm.

As can be seen from Fig. 1, the distribution of the pressure along the plate remained unchanged, within the limits of the accuracy of the measurements, for different bluntings. The nonuniformity of the static pressure was determined either by the imperfection of the drainage openings or by the nonuniformity of the distribution of the static pressure in the external flow.

The development of the perturbations in the flow was recorded with a TPT-2 direct-current thermoanemometer [8]. The measurements were made with a wire-type pickup made of gold-plated tungsten (diameter of the filament, 6 μ; length, ~1 mm), which could be moved freely along the direction of the flow with an accuracy of ±0.1 mm and along a normal to the surface of the plate with an accuracy of ± 0.01 mm. The pulsations of the voltage at the pickup were fed from the output of the thermoanemometer to a spectrum analyzer made by the firm Bruel and Kjaer (type 2010), which measured the total mean-square signal $\langle \varepsilon \rangle$ and its values at discrete frequencies $\langle \varepsilon_f \rangle$. The transmission band was selected with a width on the order of 1% of the frequency for which the measurements were made.

§2. The method of conducting the experiment was analogous to that described in [1]. In the last cross section along $x$ ($x = 70$ mm) the pickup of the thermoanemometer was displaced along a normal to the surface and the maximum of the mean-square value $\langle \varepsilon \rangle$ was determined. A maximum was observed for all cross sections along $x$ at which measurements were made, including that closest to the tip of the plate $x = 4$ mm.