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LAMINARIZATION OF A BOUNDARY LAYER IN A SUPERSONIC NOZZLE BY COOLING OF THE SURFACE

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16. Abstract

The concept of cooling of the surface of the walls of a wind tunnel in order to laminarize the boundary layer, and thereby eliminate perturbations in the working area, is discussed in the article. Equations are given, which are used to calculate the temperature conditions under which the flow in the boundary layer will be stably laminar.

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LAMINARIZATION OF A BOUNDARY LAYER IN A SUPERSONIC NOZZLE BY COOLING OF THE SURFACE

V. P. Maksimov and A. A. Maslov

The basic source of perturbations in the working portion of a supersonic wind tunnel is the noise of the turbulent boundary layer on its walls. This noise is considerably less if the current in the boundary layer of the nozzle in the working portion is laminar. One of the means of laminarization of the boundary layer may turn out to be cooling of the surface. Given in study [1] is a program of calculation which makes it possible to find the distribution of surface temperatures, which ensure a stable laminar flow in the boundary layer above a weakly-distorted surface. /110*

In the majority of the known cases, the transition of a laminar boundary layer to a turbulent layer is preceded by a loss of stability of the laminar flow, determined by the critical Reynolds number of the loss of stability Re_{cr}. Therefore, it is assumed that a sufficient condition for existence of a laminar condition of the flow is fulfillment of the relationship /112

$$Re_{x} \leqslant Re_{\kappa p} \qquad (1)$$

Here, Re_x is the Reynolds number, calculated along the longitudinal coordinate.

Cooling of the surface makes the boundary layer more stable, and increases Re_{cr}, i.e., one may determine that surface temperature distribution with which condition (1) will be fulfilled for any value of x (ratio of the longitudinal coordinate to the length of the nozzle). In the given study, the interval of integration according to x was divided into sections, and Re_{cr}

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*Numbers in the margin indicate pagination in the foreign text.

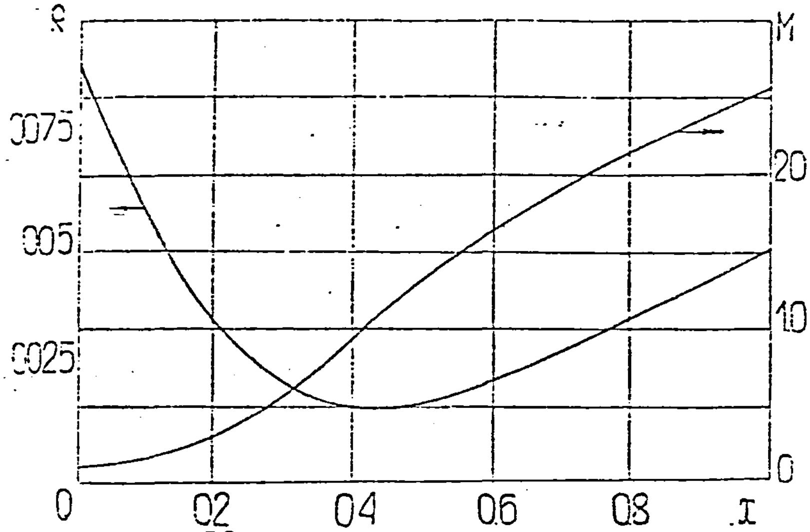

Fig. 132

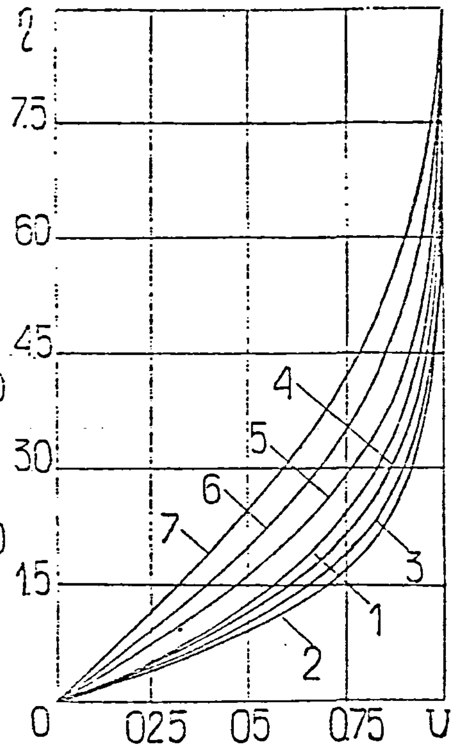

Fig. 133

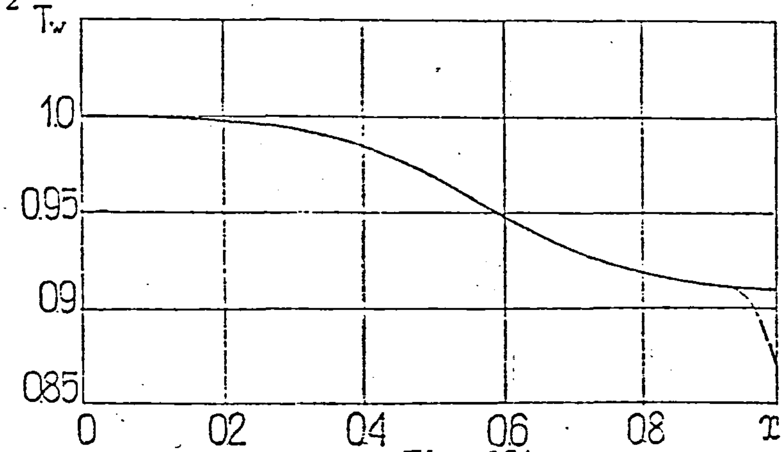

Fig. 134

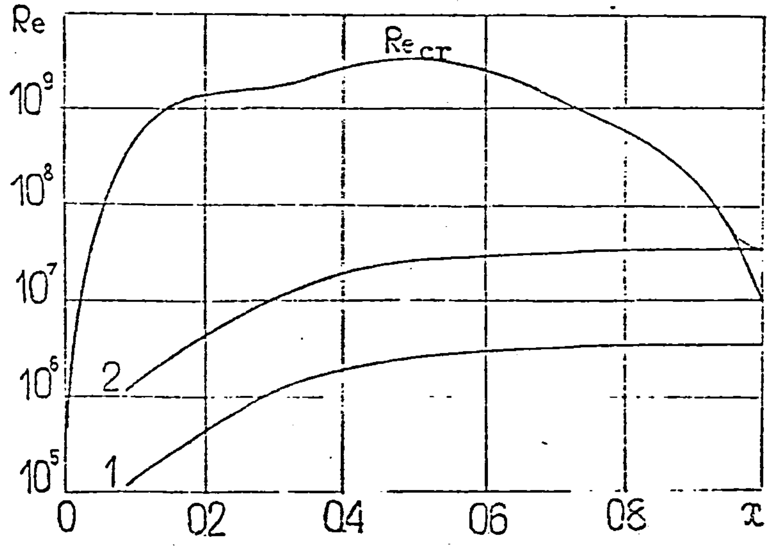

Fig. 135

was determined at the end of each section. If condition (1) was not fulfilled, then the surface temperature in this section was decreased. In order to determine Re_{cr} numerically, the stability equations of Dan and Lin were integrated for three-dimensional perturbations by the method described in [2]. An axiosymmetric boundary layer was calculated numerically by the method of I. V. Petukhov [3], the realization of which and the algorithm being described in detail in [4].

The calculation was carried out for an axiosymmetric nozzle 36 cm in length, the dependence of the Mach number M(x) and the radius R(x) for which are shown in Figure 132. Given in Figure 133 are the profiles of velocity $U(\eta)$ (η is the Blasius variable) for the thermally-insulated surface of the walls of the nozzle. The numbers from 1 to 7 denote the profiles which correspond to x=0.139; 0.278; 0.417; 0.556; 0.695; 0.834; 0.973. The distribution of the temperature factor T_w (ratio of the surface temperature to the temperature at the input to the nozzle) according to x, in this case, is given in Figure 134 by the solid line. The calculation was carried out for a braking temperature T_o=300° K. The dependences $Re_{cr}(x)$ and $Re_x(x)$ are presented in Figure 135. The numbers 1 and 2 designate the distributions of Re_x for braking pressures P_o equal to 1 absolute atmosphere and 10 absolute atmospheres, respectively. For the case P_o=1 absolute atmosphere, the curves of Re_{cr} and Re_x do not intersect. With an increase in P_o, the values of Re_x for the fixed x and T_o increase proportionally to the pressure. Then, fulfillment of the condition $Re_{cr}=Re_x$ for x=1 (nozzle edge) makes it possible to determine the maximum braking pressure, at which the flow in the boundary layer on the wall of the nozzle will by stably laminar. In the examined case, P_{omax}=2.85 absolute atmospheres.

If $P_o>P_{omax}$, then, in order to maintain the laminar flow in the boundary layer, it is necessary to reduce the surface temperature. The examined nozzle is designed for a pressure of up to 10 absolute atmospheres. Then, the stability should be lost near the nozzle edge. The distribution of the temperature factor, necessary for maintaining the laminar flow in this case, is given in Figure 134 by the dotted line. The dotted line in Figure 135 denotes the corresponding distribution of $Re_x(x)$.

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