EFFECT OF THE PROPERTIES OF A POROUS COATING ON BOUNDARY LAYER STABILITY

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16. Abstract

Drawing off gas from the boundary layer is a well-known method for increasing the stability of boundary layers. The increase in stability is primarily connected with a change in the velocity profile form in the case of suction. An analysis of increasing the stability due to a change in the profile form was made in [1-3]. In these studies, it was assumed that the velocity perturbations on a porous surface equals zero. Since the surface is permeable, more general boundary conditions must also be used. On the basis of the assumption that the velocity perturbations on a porous slate do not equal zero, this article investigated the influence of the properties of a permeable surface upon the boundary layer stability.

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EFFECT OF THE PROPERTIES OF A POROUS COATING ON BOUNDARY LAYER STABILITY /21*

S. A. Gaponov

Drawing off gas from the boundary layer is a well-known method for increasing the stability of boundary layers. The increase in stability is primarily connected with a change in the velocity profile form in the case of suction. An analysis of increasing the stability due to a change in the profile form was made in [1-3]. In these studies, it was assumed that the velocity perturbations on a porous surface equal zero. Since the surface is permeable, more general boundary conditions must be used. On the basis of the assumption that the velocity perturbations on a porous plate do not equal zero, this article investigated the influence of the properties of a permeable surface upon the boundary layer stability.

1. Let us assume that in the boundary layer we introduce perturbations of the type $\varphi(\eta)\exp(i\alpha(x-ct))$. In this case, the amplitude of the flow function $\varphi(\eta)$ satisfies the Orr-Summerfeld equation:

$$(U-c)(\varphi''-\alpha^2\varphi)-U''\varphi=\frac{1}{i\alpha \mathrm{Re}}(\varphi^{IV}-2\alpha^2\varphi''+\alpha^4\varphi). \qquad (1.1)$$

Here, U is the longitudinal velocity distribution in the boundary layer; c - perturbation propagation rate; α - wave number of the perturbation; Re - Reynolds number.

The solution of equation (1.1) must be damped at infinity

$$\varphi(\infty)=\varphi'(\infty)=0. \qquad (1.2)$$

In the case of a non-permeable surface, it is necessary that φ and φ' equal zero on this surface. For a surface which is permeable in the normal direction, the more general conditions must be used

*Numbers in margin indicate pagination in foreign text.

$$\varphi'(0)=0,\quad i\alpha\varphi(0)/p(0)=Y, \tag{1.3}$$

where p(0) is the pressure perturbation on the plate; γ - a certain proportionality coefficient. The first of the equations (1.3) corresponds to the nonslippage condition; the second describes the permeability law. Using the equation of motion, we may replace condition (1.3) by

$$\begin{gathered}\varphi'(0)=0,\\ \left(U'(0)-\frac{i\alpha}{Y}\right)\varphi(0)=-\frac{1}{i\alpha\,\mathrm{Re}}\cdot\varphi'''(0).\end{gathered} \tag{1.4}$$

Thus, the problem of stability is reduced to solving the problems (1.1), (1.2), (1.4). Conditions (1.4) are very close to the conditions obtained on a bent plate which is compliant in the normal direction [4].

Problems (1.1), (1.2), and (1.4) may only be solved on a computer. However, certain important properties may be calculated on the basis of an asymptotic method [5]. According to [5], we obtain the /22 characteristic equation

$$F(z)=\frac{(1+\lambda)(u+iv)}{1+\lambda(u+iv)+YU'(0)\frac{i}{z}}. \tag{1.5}$$

Here, F(z) is a modified Tithen function.

$$\lambda=\frac{U'(0)}{c^{3/2}}\left[\frac{3}{2}\int_0^{\eta_c}(c-U)^{1/2}\,d\eta\right]-1,$$

$$z=(\alpha\,\mathrm{Re})^{1/3}\left[\frac{3}{2}\int_0^{\eta_c}(c-U)^{1/2}\,d\eta\right]^{2/3}.$$

The function u + iv was determined in [6]. At Y = 0, the equation (1.5) completely coincides with the equation for a nonpermeable surface (see [6]).

2. To determine Y, we will use the following model. Let us assume the plate is permeable in the normal direction (perforated type). The pores have a cylindrical form. The possibility of replacing pores of an arbitrary form by pores of a cylindrical form was

studied in [7].

Examining the flow in an individual pore with a pressure drop, which changes in time according to the law $\exp(-i\alpha c\tau)$, and using the results given in [8], we may show that

$$\bar{v} = -\frac{p(0) - p_0}{i\alpha c H} \cdot \frac{J_2(\sqrt{i\alpha c \,\mathrm{Re}}\, r_1)}{J_0(\sqrt{i\alpha c \,\mathrm{Re}}\, r_1)}. \tag{2.1}$$

All of the quantities are dimensionless: H - plate thickness; r_1 - pore radius; $p(0) - p_0$ - perturbation of pressure drop; v - perturbation of flow through the pore. We selected the following as the characteristic dimensional quantities; ρU^2_∞ - pitot head pressure; δ - thickness of boundary layer; U_∞ - velocity at the external boundary of the boundary layer. Instead of $\bar{v}$, it is advantageous to introduce the following:

$$v = n\bar{v}, \tag{2.2}$$

where v is the velocity perturbation averaged over the entire suction surface; n - porosity (portion of the permeable sections in the entire surface area). In order to exclude p_0 (pressure perturbations on a plate at the side of the suction chamber), we must use the solution of the equation for perturbations within the suction chamber

$$\varphi^{IV} - 2\alpha^2\varphi'' + \alpha^4\varphi = -i\alpha c\,\mathrm{Re}\,(\varphi'' - \alpha^2\varphi) \tag{2.3}$$

The flow velocity U in the suction chamber is assumed to equal zero.

It follows from the damping condition φ and φ' at $\eta = -\infty$ (here it is assumed that the suction chamber dimensions are much greater than the thickness of the boundary layer) as well as from the fact that the longitudinal velocity perturbations on a porous plate equal zero, that

$$p_0 = \left(i\alpha c - \frac{\alpha^2}{\mathrm{Re}}\right)\frac{\alpha + \gamma}{\alpha\gamma}\, v(0). \tag{2.4}$$

Here, $\gamma = +\sqrt{-i\alpha c\,\mathrm{Re} + \alpha^2}$. The sign is selected so that $\mathrm{Re}(\gamma) > 0$. We may readily find from (2.1) and (2.4),

$$Y = -\frac{Q}{1 + XQ}, \tag{2.5}$$

where

$$Q = -\frac{n}{i\alpha c} \cdot \frac{J_1\left(\sqrt{i\alpha c\,\mathrm{Re}}\; r_1\right)}{J_0\left(\sqrt{i\alpha c\,\mathrm{Re}}\; r_1\right)}, \quad X = \left(i\alpha c - \frac{\alpha^2}{\mathrm{Re}}\right)\frac{\alpha + \gamma}{\alpha\gamma}.$$

3. The problem (1.1), (1.2), (1.4) was solved for the velocity profile $U = 1 - \exp(-y/\delta^*)$, where δ^* is the displacement thickness. The Orr-Summerfeld equation was integrated by the method of orthogonalization [9]. The wave numbers and the Reynolds numbers were compiled from the displacement thickness. The radii of the pores and the thickness of the porous covering were referred to the thickness of the layer $\delta = 5\delta^*$ and $\delta = 5\delta^*$.

Calculations showed that at $n/H = 3 \times 10^{-3}$ and $r_1 = 10^{-1}$, there are two neutral stability curves (Figure 1). The dashed line, which corresponds to the case when the velocity perturbations equal zero at the wall, was drawn for purposes of comparison. The existence of two neutral curves for small values of n/H and very large values of r_1 may be shown by using equation (1.5). When n/H increases, the disappearance of one neutral curve is possible. For example, for $n/H = 0.1$, and $r_1 = 0.02324$, there is only one neutral curve (Figure 2).

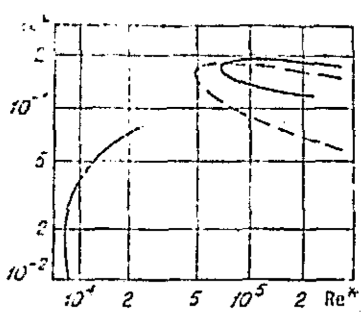

Figure 1

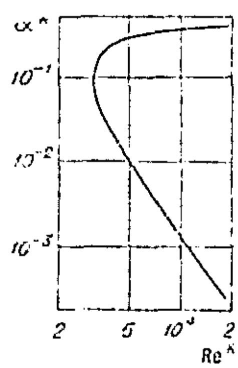

Figure 2

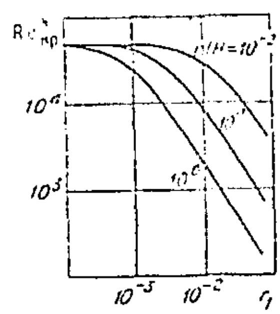

Figure 3

The results of calculating the critical Reynolds number for several values of n/H are given in Figure 3 as a function of r_1.

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