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FLOW AROUND TRANSVERSE SLOTS

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An inspection analysis of a plane two-scale problem on a stationary laminar flow around an array of slots has been carried out on the assumption that the internal scale, representing the spacing of the slots, is small compared to the external scale of the global problem. Topological and asymptotical classifications of the structure of a boundary layer have been developed with consideration of the rate of the boundary-layer suction and the spacing of the slots. The dependence of the multizone structure of a boundary layer with discontinuously distributed suction on the width of the slot and the rate of the suction was investigated. A mathematical model of a nonviscous compressible-gas flow in the weak-interaction and strong-interaction regimes is proposed.

Introduction. As early as 1904, Prandtl proposed to use the suction of the boundary layer of a flow around an airfoil for laminarization of this flow or liquidation of its separation [1]. The suction of a boundary layer 1 through a system of closely spaced transverse slots 2 positioned in the region AA of an airfoil (Fig. 1) is considered as most promising. Despite the fact that optimistic estimates were made and intensive laboratory investigations were carried out, until the present time boundary-layer suction has not been introduced into aviation practice. The discrete suction of air through a single slot in an airfoil or in the wall of a wind tunnel is considered as inefficient. The self-suction through two connecting slots is used for weakening of the transonic shock wave arising between them [2].

The idea of using a fluid flowing through the walls 1 of a transonic wind tunnel for weakening the influence of the boundaries of the flow around an array of slots 2 (Fig. 2) on the character of this flow has long been introduced into practice; however, up till now, a mathematical model of this process has not been developed [3]. Figure 2 shows a schematical representation of the actual distribution of the vertical velocity component along the longitudinal coordinate x on the upper wall of such a tunnel (a) and this distribution averaged over the spacing of the slots (b) as well as the profile of the longitudinal velocity u.

Structure of a Boundary Layer with Continuous Suction. We will consider a stationary plane laminar flow of an incompressible Newtonian fluid propagating with a velocity u_∞ around an array of slots positioned in the plane $y = 0$. The length scale l characteristic of this flow will be assumed to be large compared to the spacing of the slots τl, where $\tau << 1$. The case where $\tau = O(1)$ formally corresponds to discrete suction through a finite number of slots, and the case where $\tau = 0$ corresponds to suction through an ideal porous medium. It will be assumed that the external flow characterized by the scale l is nonviscous: $\delta^{-2} = \mathrm{Re} = u_\infty l/\nu >> 1$. The internal flow with a scale τl is characterized by the number $\mathrm{Re}_1 = \tau\mathrm{Re}$.

The existence of suction complications the flow, which leads to its layering — it becomes multizonal [4]. It is apparent that, in the case being considered, the number of zones can be as large as 3: a nonviscous-flow zone, a boundary layer, and a suction zone. To obtain more strict conclusions, we resort to the asymptotic analysis; in this case, the quantities l, u_∞, and ρ will be used as the base parameters and the x axis will be directed along the slot array and the y axis along the normal to it. Then, the equation for the transfer of the vorticity $-\Delta\psi$ (ψ is the stream function, $\Delta = \partial^2/\partial x^2 + \partial^2/\partial y^2$) in a gradient-free flow will take the form

$$[\Delta\psi, \psi] = \delta^2\Delta^2\psi\,, \tag{1}$$

where the operator on the left side of the equation is a Poisson bracket.

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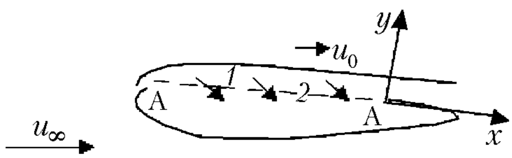


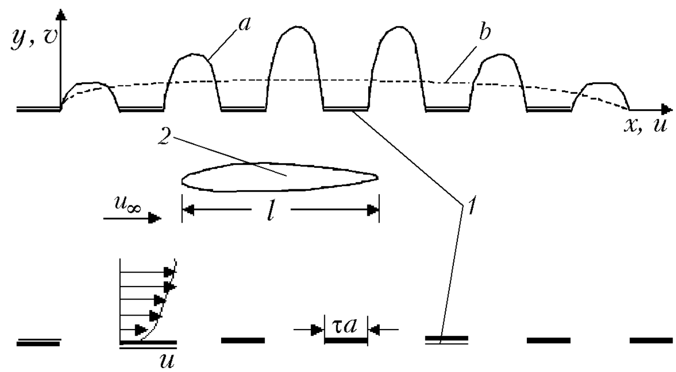


Fig. 1. Scheme of the continuous suction.

Fig. 2. Perforated working part of a wind tunnel.

It is assumed that the ordinal value of the suction rate $v(x, y) = -\partial\psi/\partial x = \varepsilon v_0(x) = O(\varepsilon)$. The problem includes four determining parameters, three of which — δ, τ, and ε — are small. The fourth parameter is the penetration coefficient of the slot array μ, which is assumed to be finite: $\mu = 1 - a/l = O(1)$, where τa is the length of the panel.

Let us introduce some definitions. The layer located above the slot array will be considered as the main boundary layer (layer 1). Here, the usual expansion $\psi(x, y) = \delta\psi_1(x, y) + O(\delta)$, where $y = \delta y_1$, is true. The subscript denotes the number of a zone. The near-wall region with a longitudinal size $O(\tau)$ is assumed to be local. To describe the flow in this region, we will introduce the "rapid" variable $\xi = (x - m\tau)\tau^{-1}$, where $m = 1, 2, 3, \ldots$ is the number of a slot. It is assumed that there are two such regions: a "square" local zone 2, where $y_2 = y/\tau = O(1)$, and a local boundary layer combined with a local mixing layer 3, where $y_3 = y/\beta = O(1)$; $\beta \ll 1$ is an unknown thickness of the boundary layer.

Depending on the pressure differential across the slot array, we will separate the characteristic regimes of flow at a weak suction ($\varepsilon \ll \delta$), a moderate suction ($\varepsilon = \delta$), and a strong suction ($\varepsilon \gg \delta$). Let us consider, first, the case of moderate suction.

1. If $\tau \gg \delta$ (a coarse slot array), the thickness of the local zone 2 exceeds the characteristic thickness of the main boundary layer 1. Here, the flow is nonviscous because the inertial terms are larger in order of magnitude than the viscous terms:

$$u\frac{\partial u}{\partial x} = O(\tau^{-1}) \gg \delta^2 \frac{\partial^2 u}{\partial y^2} = O(\delta^2\tau^{-3}),$$

where $u = \partial\psi/\partial y$ is the longitudinal velocity component. In this case, the suction represents a linear addition to the uniform flow (the regime of boundary-layer outflow). Different schemes of an ideal-liquid flow are known. Of these schemes, only the Helmholtz scheme of a flow with free boundaries at both edges of an airfoil (Fig. 3a) adequately describes the flow in the laminar region of a jet.

The adhesion condition is not fulfilled at the solid boundaries of zone 2. Therefore, here there arises a local boundary layer 3 that goes into the mixing layers (shown by the dashed lines) framing the free boundaries of the flow. The region of $y < 0$ represents a multicoat "pie" consisting of such layers. For estimating the thickness of a local boundary layer β, we will equate the orders of magnitude of the viscous and nonviscous terms in Eq. (1):

$$\frac{1}{\tau} = \frac{\delta^2}{\beta^2}.$$

It follows herefrom that $\beta = \delta\tau^{1/2}$. Since vorticity is absent in the layer of thickness $O(\delta)$, the notation of the main boundary layer loses its meaning because this layer outflows completely through the slot array into the suction chamber.

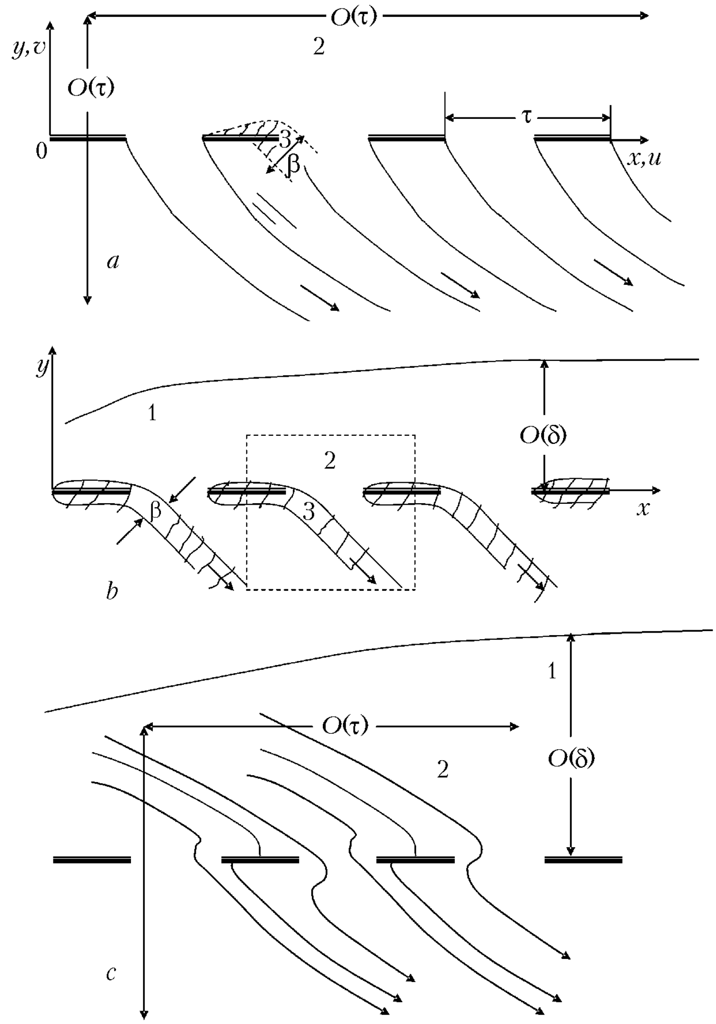


Fig. 3. Scheme of an outflow at a moderate suction in a coarse slot array (a), in a moderate-spacing slot array (b), and in a fine slot array (c).

2. If $\delta^{3/2} \ll \tau \ll \delta$ (a moderate-spacing grid), the main boundary layer 1 is located above the local zone 2, as shown in Fig. 3b. It is formed at $\tau \ll \delta$; therefore, $\tau = \delta$ is a lower critical value for the existence of the classical conception on a boundary layer with a suction [5].

At $y_1 \to 0$, we have $u_1 \to \lambda y_1 = \lambda y_2 \dfrac{\tau}{\delta}$, where $\lambda = O(1)$ is the friction at the bottom of the main boundary layer. From the condition of joining of the velocities of the flows in regions 1 and 2 we find that $u_2 = O(\tau/\delta)$. In zone 2, the flow continues to be nonviscous but whirling. The same estimate determines the order of the velocity of the slip flow at the bottom of the main boundary layer $O(\tau/\delta)$.

The main approximation of the stream function in zone 2 has the order $O(\tau^2/\delta)$. An addition to the main approximation, responsible for the fluid suction, has the order $O(\tau\delta)$. Therefore, the vorticity transfer is of primary importance as compared to the fluid flow through the slots. Since the flow is nonviscous here, the adhesion condition is not fulfilled at the solid walls. Therefore, it is necessary to introduce a local boundary layer 3, the thickness of which β is determined from the balance between the inertial and viscous terms of Eq. (1):

$$\frac{1}{\tau}\left(\frac{\tau}{\delta}\right)^2 = \frac{\delta^2}{\beta^2}\frac{\tau}{\delta}.$$

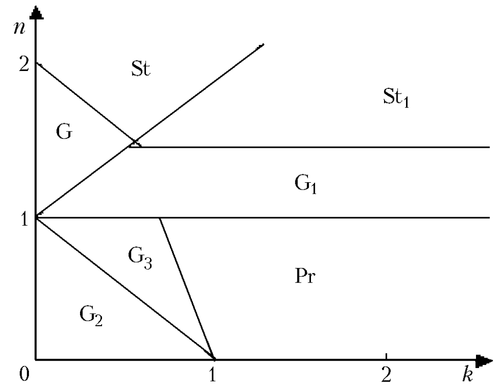


Fig. 4. *k–n* diagram of the outflow regimes at a discrete suction.

It follows herefrom that $\beta = \delta^{3/2}$. Figure 3b shows the scheme of a flow without separation around a slot array with local boundary layers and a "pie" of mixing layers 3 at $y < 0$. Unlike the flow around a coarse slot array, in the case being considered there are two boundary layers (the main and local layers), and the fluid sucked has a constant vorticity.

3. If $\tau << \delta^{3/2}$ (a fine slot array), the flow under the main boundary layer 1 of the local zone 2 represents a creeping motion, and a local boundary layer is absent here (Fig. 3c). The velocity of the slip flow at the bottom of the boundary layer is small — of the order of $O(\tau/\delta)$. This case was investigated in detail in [6].

The case of a weak suction ($\varepsilon << \delta$) is similar to the above-described case: the impenetrability condition is set at the bottom of the main boundary layer ($y = 0$) and the suction is considered as a linear addition to the first approximation. In the case of a strong suction ($\varepsilon >> \delta$), the regime of blowing of the main boundary layer 1 is realized. The flow in the local zone 2 is nonviscous as long as $n < 2$. In this case, $\beta = \delta\tau^{1/2}$ as well.

Asymptotic Structure of a Boundary Layer with a Suction through a Single Slot. We will consider a flow around a slot of width *sl* positioned at the bottom of a boundary layer. It will be assumed as before that the rate of suction is equal to $O(\varepsilon)$ and the external flow is noneddying. Some exact solutions of the problems on ideal fluids and high-viscosity fluids flowing through a single slot without a carrying flow are presented in [7–9].

The problem being considered includes three dimensionless parameters: δ, s, and ε. Let us relate them by the power laws $s = O(\delta^n)$ and $\varepsilon = O(\delta^k)$, where $0 \le n \le 2$ and $k > 0$. This relation formally decreases the number of parameters by unity: instead of the three small parameters δ, s, and ε, the two finite parameters k and n remain, and the rate of the fluid flow through the slot is equal to $O(\delta^{k+n})$. Before we determine the type of the flow in each characteristic polygon of the *k–n* diagram (Fig. 4), we formulate some definitions.

In the main boundary layer 1, the following ordinary expansion is true:

$$\psi (x, y; \delta) = \delta\psi_0 (x, Y) + o (\delta) , \quad y = \delta Y . \tag{2}$$

The near-wall region of size $O(\delta^n) \times O(\delta^n)$, i.e., the zone where $\xi = x\delta^n = O(1)$ and $\eta = y\delta^{-n} = O(1)$, will be named the local region. In this "square" region, the Euler, Stokes, or, at certain (boundary) values of the parameters k and n, Navier–Stokes equations are true. The local boundary layer exists at $\xi = O(1)$ and $y_1 = y/\delta_1 = O(1)$, where δ_1 is its conditional thickness. At $n < 1$, the thickness of the local zone $O(\delta^n)$ is larger than the thickness of the main boundary layer $O(\delta)$. If the boundary layer is completely sucked, which is possible at $n < 1$, the longitudinal velocity is finite, and the first term of the asymptotic expansion of the stream function is equal to $O(\delta^n)$.

We now estimate the order of magnitude of the terms in the local asymptotic expansion of the stream function at $\eta = O(1)$. To constant values of the velocity, friction (vorticity), and suction correspond, respectively, terms of order $O(\delta^n)$, $O(\delta^{2n-1})$, and $O(\delta^{k+n})$. The ratio between these quantities determines the type of a mathematical model and the parametric region of its existence in the *kn*-plane as well as the sequence of terms in the local asymptotic expansion of the function ψ. Such a classification will be done below without considering the conditions in the suction chamber and the details of the multizone structure of the flow, including the known features of it in the neighborhood of the edges. The finite result was presented earlier, in Fig. 4, to give a total insight into the problem. Thus, in each subregion, local asymptotic expansions will be constructed.

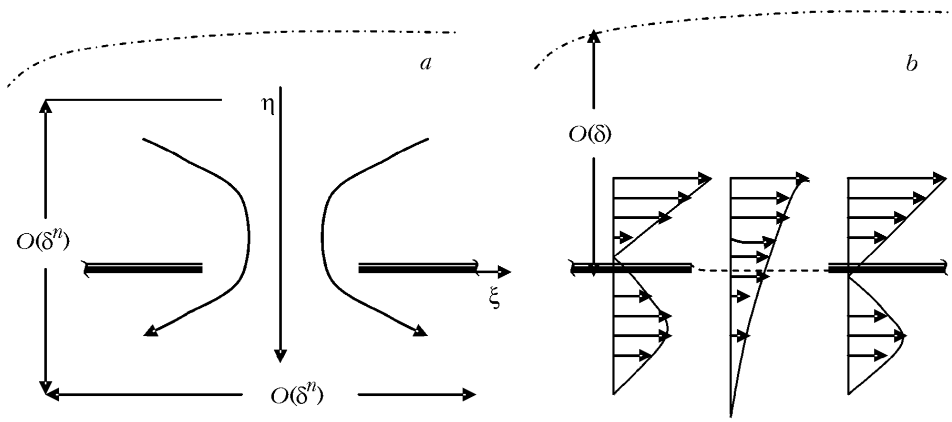


Fig. 5. Outflow of a highly viscous fluid: a) symmetric flow; b) nonsymmetric flow.

1. In the case where $n > 1 + k$, the friction is of the secondary importance as compared to the suction, and the local expansion has the form

$$\psi(x, y; \delta) = \delta^{k+n}\psi_1(\xi, \eta) + \ldots + \delta^{2n-1}\psi_2(\xi, \eta) + o(\delta^{2n-1}) . \tag{3}$$

The dots between the neighboring terms of the series can be replaced by the intermediate terms insignificant for the problem being considered.

A. At $k > 2 - n$, the solution is determined from the Stokes equation (region St in Fig. 4). Each function $\psi_{1,2}$ is determined independently from the solution of the biharmonic equation $\Delta^2\psi_{1,2} = 0$ with corresponding adhesion and joining conditions. The function ψ_1 is a solution of the problem on a symmetric flow of a high-viscosity fluid (Fig. 5a), and the function ψ_2 is a solution of the problem on the ejection of a fluid in the suction chamber (Fig. 5b). The conditional boundaries of the main boundary layer are shown in Figs. 5 and 6 by the dash-dot lines.

B. The case where $k < 2 - n$ corresponds to an ideal fluid flow (region G in Fig. 4), and the functions $\psi_{1,2}$ satisfy the Laplace equation $\Delta\psi_{1,2} = 0$. The function ψ_1 defines the fluid flow through a slot, arising due to the difference in pressure between the external flow and the suction chamber. The vorticity is determined by the function ψ_2; therefore, it can be disregarded in the problem on outflow. The outflow realized by the Helmholtz scheme is shown in Fig. 6a. In this figure, the dashed lines represent the free boundaries, and the local boundary layer and the mixing layers are shaded; in this case, $\delta_1 = \delta^{1+(n-k)/2}$.

2. In the case where $1 < n < 1 + k$, the friction is a determining parameter. In expansion (3), the terms change places:

$$\psi(x, y; \delta) = \delta^{2n+1}\psi_3(\xi, \eta) + \ldots + \delta^{k+n}\psi_4(\xi, \eta) + o(\delta^{k+n}) . \tag{4}$$

As in the above-described problem on continuous suction, at $n > 3/2$ the flow represents creeping motion (region St_1 in Fig. 4). The function $\psi_{3,4}$ is determined in much the same way as the functions $\psi_{1,2}$.

The subcase where $n < 3/2$ also corresponds to nonviscous flow (region G_1 in Fig. 4). The pattern of this flow is shown in Fig. 6b. The suction is realized through the narrow channel between the zero stream line and the right wall; the width of the channel is determined as

$$h = O\left(\delta^{\frac{k+n+1}{2}}\right) << s .$$

Since the local region is at the bottom of the main boundary layer, the vorticity of the fluid being sucked is constant. A local boundary layer is formed at the left panel of the airfoil; it flows in the form of a mixing layer into the suction chamber. Another local boundary layer of thickness $\delta_1 = \delta^{1+n/3}$ is formed at the right panel.

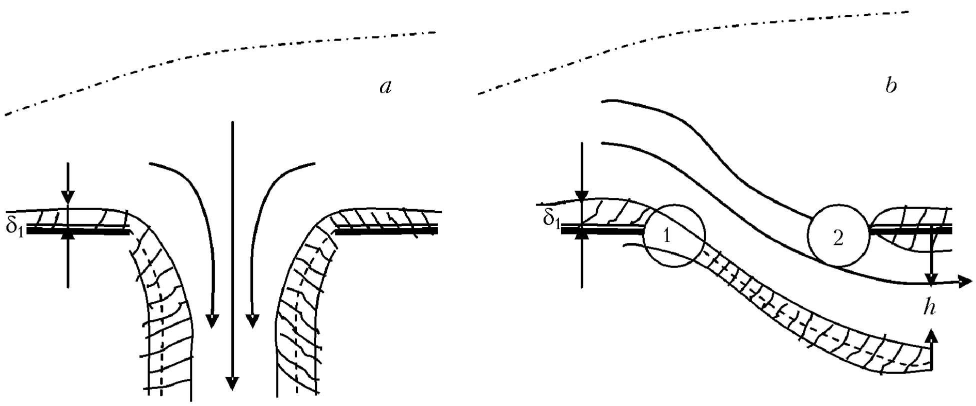


Fig. 6. Regime of a nonviscous outflow: a) symmetric flow; b) nonsymmetric flow.

3. In the case where $n < 1 - k$, the flow in the local zone propagates with a constant velocity u_0 equal to the velocity of the external flow at the suction "point". The local expansion represents an addition to this flow:

$$\psi(x, y; \delta) = \delta^n u_0 \eta + \ldots + \delta^{k+n} \psi_5(\xi, \eta) + o(\delta^{k+n}) . \tag{5}$$

This expansion differs from (4) in that, here, the first term defining uniform flow is known; the flow is nonviscous and noneddying (region G_2 in Fig. 4, corresponding to the regime of boundary-layer outflow). The scheme of the boundary-layer outflow is identical to the scheme presented in Fig. 6b; however, a local boundary layer is not formed in this case, and not the local layer but the main boundary layer flows into the suction chamber through the channel of width $h = O(\delta^{n+k})$, where $\delta_1 = \delta$.

4. In the case where $1 - k < n < 1$, only an asymptotically small part of the fluid, having a constant vorticity, is sucked from the bottom of the main boundary layer. As in expansion (4), the first term of the local series is known:

$$\psi(x, y; \delta) = \frac{1}{2} \lambda \delta^{2n-1} \eta^2 + \ldots + \delta^{k+n} \psi_6(\xi, \eta) + o(\delta^{k+n}) ;$$

here, the flow is also nonviscous. The Helmholtz scheme can be used if $h >> \delta_1$. Since $h = O(\delta/(k + n + 1)/2$ and $\delta_1 = \delta^{1+n/3}$, this regime is realized when $n < 3(1 - k)$ (region G_3 in Fig. 4). At $n = 3(1 - k)$, the thickness of the channel, through which the fluid is sucked, is comparable in order of magnitude to the thickness of the local boundary layer.

5. At $3(1 - k) < n < 1$, the boundary-layer expansion is true (region Pr in Fig. 4). In this case, the main effect is the ejection of the fluid found in the suction chamber at rest. The ejection scheme is similar to the scheme presented in Fig. 6b. The following expansion satisfies the condition of joining of the ejection flow with the shear flow at the bottom of the main boundary layer:

$$\psi(x, y; \delta) = \delta^{1+2n/3} \Psi_1(\xi, Y_1) + \ldots + \delta^{k+n} \Psi_2(\xi, Y_1) + \ldots ,$$

where $y = \delta^{1+n/3} Y_1$. The width of the channel $h = O(\delta^{k+2n/3})$ is smaller than the thickness of the local boundary layer $\delta_1 = \delta^{1+n/3}$. The quantity h and the solution as a whole are determined by the pressure in the suction chamber. In the neighborhood of the edges of the slots (regions 1 and 2 in Fig. 6b), the known local expansions of the stream function [10] are true.

Nonviscous Interaction of a Compressible Gas with the Boundary of a Slot. The problem on flow around an array of slots is divided into the outer problem (in the scale l) and the inner problem (in the scale τl). For example, in a wind tunnel with perforated walls, the outer problem is the problem on flow around a flying vehicle (see Fig. 2). To solve this problem, it is necessary to set a boundary condition at the walls of the working

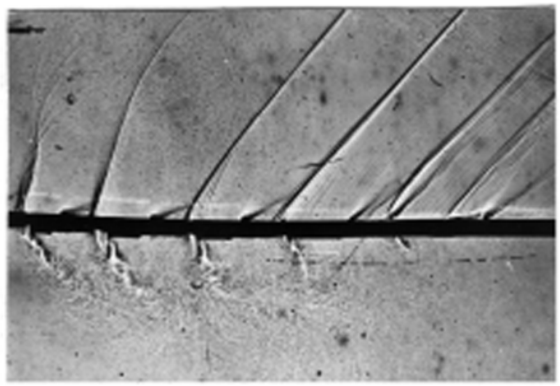


Fig. 7. Interaction of a supersonic flow with transverse slots.

part of the tunnel — the penetrability condition. It is determined from the joining of the outer and inner problems (the inner problem describes a fluid outflow from a periodic array of slots). The equations for the outer and inner problems are formally identical. The physical meaning of the boundary condition is clear. The rate of the gas flow through the penetrable boundary depends on the pressure differential across the inner layer and determines the transverse velocity component v, and the pressure difference is related to the quantity $u^2 + v^2$ by the Bernoulli law; in this case, the deficient boundary condition at the penetrable wall has the form $u = f(v)$, where f is a definite function. The internal variables are $\xi = x/\tau$ and $\eta = y/\tau$. Moreover, the solution depends parametrically on the "frozen" variable x fixing the coordinate of the cross section, in which the flow is considered. In the inner problem, the body, around which a stream flows, is considered as though it is at infinity. The gas is assumed to be perfect. At $\eta \to \infty$, a uniform flow is defined: $u = u_\infty$, $v = v_\infty$; at $\eta \to \infty$, $u = 0$. This problem is fairly universal, and its solution depends on the three dimensionless parameters: $M_\infty = (u_\infty^2 + v_\infty^2)^{1/2}/a_\infty$, $\alpha = \arctan (v_\infty/u_\infty)$, and γ is an adiabatic index, where a_∞ is a nondisturbed velocity of sound. If the flow is subsonic ($M_\infty < 1$), it would be reasonable to use, as the scheme of outflow, the scheme of a separation flow with free boundaries at the edges of the slots (Helmholtz scheme). If the flow is supersonic ($M_\infty > 1$), it is necessary to use the scheme of a flow with compression shocks and rarefaction waves, propagating from the edges of the slots.

In the case of a supersonic flow, the change in the entropy in the spacing of the slots is due to the formation of shock waves and contact discontinuities at the "trailing" edges of the panels. In the general case, a supersonic flow around a slot array is impossible since the losses in the total pressure for the whole length Δp_0 of the array are small or finite as compared to the total pressure at the leading edge of the array p_0. In the first case, where $N\Delta p_0/p_0 = O(1)$, the flow is quasi-periodic, i.e., it depends not only on ξ and η, but also on x.

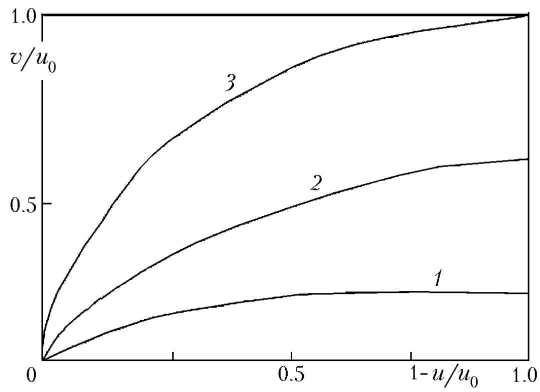
Figure 7 shows a Toepler photography representing the interaction of a supersonic flow with the boundary of a transverse slot, obtained at $M_\infty = 1.4$ in a T-115 wind tunnel of the Central Aerohydrodynamics Institute. Jets with intensity decreasing in the direction of the x axis are seen in this photography.

The interaction is considered as strong when the angle of attack $\alpha = O(1)$, and it is weak at $\alpha \ll 1$. A closed-form solution was not obtained for the general case of a strong interaction. In this case, there is only a partial solution [11] for a subsonic flow ($M_\infty = 0$). The desired dependence $u = f(v)$ for this case is presented in Fig. 8. At $v \ll u_0$, the condition $v = (u_0 - u) \tan (\pi\mu/2)$, known from the linear theory [3], is obtained. The other limiting case, where $u = 0$, corresponds to a symmetric outflow.

In the case of a weak interaction, $\Delta p_0/p_0 = O(\alpha^2)$. The linear theory is true: we have a Laplace equation at $M_\infty < 1$ and a wave equation at $M_\infty > 1$. For a subsonic flow, the outer limit of the expansion is obtained by linearization of the function $f(v)$:

$$u = u_\infty + \alpha k v \; . \tag{6}$$

The flow propagating around an array of slots is represented in accordance with the linear supersonic theory in Fig. 9a (the solid lines represent Mach waves, the dash-dot lines represent rarefaction waves, and the dotted lines represent contact discontinuities). The problem is solved in the closed form; the velocity of the flow is piecewise in



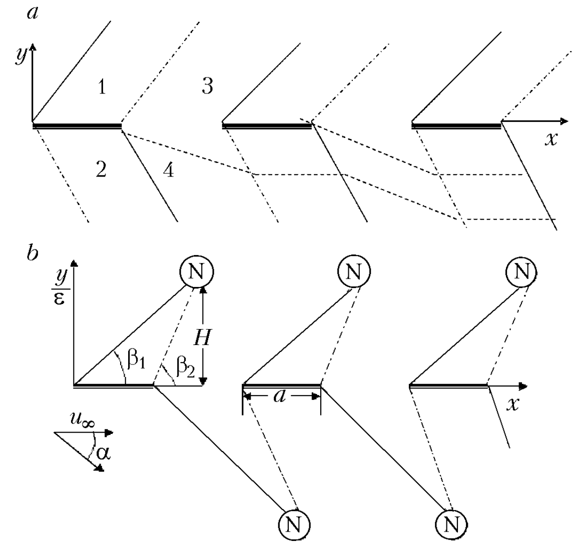


Fig. 8. Boundary condition at the longitudinal-slot boundary for an incompressible fluid: μ = 0.3 (1), 0.8 (2), and 1.0 (3).

Fig. 9. Scheme of a flow around a slot array constructed in accordance with the linear supersonic theory: a) first approximation; b) second approximation.

regions 1–4. In this limit, the boundary condition of the form of (6) is true; however, the quantity k has a different value dependent on M_∞.

A weak interaction is realized in the case where the linear theory is true for the external flow.

At large distances from the array of slots, the second approximation of the linear supersonic theory (Fig. 9b) should be used. Since the angle of inclination of a rarefaction wave β_2 is larger than the angle of inclination of a shock wave β_1 and $\beta_2 = \beta_1 + \varepsilon$, where $1 < \varepsilon << 1$, they meet at a distance

$$H = \frac{a \tan\beta_1 \tan\beta_2}{\tan\beta_2 - \tan\beta_1} \approx \frac{a}{\varepsilon M_\infty^2}\,.$$

In the neighborhood of their intersection, an N-wave is formed [12].

The longitudinal velocity of the quasi-periodic flow (zone 3 in Fig. 9a) depends linearly on x. Actually, since $u_3 = u_\infty + j\alpha^2 u_0$, where j is a serial number of a slot ($j = x/N$, $N = \alpha^2 N_0$), we have $u_3 = u_\infty + x u_0/N_0$.

If the wall is weakly penetrable, i.e., $\mu << 1$, the scale $O(\mu\tau)$ is used in addition to the characteristic scales $O(1)$ and $O(\tau)$. Because of this, one more inner region — the neighborhood of a single slot with a penetrable wall — should be considered. In the main inner region, the solution of the problem will have the form of the sum of point sources/sinks positioned at regular intervals.

Conclusions. Using the method of joining of asymptotic expansions, we divided the problem on a flow around a fine array of transverse slots into two simpler inner and outer problems.

The problem on the suction of a boundary layer through transverse slots includes three small dimensionless parameters: the spacing of the slots τ, the Reynolds number Re, and the rate of suction ε. Depending on the ordinal ratio (<<, =, >>) between ε and $\mathrm{Re}^{-1/2}$, the regimes of weak, moderate, and strong suction are realized. For the regime of moderate suction, it is necessary to additionally classify the types of flows depending on the ordinal number of the parameter τ determined by the type of a slot array: a coarse, a moderate, or a fine array.

At present, a deterrent to bringing the boundary-layer suction into aviation practice is the formation, in the main flow, of two antisymmetric spiral vortices, similar to the longitudinal vortices propagating from the edges of an airfoil [13]. According to the classification proposed in the present work for the main flow and the three-dimensional flow around a perforation, for elimination of parasitic vortices in these flows it is necessary to properly select their type with account for the rate of the suction. Moreover, of importance is choosing the optimum geometry of a slot: the shape in plan and the distance from the surface to the plane. If an airfoil around which a subsonic stream flows has a sharp-pointed trailing edge and a rounded leading edge, a slot should have a sharp-pointed leading edge and a rounded trailing edge. The flow leaves the sharp-pointed edge and adds to the rounded edge.

It has been established that, in the case of a discrete boundary-layer suction through a single slot, seven different regimes of flow are realized; mathematical models have been proposed for each of these regimes.

It may be suggested that, in the problem of a gas infiltrated with a high flow rate through the slot walls of a wind tunnel, the main boundary layer is blown and the outflow is realized by the Helmholtz scheme. This approach allows one to determine the boundary conditions for the outer problem of flow around a body located in a channel with penetrable boundaries in both the weak-interaction and strong-interaction regimes.

NOTATION

l, characteristic size; M, Mach number; N, total number of slots in an array; p, pressure; Re, Reynolds number; s, small parameter characterizing the width of a slot; u, v, velocity components along the Cartesian axes x and y; α, angle of attack; β, characteristic thickness of a local boundary layer; β_1, angle of inclination of a shock wave; β_2, angle of inclination of a rarefaction wave; γ, adiabatic index; δ, characteristic thickness of a boundary layer; ξ, η, auxiliary coordinates; ε, small parameter characterizing the rate of suction; λ, coefficient of friction at the bottom of the boundary layer; μ, permeability coefficient of the slot array; ν, coefficient of kinematic viscosity; ρ, density of the fluid; τ, small parameter characterizing the spacing of slots; τa, length of a panel; ψ, stream function. Subscripts: ∞, parameters of a nondisturbed flow.

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