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INTERACTION OF THE WAKE OF A POORLY STREAMLINED BODY WITH A BARRIER

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Continuing the work begun in [1], we investigate the problem of calculating the plane rotational flow of an ideal incompressible fluid near a plane barrier set up in a transverse position relative to the flow. Nonzero vorticity is induced in the outer flow by the formation of a wake after a poorly streamlined bodyplaced in front of the barrier. We illustrate the solution of the stated problem in the example of the flow configuration created by uniform symmetric flow with velocity U past two parallel plates, one of which simulates the body, and the other the barrier.

For the analytical model of the flow past the plates we use the unsteady vortex model, which has been realized in practice by the method of discrete vortices [2] for the case of two plates of the same size (Ryabushinskii flow). Unlike the cited work, here we investigate flow past plates of different dimensions. The half-width of the second plate downstream is denoted by R, and that of the first by H, where $H < R$. The ratios between the plate dimensions H/R and L/R, were L is the distance between the plates, are adopted as the parameters to be varied.

An analysis of the vortex structures and fields of directions of the flow velocity vector in the wake of the plates for H/R = 0.1-1.0 and L/R = 0.4-2.2 shows that the flow cutoff

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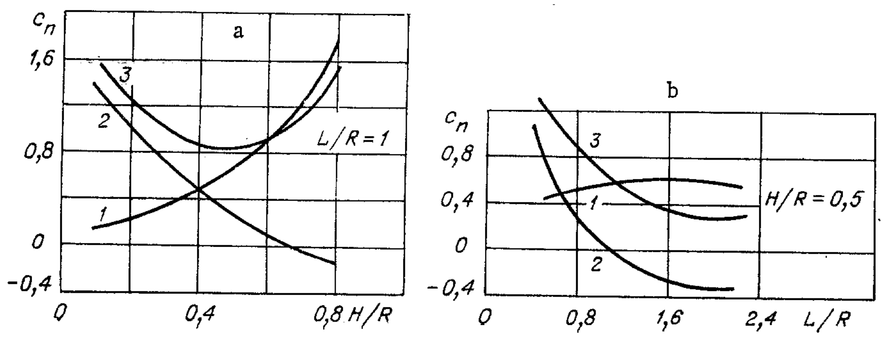

Fig. 1

at the first plate results in the formation in the space between the plates of a fully developed circulation flow (vortex), the intensity and space scales of which are determined by the values of the varied parameters. The maximum flow velocity in the vortex attains a value of the order of 0.5 U. As a result, the considerable rarefaction in the interim space causes the flow to exert a suction action for definite ratios H/R and L/R, and this effect, in turn, has a profound influence on the fluid resistance of the plates.

Figures 1a and 1b gives the results of calculations at a time close to stabilization of the solution ($Ut/R \simeq 10$, where t is the time), including: the normal force (resistance) coefficients c_{n1} (curve 1) and c_{n2} (curve 2) for the first and second plate, as well as the total normal force coefficient for the pair of plates $c_n = c_{n1} + c_{n2}$ (referred to $\rho U^2 R/2$, where ρ is the density of the fluid; curve 3). For a fixed distance between the plates we infer from the results of the calculations that the resistance of the first plate increases with the ratio H/R. On the other hand, the pressure reduction in front of the first plate lowers its resistance considerably, causing it to revert to zero at a certain value of the given ratio (H/R = 0.65 for L/R = 1; Fig. 1a) and then become negative. The inception of a tractive force for the second plate has the effect that for a certain ratio H/R, which we call the optimal value ($H/R \simeq 0.55$ for L/R = 1; Fig. 1a), the total resistance of the plates for the given L/R is a minimum. The function $c_n(L/R)$ behaves analogously for a fixed ratio H/R. The total resistance of the plates in this case decreases as the distance between the plates is increased to the optimal ratio ($L/R \simeq 1.9$ for H/R = 0.5; Fig. 1b), which is characterized by the minimum value of c_n. An appreciable increase in L/R above the optimal value has the effect that, instead of a single vortex in the interim space, at first a pair of smaller vortices of lower intensity is formed, and then a wake is formed after the first plate without closure at the surface of the second plate. The mutual influence of the plates in this case is attenuated, so that the total resistance of the plates tends to the sum of the resistances of the plates in isolation, as in the case of Ryabushinskii flow.

A comparison of the minimum calculated values of c_n for the plates in the pair with the corresponding values for the isolated plates and plates of identical size in the pair elicits some rather interesting observations. For L/R = 1 and H/R = 0.55 the minimum resistance of the plates $c_n \simeq 0.8$ practically coincides with the value $c_n = 2\pi/(\pi + 4)$ for an isolated plate of characteristic dimension R [3]. The sum of the resistances of the isolated plates of the given geometry in this case has a value $2\pi(1 + H/R)/(\pi + 4) = 1.362$. For H/R = 0.5 and L/R = 2 (values close to the optimal for the paired plates) the resistance coefficient $c_n \simeq 0.35$. This value differs almost 2.5-fold from the resistance of the isolated plate of characteristic dimension R and more than threefold from the sum of the resistances of the investigated plates in isolation. We note that for each plate of the pair of equal-size plates $c_n = 2\pi(1 + Q)/(\pi + 4)$, where Q is the rarefaction ratio in the wake or the so-called cavitation coefficient Q = 1.4 for L/R = 5, and Q = 0.25 for $L/R \simeq 85$ [3]). According to the data of a calculation of symmetric flow past two plates of the same size [2], for $L/R \geqslant 14$ the values of the normal force coefficient for both plates are practically equal and coincide with the coefficient c_n for the isolated plate. With a reduction in the distance between the plates the normal force on the first plate increases, while that on the second decreases, becoming negative for L/R < 10. The minimum value of c_n in this case is attained roughly for $L/R \simeq 2$. The results of this study also yield the resistance-optimal value of the ratio $L/R \simeq 2$, although for considerably lower values of the minimum resistance.

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LOCAL FORCE LOADS FROM A SUPERSONIC UNDEREXPANDED STREAM ON A FLAT SURFACE PARALLEL TO THE STREAM AXIS

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The action of the force of a stream with a large degree of nonsimilarity ($n = 2\cdot 10^1-8\cdot 10^4$) on a flat surface, displaced from the nozzle axis at distances $h = h/r_a = 2-10$, is studied experimentally for an interaction region along the flow line for Reynolds numbers $Re_* = 1.7\cdot 10^3-2.1\cdot 10^4$ (the Reynolds number is determined according to the parameters in the critical cross section). The working fluids consist of argon, air, and propane, flowing from conical nozzles with an aperture half-angle at the exit $\theta_a = 10°$ and the ratio of the diameters of the exit and critical cross sections $\xi = d_a/d_* = 1.0-4.8$. A simple empirical dependence is suggested, as a result of this work, for the determination of the location of the second maximum of the force loads and their maximum magnitudes. A universal profile is presented for the pressure along the flow line.

The interaction between a supersonic underexpanded stream and a flat surface parallel to the stream axis is accompanied by the formation of a complex shock wave structure with the presence of a large number of gasdynamic explosions, as well as subsonic and supersonic flow regions. A rigorous analytic solution is hardly possible for the problem. At the same time, such problems are solved by using numerical [1-4] as well as approximate methods [5-9].

The errors involved in these methods can attain significant magnitudes, while the calculations can be quite laborious. In addition, in engineering, it is often necessary to estimate the magnitudes of the force loads on a flat surface interacting with a supersonic underexpanded stream, the parameters of which vary over a wide range of values. In the present work, simple dependences are obtained on the basis of the results of experimental research for calculating the force loads along the flow line in the interaction region.

The experiments were performed in the stationary regime in a low-density gasdynamic tube equipped with a nitrogen cryogenic pump [10]. The residual pressure in the working volume of the vacuum chamber in these experiments varied over the range $1\cdot 10^{-3}-1\cdot 10^{-2}$ mm Hg ($1.33\cdot 10^{-1}-1.33$ Pa) and was measured by a PMT-2 transducer on a VT-3 vacuum gauge. The source of the supersonic stream was a heated receiver with a replaceable conical nozzle, having a half-angle at the exit $\theta_a = 10°$ and a ratio of diameters at the exit and critical cross sections given by $\xi = d_a/d_* = 1.0$; 1.3; 2.0; 3.25; 4.8.

Argon, air, and propane were used as the working fluids. Their mass flow rates varied in the range 0.07-0.75 g/sec. The deceleration pressure p_0 varied over the range 0.25 kg/cm² ($2.45\cdot 10^4$ Pa)–2.1 kg/cm² ($2.06\cdot 10^5$ Pa), the deceleration temperature varied over the range $T_0 = 400-1000°K$, and the Reynolds number, determined from the parameters in the critical cross section of the nozzle, attained the values $Re_* = 1.7\cdot 10^{-3}-2.1\cdot 10^4$. The degree of nonsimilarity flow as a function of the type of gas, Mach number at the edge of the nozzle, deceleration parameters, and pressure in the vacuum chamber varied over the range $n = 2\cdot 10^1-7.8\cdot 10^4$.

The basic results concerning the location of the maximum loads as a result of the interaction between a supersonic stream with a large degree of nonsimilarity and a contiguous flat surface were obtained using heat-sensitive coatings. A thin layer of heat-sensitive melting indicator coating (TI-65, TI-120) was placed on the surface of a plate made of a thermally insulating material. The material $T_* < T_e$ was satisfied in all the experiments

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