the film are linear. We have observed anomalous behavior in the liquid film in the vicinity of the spread line of the sliding cylinder.

NOTATION

M_∞, Mach number for the outlet cross section of the nozzle; $Re_{\infty D}$, Reynolds number calculated from the parameters of the unperturbed flow at the outlet section of the nozzle and from the diameter of model rounding; P_0, total pressure in the pressure chamber of the wind tunnel, Pa; T_0, deceleration temperature; χ, sweepback angle of leading edge of plate (between the normal to the direction of the unperturbed flow and the generatrix of the leading edge), deg; d, orifice diameter, mm; ω, angle between direction of unperturbed flow and radius vector of orifice, deg; τ, frictional stress at boundary separating fluid and gas, Pa; Q, volumetric fluid flow rate, cm^3/sec; ν, kinematic viscosity of fluid, cSt; q_ℓ/q_g, ratio of the velocity head of the fluid at the outlet from the orifice to the local velocity head of the gas; δ, thickness of fluid film, mm; b, width of fluid film, mm; γ, angle between tangents to the side boundaries of the fluid film, deg; s, coordinate calculated from the center of the orifice along the midline of the film or along the axis of wedge symmetry, mm; z, coordinate calculated along the normal to the axis, mm.

LITERATURE CITED

1. B. V. Rayshenbakh et al., *Physical Fundamentals of the Working Process in Jet-Engine Combustion Chambers* [in Russian], Moscow (1964).
2. V. A. Gorelov, M. K. Glad'shev, and A. S. Korolev, *Scientific Notes of the Central Aerohydrodynamic Institute,* No. 1, 115-120 (1978).
3. Yu. S. Karasov, M. N. Osin, and É. B. Vasilevskii, in: All-Union Scientific-Engineering Conference. Methods of Two-Phase and Reaction Flow Diagnostics, Kharkov (1988), pp. 29-30.

CHARACTERISTIC AERODYNAMIC FEATURES OF NONSYMMETRIC JET FLOWS

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We present results from an experimental study of the relationship between the angle of jet rotation and the curvature radius and length of a rectangular curvilinear nozzle.

Jets flowing out of curvilinear nozzles of various geometry with R_ω = const were studied in [1-5]. The distribution of statistical dynamic characteristics of a jet flowing out of a plane curvilinear nozzle was studied in [5], where it was demonstrated that the Gertler vertices are retained downstream in a free jet, all the way to distances on the order of 10 calibers, and that they significantly affect the distribution of the averaged velocity and the mean-square values of velocity pulsations. Owing to centrifugal forces, the pressure at the nozzle outlet is not distributed uniformly, so that there exists, therefore, some angle α (Fig. 1) between the tangent to the axis of the channel and the geometric axis of the jet. The influence exerted by the curvature radius R_ω and the length L of the nozzle on the nonsymmetricity of the jet can be seen in the extent to which the deflection angle α changes.

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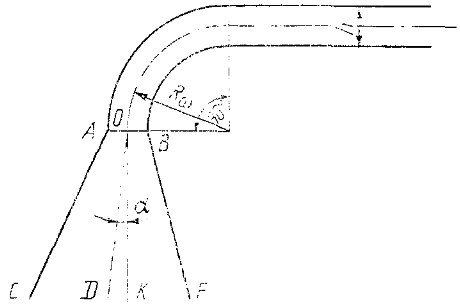

Fig. 1

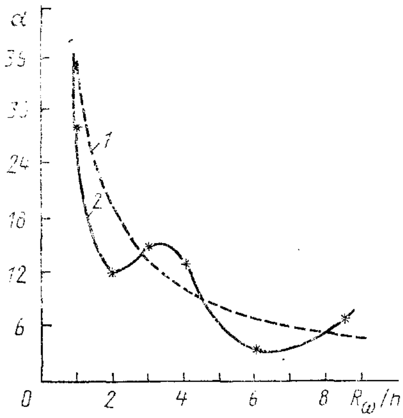

Fig. 2

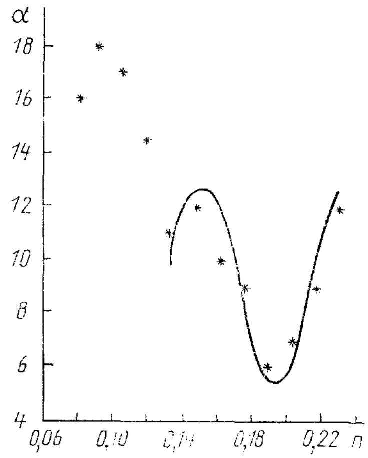

Fig. 3

Fig. 1. Cross section of the channel and of the jet flowing out of that channel: 0K) tangent to the channel axis; 0D) geometric axis of jet; AC, BF) boundaries of the jet.

Fig. 2. Angle of jet rotation as a function of R_ω/h: 1) calculation based on formula (1); 2) based on formula (2); the points represents experimental data.

Fig. 3. Angle of jet rotation as a function of $n = L/(2\pi R_\omega)$ (L, m): the curve represents calculation based on formula (2); points denote experimental data.

The present study presents the results of an experimental investigation into this relationship. The ratio of the width to the height of the nozzle outlet is $b/h = 10$, $h = 10^{-2}$ m. At the inlet to the curvilinear segment the profile of the averaged velocity was steady, since the length of the previous rectilinear segment amounted to 40h. An IZK-463 unit was used to visualize the jet, and with a field of view of 800 mm it was possible to observe the process of jet propagation at rather substantial distances (80 calibers). The photographic exposure time was 10^{-3} sec. The angle α was determined from the results obtained in processing the shadow photographs, and here the geometric axis of the jet was assumed to be located in the middle of the shadow pattern. The average velocity of discharge varied in the range 5-25 m/sec. It is important to note that no relationship between the angle α and Re was observed.

It might be assumed that the differences in longitudinal and transverse pressures, both at the outlet and at any cross section of the curvilinear channel, are, respectively, proportional to $\rho U_{av}^2/2$ and $\rho U_{av}^2 h/R_\omega$. It then becomes obvious that

$$\alpha = \operatorname{arctg}\left(\beta \frac{h}{R_\omega}\right). \tag{1}$$

With β = const = 0.7 and an angle equal to 90° between the plane of the outlet and the plane of the initial cross section of the curvilinear segment the theoretical relationship (curve 1, Fig. 2) is in agreement with the experimental data in rather approximate terms. Figure 3 shows the function $\alpha(n)$, where the parameter $n = L/(2\pi R_\omega)$ characterizes the length of the curvilinear segment. The experimental results (the points in Figs. 2 and 3) are rather well described by the expression

$$\alpha = \operatorname{arctg}\left(\frac{h}{R_\omega}\left[0{,}65 + \left(0{,}195 + 0{,}021\,\frac{R_\omega}{h}\right)\sin\left(21{,}1 - 75{,}7n + 1{,}51\,\frac{R_\omega}{h}\right)\right]\right). \tag{2}$$

It should be noted that when $n < 0.15$, approximation (2) is nonuniform as a result of the predominant influence of the flow in the rectilinear segment of the channel on the distribution of the transverse pressure gradient.

Formula (2) thus makes it possible to evaluate the angle of jet rotation as a function of curvature radius and the length of the curvilinear segment. The derived result can be utilized to resolve numerous practical problems such as, for example, the development of automatic pneumatic systems and the design of gas-burner devices where the flame can be regulated [6].

NOTATION

ρ, gas density, kg/m^3; U_{av}, flow velocity averaged over the cross section, m/sec; R_ω, curvature radius of channel axis, m; Re, Reynolds number; ν, kinematic viscosity of the gas, m^2/sec.

LITERATURE CITED

1. O. G. Martynenko, N. I. Lemesh, I. A. Vatutin, et al., *Inzh. Fiz. Zh.*, **51**, No. 1, 32-36 (1986).
2. N. I. Lemesh, I. A. Vatutin, and L. A. Senchuk, *Energy Transfer in Vortex and Circulation Flows* [in Russian], Minsk (1986).
3. T. Toshihiro and H. Hideki, *Trans. Jpn. Soc. Mech. Eng.*, **B53**, No. 487, 839-842 (1987).
4. O. G. Martynenko, N. I. Lemesh, I. A. Vatutin, et al., *Vestsi Akad. Nauk BSSR, Ser. Fiz. Énerg. Navuk.*,No. 3, 38-41 (1987).
5. I. A. Vatutin, N. I. Lemesh, O. G. Martynenko, et al., *Inzh. Fiz. Zh.*, **55**, No. 1, 12-15 (1988).
6. R. K. Narkhodzhaev and A. Akbarov, *Inzh. Fiz. Zh.*, **55**, No. 2, 198-201 (1988).