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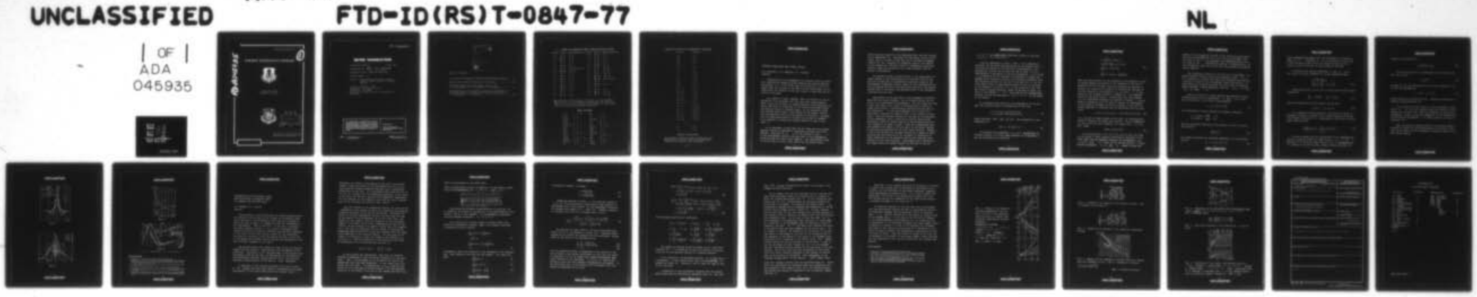

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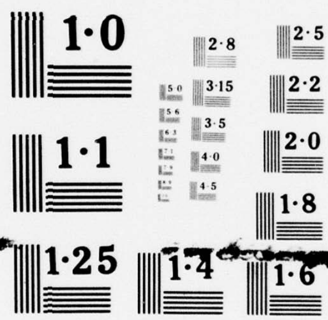

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FOREIGN TECHNOLOGY DIVISION

TURBULENT FLOWS
(Selected Articles)

EDITED TRANSLATION

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TURBULENT FLOWS (SELECTED ARTICLES)

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FOREIGN TECHNOLOGY DIVISION
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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	∝	Nu	Ν	ν	
Beta	Β	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	Ο	ο	
Delta	Δ	δ		Pi	Π	π	
Epsilon	Ε	ε	ϵ	Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ		Sigma	Σ	σ	ς
Eta	Η	η		Tau	Τ	τ	
Theta	Θ	θ	ϑ	Upsilon	Υ	υ	
Iota	Ι	ι		Phi	Φ	φ	ϕ
Kappa	Κ	ϰ κ	ϰ	Chi	Χ	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	Μ	μ		Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	sin^{-1}
arc cos	cos^{-1}
arc tg	tan^{-1}
arc ctg	cot^{-1}
arc sec	sec^{-1}
arc cosec	csc^{-1}
arc sh	$sinh^{-1}$
arc ch	$cosh^{-1}$
arc th	$tanh^{-1}$
arc cth	$coth^{-1}$
arc sch	$sech^{-1}$
arc csch	$csch^{-1}$
rot	curl
lg	log

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TURBULENT WAKES WITH ZERO EXCESS IMPULSE

A.S. Ginevskiy, L.N. Ukhanova, K.A. Pochkina
(Moscow)

Regularities of the propagation of turbulent jets in a wake with positive and negative excess impulses are being studied at the present [1]. In the first case the velocity in the jet is higher than the velocity of the wake; in the second case, on the other hand, the velocity in the jet (trace) is less than the velocity of the wake.

In a number of cases, however, there is interest in the examination of the turbulent jet flow with zero excess impulse. Such a flow, as is known, is formed behind the self-propelling objects, for which in conditions of the steady rectilinear motion the tractive force is precisely equal to the resistance force. The concrete form of such a flow depends on the mutual location of the propulsive device and the source of resistance. Assuming that the propulsive device is located on the axis of symmetry, it is possible to obtain the velocity profile of such a flow (Fig. 1).

It is necessary to note that the jet flows with zero excess impulse (traces of hydrodynamic propulsive devices) are little studied. Described in the work of the authors [2] are results of the experimental study of the near part of the axisymmetric turbulent wake with zero excess impulse. The experimental study of the far part of such a flow, where the velocities differ little from the velocity of the advancing flow, has been carried out by Naudascher [3]. Regarding the theoretical study of such flows, here it follows to note the book of Birkgoff and Zarantonello [4], who obtained the asymptotic laws of the damping of the laminar and turbulent traces of hydrodynamic propelling devices, which are correctable at a great distance from the source of disturbance.

An account is given in this article of the approximate integral method of the calculation of the velocity field of the near and far parts of axisymmetric turbulent traces of the hydrodynamic propelling devices, where for the substantiation of the accountable method of the calculation results of the experimental study of the micro- and macrostructure of the considered turbulent flow are used.

Calculation of the near part of the axisymmetric turbulent wake with zero excess impulse. Let us discuss briefly the results of the experimental investigation. The jet flowed out into a wake flow from a pipe, which is completed with a nozzle of round cross section. Concentrically fastened with the axis of the nozzle was a ring the streamline flow of which by a wake made it possible to obtain a "dip" in the velocity in the trace. With the recorded velocity of the wake at the beginning of the experiment, such a value of the outflow velocity was selected at which the excess impulse in the selected cross section proved to be equal to zero. Since the longitudinal pressure gradient was absent, the zero value of the excess impulse in practice was preserved in all other cross sections. Figures 1 and 2 give profiles of the mean velocity in a number of cross sections and also profiles of the intensity of turbulence of three components of the pulsation velocity and Reynolds shear stresses in two cross sections. Measurements were conducted in the region where the excess velocity on the axis of the jet

$u_{1m} = u_m - u_\delta$ **is commensurable with the velocity of the wake** u_δ**, i.e.,** $\bar{u}_{1m} = u_{1m}/u_\delta = 0,5 \div 3$.

From an examination of Figs. 1 and 2, it is possible to establish the following characteristics of the studied flow: 1) the velocity profile of the flow can be approximated by two standard jet profiles on sections ABC and CD (Fig. 1), i.e., this profile is determined by the four parameters: u_{1m}, u_{2m}, δ_1 and δ_2; 2) profiles of the intensity of turbulence of three components of the pulsation velocity are noticeably different from the analogous profiles for the jet in the wake [5]; 3) the Reynolds shear stress is approximately equal to zero at the point of the minimum of velocity, i.e., on the junction of the "jet" and "trace" velocity profiles, where for each of these sections of the profile $\tau = -\rho\, \overline{u'v'}$ are close to the corresponding profiles for the jet and trace ($\bar{x} = x/\delta_0$, $\bar{y} = y/\delta_0$, δ_0 is the radius of the nozzle).

In accordance with results of the experiment, let us present the velocity profile by expressions of the form

$$u = u_\delta - u_{2m} + (u_{1m} + u_{2m}) f(y/\delta_1) \quad (y \leqslant \delta_1),$$
$$u = u_\delta - u_{2m} f[(y - \delta_1)/\delta_2] \quad (\delta_1 \leqslant y \leqslant \delta_1 + \delta_2), \qquad (1)$$

where functions $f(y/\delta_1)$ and $f[(y-\delta_1)/\delta_2]$ are determined by the expression [6]

$$f(\eta) = 1 - 6\eta^2 + 8\eta^3 - 3\eta^4. \qquad (2)$$

To calculate the parameters $u_{1m}, u_{2m}, \delta_1, \delta_2$, determining the velocity profile (1) in each cross section, it is possible to use the following four relations:

$$I = 2\pi\rho \int_0^\delta u\,(u - u_\delta)\, y\, dy = 0,$$

$$\frac{1}{2}\rho u_m \frac{du_m}{dx} = \left(\frac{\partial\tau}{\partial y}\right)_{y=0} \quad (\delta = \delta_1 + \delta_2),$$

$$\frac{d}{dx}\int_0^{y_1} u\,(u - u_\delta)\, y\, dy = \frac{\tau_1 y_1}{\rho}, \tag{3}$$

$$\frac{d}{dx}\int_0^\delta u\,(u^2 - u_\delta^2)\, y\, dy = -2\int_0^\delta \frac{\tau}{\rho}\frac{\partial u}{\partial y}\, y\, dy.$$

Here the first relation is the condition of the equality to zero of excess impulse; the second is the condition on the axis of symmetry which is obtained from the differential equation of motion; the third is the equation of momentum for the part of the flow limited by the surface $y = y_1$, on which $u = u_\delta$; the fourth is the integral relation of energy [6]. The Reynolds values of the shear stress τ, which enter into the relation (3), are determined according to equation of Prandtl $\tau = \rho\nu_t\, du/dy$ where in conformity with the ideas of Prandtl the coefficient of the turbulent exchange in the two regions of flow with velocity gradients of different sign is determined from the equations:

$$\nu_t = \varkappa\delta_1(u_{1m} + u_{2m}) \ (y < \delta_1), \quad \nu_t = \varkappa\delta_2\, u_{2m} \ (\delta_1 < y < \delta_1 + \delta_2), \tag{4}$$

i.e., in each of these regions of the flow, its characteristic scales of velocity and length are selected. For the finding of y_1, let us use the first equation (1), whence with $u = u_\delta$ we will have:

$$f(y_1/\delta_1) = u_{2m}/(u_{1m} + u_{2m}). \tag{5}$$

The substitution of (1), (2), (4), and (5) into (3) leads to the system of three ordinary differential equations of the first order and one algebraic equation for determining $u_{1m}(x)$, $u_{2m}(x)$, $\delta_1(x)$ and $\delta_2(x)$, where in the initial section x_H there should be assigned u_{1mH}, u_{2mH} and δ_{1H}. Figure 3 gives the results of the comparison of data of the calculation and experiment for the axisymmetric flow, the velocity profiles of which are given on Fig. 1. The agreement was found satisfactory with the value of the experimental constant $\varkappa$, characteristic for the axisymmetric wakes and traces with the positive and negative excess impulses.

The linearized solution for the far part of the trace. At great distances from the source of disturbance where $\bar{u}_{1m} \ll 1$, it is possible to obtaine the simple step equations for the calculation of traces of the hydrodynamic propelling devices. In this region the solution accounted for above shows the sharply marked tendency to self-similarity, that is, $u_{1m}/u_{2m} \to \text{const}$ and $\delta_1/\delta_2 \to \text{const}$ when $x \to \infty$.

Here the profiles of excess velocity are universal and are characterized by the two parameters: u_{1m} and δ. Let us present this profile in the form of the polynomial

$$\bar{u}_1 = \frac{u_1}{u_{1m}} = \sum c_i \eta^i \quad \left(\eta = \frac{y}{\delta}\right), \tag{6}$$

the coefficients of which satisfy the boundary conditions:

$\bar{u}_1 = 1,\ \partial \bar{u}_1/\partial \eta = 0$ when $\eta = 0,$

$\bar{u}_1 = \partial \bar{u}_1/\partial \eta = 0$ when $\eta = 1$

and the linearized condition of the equality to zero of the excess impulse:

$$\int_0^1 \bar{u}_1 \eta \, d\eta = 0. \tag{7}$$

As a result we obtain the universal expression for the velocity profile:

$$\bar{u}_1 = 1 - 12\eta^2 + 20\eta^3 - 9\eta^4, \tag{8}$$

which satisfactorily agrees with the experiments of Naudascher when $\bar{u}_{1m} < 0{,}1$ (see Fig. 4). It is interesting to note that in the far part of the x trace the Reynolds shear stress is equal to zero at the point of the minimum of velocity.

To find the two unknown parameters (δ and u_{1m}) we use the second and third relations (3) in the linearized form:

$$\frac{1}{2}\rho u_\delta \frac{du_{1m}}{dx} = \left(\frac{\partial\tau}{\partial y}\right)_{y=0},$$
$$\frac{d}{dx}\int_0^{y_1} u_1 y\,dy = \frac{\tau_1 y_1}{\rho u_\delta} \qquad [\tau_1 = \tau(y_1)]. \tag{9}$$

Substituting here (4) and (8), we obtain after simple transformations:

$$\frac{d\bar{u}_{1m}}{d(\varkappa x)} = -38{,}08\frac{\bar{u}_{1m}^2}{\delta}, \qquad \frac{d\delta}{d(\varkappa x)} = 13{,}19\bar{u}_{1m}; \tag{10}$$

after the integration of this system, we will have:

$$\delta \sim (\varkappa x)^{0,257}, \qquad \bar{u}_{1m} \sim (\varkappa x)^{-0,743}. \tag{11}$$

By a somewhat different means it is possible to obtain an analogous solution if instead of the second relation (9) we use the integral relations of L.G. Loytsyanskiy, which after linearization take the form

$$u_\delta \frac{d}{dx}\int_0^\delta u_1(y)\,y^{k+1}dy = -k\int_0^\delta \nu_t(y,x)\,u_1(y)\,y^{k-1}dy \tag{12}$$
$$(k = 0, 1, \ldots).$$

If now we assume that the coefficient of the turbulent viscosity is constant along the cross section, i.e., $\nu_t = \nu_t(x)$, and take k = 2, then the right side of (12), in conformity with (7), proves to be equal to zero, owing to which we obtain the condition of conservation:

$$N = \int_0^\delta u_1(y)\, y^3\, dy = \text{const}. \tag{13}$$

By substituting here the expression for the velocity profile (8), we get:

$$N = \frac{1}{56} u_{1m} \delta^4. \tag{14}$$

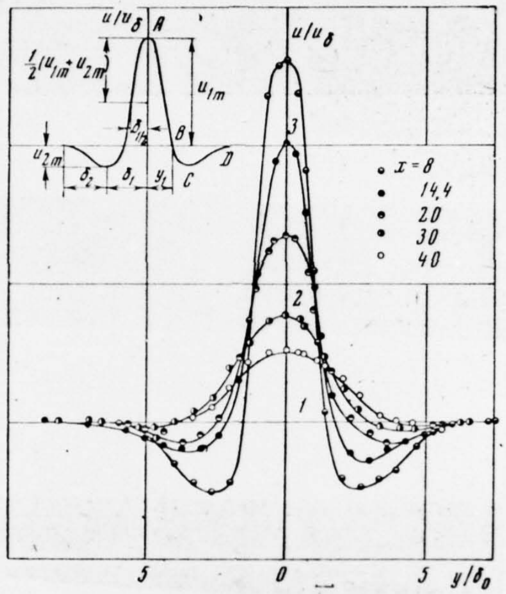
By means of the last expressinn and the first equation of (9), we find the dependences:

$$\delta \sim (\varkappa x)^{1/4}, \qquad \bar{u}_{1m} \sim (\varkappa x)^{-4/4}, \tag{15}$$

which coincide in accuracy with the analogous dependences of Birkgoff and Sarantonello [4].

It is natural that the problem of the advantages of equations (11) or (15) with somewhat differing values of the exponents can be solved only with the attraction of data of the experiment. Figure 4 gives the comparison of the experimental and calculation dependences $\delta(x)$, which indicate in favor of equations (11).

Thus the proposed integral method of calculation makes it possible to obtain the basic regularities of the flow in the near and far parts of the axisymmetric turbulent traces in the zero excess impulse.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u/uδ
u1m
B
C
D
u2m
δ2
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20
30
40
3
2
1
5
0
5
y/δ0

Fig. 1

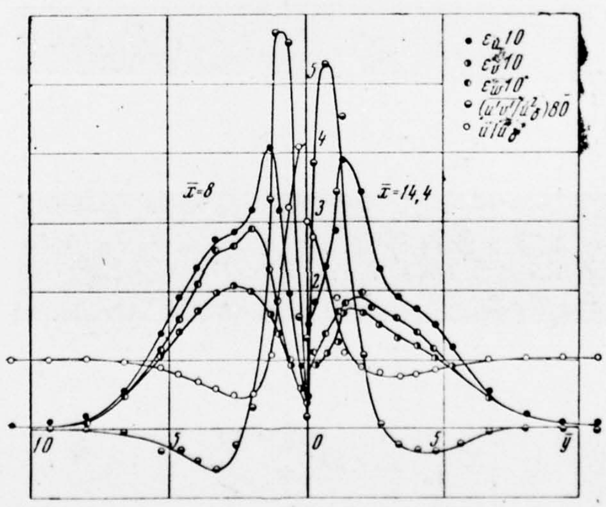
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Fig. 2.

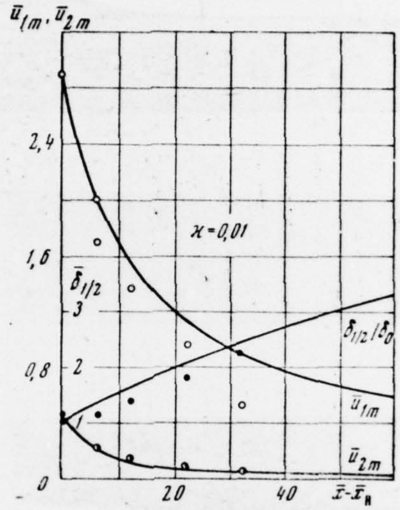

Fig. 3.

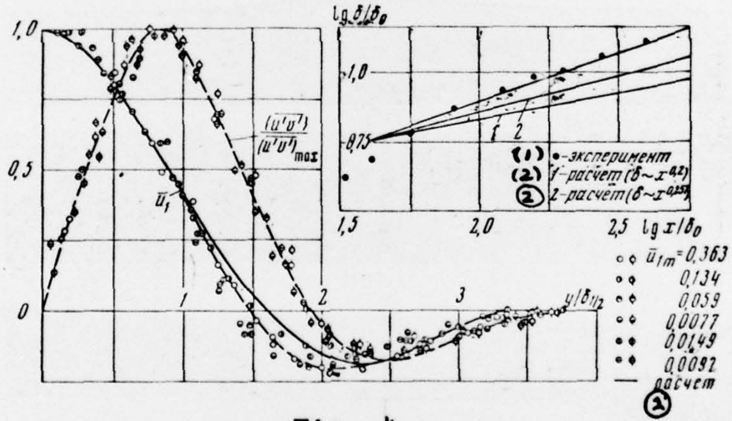

Fig. 4.

Key: (1) Experiment, (2) Calculation.

Bibliography

1. *Абрамович Г. Н.* Теория турбулентных струй. Физматгиз, 1960.
2. *Гиневский А. С., Почкина К. А., Уханова Л. Н.* Закономерности распространения турбулентного струйного течения с нулевым избыточным импульсом. Изв. АН СССР, Механика жидкости и газа, № 6, 1966.
3. *Naudascher E.* Flow in the wake of self-propelled bodies and related sources of turbulence. J. Fluid Mech., 22, part 4, 1965.
4. *Биркгоф Г., Сарантонелло Э.* Струи, следы и каверны. Изд-во «Мир», 1964.
5. *Гиневский А. С., Илизарова Л. И., Шубин Ю. М.* Исследование микроструктуры турбулентной струи в спутном потоке. Изв. АН СССР, Механика жидкости и газа, № 4, 1966.
6. *Гиневский А. С.* Метод интегральных соотношений в теории турбулентных струйных течений. В сб. «Промышленная аэродинамика», вып. 27, изд-во «Машиностроение», 1966.

DETERMINATION OF THE MINIMAL LOSSES WITH THE MIXING OF TURBULENT WAKES IN CHANNELS WITH PROFILED WALLS

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(Moscow)

The solution to the problem about the losses appearing with the mixing of the gas jets in the channel of cylindrical shape can be obtained if the mechanism of the turbulent exchange between the jets is known. In connection with the limitedness of the experimental data on the flow of the jets in channels and their different circuit [1, 3], special experiments were conducted in which by means of creating large velocity gradients in the "core" of the flow (central active jet was supersonic) the effect of friction of the flow against the wall on the rate of the mixing was excluded, and the process was determined in the main turbulent exchange in the "core."

The measured mean (with respect to time) fields of velocity, temperature and pressure were analyzed for the purpose of exposing the similarity of the flow and shape of the velocity and temperature profiles and also for determining the connection of the generalized turbulent characteristics of the flow with the analogous characteristics of the free or pipe turbulence.

A comparison of the external patterns of the flow of jets in the channels and free space showed a considerably more rapid equalization of the fields with flow in the channel (Fig. 1).

Therefore, the theory of the mixing of the jets in an ejector chamber, using the concept of the equivalent free jet [1], at large positive pressure gradients can give only a qualitative description of the flow. It is determined that with the flow of the jet in a channel with the dominating turbulence in the "core" of the flow, the fields of velocity and stagnation temperature are self-similar but are formed so that they are only a central part of the universal jet profile (Fig. 2 and 3).

With the forming of the temperature fields, the level of the temperature, with respect to which the fields are self-similar, increases according to the rate of the mixing. Physically the growth of the base temperature reflects the fact that the heat in the channel is not dissipated, as it is in free flow. The diameter of the channel, with the exception of the concluding stage of the mixing, is not the characteristic scale of similarity, as was accepted in a number of works (see, for example, [3]). The scale of similarity for the fields of velocity and stagnation temperature is unique and connected with the transverse dimension of the velocity profile. For the scale of the length it is possible to take, for example, the quantity $r_{0,5}$ (see Fig. 1). Then the equations of the profiles u and T_0 can be represented in the following form (see Fig. 4):

$$\frac{u - u_2}{u_m - u_2} = f\left(\frac{y}{r_{0,5}}\right), \qquad \frac{T_0 - T_{0x}}{T_{0m} - T_{0x}} = f_T\left(\frac{y}{r_{0,5}}\right).$$

By substituting the experimental data into the integral relation of momentum (1) and the Prandtl equation (6), the quantities τ and l in the region of the mixing of the jets in the channel and free flow were determined. It was found that if we assume that the scale l is proportional to $r_{0,5}$, then the magnitude of the coefficient of proportionality C is approximately identical in the mixing of the jets in the channel and free flow, which is illustrated by the given table.

Table of Experimental Values of Constant C in the Region of Mixing of the Axisymmetric Jet ($M_1=2,85$; $\overline{T}_{02}=0,125$) when $\bar{y}=y/d=0,8$

(1) Расстояние от среза сопла $\bar{x}$	12,6	15,4	18,3	21,1	24
(2) Свободная струя: $M_2=0$	0,200	0,205	0,200	0,205	0,23
(3) Канал: $S=0,1$; $M_2=0,28$	0,195	0,205	0,215	0,220	—
(3) Канал: $S=0,1$; $M_2=0,46$	0,195	0,210	0,225	0,245	0,240

Key: (1) Distance from nozzle section; (2) Free jet; (3) Channel.

Considering the revealed characteristics of the flow, let us construct the scheme of calculation of the equalization of the fields u and T_0 in the channels. It is necessary to determine the five unknown quantities: u_m; T_{0m}; T_{0x}; $r_{0,5}$; P.

Let us write for a certain region of mixing, which lies within the axisymmetric chamber ($y<R$), the integral relations of momentum and heat transfer:

$$\frac{d}{dx}\int_0^y y\rho u^2 dy - u_y \frac{d}{dx}\int_0^y y\rho u dy = -\frac{y^2}{2}\frac{dP}{dx} + y\tau, \quad (1)$$

$$\frac{d}{dx}\int_0^y y\rho c_p T_0 u dy - c_{py} T_{0y} \frac{d}{dx}\int_0^y y\rho u dy = yq. \quad (2)$$

Furthermore, under the condition of the disregard of the friction and heat removal on the wall for the channel as a whole we have:

$$\frac{d}{dx}\int_0^R y\rho u dy = 0, \quad (3)$$

$$\frac{d}{dx}\int_0^R y\rho c_p T_0 u dy = 0, \quad (4)$$

$$\frac{d}{dx}\int_0^R y\rho u^2 dy = -\frac{R^2}{2}\frac{dP}{dx}. \quad (5)$$

According to Prandtl, we assume:

$$\tau = \rho l^2 \left| \frac{\partial u}{\partial y} \right| \cdot \left(\frac{\partial u}{\partial y} \right), \tag{6}$$

$$q = c_p \rho l^2 \left| \frac{\partial u}{\partial y} \right| \left(\frac{\partial T_0}{\partial y} \right). \tag{7}$$

Using the equation of state $\rho = P/RT$ and the condition $P(y) = \text{const}$ it is possible to solve each of the equations of the system (1)-(5) with respect to the logarithmic derivative of pressure with respect ot x. Thus, for example, equation (1) acquires the form (it is assumed that y = R/2):

$$-\frac{1}{P}\frac{dP}{dx} = \frac{\frac{d}{dx}\int\limits_0^{R/2} \frac{u^2}{RT} y dy - u \frac{d}{dx}\int\limits_0^{R/2} \frac{u}{RT} y dy + \frac{R}{2} \cdot \frac{1}{RT} l^2 \left(\frac{du}{dy}\right)^2}{\int\limits_0^{R/2} \frac{u^2}{RT} y dy - u \int\limits_0^{R/2} \frac{u}{RT} y dy + \frac{R^2}{8}}. \tag{8}$$

By equating the right sides of the thus transformed equations (1)-(5), it is possible to obtain four equations which already do not contain the pressure and its derivative. Having taken on the basis of the experimetal data

$$\bar{u} = (\bar{u}_m - \bar{u}_2) f(\eta) + \bar{u}_2, \tag{9}$$

$$\bar{T}_0 = (\bar{T}_{0m} - \bar{T}_{0x}) f_T(\eta) + \bar{T}_{0x}, \tag{10}$$

$$\bar{l} = C\bar{r}_{0,5} \tag{11}$$

(all the quantities refer to parameters on the section of the active nozzle), and having substituted (9)-(11) into the system of equations (1)-(5), we obtain four linear differential equations relative to the functions $\bar{u}_m, \bar{T}_{0m}, \bar{T}_{0x}, \bar{r}_{0,5}$ (due to the saving of space the total system of equations is not given). In the particular case of the mixing of the isothermic jets, the system of equations has the form

$$\left[\frac{[(\bar{u}_m-\bar{u}_2)f(i)+\bar{u}_2]\,i}{\tau(\bar{u})}\left(\frac{1}{i^2}\{B_4[(\bar{u}_m-\bar{u}_2)f(i)+\bar{u}_2]-B_1\}-\frac{1}{4}\nu\right)+\right.$$
$$\left.+\frac{1}{2i}\nu B_4\right]\frac{di}{d\bar{x}}+\left[\frac{1}{i^2}(2B_4B_3-B_2B_1)-\frac{1}{4}\nu B_2\right]\frac{d\bar{u}_m}{d\bar{x}}=$$
$$=\frac{1}{2}\nu B_4\frac{1}{\bar{R}}\frac{d\bar{R}}{dx}, \tag{12}$$

$$\left[\frac{1}{8i}\nu B_4-\frac{[(\bar{u}_m-\bar{u}_2)f(i)+\bar{u}_2]\,i}{\tau(\bar{u})}\left\{\frac{1}{i^2}\left(\beta_1-\left[(\bar{u}_m-\bar{u}_2)f\left(\frac{i}{2}\right)+\bar{u}_2\right]\beta_4\right)+\right.\right.$$
$$\left.\left.+\frac{1}{16}\nu\right\}\right]\frac{di}{d\bar{x}}+\left[\frac{1}{i^2}\left\{2B_4\beta_3-\left[(\bar{u}_m-\bar{u}_2)f\left(\frac{i}{2}\right)+\bar{u}_2\right](B_4\beta_2-B_2\beta_4)\right\}-\right.$$
$$\left.-B_2\left(\frac{1}{i^2}\beta_1+\frac{1}{16}\nu\right)\right]\frac{d\bar{u}_m}{d\bar{x}}=-\frac{B_4}{\bar{R}}\frac{C^2}{2}(\bar{u}_m-\bar{u}_2)^2\frac{\left[f'\left(\frac{i}{2}\right)\right]^2}{\tau(\bar{u})}+$$
$$+\frac{1}{8}\nu B_4\frac{1}{\bar{R}}\frac{d\bar{R}}{dx}. \tag{13}$$

The following notations are introduced:

$$\tau(\bar{u})=1-\frac{k-1}{k+1}\lambda_1^2\bar{u}^2;\qquad \nu=\frac{k+1}{k}\frac{1}{\lambda_1^2};\qquad i=\frac{R}{r_{0,5}};\qquad \eta=\frac{y}{r_{0,5}};$$

$$\lambda=\frac{u}{a_{\text{кр}}};\qquad \bar{R}=\frac{R}{d};\qquad B_1=\int_0^i\frac{\bar{u}^2\eta d\eta}{\tau(\bar{u})};\qquad B_2=\int_0^i\frac{[2-\tau(\bar{u})]f(\eta)\eta d\eta}{[\tau(\bar{u})]^2};$$

$$B_3=\int_0^i\frac{\bar{u}f(\eta)\eta d\eta}{[\tau(\bar{u})]^2};\qquad B_4=\int_0^i\frac{\bar{u}\eta d\eta}{\tau(\bar{u})}\qquad \beta_1=\int_0^{i/2}\frac{\bar{u}^2\eta d\eta}{\tau(\bar{u})};$$

$$\beta_2=\int_0^{i/2}\frac{[2-\tau(\bar{u})]f(\eta)\eta d\eta}{[\tau(\bar{u})]^2};\qquad \beta_3=\int_0^{i/2}\frac{\bar{u}f(\eta)\eta d\eta}{[\tau(\bar{u})]^2};\qquad \beta_4=\int_0^{i/2}\frac{\bar{u}\eta d\eta}{\tau(\bar{u})}.$$

The change in pressure along the length can be found from equation (8). It is expedient to solve the system of equations (12)-(13) by the numerical methods on a digital computer.

It is convenient to represent function $f(\eta)$ in the form of a polynomial. In the example given below the polynomial of A. Ginevskiy was taken [2]. Constant C can be taken the same as that in the free jets.

A comparison of the calculation conducted with the experimental data show the satisfactory agreement (Fig. 5). The term with $d\bar{R}/dx$ allows considering the effect of the shape of the chamber on the mixing rate.

Let us assume that the free turbulent jet at a certain distance from the nozzle section is included into the channel in which its further flow occurs (Fig. 6). We will assign the different laws of $\bar{R}(x)$ and determine the resultant pressure of the mixing of the gases. To determine the energy losses the parameters of mixing can be compared with parameters of the initial field averaged without losses [4]. We must, however, keep in mind that for the flow averaged with constant entropy S, the adiabatic work of expansion is greater than that for the initial nonuniform flow. (It is easy to show that when $\bar{T}_{02} = 1{,}0$ the averaging of the parameters under condition S = const leads to a retention of the isothermic (and not adiabatic!) works of expansion, and when $\bar{T}_{02} \neq 1{,}0$ the mean total pressure can prove to be greater than the total pressure of the active gas.) Let us examine, therefore, the change in the efficiency of the mixing, which is calculated as the ratio of the adiabatic work of the expansion of the mixture of the gases to the integral adiabatic work of the expansion of the initial field ($\eta_{ад}$). Figure 7 gives results of the calculations of coefficients η_S and $\eta_{ад}$ for the case when the free flooded jet (M = 3.0) is included into the convergent conical channel at the beginning of the main section. Let us note that with the integration of the system (12)-(13), with a certain narrowing of the channel the smoothness of the solution is disrupted. This corresponds to the "passage through unity" of the quantity $\int_F dF/\lambda^2$, which represents the choking criterion for the nonuniform flow [5]. Therefore, the calculation was conducted under the asssumption that the narrowing of the channel occurs up to the choking section, and further the process is completed in the cylindrical chamber (see Fig. 6).

From Fig. 7 it is evident that with an increase in the angle of taper α the minimum area of narrowing of the channel is decreased, and the efficiency of the mixing increases, asymptotically approaching the maximum value. It is easy to obtain the magnitude of the limit if we conditionally accept that up to the choking section the stagnation of the field occurs without a turbulent exchange ($C = 0$) (see Fig. 7).

Of practical interest is the fact that for the isothermic jets the relationship between the rate of equalization owing to the turbulent exchange and the geometric effect is such that when $\alpha \approx 0{,}15$ rad the efficiency of the mixing is already close to the maximum value. In the case of the flow in the channel of the high-temperature and supersonic jet, in connection with an improvement in the turbulent exchange, the taper angles, which correspond to values of η close to the maximum, are increased and found in that region of values when it is necessary to consider the radial currents and hydrodynamic chaacteristics of the flow near the walls. Thus the losses to mixing of the jets can be decreased if the shape of the mixing chamber allows carrying out the equalizing of the velocity fields with the critical parameters.

Bibliography

1. *Абрамович Г. Н.* Теория турбулентных струй. Физматгиз, 1960.
2. *Гиневский А. С.* Турбулентный след струи в спутном потоке при наличии продольного градиента давления. Изв. АН СССР, Механика и машиностроение, № 2, 1959.
3. *Яковлевский О. В.* Смешение струй в канале с переменным поперечным сечением. Изв. АН СССР, Механика и машиностроение, № 1, 1962.
4. *Седов Л. И., Черный Г. Г.* Об осреднении неравномерных потоков газов в каналах. В сб. «Теоретическая гидродинамика», вып. 12. Оборонгиз, 1954.
5. *Hoge H. J., Segars R. A.* Choked Flow: A Generalization of the Concept and some Experimental, AJAA Journal, 3, No. 12, December 1965.

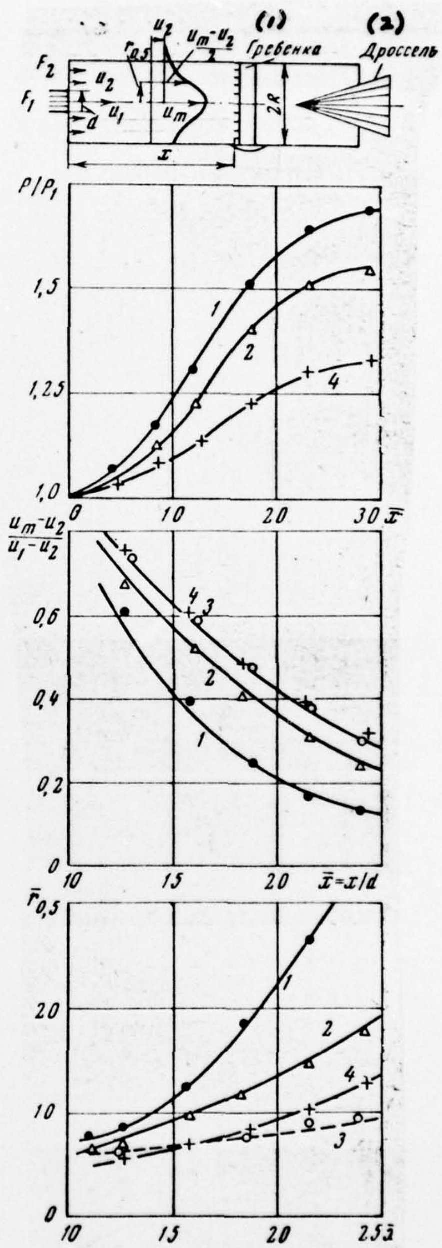

Fig. 1. Nature of the change in the main parameters of the jet with a flow in a free gradientless flow and in a channel with different longitudinal pressure gradients.

Parameters of mixing:

$M_1 = 2,85$; $\bar{P} = 1$; $T_{02}/T_{01} = 0,125$. **1, 2, 4 - ejector:** $S = F_1/F_2 = 0,1$; $dR/dx = 0$;

cross: $u_2/u_1 = 0,12$; **triangle:** $u_2/u_1 = 0,08$; **black dot:** $u_2/u_1 = 0,05$;

3 - free jet, light dot: $u_2/u_1 = 0$

KEY: 1) Crest; 2) Choke.

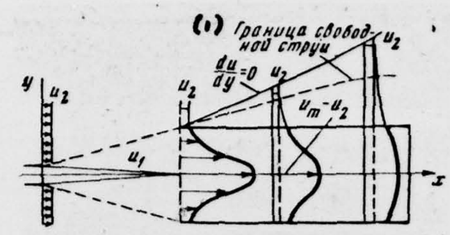

Fig. 2. Diagram of the shaping of the velocity profile. KEY: 1) Boundary of the free jet.

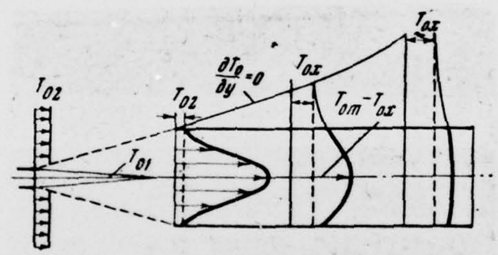

Fig. 3. Diagram of the stagnation temperature profile.

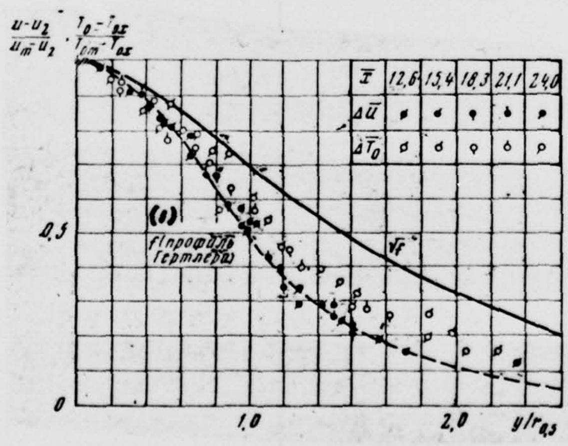

Fig. 4. Example of the treatment of fields u and T_0 in accordance with diagrams of Fig. 2 and 3. Parameters of mixing:

$M_1 = 3{,}0;$
$\overline{T}_{02} = T_{02}/T_{01} = 0{,}146;\ M_2 = 0{,}47;$
$S = F_1/F_2 = 0{,}1;\quad dR/d\overline{x} = -0{,}01$

KEY: 1) f(Hertler profile)

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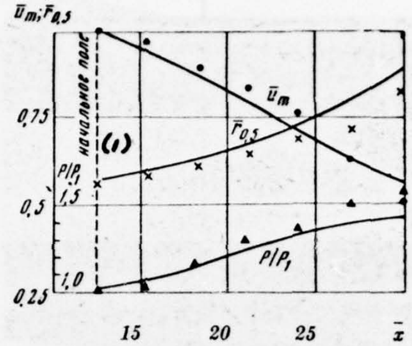

Fig. 5. Comparison of the calculation with experimental data (conic chamber) $M_1 = 3,1$; $M_2 = 0,35$; $\bar{P} = 1$; $\bar{u}_2 = 0,19$; $\bar{T}_{02} = 1$; $dR/dx = -0,01$; $f = 0,68$
KEY: 1) initial field.

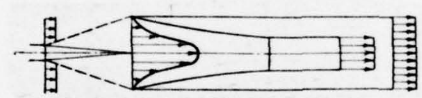

Fig. 6. Calculation diagram of the equalization of the jet field

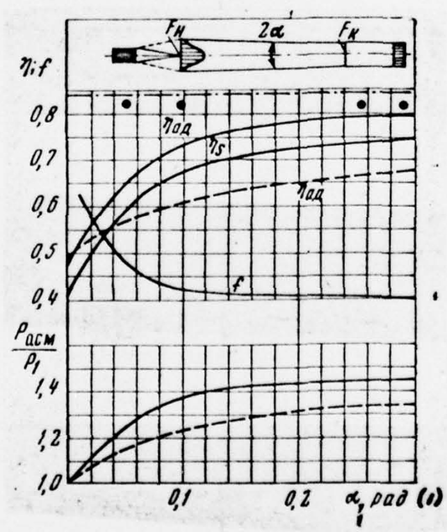

Fig. 7. Efficiency of the mixing η and maximum values of $f = F_K/F_H$ Variant 1 - solid lines: $M = 3,0$; $T_{02} = 1,0$; $C = 0,15$; variant 2 - dashed lines : $M = 3,0$; $T_{02} = 0,1$; $C = 0,24$; dots - calculation when C = 0 (variant 1); dot-dash line $\eta_{ад}$ of the optimal ejector with a cylindrical chamber (variant 1). KEY: 1) rad.

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