LITERATURE CITED

1. A. Kh. Bokovikova, V. I. Shcherbinin, and F. R. Shklyar, "Complex heat exchange in short channels," in: Heat and Mass Exchange-5, Vol. 8, ITMO im. A. V. Lykova Akad. Nauk BSSR, Minsk (1976), pp. 90-94.
2. R. Echigo, S. Hasegawa, and K. Kamiuto, "Composite heat transfer in a pipe with thermal radiation of two-dimensional propagation – in connection with the temperature rise in flowing medium upstream from heating section," Int. J. Heat Mass Transfer, 18, No. 10, 1149-1159 (1975).
3. G. C. Davis, "The effect of axial radiation on the Cartesian Graetz problem," Int. J. Heat Mass Transfer, 19, No. 2, 157-164 (1976).
4. S. Desoto, "Coupled radiation, conduction and convection in entrance region flow," Int. J. Heat Mass Transfer, 11, No. 1, 39-53 (1968).
5. Yu. A. Popov and V. I. Shcherbinin, "Complex heat exchange in laminar flow of a scattering medium in a cylindrical channel," Zh. Prikl. Mekh. Tekh. Fiz., No. 3, 99-102 (1977).
6. N. A. Rubtsov and N. M. Ogurechnikova, "Radiative and convective heat exchange in the channel of an electric arc with turbulent gas flow," in: Radiative and Combined Heat Exchange, Inst. Teplofiz. Sib. Otd. Akad. Nauk SSSR, Novosibirsk (1981), pp. 24-29.
7. M. N. Ocisik, Complex Heat Exchange [Russian translation], Mir, Moscow (1976).
8. Yu. A. Popov and V. I. Polovnikov, "Radiative and convective heat exchange with turbulent flow of a scattering medium in a plane channel," Teplofiz. Vys. Temp., 18, No. 1, 139-143 (1980).
9. M. T. Smirnov, "Heat transfer by gases simultaneously by radiation and contact," Izv. VTI, No. 3 (46), 119-123 (1929).

ANALOGY BETWEEN TURBULENT MOMENTUM AND HEAT TRANSFER UNDER COMPLEX CONDITIONS

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The analogy between turbulent momentum and heat transfer under complex conditions, i.e., under the action of several perturbing factors on the flow, is extended for a broad range of variation of the Prandtl number.

Because the systems of differential equations for the mean characteristics of the turbulent boundary layer are not closed, empirical relationships must be utilized. As the number of perturbing factors increases, the setting up of such relationships becomes more and more difficult; moreover, the formulas obtained can be applied only for the conditions of the experiment performed. The complexity of the computation is aggravated by the fact that the Reynolds analogy between the turbulent momentum and heat transfer is spoiled [1, 2].

The question of a more general analogy between the momentum and heat transfer is considered below in the turbulent core of a stationary near-wall flow under complex flow conditions that permit simplification of the heat-exchange parameter analysis.

The basic dimensionless variables used to analyze forced turbulent heat transfer are the Reynolds Re, Stanton St, or Nusselt Nu numbers, and the friction coefficient $c_f/2$, which are represented for convenience in the subsequent analysis as

$$\mathrm{Re} = u_\delta^+ \delta^+, \quad (1)$$

$$\mathrm{St} = \frac{1}{u_\delta^+ \vartheta_\delta^+}, \quad (2)$$

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TABLE 1. Development of the Turbulent Thermal Boundary Layer into a Dynamic behind a Section with Jump Change in the Wall Temperature according to Experimental Results Presented in [3]

x_c/δ_c	$\vartheta^+_{\delta_T}$	$K = u^+_\delta / \vartheta^+_{\delta_T}$	$\tilde{X}_\delta$	$\tilde{\Psi}_\delta$	$\tilde{\Psi}_\delta/\tilde{X}_\delta$
1,4	11,3	1,74	0,45	0,35	0,78
5,8	14,3	1,42	0,45	0,34	0,76
7,3	15,8	1,56	0,44	0,31	0,70
10,1	15,9	1,30	0,42	0,33	0,79
18,8	16,8	1,21	0,42	0,35	0,83
24,0	18,1	1,42	0,41	0,30	0,73
29,7	18,4	1,12	0,39	0,35	0,90
40,7	19,4	1,35	0,40	0,30	0,75
57,3	20,0	1,32	0,40	0,30	0,75

$$\mathrm{Nu} = \mathrm{Pr}\,\frac{\delta^+}{\vartheta^+_\delta}, \tag{3}$$

$$\frac{c_f}{2} = \frac{1}{u^{+2}_\delta}. \tag{4}$$

We obtain from (2) and (4) for the coefficient of the Reynolds analogy $K = \mathrm{St}/{}^1/_2 c_f$ [3]

$$K = u^+_\delta / \vartheta^+_\delta. \tag{5}$$

For Pr = 1 and $\mathrm{Pr}_t = 1$ there is a Reynolds analogy between the turbulent momentum and heat transfers: K = 1.

An analogy is also used with respect to the turbulent transfer coefficients ν_t and a_t by the introduction of the turbulent Prandtl number

$$\mathrm{Pr}_t = \nu_t / a_t, \tag{6}$$

by considering that $\mathrm{Pr}_t = 1$ in many computations [4].

In the domain of the turbulent core

$$u^+ = A \ln y^+ + B, \tag{7}$$

$$\vartheta^+ = C \ln y^+ + D, \tag{8}$$

and if $q^+ \sim 1$, $\tau^+ \sim 1$ here, then Pr_t [4] is determined from the slopes of the logarithmic velocity (7) and temperature (8) profiles in the form

$$\mathrm{Pr}_t = C/A, \tag{9}$$

where A, C (exactly as B and D) are empirical constants.

For complex turbulent flow conditions, the simple relationships (5) and (9) are not applicable under the simultaneous action of several factors such as substantial nonisothermy, mass force fields (gravitational, electromagnetic, centrifugal), mass transfer on the boundary surfaces with changing configurations in space, etc., perturbing the stream. Giving the functional dependences of K and Pr_t on these perturbing factors in (5) and (9) is quite difficult.

Simple relationships characterizing the analogy between the turbulent momentum and heat transfer under complex conditions can be obtained on the basis of a turbulent boundary layer model [5].

Universal velocity and temperature distributions are described in [6] for the turbulent core in the form of generalized functions whose running values over the section $f_i(x, y)$ equal the values along the upper boundary of the core $f_{\delta i}(x)$

$$\tilde{\Psi} = \tilde{\Psi}_\delta, \tag{10}$$

$$\tilde{X} = \tilde{X}_\delta, \tag{11}$$

$$\Psi = \Psi_\delta, \tag{12}$$

TABLE 2. Heat Transfer in the Initial Section of a Smooth Pipe from Data of Barbin and Jones [9] and Jonka and Hanratty Presented in [7]

x/d	[9] u_δ^+	[9] $\tilde{\Psi}_\delta$	[7] $\vartheta_{\delta_T}^+$	[7] $\tilde{X}_\delta$	$\tilde{\Psi}_\delta / \tilde{X}_\delta$
1,0			10,8	0,48	
1,5	20,1	0,37			0,77
2,5			14,0	0,41	0,90
4,0			15,2	0,41	
4,5	22,5	0,35			0,86
6,0			16,1	0,41	
7,5	22,7	0,36			0,88
10,0			17,3	0,40	
10,5	25,7	0,32			0,80
15,5			18,8	0,38	
16,5	26,9	0,32			0,84

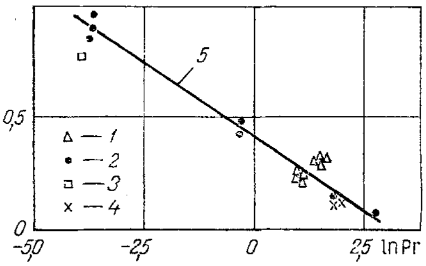

Fig. 1. Dependence of the thermal boundary function $\tilde{X}_\delta$ on the molecular Prandtl number Pr according to the data: 1) [2]; 2) [4]; 3) [7]; 4) [8]; 5) from (23).

$$X = X_\delta. \tag{13}$$

Here $\tilde{\Psi} = \ln y^+/(u^+ - 1)$; $\tilde{X} = \ln y^+/(\vartheta^+ - 1)$; $\Psi = \ln(y/\delta_0)/(u^+ - u_0^+)$; $X = \ln(y/\delta)/(\vartheta^+ - \vartheta_0^+)$. The subscript 0 refers to the lower boundary of the turbulent core, for instance, to the boundary of the Karman transition region. The boundary functions $\tilde{\Psi}_\delta$, $\tilde{X}_\delta$, Ψ_δ, X_δ contain all the dimensionless boundary variables that are in the complex (1)-(4): u_δ^+, ϑ_δ^+, δ^+.

As is shown in [4, 5], the velocity distribution (10) is conservative to the action of mass force fields, nonisothermy, etc. on the stream for a zero pressure gradient. The temperature formula (11) satisfactorily generalizes the known experimental data for Pr ~ 1. For Pr ≠ 1 (13) holds.

Expanding the running values of $\tilde{\Psi}$ and $\tilde{X}$ in (10) and (11), we obtain relationships analogous to (7) and (8) in the mode of writing:

$$u^+ = \frac{1}{\tilde{\Psi}_\delta} \ln y^+ + 1, \tag{14}$$

$$\vartheta^+ = \frac{1}{\tilde{X}_\delta} \ln y^+ + 1, \tag{15}$$

which, in contrast to (7) and (8), do not contain empirical constants. According to [2], we find Pr_t from (14) and (15)

$$Pr_t = \frac{d\vartheta^+/dy^+}{du^+/dy^+} \frac{\tau^+}{q^+} = \frac{\tilde{\Psi}_\delta}{\tilde{X}_\delta} \frac{\tau^+}{q^+}. \tag{16}$$

For the zone in which $\tau^+ \sim q^+ \sim 1$,

$$Pr_t = \tilde{\Psi}_\delta / \tilde{X}_\delta. \tag{17}$$

For Pr ≠ 1 also, from (12), (13) and the condition that $\tilde{\Psi}_\delta = \Psi_\delta$ [6] for a zero pressure gradient

$$Pr_t = \frac{\Psi_\delta}{X_\delta} = \frac{\tilde{\Psi}_\delta}{X_\delta}. \tag{18}$$

As Pr → 1 $X_\delta \to \tilde{X}_\delta$ and (18) goes over into (17).

TABLE 3. Heat Transfer on a Porous Plate with Blowing (suction) from Data in [10-12]

$F = v_w/u_\delta$	$\tilde{\Psi}_\delta$	$\tilde{X}_\delta$	$\tilde{\Psi}_\delta/\tilde{X}_\delta$
0	0,35	0,40	0,87
0,0058	0,20	0,22	0,91
—0,002	0,42	0,42	1,00

Formula (18) is a generalized analogy between turbulent momentum and heat transfer. In contrast to (9) no empirical constants A, C are in (18), hence (18) can be applied for complex flow conditions.

Let us show that the Reynolds analogy (5), where K = 1, is a particular case of (18). In fact, for $Pr_t \sim 1$ and $Pr \sim 1$, from (17)

$$\frac{\ln \delta^+}{u_\delta^+ - 1} = \frac{\ln \delta_T^+}{\vartheta_{\delta_T}^+ - 1}, \tag{19}$$

and if the thicknesses of the thermal δ_T and dynamic boundary layers agree, then (19) is identical to (5) for K = 1.

However, (17) and its analog (19) for $Pr_t = 1$ are of more general nature than (5) for K = 1 since they are applicable to describe a broader circle of phenomena, for instance, for the case of the development of a thermal layer into a dynamic behind the section with a jump change in the wall temperature. This is because although $\delta_T < \delta$ in the development of a thermal stationary layer into a dynamic one, for any value $y = \delta_T$ in the domain of the turbulent core ($\delta_0 \le y \le \delta$), $\tilde{\Psi}(\delta_T) = \tilde{\Psi}_\delta(\delta)$ since (10) is satisfied.

As an illustration (Table 1), the data of Blum (x_c/δ_c = 1.4; 5.8; 10.1; 18.8; 29.7) and Perry, Hoffman (x_c/δ_c = 7.3; 24.0; 40.7; 57.3) presented in [3] are considered. Here δ_c is the dynamic boundary layer thickness at the location of the wall temperature jump, and x_c is the distance downstream from it. It is seen from Table 1 that for relatively small x_c/δ_c for the data under consideration it is impossible to use the Reynolds analogy (K = 1 in [5]). At the same time, the ratio $\tilde{\Psi}_\delta/\tilde{X}_\delta$ in (17) varies between 0.76 and 0.90 according to the Blum data, between 0.70 and 0.75 according to the Perry, Hoffman data, and corresponds to Pr_t values obtained, and therefore to (17).

For a better comprehension of the influence of the molecular Prandtl number Pr on the analogy (18), we represent this expression in the form of three dependences:

$$\text{for} \quad Pr < 1 \quad \frac{\tilde{\Psi}_\delta}{Pr_t} = X_\delta < \tilde{X}_\delta, \tag{20}$$

$$\text{for} \quad Pr \sim 1 \quad \frac{\tilde{\Psi}_\delta}{Pr_t} = X_\delta = \tilde{X}_\delta, \tag{21}$$

$$\text{for} \quad Pr > 1 \quad \frac{\tilde{\Psi}_\delta}{Pr_t} = X_\delta > \tilde{X}_\delta. \tag{22}$$

The inequalities in (20) and (22) are satisfied because as Pr diminishes or increases in $\tilde{X}_\delta$ the value $\vartheta_{\delta_T}^+$ diminishes or increases substantially while $\ln \delta_T^+$ depends relatively weakly on Pr.

Because Pr ≠ 1 in (20) and (22), the thermal boundary function $\tilde{X}_\delta$ that is convenient for computations is not related directly to the dynamic boundary function $\tilde{\Psi}_\delta$, it is not at all convenient to use the relationships (20) and (22) since the quantities ϑ_0^+ and δ_0^+ in X_δ are difficult to determine in the blurred boundary δ_0 of the mixed transfer zone. However, if $\vartheta_{\delta_T}^+$ or δ_T^+ is known, the temperature profile can be determined in the coordinates ϑ^+, $\ln y^+$ even for an indefinite boundary δ_0 if the dependence $\tilde{X}_\delta(Pr)$ is given. The method elucidated in [5]

$$\tilde{X}_{\delta 1}(Pr = 1) = \tilde{X}_\delta(Pr \neq 1) + C \ln Pr \tag{23}$$

can be used to set it up. According to the data in [2, 4, 7, 8], C = 0.13 (Fig. 1). Because of the degeneration of $\tilde{X}_\delta$ as Pr grows, the relationship (23) is applicable for $Pr \leqslant 10$.

TABLE 4. Data from [13] about the Average Vertical Temperature Profile in the Northeastern Part of the Pacific Ocean, Obtained by Multiple Soundings

y, m	T, °C	$T-T_0$	$\ln(y/\delta_{0T})$	Θ	R
110	11,0	0	0	0	0
125	10,0	−1,0	0,128	0,20	0,12
160	9,0	−2,0	0,375	0,40	0,36
205	8,0	−3,0	0,623	0,60	0,59
260	7,0	−4,0	0,860	0,80	0,82
315	6,0	−5,0	1,052	1,00	1,00

Sketching the line (15) on a plane with coordinates ϑ^+, $\ln y^+$ with $\tilde{X}_\delta = \tilde{X}_\delta$ (Pr ≠ 1), the point of its intersection with the line $\vartheta^+ = \vartheta_{\delta_T}{}^+$ or $\ln y^+ = \ln\delta_T{}^+$ can be found. Drawing a line with the slope $Pr_t/\tilde{\Psi}_\delta$ through the point obtained, we obtain the desired temperature profile.

As is known in [5], upon the simultaneous action of perturbing factors K_i (i = 1, 2, ..., N) that are weakly intercorrelated, on a turbulent flow characterized initially by the value $\tilde{\Psi}_{\delta 0}$.

$$\tilde{\Psi}_{\delta 1,\,2,\ldots,\,N}(K_1,\ K_2,\ldots,\ K_N) = \tilde{\Psi}_{\delta 0} - \sum_{i=1}^{N} \ln f(K_i), \tag{24}$$

where

$$\sum_{i=1}^{N} \ln f(K_i) = N\tilde{\Psi}_{\delta 0} - \sum_{i=1}^{N} \tilde{\Psi}_{\delta i}(K_i). \tag{25}$$

Then for heat transfer with (21) taken into account

$$\tilde{X}_{\delta 1,\,2,\ldots,\,N}(K_1,\ K_2,\ldots,K_N) = \frac{\tilde{\Psi}_{\delta 1,\,2,\ldots,\,N}(K_1,\ K_2,\ \ldots,\ K_N)}{Pr_t}. \tag{26}$$

Analogous expressions can be obtained for the functions Ψ_δ, X_δ. Therefore, when $\tilde{\Psi}_{\delta 0}$, $\Psi_{\delta 0}$, Pr_t and the laws of variation of the boundary functions $\tilde{\Psi}_\delta$, Ψ_δ are known, under the action of independent causes K_i the values $\tilde{\Psi}_{\delta_{1,2},\ldots,N}$, $\tilde{X}_{\delta_{1,2},\ldots,N}$, $\Psi_{\delta 1,2,\ldots,N}$, $X_{\delta 1,2,\ldots,N}$ are determined uniquely, which permit a judgment about the characteristics of near-wall turbulent heat transfer under the simultaneous action of K_i factors on a flow N. By virtue of (10)-(13), the running values of functions for a given section can be determined under complex conditions, on the basis of knowing the boundary functions (the subscript δ). The superposition principle (24), (25) and the generalized analogy between the momentum and heat transfer (20)-(22), (26) permit simplification of the analysis of the characteristics of a complex near-wall turbulent flow.

As illustrations of the applicability of (21) to complex flow conditions, the data from [9] and from Jonka and Hanratty [7] about the hydrodynamics and heat transfer in the initial section of a smooth pipe for x/d < 17 are systematized in Table 2 (x is the distance from the tube exit, and d is its diameter), while the data from [10-12] on heat transfer on a porous plate for different blowing (suction) parameters $F = v_w/u_\delta$ are presented in Table 3 (v_w is the blowing velocity, x = 350 mm, zero pressure gradient). It is seen from the table that the ratio $\tilde{\Psi}_\delta/\tilde{X}_\delta$ corresponds approximately to known values of Pr_t. The data presented show that the dependence (26) is reliable.

Besides (23), another approach to the simplification of utilizing (20), (22) for Pr ≠ 1 is that the functions δ_{0T}, δ_T, ϑ_{0T}, ϑ_{δ_T} in X_δ are sought as boundary functions for zones in which (13), representable in the form

$$\Theta = R, \tag{27}$$

is satisfied, where $\Theta = (T - T_{0T})/(T_{\delta_T} - T_{0T})$; $R = \ln(y/\delta_{0T})/\ln(\delta_T/\delta_{0T})$.

As an illustration, data from [13] about the average vertical temperature profile in the northwestern part of the Pacific Ocean, obtained by multiple sounding, are presented in Table 4. Here y is the distance between the free surface and the ocean depths. Satisfactory correlation is seen between (27) and these data. According to [13], the rms spread $\sigma_T(y)$ in the temperature values in the layer from 145 to 185 m is ~ 0.4° according to separate soundings. Then taking into account that the temperature scale ϑ_* should be on the order of $\sigma_T(y)$,

$X_\delta \sim \ln(205/125)/[(10-8)/0.4] \sim 0.10$. Furthermore, let us calculate $\tilde{X}_\delta$ for comparison with the value X_δ obtained. For sea water Pr ~ 8.6 for T ~ 10°C. From (23) $\tilde{X}_{\delta 1}$ (Pr = 1)-$\tilde{X}_\delta$(Pr) = 0.28. Taking $\tilde{X}_{\delta 1} = 0.40$ (Fig. 1), we obtain that $\tilde{X}_\delta \sim 0.12$, i.e., $X_\delta \approx \tilde{X}_\delta$. From this example follows the deduction that in the absence of shear flow, when the change in temperature in a continuous medium is determined by turbulent fluctuations, $X_\delta = \tilde{X}_\delta$.

NOTATION

x, coordinate along the wall being streamlined, m; y, coordinate along the normal to the wall, m; u, mean longitudinal velocity, m/sec; T, mean temperature, °K; T_w, wall temperature, °K; ν, kinematic coefficient of viscosity, m^2/sec; ν_t, turbulent kinematic coefficient of viscosity, m^2/sec; ρ, density, kg/m^3; c_p, specific heat, J/kg; τ, tangential stress, N/m^2; τ_w, tangential stress on the wall, N/m^2; q, specific heat flux, W/m^2; q_w, specific heat flux at the wall, W/m^2; a, coefficient of thermal diffusivity, m^2/sec; a_t, turbulent coefficient of thermal diffusivity, m^2/sec; δ, dynamic boundary layer thickness, m; δ_T, thermal boundary layer thickness, m; δ_0, lower boundary of the turbulent core, m; $u_* = \sqrt{\tau_w/\rho}$, dynamic velocity, m/sec; $\vartheta_* = q_w/\rho c_p u_*$, characteristic temperature, °K; $y^+ = yu_*/\nu$, a dimensionless coordinate; $u^+ = u/u_*$, dimensionless velocity; $\vartheta^+ = (T_w - T)/\vartheta_*$, dimensionless temperature; $\tau^+ = \tau/\tau_w$, dimensionless tangential stress; $q^+ = q/q_w$, dimensionless heat flux; $\tilde{\Psi} = \ln y^+/(u^+ - 1)$, $\Psi = \ln(y/\delta_0)/(u^+ - u_0^+)$, dynamical functions of the turbulent core; $\tilde{X} = \ln y^+/(\vartheta^+ - 1)$, $X = \ln(y/\delta_0)/(\vartheta^+ - \vartheta_0^+)$, thermal functions of the turbulent core; $R = \ln(y/\delta_0)/\ln(\delta/\delta_0)$, generalized dimensionless coordinate; $\Theta = (T - T_0)/(T_\delta - T_0)$, generalized dimensionless temperature; $Re = u_\delta^+\delta^+$, Reynolds number; $c_f = 2/u_\delta^{+2}$, friction coefficient; $Pr = \nu/a$, molecular Prandtl number; $Pr_t = \nu_t/a_t$, turbulent Prandtl number; $K = u_\delta^+/\vartheta_\delta^+$, Reynolds analogy factor; $St = 1/u_\delta^+\vartheta_\delta^+$, Stanton number; $Nu = Pr\delta^+/\vartheta_\delta^+$, Nusselt number; Subscripts: *, stream parameter for $y^+ = 1$; δ, stream parameter for y = δ; 0, stream parameter for $y = \delta_0$; t, turbulent core parameter; w, wall parameter; and T, thermal layer parameter.

LITERATURE CITED

1. V. M. Ievlev, Turbulent Motion of High-Temperature Continuous Media [in Russian], Nauka, Moscow (1975).
2. A. A. Zhukauskas and A. A. Shlanchyauskas, Heat Elimination in a Turbulent Fluid Flow [in Russian], Mintis, Vilnius (1973).
3. A. Brown, "Analysis of the turbulent boundary layer behind a section with a jump change in surface temperature," Trans. ASME, Ser. C. Heat Transfer, No. 1, 168-175 (1979).
4. M. Kh. Ibragimov, V. I. Subbotin, V. P. Bobkov, et al., Structure of the Turbulent Flow and Heat Transfer Mechanism in Channels [in Russian], Atomizdat, Moscow (1978).
5. V. F. Potemkin, "On molar transfer," Inzh.-Fiz. Zh., 42, No. 6, 917-923 (1982).
6. V. F. Potemkin, "On the question of molar momentum and heat transfer," Inzh.-Fiz. Zh., 41, No. 3, 441-448 (1981).
7. M. A. Elhadidy and L. C. Thomas, "A new approach for calculating heat transfer characteristics of turbulent wall flows," Heat Transfer 1982. Proceedings of the Seventh International Heat Transfer Conference, München, FRD. Vol. 3. Forced Convection, Mixed Convection, 247-252. Hemisphere Publ. Corp., Washington, New York, London (1982).
8. Che Pen Chen, "Determination experimentale du nombre de Prandtl turbulent pres d'une paroi lisse," Int. J. Heat Mass Transfer, 16, 1849-1862 (1973).
9. Barbin and Jones, "Turbulent flow in the initial section of a smooth pipe," Trans. ASME, Ser. D., Eng. Mech., No. 1, 34-42 (1963).
10. Case, Moffat, and Tilbar, "Heat transfer in a turbulent boundary layer of a strongly accelerated flow with blowing and suction," Trans. ASME, Ser. C. Heat Transfer, No. 3, 190-198 (1970).
11. Julian, Case, and Moffat, "Experimental investigation of the turbulent boundary layer with suction and blowing for a flow with acceleration," Trans. ASME, Ser. C. Heat Transfer, No. 4, 51-59 (1971).
12. Tilbar, Case, and Moffat, "Turbulent boundary layer on a porous plate. Experimental investigation of heat elimination," Trans. ASME, Ser. C. Heat Transfer, No. 1, 116-123 (1972).
13. R. V. Ozmidov, "Turbulence in the ocean upper layer," Science and Engineering Surveys, Mechanics of Fluids and Gases [in Russian], VINITI, Moscow (1978), pp. 52-143.