OPTICAL CHARACTERISTICS OF TURBULENT NONISOTHERMAL JET FLOWS

O. G. Martynenko, I. A. Vatutin,
N. I. Lemesh, and P. P. Khramtsov

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Total cross-section distribution and scattering indicatrices for scattering of radiation from an external source on pulsations in dielectric permittivity are calculated in a nonisothermal turbulent jet.

Recently, in connection with various practical problems, the necessity has arisen of calculating the statistical energy characteristics of light beams propagating in turbulent liquid shear flows (boundary layers, jets, etc.) [1]. The mean value and dispersion of the intensity can be calculated commencing from the radiation transport equation [2]. This requires a knowledge of the scattering parameters. Since a gaseous medium is quite transparent, the effect of absorption of light energy on the scattering process will be neglected below.

The equation for calculating the differential scattering section has the form [3]

$$\sigma(\theta,\ \varphi) = \frac{1}{2}\pi k_0^4 E_\varepsilon(\mathbf{q}). \tag{1}$$

The scattering indicatrix is related to the differential scattering section by the normalizing expression

$$f(\theta,\ \varphi) = \sigma(\theta,\ \varphi)/\sigma_{\max}, \tag{2}$$

while the total transverse scattering section is defined by the expression

$$\sigma_0 = \frac{1}{2}\pi k_0^4 \int_0^{2\pi}\int_0^{\pi} E_\varepsilon(\mathbf{q}) \sin\theta d\theta d\varphi. \tag{3}$$

The limits of applicability of Eqs. (1)-(3) coincide with the necessary conditions for use of the Born approximation [3], i.e.,

$$\sigma_0 L \ll 1, \tag{4}$$

where L is the size of the scattering volume.

For the jet to be considered $\sigma_{\max} L = 0.6 \cdot 10^{-3}$.

The spectral function of the temperature pulsation field from the experimental data of [4] will be approximated over the entire wave number range by the expression

$$E_T(q) = C_T^2 (q + q_0)^{-5/3} \exp(-\alpha (q/q_m)^\beta), \tag{5}$$

where $q_0 = K/\ell_c$, $\ell_c = x - x_0$, $q_m = R_c^{3/4}/\ell_c$, $R_c = u_c \ell_c/\nu$, $u_c = u_0 D^{1/2} \ell_c^{-1/2}$. The structural characteristic of the temperature pulsation field was calculated with the equation [3]

$$C_T^2 = B\chi\varepsilon_T^{-1/3}, \tag{6}$$

where $\chi = \gamma\langle(\partial t/\partial x_k)^2\rangle$, $\varepsilon_T = \nu\langle(\partial u_i/\partial x_k)^2\rangle$.

The quantities χ and ε_T, calculated in [5, 6], are functions of the self-similar coordinate $\eta = y/\ell_c$ and can be approximated by fourth order polynomials

$$\begin{gathered} \chi \frac{l_c}{T_c^2 u_c} = a_\chi \eta^4 + b_\chi \eta^2 + c_\chi, \\ \varepsilon_T \frac{l_c}{u_c^3} = a_\varepsilon \eta^4 + b_\varepsilon \eta^2 + c_\varepsilon, \end{gathered} \tag{7}$$

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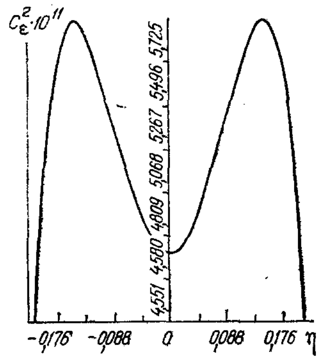

Fig. 1

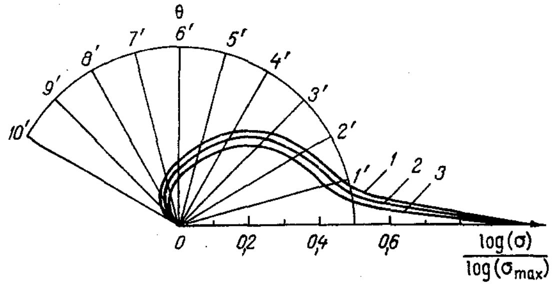

Fig. 2

Fig. 1. Dielectric permittivity pulsation field structural characteristic distribution in semisimilar jet region. C_ε^2, $m^{-2/3}$.

Fig. 2. Radiation scattering indicatrices for various values of θ, r = log σ/log (σ_{max}); 1, 2, 3) η = 0.11; 0; 0.22, respectively.

where $T_c = T_0 D^{1/2} \ell_c^{-1/2}$.

The spectral function of the temperature pulsation field is of a three-dimensional character. But that which is normally determined by the corresponding experimental equipment is merely its one-dimensional section. Therefore we will use the following relationship [7]:

$$E_T(|\mathbf{q}|) = -\frac{1}{4\pi |\mathbf{q}|}\left[\frac{d}{dq} E_T(q)\right]_{q=|\mathbf{q}|}. \tag{8}$$

After simple transformations we obtain

$$E_T(q) = \frac{C_T^2}{4\pi}\left[\frac{5}{3}(q+q_0)^{-11/3} + \frac{\alpha\beta q^{\beta-1}}{q_m^{\beta-1}}(q+q_0)^{-8/3}\right]\exp(-\alpha(q/q_m)^\beta). \tag{9}$$

For isobaric conditions

$$\varepsilon = \langle \varepsilon \rangle + \varepsilon' = \frac{(\varepsilon_0 - 1)T_0}{\langle T \rangle}\left(1 + \frac{t}{\langle T \rangle}\right)^{-1}. \tag{10}$$

After expansion in a Maclaurin series

$$\langle \varepsilon \rangle = \frac{(\varepsilon_0 - 1)T_0}{\langle T \rangle}\left(1 + \sum_{n=2}^{\infty}(-1)^n\left\langle\left(\frac{t}{\langle T \rangle}\right)^n\right\rangle\right), \tag{11}$$

$$\varepsilon' = \varepsilon - \langle \varepsilon \rangle = \frac{(\varepsilon_0 - 1)T_0}{\langle T \rangle}\left(\frac{t}{\langle T \rangle} + \sum_{n=2}^{\infty}\frac{t^n - \langle t^n \rangle}{\langle T \rangle^n}\right). \tag{12}$$

We note that the quantities $\langle t^2\rangle/\langle T\rangle^2$, $\langle t^3\rangle/\langle T\rangle^3$ in Eqs. (11), (12) can be neglected as compared to unity.

It follows from Eqs. (1), (9), (12) that

$$\sigma(\theta, \varphi) = \frac{C_\varepsilon^2 k_0^4}{8}\left[\frac{5}{3}\left(q + \frac{|\mathbf{K}|}{l_c}\right)^{-11/3} + \frac{\alpha\beta q^{\beta-1} l_c^{5\beta/8} \nu^{3\beta/4}}{u_0^{3\beta/4} D^{3\beta/8}}(q + |\mathbf{K}|/l_c)^{-8/3}\right]\exp\left(\frac{\alpha q^\beta l_c^{5\beta/8}\nu^{3\beta/4}}{u_0^{3\beta/4} D^{3\beta/8}}\right), \tag{13}$$

where $|\mathbf{K}| = K\sqrt{3}$, $C_\varepsilon^2 = \frac{(\varepsilon_0 - 1)^2 T_0^2}{\langle T \rangle^4} C_T^2$. The total scattering section can be approximately evaluated by taking a model of the dielectric permittivity pulsation spectrum in the form

$$E_\varepsilon = \frac{5}{12\pi} C_\varepsilon^2 (q + |\mathbf{K}|/l_c)^{-11/3}. \tag{14}$$

From Eqs. (3), (14) we obtain

$$\sigma_0^1 = 0.295 C_\varepsilon^2 k_0^2 q_0^{-5/3}. \tag{15}$$

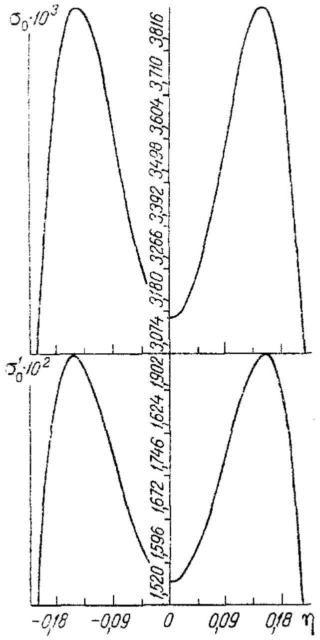

Fig. 3. Total radiation scattering section: σ_0, calculated by computer for spectral model of Eq. (5); σ_0^1, approximate value from Eq. (15), m^{-1}.

For the spectral model of Eq. (5) σ_0 was calculated by a computer. The jet turbulence parameters and all experimental constants corresponded with [4].

Calculated data for optical characteristics at a wavelength of $\lambda = 10.6$ μm are shown in Figs. 1-3.

The dielectric permittivity pulsation field structural characteristic (Fig. 1) in the jet is similar to the distribution of the mean square of temperature pulsations, and at the center of the jet has an absolute value approximately two orders of magnitude greater than the corresponding value in the ground layer of the troposphere: $C_\varepsilon^2 \approx 10^{-14}$ $m^{-2/3}$ [3, 8].

The scattering indicatrices for various values of η (Fig. 2) are sharply elongated and directed toward the incident radiation. This is to be expected, since in the energy spectrum of the temperature pulsations the ratio of the minimum (Kolmogorov) scale to the radiation wavelength $\ell_k/\lambda \gg 1$.

The value of the total scattering cross section for radiation at a wavelength $\lambda = 0.5$ μm in the ground layer of the troposphere is equal to $5 \cdot 10^{-2}$ m^{-1} [3], while its value at the center of the jet at the same wavelength comprises 1.2 m^{-1}.

The range of application of the results obtained is limited by the condition of applicability of the single scattering approximation.

NOTATION

B, K, α, β, a_χ, b_χ, c_χ, a_ε, b_ε, c_ε, experimental constants; x, y, z, Cartesian coordinates; θ, φ, z, cylindrical coordinates; D, transverse nozzle dimensions; u_0, velocity in nozzle section; T_0, temperature in nozzle section; $\langle T\rangle$, average temperature; t, temperature pulsation component; ε, dielectric permittivity; γ, thermal diffusivity coefficient; ν, kinematic viscosity coefficient; k, wave number of propagating radiation; $|q|$, modulus of scattering vector; ε_T, mean rate of kinetic energy dissipation by turbulence; χ, mean rate of temperature pulsation dissipation.

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VISCOUS LIQUID FLOW IN THE INITIAL PORTION OF A PERMEABLE CHANNEL WITH TRANSVERSE SLOT

A. S. Lebedev and F. F. Spiridonov

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The problem of flow in the initial segment of a permeable channel with transverse impermeable slot is solved. Behavior of the solution with change in geometric parameters and characteristic injection Reynolds number is analyzed.

1. Flow in channels with permeable walls has recently attracted the ever greater attention of researchers. This is due to the importance of its practical applications. Flow of this type is found, for example, in gas motion in plasmotrons with porous electrodes, liquid motion in wells, in intense sublimation and condensation in a number of chemical technology processes, etc.

The majority of studies have considered developed flows in circular cylindrical [1-4] or annular [5, 6] channels. A number of investigators [7-9] have observed that distributed draft into the channel significantly increases the value of the critical Reynolds number for transition from a laminar to a turbulent flow regime, as compared to flow in a conventional tube. In addition it has been shown that conditions in the initial segment of the channel by its forward face affect the transition.

Significantly fewer studies [10-12] have considered flows in initial sections of permeable channels. In [10] a numerical modeling of flow in the initial segment of a planar channel was performed for initial injection Reynolds numbers in the range $10 \le R_b \le 300$. Flow in a planar channel with permeable transverse slot located near the forward face was considered for the same R_b range in [11]. Flow in the initial section of a planar channel with impermeable slot near its face was studied in [12] for the range $100 \le R_b \le 1000$. The present study will numerically model flow in the initial segment of a planar, circular, or annular channel (Fig. 1) with an impermeable transverse slot for change in slot geometric parameters and injection Reynolds numbers in the range $10 \le R_b \le 3000$.

The liquid is assumed incompressible with a constant dynamic viscosity coefficient.

2. The equations defining the flow in dimensionless form are

$$y^{2\nu}\left[\frac{\partial}{\partial z}\left(\frac{\omega}{y^{\nu}}\frac{\partial\Psi}{\partial y}\right)-\frac{\partial}{\partial y}\left(\frac{\omega}{y^{\nu}}\frac{\partial\Psi}{\partial z}\right)\right]-R_b^{-1}\left\{\frac{\partial}{\partial z}\left[y^{3\nu}\frac{\partial}{\partial z}\left(\frac{\omega}{y^{\nu}}\right)\right]+\frac{\partial}{\partial y}\left[y^{3\nu}\frac{\partial}{\partial y}\left(\frac{\omega}{y^{\nu}}\right)\right]\right\}=0, \quad (1)$$

$$\frac{\partial}{\partial z}\left(\frac{1}{y^{\nu}}\frac{\partial\Psi}{\partial z}\right)+\frac{\partial}{\partial y}\left(\frac{1}{y^{\nu}}\frac{\partial\Psi}{\partial y}\right)=-\omega;\ R_b=\rho^\circ \mathring{q}_b\Delta^\circ/\mu^\circ.$$

On the impermeable boundaries $\Psi = 0$, while on the permeable boundary $\Psi = -R_2^{\nu}(z - b)$. The values of ω on the permeable ($y = R_2$) and impermeable boundaries are calculated during solution of the problem using the condition of absence of slippage, while on the right-hand boundary ($L \gg 1$) the values of Ψ and ω are calculated by extrapolation from the calculation region with the assumption of absence of longitudinal diffusion (for details, see [13, 14]). As length and velocity scales in Eq. (1) we use the channel width $\Delta^\circ = R_2^\circ - R_1^\circ$ and draft velocity q_b°.

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