
UTILIZATION OF MODEL PASSIVE IMPURITY CONCENTRATION DISTRIBUTION FUNCTIONS TO COMPUTE TURBULENT FLOW RADIATION

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The adequacy of different semi-empirical methods of taking account of passive impurity concentration fluctuations is investigated for numerical modelling of radiating turbulent flows on the basis of comparisons between computed and measured energetic brightness fields.

The rise in the accuracy of computations of energetic brightness fields of turbulent heated gas flows is associated with the solution of the problem of the influence of temperature and concentration fluctuations on the optical characteristics of a medium. The contribution of turbulent fluctuations to IR radiation of a heated gas jet was investigated in [1]. Since the range of temperature variation in the jet was not large (approximately 300-700 K), the fluctuation characteristics of the temperature field were considered similar to the fluctuation characteristics of the passive impurity concentration field. An analogous approach is used in the present research also. It was shown in [1] that satisfactory agreement between the experimental and computed data is achieved when using probability density functions (PDF) in which the appearance of intermittency in the jet is taken into account in a model fashion. In recent years, intermittency in jet type flows has been investigated quite intensively both theoretically and experimentally [2]. A number of PDF models has been proposed for passive impurity concentration with the intermittency taken into account [2-5]. The purpose of this paper is to confirm the possibility of utilizing such PDF to compute the radiation. Moreover, the influence of temperature and concentration fluctuations on the radiation is studied as a function of the initial turbulence level in the stream.

The measurements and computations were performed for an axisymmetric subsonic heated jet. A description of the experimental installation and the method of measuring the gas dynamic parameters and the spectrum characteristics are presented in [1, 6].

The jet efflux conditions were changed by using different reducers for an unchanged mode of combustion chamber operation. Three modes were realized: mode 1 without the reducer (jet initial section radius R0 = 15 cm, initial efflux velocity u0 = 13 m/sec), mode 2 with two...
Fig. 1. Comparison of computed (curves) and measured (points) mean values of the temperature: a) axial distributions, mode 3; b) radial distributions, mode 1; 1) $x = 2.9R_0$ and 2) $x = 5.8R_0$, $T$, K.

axisymmetric reducers ($R_0 = 10$ cm, $u_0 = 23$ m/sec), and mode 3 ($R_0 = 5$ cm, $u_0 = 130$ m/sec).

The initial jet working gas temperature was $T_0 = 675$ K for all three efflux modes. Jet radiation in the IR band was determined by the presence of CO$_2$ therein (0.022 atm partial pressure at the nozzle exit), H$_2$O (0.035 atm), and CO (0.0004 atm). Both N$_2$ and O$_2$ are also in the working mixture composition in practically the same relationship as in air.

Computation of the mean jet gasdynamic parameters was performed by using a $k$-$\varepsilon$ model of turbulent viscosity. Within the framework of this model the turbulent viscosity is determined in terms of two characteristics of the turbulence field, the fluctuation kinetic energy $k$ and the fluctuation energy dissipation rate into heat $\varepsilon$. As is known utilization of reducers results in diminution of the relative level of the fluctuation kinetic energy. The appropriate linear theory governing the dependence of the fluctuation kinetic energy on the degree of compression $C$ (i.e., the ratio between the inlet and exit sections of the reducers) was proposed by Batchelor [7]. The ratio between the fluctuation kinetic energies at the reducer outlet and inlet $k^{(1)}$ and $k^{(0)}$ within the framework of the theory mentioned with a correction obtained on the basis of experimental studies [8] taken into account, is determined by the expression

$$k^{(1)}/k^{(0)} \approx \left( C/2 + \frac{1}{3} C^{-2/3} \right).$$

Therefore, the initial relative level of turbulent fluctuation kinetic energy $k_0/u^2_0$ for mode 1 exceeds the analogous ratios for modes 2 and 3 by approximately 4 and 20 times, respectively.

The relationship (1) was used to convert the initial values of $k_0$ and $\varepsilon_0$ during the passage from one efflux mode to another. Relied upon here for $\varepsilon_0$ is the relationship $\varepsilon_0 \sim k^{3/2}/\Lambda$ and it was assumed proportional to the dependence of the turbulence scale $\Lambda$ on the characteristic scale of the flow $R_0$. Conformity between the computed and measured axial velocity and/or temperature distributions remained the main criterion for selection of the initial value $\varepsilon_0$. Such a correspondence was achieved only after a substantial correction $k_0/u^2_0$ and $\varepsilon_0\cdot R_0/u^2_0$ were utilized in the computation: 0.04 and 0.0037 (mode 1), 0.01 and 0.0007 (mode 2), 0.0022 and 0.00015 (mode 3).

The mean gasdynamic parameter distributions computed on the basis of the $k$-$\varepsilon$-models, that agree with the appropriate measured quantities with good accuracy, are then used to compute the radiation. Separate results of a comparison between theoretical and experimental data for the modes 1 and 3 are represented in Fig. 1. The results of comparisons for the mode 2 are presented in [1].

The computed and measured values of the radiation were compared in the spectrum range $2200$-$2300$ cm$^{-1}$, where CO$_2$ (wing of the band is $4.3$ $\mu$m) induces the main contribution to jet radiation. Estimates executed in [1] showed that conditions for the applicability of the optically thin fluctuations approximation are satisfied for the jets under investigation in this spectrum range, and can be written in the form

$$k_\nu A \ll 1.$$

The maximal $s/d$ ratios were used here as estimates of the absorption coefficient $k_\nu$ while the correlation length of the temperature fluctuations was used as the estimate of the characteristic dimension of the fluctuations $A$. Taking account of turbulent fluctuations within