UNSTABLE STRATIFIED TURBULENT FLOW IN OPEN CHANNELS

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Abstract This work considers an unstable stratified turbulent flow in the open channel. Constructed mathematical model allows to simulate the unstable stratified flows and define averages and pulsation characteristics of turbulent flow. Developed the algorithm to solve of the problem and receive results of calculations which well coordinated with the known experiment data.

INTRODUCTION

Unstable stratified turbulent flow is a common type of geophysical flows. The main property of unstable stratified flow is the process of turbulence generation. The basic part of the turbulent energy in stratified flows is generated by the buoyancy force. The mechanism of this process is one of the weak-studied problems of atmospheric and ocean science, as it differs from natural convection.
In this paper we consider the problem of practical meaning, when the chilled liquid on the surface interacts with the main traffic flow and changes its temperature. In this case, the temperature can not be considered passive, since there is a complex correlation of velocity and temperature.

MATHEMATICAL MODEL

To study the interaction of velocity and temperature fields, we consider the turbulent flow in the three-dimensional open channel. In order to the problem we use the three-dimensional unsteady Reynolds equation for the motion and the turbulent heat transfer [1, 2]:

$$
\begin{aligned}
&\frac{\partial U_1}{\partial \tau}+U_1\frac{\partial U_1}{\partial x_1}+U_2\frac{\partial U_1}{\partial x_2}+U_3\frac{\partial U_1}{\partial x_3}=-\frac{1}{\rho_0}\frac{\partial P}{\partial x_1}+\frac{\partial}{\partial x_1}\left\langle -u_1^2\right\rangle+\frac{\partial}{\partial x_2}\left\langle -u_1u_2\right\rangle+\frac{\partial}{\partial x_3}\left\langle -u_1u_3\right\rangle,\\
&\frac{\partial U_2}{\partial \tau}+U_1\frac{\partial U_2}{\partial x_1}+U_2\frac{\partial U_2}{\partial x_2}+U_3\frac{\partial U_2}{\partial x_3}=\\
&=-\frac{1}{\rho_0}\frac{\partial P}{\partial x_2}+\frac{\partial}{\partial x_1}\left\langle -u_2u_1\right\rangle+\frac{\partial}{\partial x_2}\left\langle -u_2^2\right\rangle+\frac{\partial}{\partial x_3}\left\langle -u_2u_3\right\rangle,\\
&\frac{\partial U_3}{\partial \tau}+U_1\frac{\partial U_3}{\partial x_1}+U_2\frac{\partial U_3}{\partial x_2}+U_3\frac{\partial U_3}{\partial x_3}=\\
&=-\frac{1}{\rho_0}\frac{\partial P}{\partial x_3}+\frac{\partial}{\partial x_1}\left\langle -u_3u_1\right\rangle+\frac{\partial}{\partial x_2}\left\langle -u_2u_3\right\rangle+\frac{\partial}{\partial x_3}\left\langle -u_3^2\right\rangle-g\rho',\\
&\frac{\partial U_1}{\partial x_1}+\frac{\partial U_2}{\partial x_2}+\frac{\partial U_3}{\partial x_3}=0,\\
&\frac{\partial T}{\partial \tau}+U_1\frac{\partial T}{\partial x_1}+U_2\frac{\partial T}{\partial x_2}+U_3\frac{\partial T}{\partial x_3}=\frac{\partial}{\partial x_1}\left(-\overline{u_1t}\right)+\frac{\partial}{\partial x_2}\left(-\overline{u_2t}\right)+\frac{\partial}{\partial x_3}\left(-\overline{u_3t}\right),\\
&\rho'=\beta\cdot T.
\end{aligned}
\tag{1}
$$

In the calculations on the rigid boundaries at x^c just outside the viscous sublayer there is the resulting velocity U_g, parallel to the wall, which is expressed through a dynamic rate using the logarithmic law of the wall [2]:

$$\frac{U_g}{U_\tau}=\frac{1}{\kappa}\ln\left(y^cG\right) \tag{2}$$

where $y^c = x^c U_\tau / \nu$, $\kappa = 0{,}4$ - von Karman constant, G=9 - coefficient of wall roughness, U_τ - dynamic velocity at the wall. x^c is defined to satisfy the condition $30 \le y^c \le 100$.

For the temperature at the sidewalls and bottom the conditions for the absence of heat and $T = T_b$ in the cooling channel surface are determined.

For the numerical solution of equation (1) with a closed model of turbulence and the boundary conditions the method of splitting by physical parameters is used.

In the first stage the equations of motion can be solved without pressure [3, 6, 7, 9]. On the second stage, the pressure is calculated, pre-split in the longitudinal and transverse components [4, 5, 8].

To close the system of equations (1) the model was used:

$$E = E_0 \psi,$$
$$\overline{u_1^2} = (\overline{u_1^2})_0 \cdot \Omega_1, \quad \overline{u_2^2} = (\overline{u_2^2})_0 \cdot \Omega_2, \quad \overline{u_3^2} = (\overline{u_3^2})_0 \cdot \Omega_3,$$
$$\overline{u_1 u_3} = (\overline{u_1 u_3})_0 \cdot \Omega_4, \quad \overline{u_2 u_3} = (\overline{u_2 u_3})_0 \cdot \Omega_5, \quad \overline{u_1 u_2} = (\overline{u_1 u_2})_0 \cdot \Omega_6,$$
$$\overline{t u_3} = (\overline{t u_3})_0 \cdot \Omega_7, \quad \overline{t u_1} = (\overline{t u_1})_0 \cdot \Omega_8, \quad \overline{t u_2} = (\overline{t u_2})_0 \cdot \Omega_9,$$
$$\overline{t^2} = (\overline{t^2})_0 \cdot \Omega_{10}.$$

Figure 1 shows a comparison of simulation results with experimental data of turbulent flow in an unstable stratified fluid.

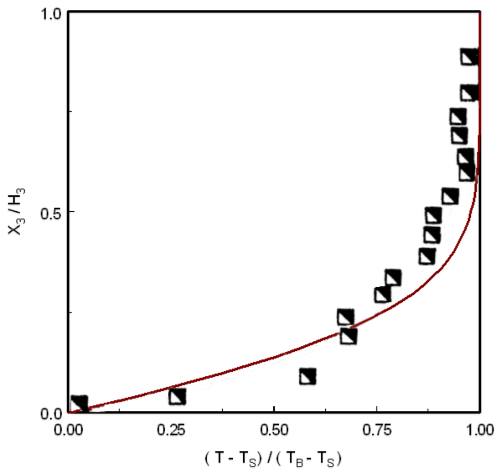

Figure 1. Steady-state dimensionless temperature profile in the middle of the channel.

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