JET MODEL OF THE TURBULENT CHANNEL FLOW

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When tributaries, colored by soil particles or by industrial wastes flow into a river, one frequently observes the following phenomenon: the water of the tributaries does not spread immediately over the entire cross section of the river, but flows from the tributary junction, along the shore independently of the main current over many kilometers.

To clarify the details of this phenomenon, an experiment was performed in a trapezoidal-cross section straight channel with an unfastened sand bottom. The channel parameters were: length - 20 m, width - 1 m, depth in central part - 0.1 m, slope - 0.001, mean flow velocity - 0.1 m/sec. The experiment consisted in investigating the mixing of water mass near shores. For this a coloring agent (aqueous solution of India ink), the density of which differed from that of water by 10^{-3}-10^{-5} kg/m^3, was alternately added to the shore region, only narrow zones along shores along the entire channel became colored, which is seen in the photograph in Fig. 1. The arrow gives the flow direction. The shore regions remained uncolored when the coloring agent was added to the central part of the flow; the result did not change when the coloring agent was added at different points along the stream.

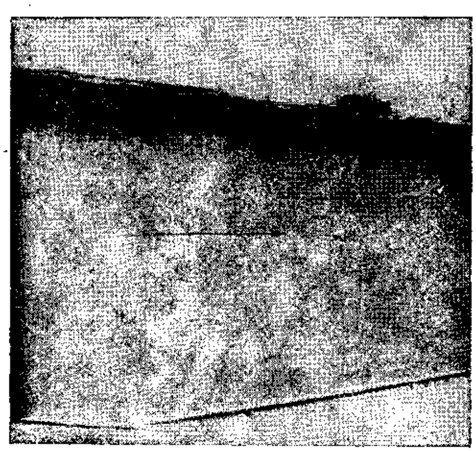

Fig. 1

It was established as a result of this study that the flow consists of three regions: the central and two shore regions, the water masses of which virtually do not mix. This fact must be explained, since the flowrate based mean velocity of the flow is 0.1 m/sec and the corresponding Reynolds number of approximately 10^5 corresponds to turbulent flow.

The present article suggests the following physical model of this phenomenon, based on analysis of in-situ and of the previously described laboratory data:

1) the flow is represented as three nonmixing turbulent jets;

2) the inception of these nonmixing turbulent jets in the flow is attributed to the presence of vortex motion in the shore region;

3) the vortex motion in the shore region is generated as a result of inhomogeneity of forces acting in the flow's cross section.

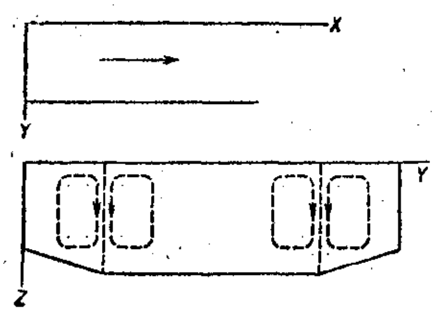

Fig. 2

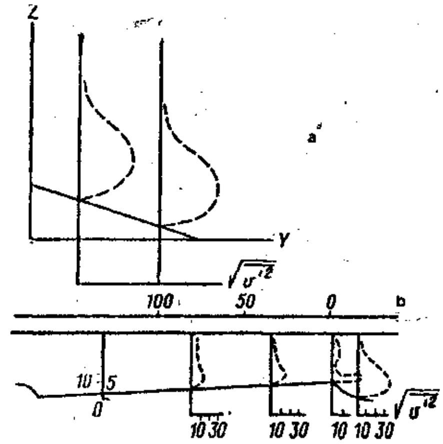

Fig. 3

Let us consider all the tenets of the model in more detail. It is clearly seen from Fig. 1 that the flow in all the regions of the stream is turbulent, the exchange between the central and shore zones is very small, consequently, the flow can be represented as three nonmixing turbulent jets.

Absence of exchange of water masses at boundaries of turbulent jets is possible only if rotational motion of water in the Y,Z plane exists near the boundary; here the rotation occurs in opposite directions from both sides of the boundary, as shown in Fig. 2.

In its turn, the force distribution in the shore region of the flow should be such that it would force the water masses to perform rotational motion. The force distribution in the flow far from the solid boundary is controlled by time-averaged turbulent flow characteristics - normal and tangential turbulent Reynolds stresses. Consequently, inhomogeneity of the derivatives of Reynolds stresses with respect to transverse coordinates as a necessary condition for the inception of rotational motion of the liquid. This can be expressed analytically by the familiar equation, following from the Navier-Stokes equation in the Reynolds form:

$$\frac{\partial \overline{\xi}}{\partial t} = \frac{\partial^2}{\partial y \partial z}(\overline{v'^2} - \overline{w'^2}) + \left(\frac{\partial^2}{\partial y^2} - \frac{\partial^2}{\partial z}\right)\overline{v'w'},$$

$$\xi = \frac{\partial v}{\partial z} - \frac{\partial w}{\partial y},$$

where v' and w' represent the velocity fluctuations along the Y and Z axes, respectively.

It is known [1,2] that the components $\overline{v'^2}$, $\overline{w'^2}$, $\overline{v'w'}$ of the stress tensor in turbulent flow are linear in the central part of the flow and represent the nonlinear dependence on coordinates in the wall region. Consequently, the forces acting on water masses are a function of the coordinates in the shore region of the flow and do not change their magnitude or direction in the center of the flow, which produces conditions for constant swirling of the liquid in the shore region.

In addition, the time averaged quantity $\overline{v'^2}$ is a function of the transverse coordinates due to the sloping of the bottom at the shore, which results in modification of the derivative of this quantity with respect to the coordinate even for shores with moderate sloping, as this follows from Fig. 3a, b, constructed following the results of Mikhailova [3].

The above analysis shows that conditions are presented in the shore region of channel flow which generate rotational motion of the liquid, whereas there are no such conditions in the central region. However, friction in the thin layer of water in the central region produces oppositely-directed rotation. These conditions for the existence of rotational motion of water in the shore region are satisfied in any flow cross section, ensuring the formation of turbulent nonmixing jets in channels flows which are dynamically similar to that explored in the present experiment.

It additionally follows from the above analysis, that this model explains the existence of independent jets in channel flow, observed in many rivers, but noted and analyzed here for the first time.

REFERENCES

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