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Investigation of Separating Flow in a Sudden Expanded Open Channel

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1.Introduction

In many technical applications of turbulent shear-layer flows containing detachment, recirculation zone and reattachment region can be found. In this study we have selected a sudden expanded open channel(SEOC) because of its importance role in water engineering structures such as channels, rivers, waterways and canals. Many of experiments in this field are limited to a qualitative investigation of flow characteristics however there are very few experiments on this subject using flow visualization technique quantitatively. We have found some new features of reattachment flows in a SEOC which have not been reported previously. The objectives of this work are twofold 1) to verify an integration method over the time line to remove the time delay between successive data sets created by image processing 2) to investigate the behavior of flow in the separating shear-layer.

2.Experimental Setup

The present experiments were carried out in a free surface water channel. The channel has a work section of 30.0 m long, 0.7 m wide and 0.12 m deep. The added parts to the channel are two prismatic obstacle each one is formed of a rectangle and a parabolic curve attached to the channel walls at the middle of the channel where the bed and walls are made of glasses(Fig. 1). The obstacles were made of acrylic plate to provide the smoothness of the expansion. The expansion depth H, at each side of the channel was 5 cm and Reynolds number Re, based on H at separation ($x = 0$) was about 1.4×10^4. A projector light was passed through a slit to produce a light sheet at the test sections, 5 mm in depth and approximately 40 cm in the streamwise direction. The light sheet was aimed at a mirror related to a stepping motor (see Fig. 2). To understand the characteristics of flow at $z/H = 0$–1.4, four cameras were used to take pictures of three horizontal sections and one longitudinal section of the testing area. When the light sheet has illuminated section 1, only camera 1 should take a picture and when it has illuminated section 2, only camera 2 should take a picture and etc. As tracers Nylon12 beads with an average diameter of 0.6 mm and specific density of 1.01 were used.

3.Interpolation Method and Variational Technique

In order to obtain a 3-D image of flow, the original three pictured sections which produce a 2-D velocity field should be increased to a volume which is called frame. By considering section 2 as a reference section the time delay between this section and three other sections should be removed. We used Taylor Hypothesis to overcome the time delay problem. Here the role of camera 4 is to provide a check point of created data by variational method, since at first, there is no data in x-z plane, the produced data should be compared to the measured one. The time delay between section 4 and 2 is about 0.3 s therefore, a cubic spline function fitted over the corresponded points from ten successive pictures at section 4 point by point was used to remove this lag. Here we could not use Taylor Hypothesis because of hight speed flow and limitation in the area of photographs. In the next step, variational technique is used to solve numerical equivalent of the flow in the integral approach. In most physical problems it would be formed based on energy consideration. Using this technique and an iteration method, say SOR, we could obtain 3-D velocity field over the domain of interest, a rectangular box confined on two sides by the channel bed and wall. For further information reader is referred to Kawanisi et al [1]. Determination of an appropriate value for α_i in variational functional is important because it has a significant role in the quantity of two velocity components, V and W. Variations of α_1 and α_2 in the range of, say, 0.5–5.0 has no big effect on the U component of velocity. To provide this condition we used the following relations: $(W_{sec4} - W_{var} \cdot (U_m)_{sec4}/(U_m)_{var})^2 = \min, W_{sec4} = W_{var} \cdot (U_m)_{sec4}/(U_m)_{var}$, where U_m is the average of streamwise velocity component over the intersection of section 4 and the rectangular box, and indexes sec4 and var are related to section 4 and variational data, respectively. For both measured and calculated data U has a positive value. Since these two relations are independent from each other sometimes satisfying these conditions needs personal judgements.

4. Results and Discussions

Dividing streamline in Fig. 3, in fact, shows the mean position of two low and high regions velocity however in this research we are engaging with instantaneous pictures of flow so let define the instantaneous dividing streamline which shows the instantaneous border of low and high velocity regions. Here after for the sake of simplicity we call it simply dividing streamline. At any time the flow has the potential of generating a vortex on the dividing streamline. When a vortex is generated, depending on its strength it can produce a secondary vortex on the border of zones Ⅲ and Ⅳ and finally they form a vortex pair. It is obvious that for the main vortex $\partial U/\partial y < 0$ and for the secondary one $\partial U/\partial y > 0$ so the z component of vorticity for the main vortex and secondary one are positive and negative, respectively. However we have $|(\omega_z)_{main}| > |(\omega_z)_{secondary}|$ because there is no effective restriction as going away from the shear-layer to the center of the channel but there are the dead zone(zone I) and wall in the opposite direction, cosequently term $\partial U/\partial y$ is much larger for the main vortex than the secondary one. Now the question is that as going downstream what happens to the vortex pair? From Figs. 4,5 it is obvious that the orientation of vortex pair at any time is perpendicular to the tangent of dividing streamline at the vortex core. The advective velocity for the main vortex in zone Ⅱ is smaller than the secondary one on the border of zones Ⅲ and Ⅳ. So after a while we are expected to see them far from each other at the downstream. However in Fig. 5 since dividing streamline shows a sudden inclination toward the wall, the vortex can be seen almost along the expansion, parallel to x axis. If the vortex pair is being generated soon after detachment there is little chance to protect its structure from destruction during advection to the downstream, however the lifetime for these vortex pairs generated at $x/H > 4$ is longer, even they can be seen at $x > x_R$[2]. The shape of vortical structures dramatically looks to be stretched along the dividing streamline (zones Ⅱ and Ⅲ) however out of those they have a regular round shape(see Fig. 5). Since zones Ⅱ and Ⅲ are located between zones I and Ⅳ they act like a transitional zone. As going downstream the width of zones Ⅱ and Ⅲ are increased and their characteristics become much closer to the ones of zones I and Ⅳ, rspectively. The edge of shear-layer is become very complex at $x/H > 3$ because in this area most of the strong vortices are occurred (see Figs. 4,5).

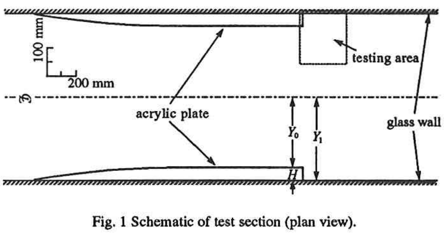

Fig. 1 Schematic of test section (plan view).

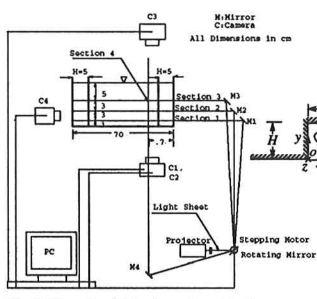

Fig. 2 Schematic sketch of experimental setup.

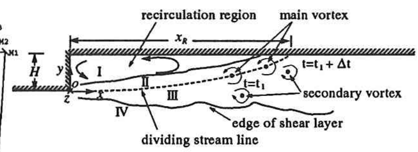

Fig. 3 Sudden expanded flow field: details of reattachment-length, recirculation region and shear-layer, specified by a dashed-rectangle in Fig. 1.

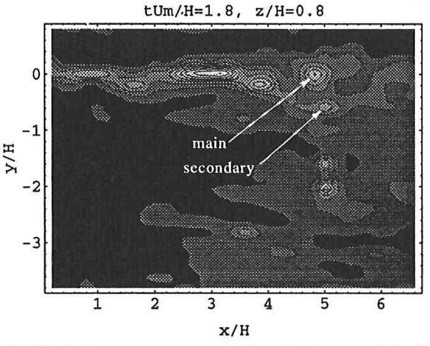

Fig. 4 Enstrophy contour map represents the main vortex generated on the dividing streamline and the secondary one on the border of zone Ⅲ, Ⅳ.

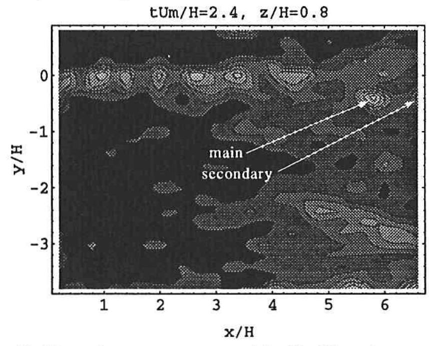

Fig. 5 Enstrophy contour map corresponded to Fig. 4 Shows the new position of vortex pair during the advection toward the downstream.

References

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