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PIV STUDIES ON REVERSE FLOW IN A CHANNEL WITHOUT OBSTRUCTION AT THE ENTRY

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ABSTRACT

It is known that reverse flow (i.e. flow in the direction opposite to the free stream) occurs when an obstruction is placed near the entry region of a channel (referred to as the test channel), kept inside another wider channel. The present investigation is focused on realizing reverse flow in the test channel without an obstruction placed at the entry. Experiments in water channel have been carried out along with visualization of the flow using PIV. The initial stages of the investigation revealed that the test channel with the two walls, forming the channel having a stagger with respect to each other and at an angle of attack would result in reverse flow even without an obstruction. Studies have been carried out for different widths (gap between the two walls forming the channel), and at an angle of attack of 30°.

INTRODUCTION

Reverse flow (i.e. flow in the direction opposite to the free stream) inside a channel occurs when an obstruction is placed at certain positions near the entry to the channel, placed in another wider channel. This phenomenon can be explained with the help of Figure 1. When the gap between the obstruction and the channel entry is sufficiently large, forward flow results, but its magnitude, even for large gap widths will be less than the free stream velocity U_∞. It was previously thought that the presence of the obstruction at the entry was essential for reverse flow to occur. In this investigation it was found that this was not a necessary precondition. In the present study we attempt to examine the flow phenomenon in a channel without an obstruction at entry.

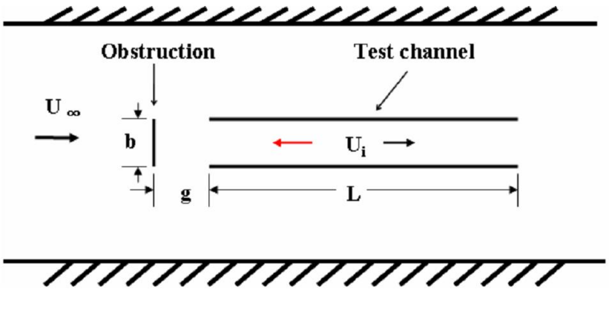


Figure 1 Realization of reverse flow

Some of the applications where the reverse flow phenomena occurs or can be employed are: control of flow, especially to obtain low velocities; heat transfer problems where it may be required to locally have different types of flows; interaction of shear layers at different distances apart; flow past obstruction/constriction in arterial flows under certain physiological situations, etc.

Gowda and Tulapurkara [1] (hereby referred to as GT) appear to be the first to have observed the reverse flow phenomenon inside a channel. In the experiments carried out by GT, a flat plate obstruction of width (b) equal to the channel width (w) of 25 mm was placed near the entry of the test channel. They studied the influence of three parameters like (i) gap (g), (ii) the length of the test channel(L) and (iii) the Reynolds number (Re) based on the channel width 'w' and free stream velocity U_∞. The magnitude of the velocity was expressed as a ratio of velocity, U_i, in the central part of the test channel, to the free stream velocity, U_∞. Studies on gap were carried out for 'g' varying from 12.5 mm to 200 mm giving a gap ratio (g/w) between 0.5 and 8.0. Two channel lengths, L = 300 mm and L = 600 mm (L/w= 12 and 24) were used. The Reynolds number was 4000. For L/w = 24 the reverse flow was found to be maximum ($-U_i/U_\infty = 0.2$) for g/w = 1.5. The flow was stagnant for g/w = 3.5 and maximum forward ($U_i/U_\infty = 0.65$) for g/w ≥ 8.0. Similar trends in variation of U_i/U_∞ but lesser reverse flow velocity was observed for L/w = 12. GT also varied Reynolds numbers between 1000 and 4000. They observed that the flow inside the test channel is almost stagnant for Reynolds numbers up to 2000. As the Reynolds number increases, the reverse flow increases. Gowda et al. [3] investigated the influence of geometry of the obstruction using different shapes like square, circle, triangle and semicircle. Maximum reverse flow of $(-U_i/U_\infty) = 0.28$, was obtained for the triangular shape. The effect of obstructions both at the entry and the rear end of the test channel were investigated by Tulapurkara et al. [6]. Studies were carried out by placing obstructions like a flat plate and semicircular scoops at the rear end, in tandem with the obstruction at the front end. Using semicircular scoops at the rear end and flat plate at the front end a maximum reverse flow of 83% of the frees stream velocity was achieved. Gowda et al. [3] investigated the influence of splitter plates at the front end only and both at front and rear ends. For the latter case, a maximum reverse flow of 37% of the free stream velocity was obtained. Gowda et al. [4] conducted both flow visualization and pressure measurements in a wind tunnel to examine whether the above features, observed at low Reynolds numbers also occur at high Reynolds numbers. The experiments were carried out at Re = 26000. The reverse flow velocity results obtained from these measurements show that the behaviour of $-U_i/U_\infty$ shows trends similar to those at lower Reynolds numbers.

The literature survey reveals that a large amount of work has been carried out on the study of reverse flow with obstructions at the entry. It would be interesting to see if reverse flow can be realized without an obstruction. This is found to occur and measurements of velocity in the channel at different configurations are made in order to better understand this new method of triggering reverse flow. Flow visualization studies are done using PIV to arrive at an understanding of the mechanism behind the reverse flow phenomena.

NOMENCLATURE

- b Obstruction width
- g Gap between obstruction and channel entry
- L Length of channel (with obstruction)
- L_1 Side dimension of channel
- L_2 Side dimension of channel
- S Stagger between sides of channel
- U_∞ Free stream velocity
- U_i Velocity inside test channel
- w Width between plates
- α Angle of attack

EXPERIMENTAL SETUP

All the experiments are carried out in the Flow Visualization Facility at the School of Mechanical Engineering, Kyungpook National University, Korea. Figure 2 shows the photograph of the setup. It consists of a tank 2.5 m x 1.5 m x 0.3 m, made out of acrylic sheets (to have it transparent). At one end of the tank, numbers of discs are provided connected to a dc motor through a gear arrangement. The discs act as paddles when rotated and create the flow in the test section.

Figure 2 Water tunnel

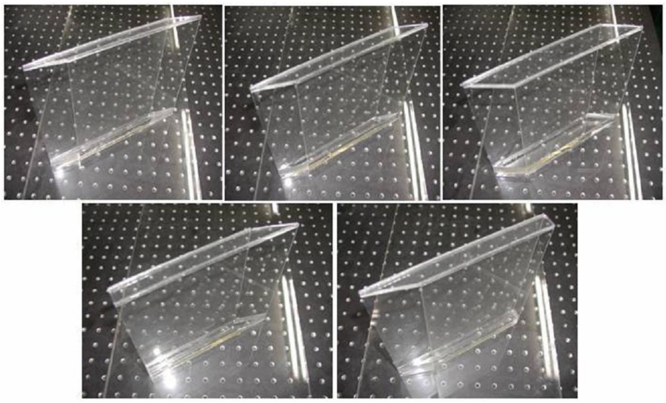


Figure 3 Test sections (angel: 30°)

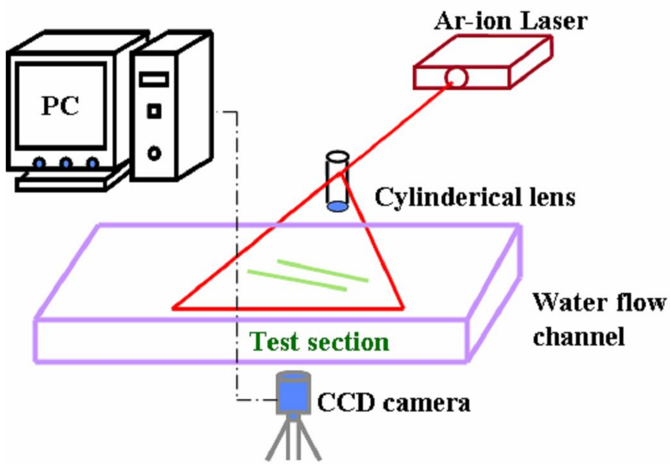


Figure 4 Basic optical arrangement of PIV system

Figure 5 PIV experimental apparatus

The flow is guided into the test section by means of suitably designed guide blocks. By varying the speed of rotation, the velocity in the test section can be varied up to 0.2 m/s without any wavy oscillations in the flow. The test sections used are shown in Fig. 3. The basic optical arrangement used for the PIV measurements is shown in Figure 4. The PIV system consisting of a 3 Watt Ar-Ion Laser with optical arrangement is shown in Figure 5. The seeding was done using high porous polymer 80-200 μm size particles. A Readlake's MotionPro HS-3 high-speed CCD with 150 fps at 1280x1024 was used to record the flow details. All the results presented are at a free stream velocity of 0.1 m/s.

RESULTS AND DISCUSSION

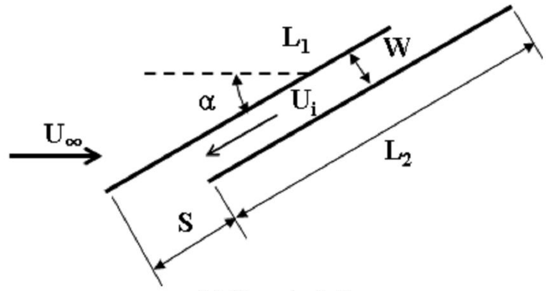
The different cases considered are shown in Figure 6. Table 1 gives the dimensions considered. All the results are obtained at an angle of 30^0 and a stagger s = 50 mm. The results for a width w = 10 mm (Case 1) is shown in Figure 7. As can be seen reverse flow in the middle of the channel is clearly seen. Vortical patterns are seen at the front and the rear ends. The details of the flow at the front and at the rear end are shown in Fig. 8 for the same case. The vortical pattern formed at the rear end which results in pushing the fluid in the reverse direction into the channel is evident. More or less very similar features are observed for the cases 2 and 3 with w = 15 and 30 mm in Figure 9 to Figure 12 except that the magnitude of the reverse flow vary as can be made out by the velocity vectors.($-U_i/U_\infty$=0.47, 0.39, 0.29, for w = 10, 15, 30 mm respectively)

However, in case 4 (Figure 13 and Figure 14), where there is stagger at the rear end only, no reverse flow is seen. This configuration fails to give raise to any flow in the reverse direction. There is no vortical pattern created at the rear end which can push/pump the flow into the channel. But it is seen that in case 5 (Figure 15), where there is stagger only at the front end, a strong reverse flow ($-U_i/U_\infty$=0.47) is seen. This is more clearly seen in Fig. 16.

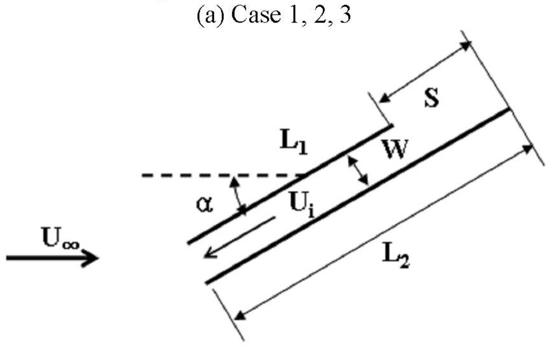
The physical explanation for the triggering and maintenance of reverse flow in a channel with an obstruction at the entry is due to the pressure difference between the entry and exit of the channel caused by the obstruction. However the reasons appear to be different in the cases presented. In cases 1 to 3, the shear layers separating from the leading edge of the does not cover the entrance to the channel and at the rear end the shear layer from the bottom plate rolls up, causing the reverse flow in the channel. In case 4, the configuration of the plates is such that the flow can enter at the front end and no reverse flow results. However, in case 5, the separating shear layer at the front end appear to give raise to a low pressure and the conditions at the rear end result in the flow being pushed in the reverse flow direction.

Table 1 Details of test section

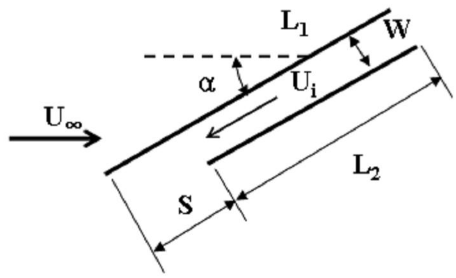
	L_1 (mm)	L_2 (mm)	W (mm)
case1	200	200	10
case2	200	200	15
case3	200	200	30
case4	150	200	15
case5	200	150	15



(a) Case 1, 2, 3



(b) Case 4



(c) Case 5

Figure 6 Configurations considered

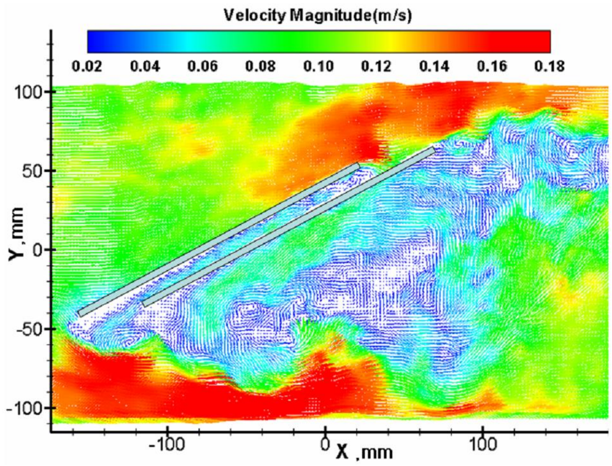
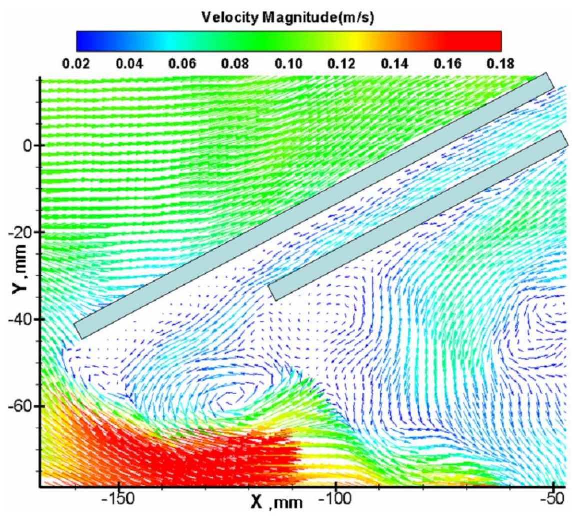
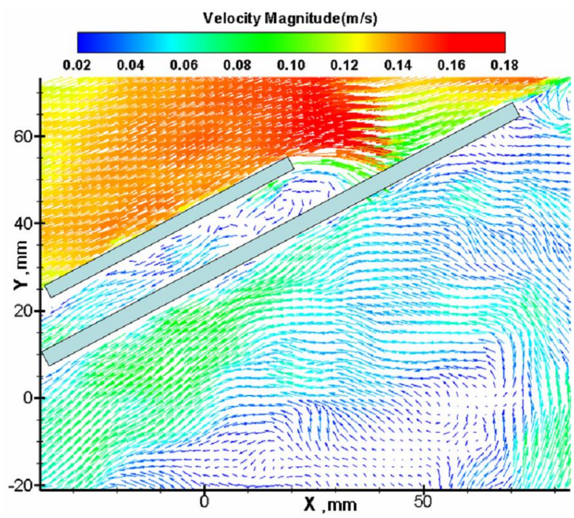


Figure 7 Velocity vectors for case 1.



(a) At the front end



(b) At the rear end

Figure 8 Detailed velocity vectors for case 1.

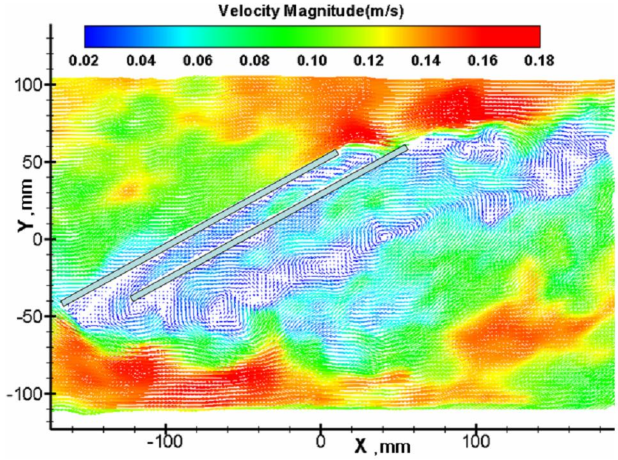
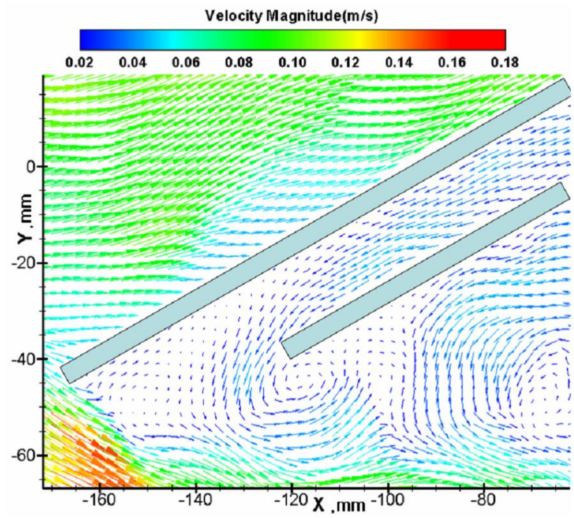
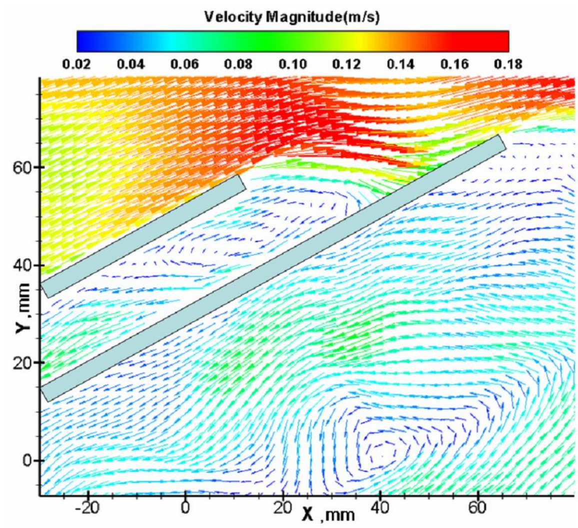


Figure 9 Velocity vectors for case 2.



(a) At the front end



(b) At the rear end

Figure 10 Detailed velocity vectors for case 2.

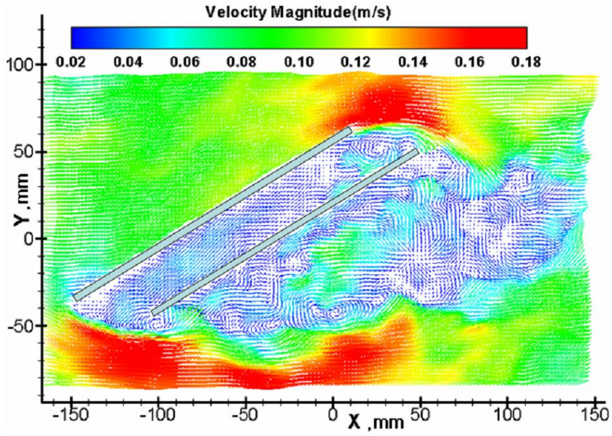
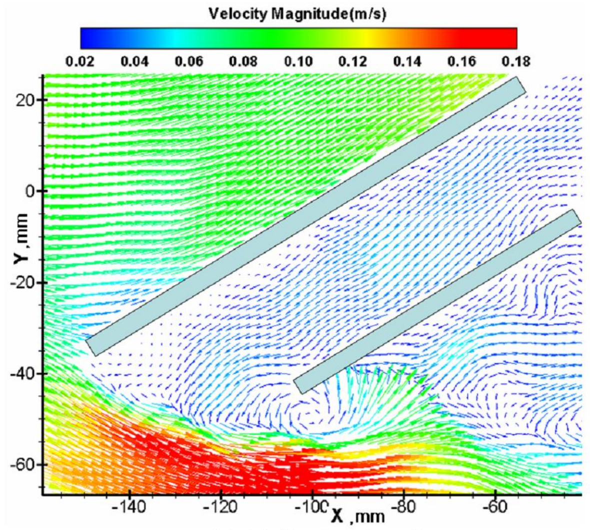
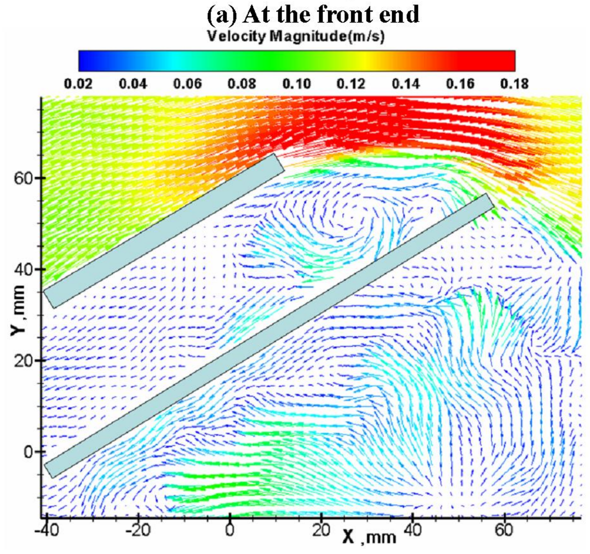


Figure 11 Velocity vectors for case 3.



(a) At the front end



(b) At the rear end

Figure 12 Detailed velocity vectors for case 3.

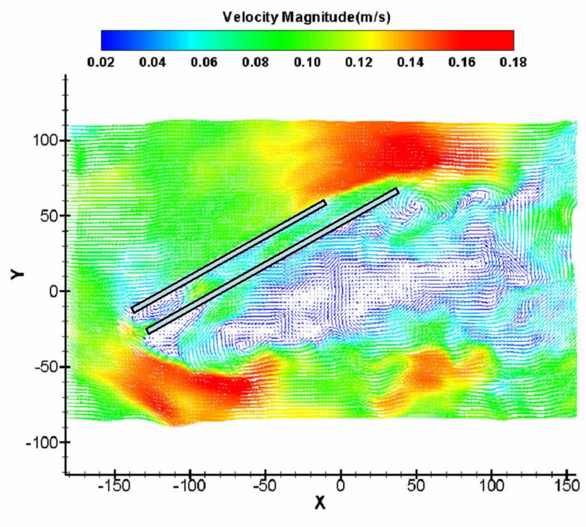
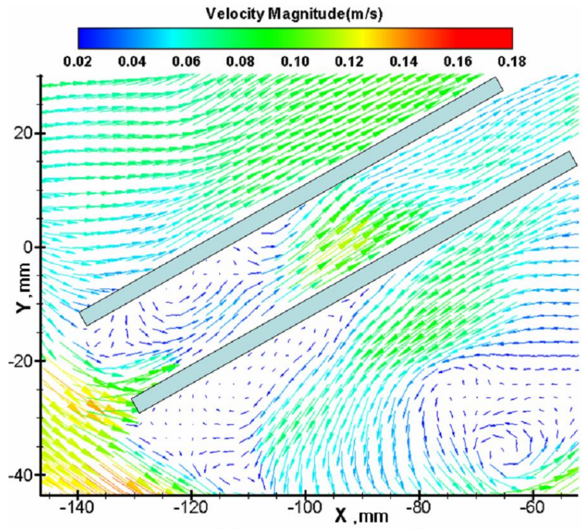
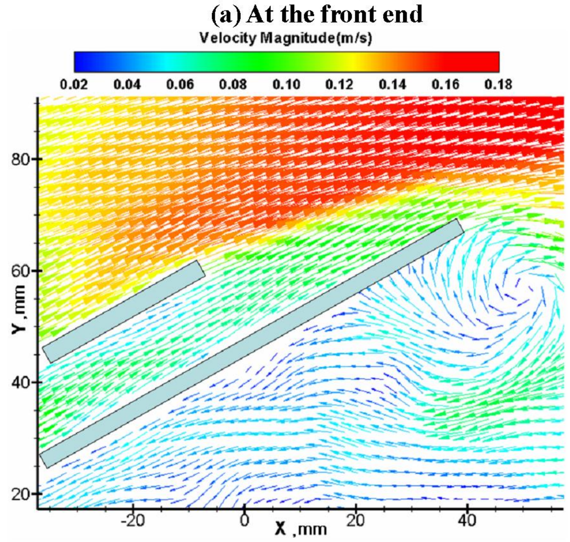


Figure 13 Velocity vectors for case 4.



(a) At the front end



(b) At the rear end

Figure 14 Detailed velocity vectors for case 4.

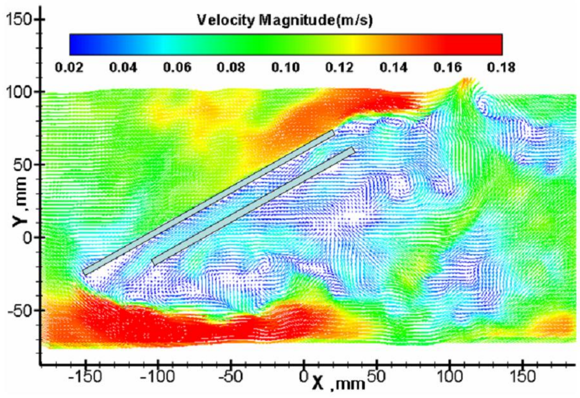
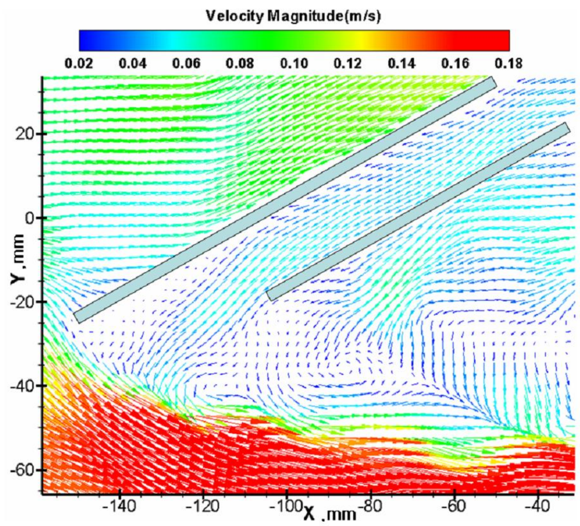
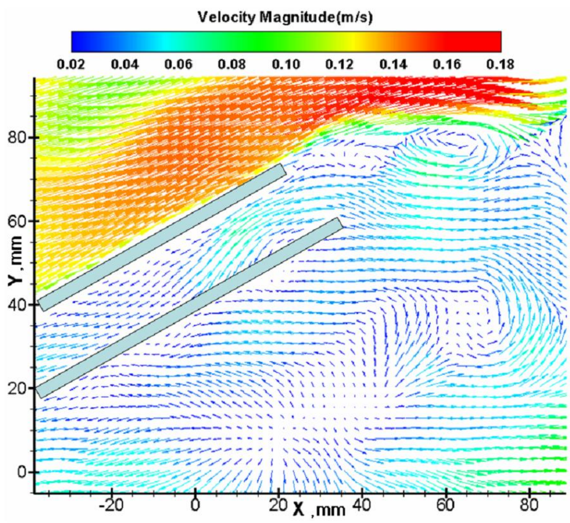


Figure 15 Velocity vectors for case 5.



(a) At the front end



(b) At the rear end

Figure 16 Detailed velocity vectors for case 5.

CONCLUSIONS

The study carried out using PIV has shown that reverse flow is achievable even without an obstruction at the entry.

The investigations at a constant angle of attack of 30^0 and stagger of 50 mm have shown that the width does influence the magnitude of reverse flow as shown in cases 1 to 3.

Case 4 and 5 have shown that it is not possible to have reverse flow with stagger at the back but reverse flow can occur for the case when the stagger is at the front.

In the case of channel with an obstruction, the low pressure behind the obstruction triggers the reverse flow, whereas in the present case it is the flow field at the front and rear ends which control the reverse flow.

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