원형 덕트 입구의 장애물이 있는 경우의 역류 유동 현상

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Reverse Flow Phenomena in a Circular Duct with an Obstruction at the Entry

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Abstract

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. In this paper the reverse flow in a duct (diameter D) with an obstruction at the front (which is a disc), is investigated using PIV. The gap g between the obstruction and the entry to the duct is systematically varied and it is found that maximum reverse flow occurs at a g/D value of 0.5. The flow is stagnant around g/D of 1.25 and forward flow occurs for g/D values of 1.5 and above.

Key Words : Reverse flow(역류 유동), Circular Duct Flow(원관 유동), Unsteady Flow(비정상 유동), PIV, Disc Obstruction(원판 장애물)

1. 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 Fig. 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_∞.

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 (1989) (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

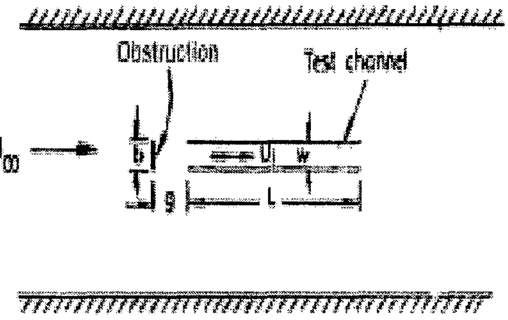

Fig. 1 Realization of reverse flow

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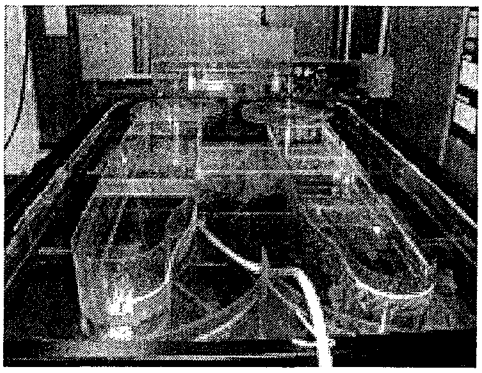


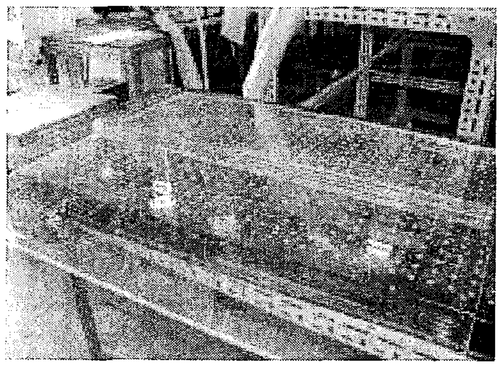
Fig. 2 Water tunnel

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.(1993) 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 triangularshape. The effect of obstructions both at the entry and the rear end of the test channel were investigated by Tulapurkara et al. (1994). 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. (1997) 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. (1998) 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 behavior of $-U_i/U_\infty$ shows trends similar to those at lower Reynolds numbers.

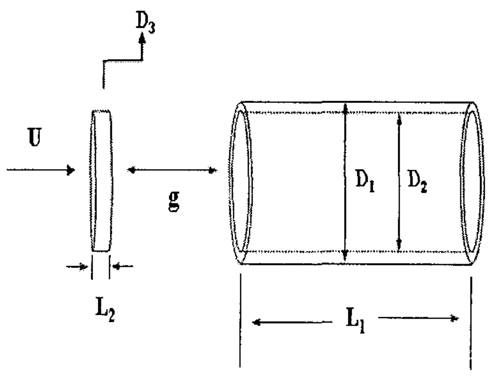
In the present study the reverse flow phenomenon in a circular duct is investigated. The obstruction is a circular disc unlike a plate as in the case of a channel. The flow features are different in this case compared to the channel as we are dealing with duct flow and a disc as the obstruction. The flow at the rear end where the shear layers interact to generate the reverse flow will also be different as the flow is axisymmetric. PIV is used for the measurements.

2. EXPERIMENTAL ARRANGEMENT

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.



(a) A photo of disc obstruction and circular duct



(b) Detail dimensions of disc and circular duct

Fig. 3 Test section (U = 0.1 m/s , L_1 = 600mm, L_2 = 2mm, D_1 = 30mm, D=D_2=D_3 = 26mm, g =0.125D, 0.25D, 0.5D, 1D, 1.25D, 1.5D, 2D)

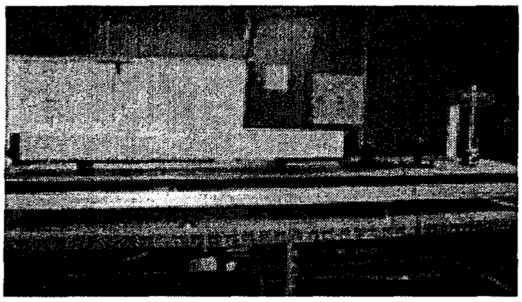


Fig. 4 Ar-Ion Laser

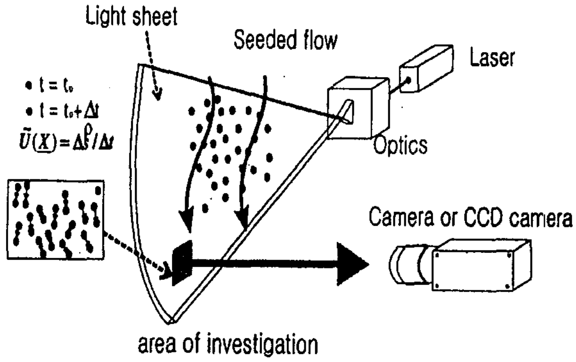


Fig. 5 Basic optical arrangement of PIV system

The discs act as paddles when rotated and create the flow in the test section. 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 circular duct used for the reverse flow studies with the obstruction (a disc) is shown in Fig.3a. The various dimensions are shown in Fig.3b. The gap g between the entry to the duct and the obstruction is systematically varied. For the measurement of velocities a PIV system consisting of a 300 mw Ar-Ion Laser with a AOM synchronizer is used (Fig.4). The seeding was done using high porous polymer 44 μm size particles. A CCD camera (640x480 pixel) was used to record the flow details. The optical arrangement used is shown in Fig.5. All the results presented are at a free stream velocity of 0.1 m/s, at a Reynolds number of 2600 referred to the diameter of the duct.

3. RESULTS

The PIV results at g/D = 0.125, 0.25, 0.5, 1.0, 1.25, 1.5 and 2.0 are presented in Figs.6 to 12 respectively. In each of the figures the flow details are shown in limited portions at the front end, at the center and rear end due to the large length of the duct. These are indicated by the small gaps between the various portions. The flows at the two ends are unsteady; however, there is steady mean flow at the center of the duct. The velocity vectors indicate the direction of the flow and reverse flow is clearly seen at g/D = 0.125 (Fig.6). The reverse flow persists up to g/D of 0.5 (Fig.8), where it appears to be strongest. As g/D increases further, the reverse flow

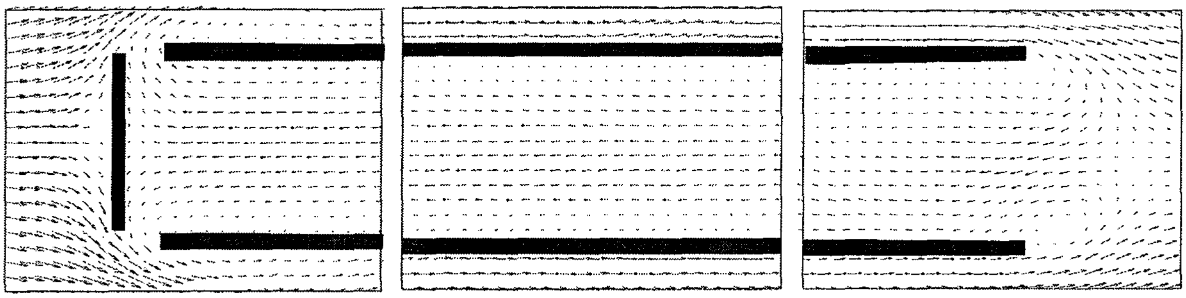


Fig. 6 Velocity vectors at the front end, at the center and rear end for g/D =0.125

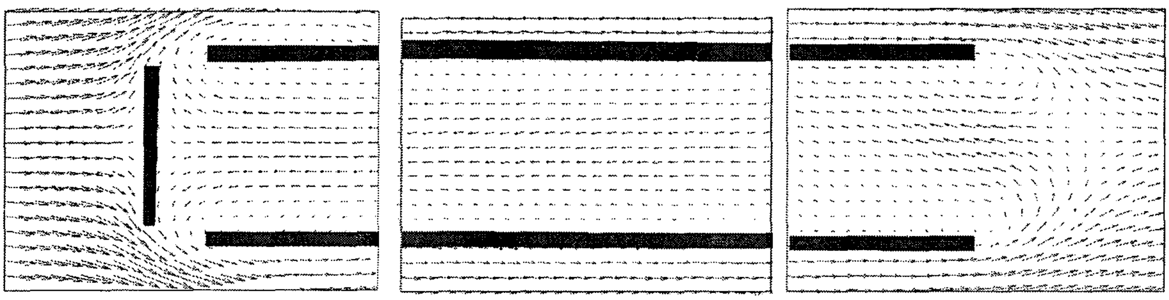


Fig. 7 Velocity vectors at the front end, at the center and rear end for g/D =0.25

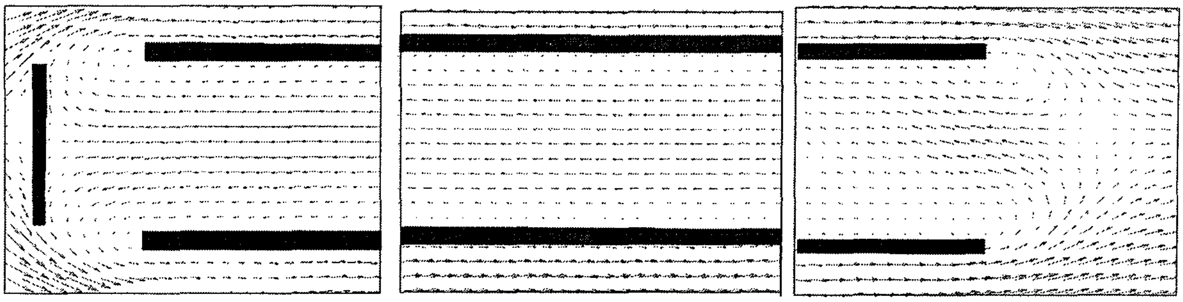
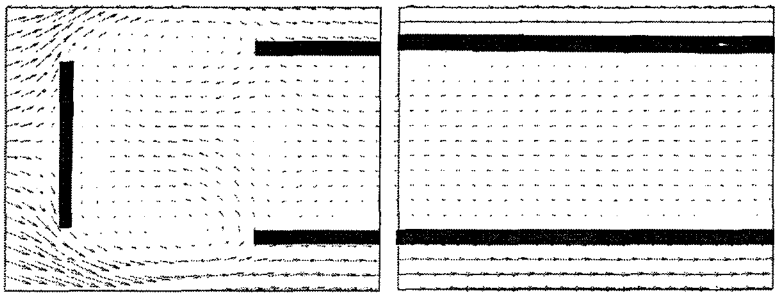


Fig. 8 Velocity vectors at the front end, at the center and rear end for g/D = 0.5



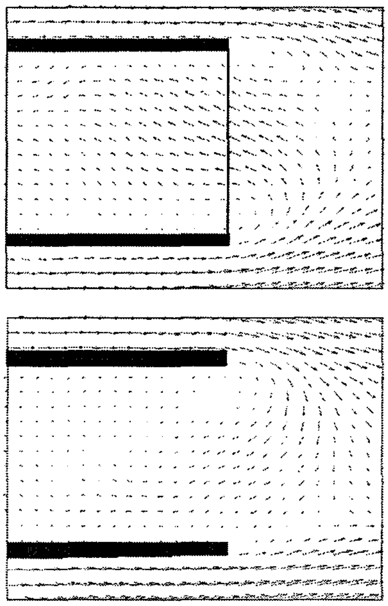


Fig. 9 Velocity vectors at the front end, at the center and rear end for g/D=1.0

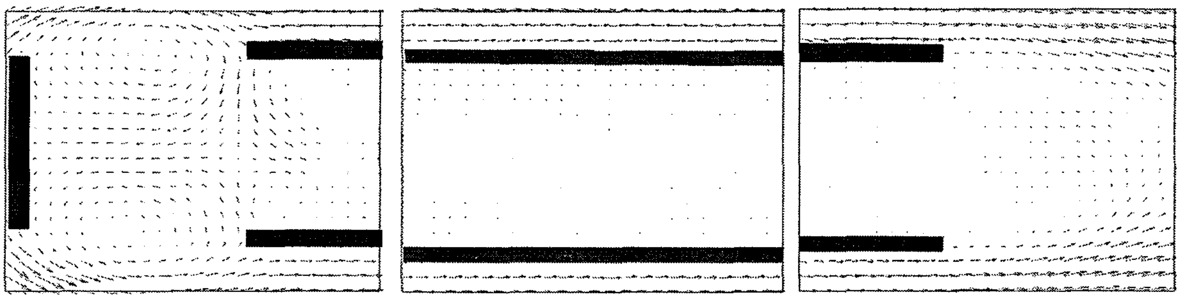


Fig. 10 Velocity vectors at the front end, at the center and rear end for g/D=1.25

weakens (as can be made out by the vectors in Fig.9 and 10). At g/D=1.25 (Fig.10), the flow oscillates between very slow forward and reverse flow; sometimes it is stagnant. At a g/D value of 1.5 (Fig.11), there is forward flow in the entire length of the duct. In the case of the channel (GT, 1989), the maximum reverse flow occurred at a g/b of 1.5, the flow was stagnant at g/b = 3.5 and forward flow occurred for values of g/b greater than 3.5. The magnitude of reverse flow at various gaps is given in Fig.13. As can be seen the maximum reverse flow occurs at g/D = 0.5 and averaged velocity at central section area is $(-U_i/U_\infty)$ = 0.26. The flow is nearly stagnant at g/D = 1.25 beyond which forward flow occurs. However, it is interesting to see that the maximum reverse flow magnitude is nearly same as that observed in channel flow.

The reason for the observed features can be explained in the following way. The pressure behind the obstruction (circular disc) is less than the surrounding value. When the gap between the obstruction and the entry to the channel is small, this low pressure triggers the reverse flow at the rear end of the duct. This occurs

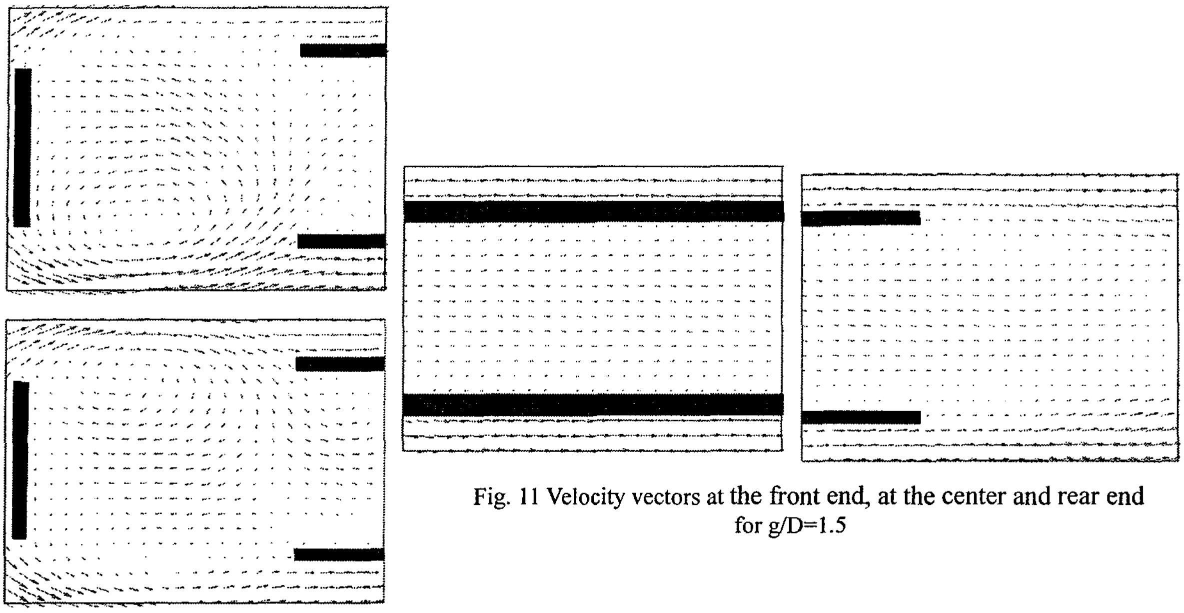


Fig. 11 Velocity vectors at the front end, at the center and rear end for g/D=1.5

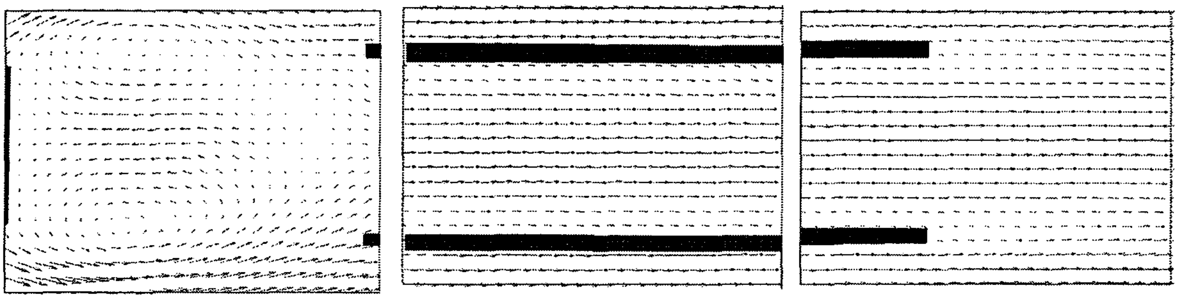


Fig. 12 Velocity vectors at the front end, at the center and rear end for g/D=2.0

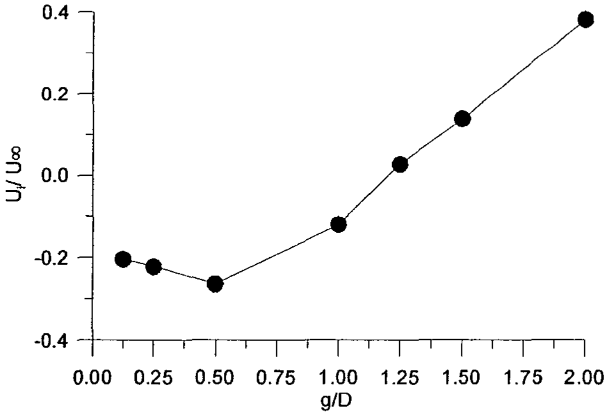


Fig. 13 Magnitude of reverse flow velocity at various gaps

up to a value of g/D of 1.0. Up to this value of g/D, the gap between the obstruction and the entry to the duct is sufficient enough for the shear layers behind the obstruction to interact within the gap and low pressure occurs at the entry to the duct and thus the reverse flow persists.

However, when the gap is larger than 1.5D, the recirculation region behind the obstruction is smaller than the gap between the obstruction and the duct entry. Possibly this is the reason why the suction pressure created behind the obstruction is not communicated to the rear of the duct. Thus the reverse flow is not triggered any more and only forward flow occurs along the duct. It is pointed out here that under this condition the flow is still periodic behind the obstruction (Figs. 11 and 12); however on the average the flow is pushed in the forward direction at the entry to the duct. The differences between the values of the gaps at which reverse flow, stagnant flow and forward flow occurs between the present case and that in the channel case (GT) are mainly due to the way in which the shear layers interact in the case of two – dimensional and axisymmetric cases. In the later case the vortex formation length can be expected to be smaller than in the former case. This could be the reason for the reverse flow to cease already at a g/D value of 1.25 for the present case.

4. CONCLUDING REMARKS

It is shown that reverse flow occurs in the case of a circular duct similar to a channel when an obstruction is placed at the front end. However, the variation of the magnitude of reverse flow with the gap g between the obstruction and the front end differs considerably. This can obviously be attributed to the change in the geometry of the system. In the case of the channel the reverse flow occurs due to the pumping mechanism resulting from the interaction of the shear layers at the rear. Such a mechanism may not be there in the present system as it is an axisymmetric configuration. It would be very interesting to investigate in detail the interaction of the axisymmetric shear layers both at front and rear ends to understand the mechanism of reverse flow generation in the present case. Such studies involving the structure of flow at the two ends are planned for the future.

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