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Computation of Reverse Flow in a Channel with an Obstruction in Front

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Reverse flow occurs in a channel when an obstruction is placed at the entry. The phenomenon involves separation, reattachment and shear layer interaction. The various facets of the phenomenon have earlier been investigated experimentally. Presently, an attempt has been made to compute this flow both steady and unsteady equations of motion. Results predict the occurrence of reverse flow, and bring out other features of flow like vortex shedding behind the channel.

1. Introduction

When an obstruction is placed at the entry to a parallel walled channel (test channel) placed within another wider channel (Fig.1), it is observed that for certain positions of the obstruction the flow within the test channel can be either stagnant or in a reverse direction i.e. in a direction opposite to that outside [1]. When the gap between the obstruction and the channel entry is sufficiently large, forward flow results, but it's magnitude, even for very large gap widths will be less than the free stream velocity U_∞. Gowda and Tulapurkara [1], used a flat plate obstruction and studied the influence of various parameters like gap (g), the length of the channel (L) and the Reynolds number (Re), based on the test channel width (w) and velocity U_∞, on the velocity inside the test channel (U_i). In subsequent studies, various facets of the phenomenon like influence of geometry of the obstruction (Gowda et al, [2]), effect of obstructions both at entry and rear end of the test channel (Tulapurkara et al, [3]), and influence of splitter plates (Gowda et al, [4]) have been investigated. Further studies, both flow visualization and pressure measurements have been carried out to obtain a better understanding of the mechanism, which triggers and sustains the reverse flow (Gowda et al, [5]).

Some of the applications where the reverse flow phenomenon can occur 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.

The aim of the present study is to compute this flow, which involves separation, unsteadiness, vortex pairing and convection. It would also provide better insight into the mechanism of pumping of fluid.

2. Governing Equations and Boundary Conditions

The flow domain is shown in Fig.2. It is the same as the domain for the flow visualization studies by Gowda and Tulapurkara [1]. The flow through and around the test channel is computed by solving the unsteady Navier-Stokes equations for an incompressible fluid in a two-dimensional geometry. The continuity and momentum equations in dimensionless form with standard notation are

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0.$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial y}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)$$

The reference velocity is U_∞ . The width, w, of the channel (same as the width of the obstruction in the present case) is the reference length. The boundary conditions are 1) no-slip condition on (a) top and bottom walls of the outer channel (b) walls of test channel and (c) surfaces of the obstruction; 2) a uniform velocity profile at the entrance to the domain.

3. Analysis

The solutions for the governing equations are obtained by using the PHOENICS code [6] which uses finite difference method for the solution. A grid of 351x151 is employed. Closer spacings are made use of around the obstruction, in front and behind the test channel. Results are obtained first for the steady case for g/w varying from 0.5 to 6 as even these bring out the various features of the reverse flow phenomenon. The unsteady solution is obtained for a typical value of g/w=1.5. All results are obtained at a Reynolds number Re=4000, referred to the test channel width w and the velocity $U\infty$.

4. Results

In Fig.3 are shown the results for various values of g/w obtained for steady case. It is to be noted that to present the results in manageable lengths and at the same time to a suitable scale for clarity, the printouts of the flow details at the front and the back are taken separately and then patched together. Hence there is a discontinuity in the flow at the patch.

At g/w=0.5, the flow within the channel is in the reverse direction to the outside flow. Most of the flow is 'pumped' from the top. The flow which comes out from the front end give rise to a complex pattern of vortices on the side walls.

The reverse flow and the other features described above are seen at g/w =1.5, 2.5 and 3. The magnitude of the reverse flow obtained are within 10% of the experimental values observed by Gowda and Tulapurkara [1]. At g/w = 4, the gap between the obstruction and the entry to the test channel is seen to be sufficient enough to cause forward flow in the test channel. The value of g/w when near stagnant conditions occur within the test channel can be expected to be between 3 and 4; it is 3.5 [1]. It is interesting to observe the flow behind the test channel once the forward flow occurs i.e., for g/w = 4 and above. At these values of g/w, the shear layers from either side of the sidewalls do not interact with each other to produce the vortices which ‘pump’ the fluid in the reverse direction into the channel unlike for g/w<4. The magnitude of the forward flow obtained for g/w=4 and above also compare within 10% of the experimental values [1]. It is interesting that even the steady state solutions give results quite comparable to the experiments. However, the flow phenomena is basically unsteady and the steady state solutions hence have their limitations.

The streamline pattern for the unsteady solution for a typical case (g/w=1.5) are presented in Fig.4. The computational time for this was nearly 20 times that for the corresponding steady state solution. A value of $\Delta t = 0.01$ was employed. In Fig.4 results are presented for over approximately two cycles. The results presented are after the solutions have reached a periodic state; time ‘t’ refers to such a condition.

In the first set of figures in Fig.4, results at t, t+0.5 and t+1 seconds are given. The vortex patterns at the rear end and on the sidewalls are changing with time. In the next set results at t+1.5, t+2 and t+2.5 seconds are given. When the two sets are compared, it is seen that the results with a time difference of 1.5 seconds are nearly identical indicating a periodic flow with a period of approximately 1.5 seconds. Further the results show other features like vortex splitting and vortex merger. Thus the time dependent solutions throw considerable amount of additional information on the reverse flow phenomena. To discuss the variation of the vortex patterns in detail, it is planned to obtain the results at much closer time intervals within a shedding cycle and also at some other values of g/w.

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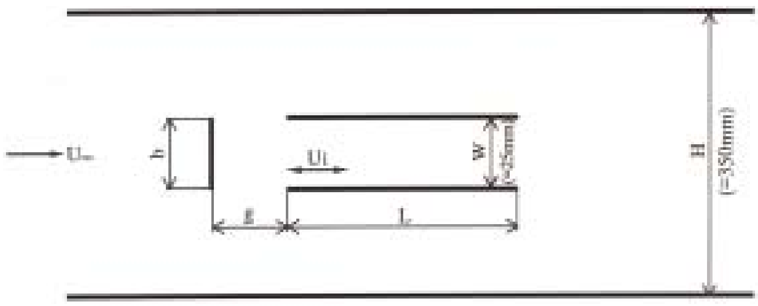


Fig. 1 Configuration considered

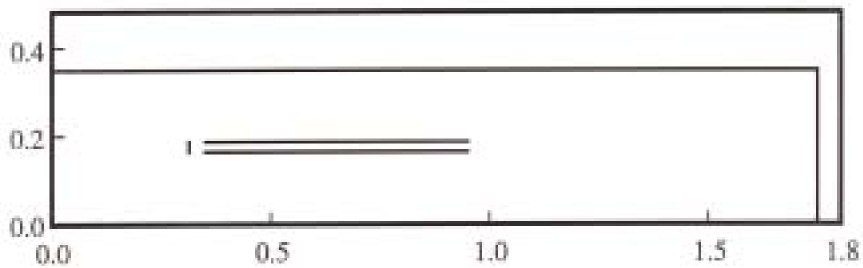
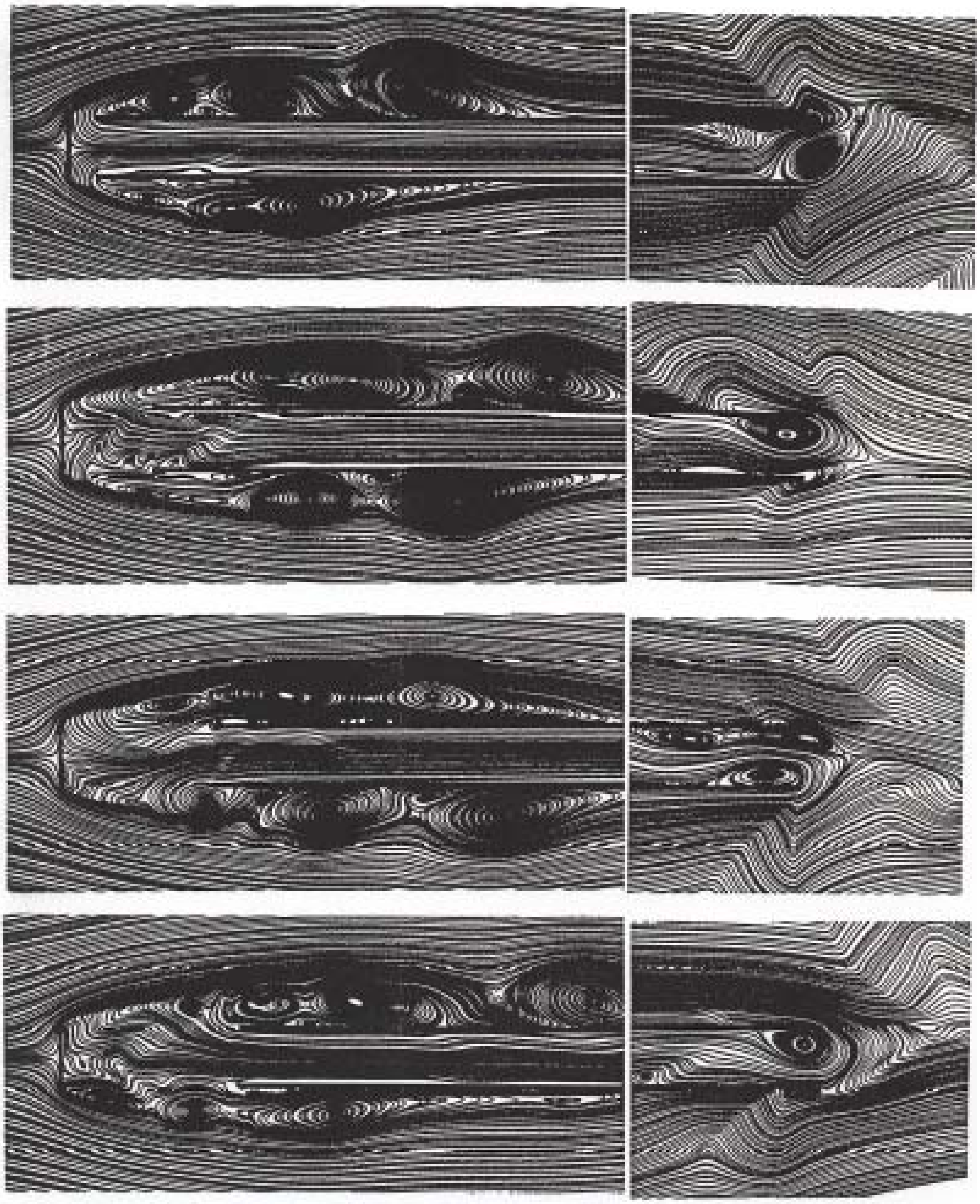


Fig. 2 Computational domain



g/w = 0.5, 1.5, 2.5, 3.0 (contd.)

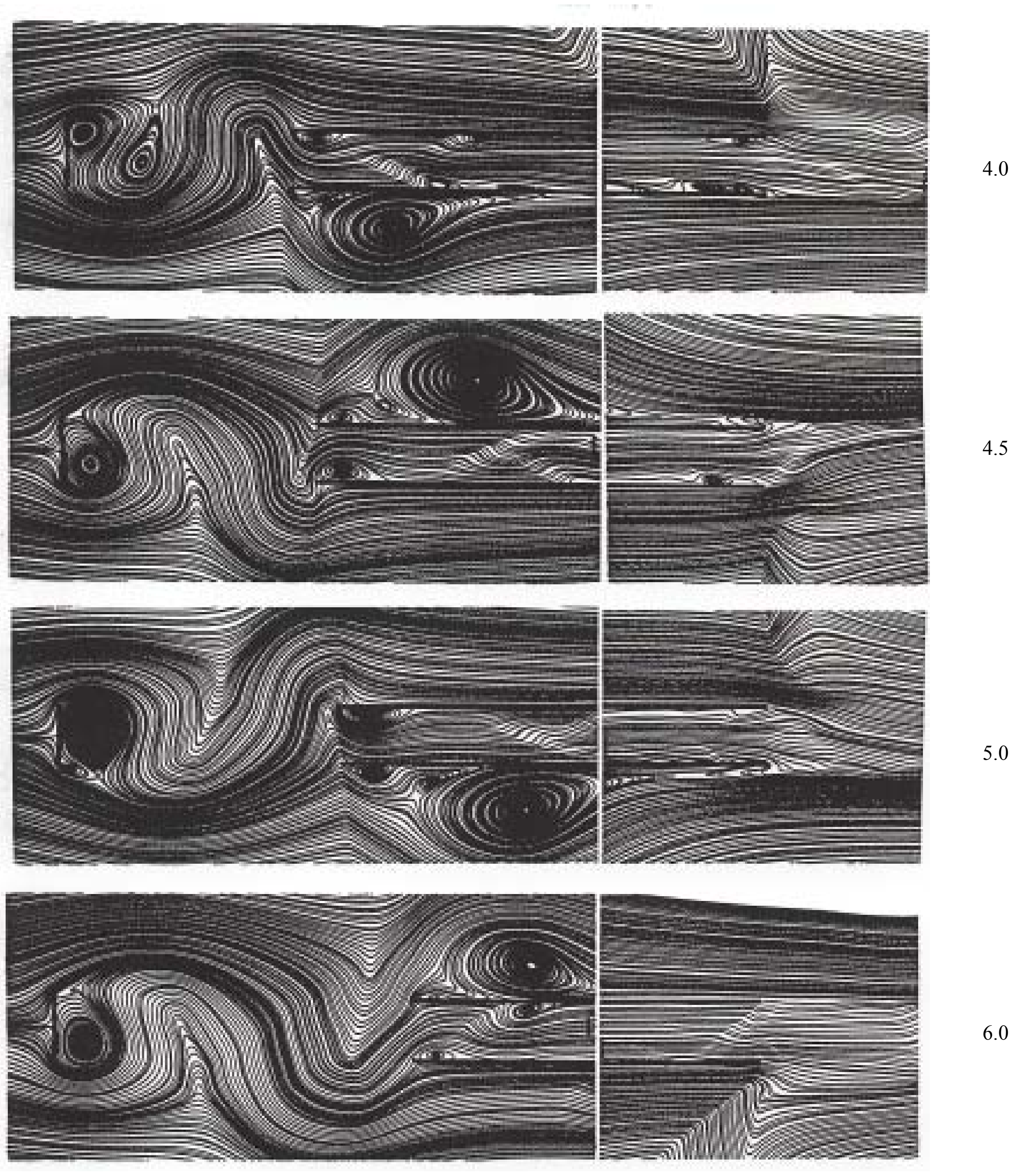
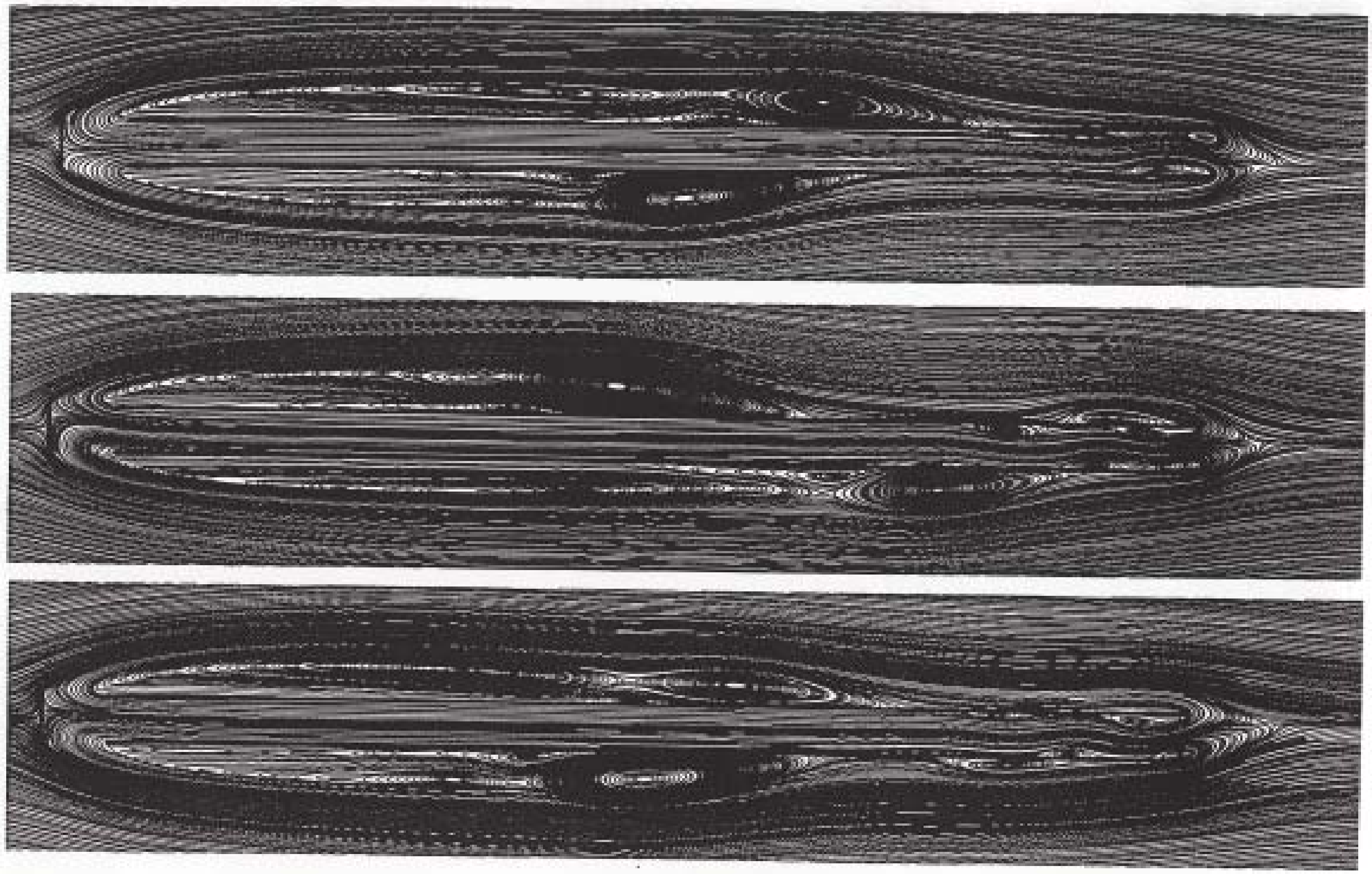


Fig.3 Flow field at different g/w for steady case (Re=4000)



At t, t+0.5s, t+1.0s (contd.)

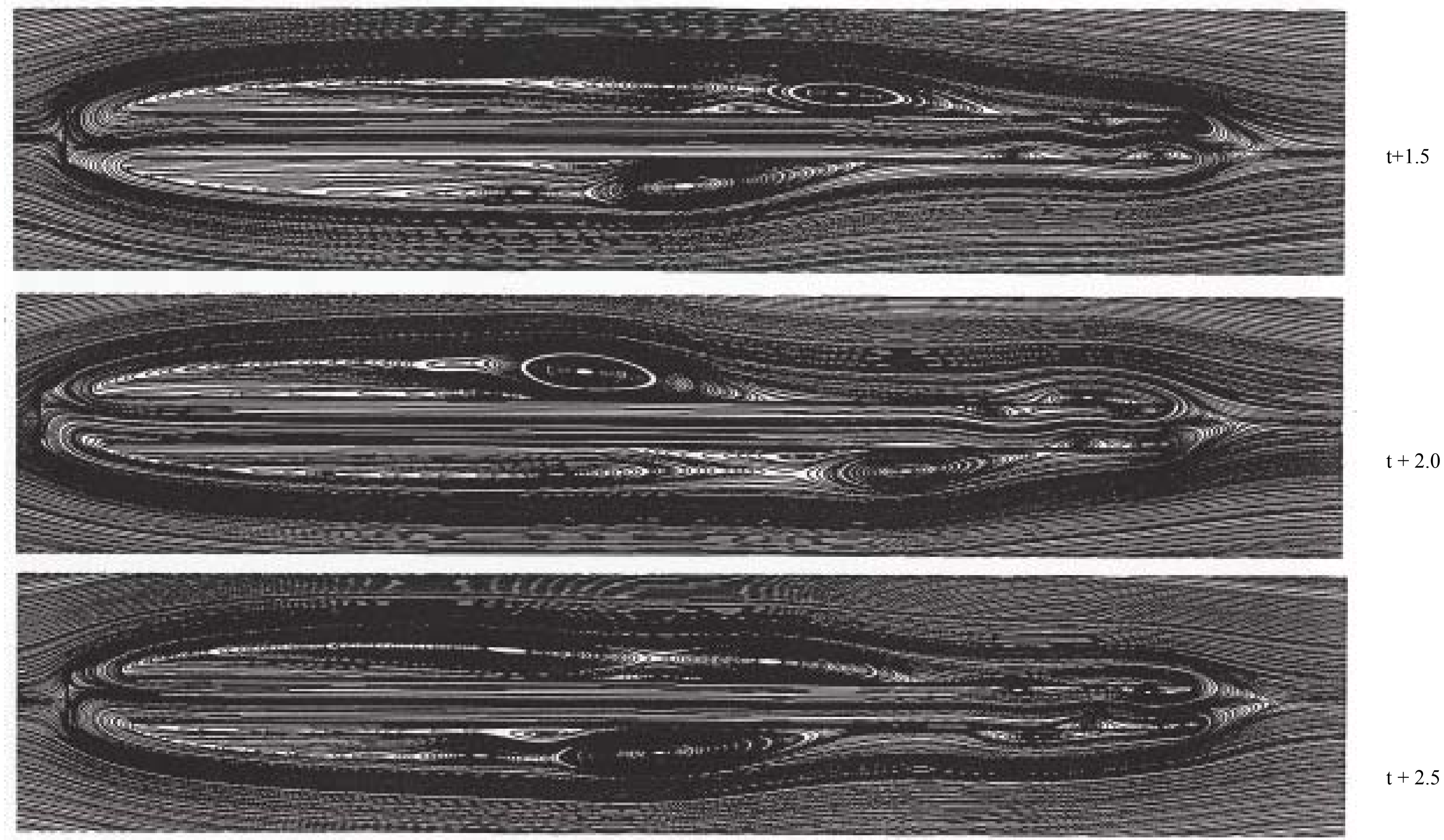


Fig.4 Unsteady case : g/w = 1.5, Re=4000

キーワード.

Channel, Obstruction, Reverse flow

Summary.

前方入口に障害物を置いた流路内に生じる逆流の数値解析

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流路入口に障害物を設置すると、流路内部に逆流が生じる。この現象は、はく離、再付着およびせん断流れの干渉を含む。この現象については、様々な観点から多くの実験的な研究がなされてきた。本研究では、逆流の挙動を解明するため、CFD(computational Fluid Dynamics)により解析した。それらの結果は、逆流の発生を予測し、壁面後方に影響を及ぼす渦のような流れの特徴を示している。

Keywords.

壁面、障害物、逆流