DRAG ESTIMATION OF FLOW PAST A SQUARE CYLINDER USING TWO SPLITER PLATE

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ABSTRACT

The primary purpose of the present study is to reduce the drag force over the square cylinder by using a detached splitter plate of length equal to one cylinder height (D) placed at the front and back side of the cylinder. The thickness of splitter plate is 4% of the dimension of square cylinder. The splitter plate gap between the square cylinder is equal to the one cylinder height (D) . The Splitter plates are placed horizontally in the upstream of the cylinder and in the near wake region.

Direct numerical simulation of two- dimensional, unsteady and incompressible laminar flow is numerically investigated at Reynolds number of 150 and 200. In the present work Navier-Stokes equations are solved by using finite difference Marker and Cell (MAC) method. The accuracy of the Navier-Stokes solver is validated by the simulation of flow past a square cylinder without the splitter plate.

The main objective of this study is to investigate the possibility of using a front and back side of the flat plate for passive bluff body wake control. The Success of this mechanisms evaluated by considering the reduction of aerodynamic loading together with the reduction in drag force on over the cylinder. The test case under investigation consists of a square cylinder as the primary bluff bodies and a flat plate as a secondary body.

Keyword: - *Square Cylinder, Reynolds Number, Wake, Grid Independence ,Drag Coefficient, Lift Coefficient, Strouhal Number.*

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1. INTRODUCTION

The problem of flow around the square and circular cylinder with splitter plate has many attractions with regards to the physics of the flow field as well as practical engineering applications. There is formation of a pair of vortices at the downstream side of the object, whenever a fluid flows past a bluff body. Behind the bluff bodies, formation of vortex shedding is of concern for many engineering applications and it is basically responsible for scour development around bridge piers in channel beds, structural movement of high rise buildings, acoustic radiation from aircraft landing gear, vibrations of industrial components and other related problems. The geometry of bluff bodies may be simple, but the flow structure is complex especially in the near wake region. Therefore, this subject requires investigation, especially when the near wake is interfered with a splitter plate, so that a better understanding about the flow behaviors for a different range of conditions can be obtained. Due to periodic surface loading, fluctuating velocity fields and the patterns of vortex shedding behind the bluff bodies can cause structural damage, which basically diminishes the life of the structure and increases the drag and the acoustic noise. Therefore, in order to control or suppress the vortex shedding phenomenon and to reduce the amplitude of fluctuating lift as well as drag, numerous methods have been performed in the literature.

There are two techniques to control the vortex shedding phenomenon: passive control technique and the active control technique which are defined as below:

Active Control

In the active control technique, the vortex shedding has been controlled by impacting external energy into the flow filed [1]. Some of the examples of the active control techniques are the acoustic excitation systems and feedback control, suction and blowing and rotary oscillation of cylinders.

Passive Control

Passive control techniques do not require any external energy in order to control the vortex shedding. It basically controls the vortex shedding by attaching additional devices in the flow stream or by modifying the s hape of the bluff body. This technique is easier and simpler to implement compared to the active control techniques and are widely used for applications of flow control. Some of the examples of passive control techniques are control cylinders, splitter plates, base bleed, roughness elements and helical wires. In control cylinder, a cylinder is placed downstream or upstream in order to control the vortex shedding where as in case of splitter plate, a rectangular plate is used to control the vortex shedding which is attached to the downstream face of the object inline to the flow direction. Among the passive control techniques, the splitter plate has been one of the most successful devices for the control of the vortex shedding behind a cylinder.
The main objective of the present study is to investigate the effect of detached splitter plate on the control of flow structure, downstream of the square cylinder and to identify the gap distance at which all the fluctuating forces are minimu m.

MATERIALS AND METHODS

Numerical Method

The numerical method which used in the present study is Marker and Cell (MAC) method. The MAC method first appeared in 1965. It was developed by Harlow and Welch [2] specifically for free surface flows as a variant of Particle-in-Cell (PIC) method. The original Particle-in-Cell (PIC) code [3] was developed in 1958, which used mass particles that carried material position, mass and species information. Despite the special capabilities of PIC for following discontinuities, it did not give accurate solutions in general because the transfer of information between the particles and the underlying grid resulted in numerical diffusion. For solving full Navier-Stokes equations, MAC method is used. In MAC method, there is an advection of marker particles with local fluid velocity and the distribution of marker particles determine the configuration of instantaneous fluid flow. If a cell contains a particle then it is also considered to contain fluid, therefore it provide flow visualization of the free surface. For the computation of velocity and pressure, Momentum and Poisson equations are used by this method respectively. It was developed to solve problems with free surfaces, but can be applied to any incompressible fluid flow problems. There have been many further developments and applications of the MAC method (Tome & Mckee, [4]; Chen, et al., [5]). Its extension to three dimensions has been difficult and the coalescence and fragmentation of fluid regions meant enhanced complexity in the algorithm required if at all programmable. The computational domain is divided into Cartesian cells. Staggered grid arrangements are used in which velocity components are defined at the midpoints of the cell sides to which they are normal and the pressure is defin ed at the centre of the cell.

Governing Equations

The simulation for the present problem has been carried out by solving unsteady, conservative form of Navier-Stokes equations for an incompressible fluid in a two- dimensional geometry. The equations for continuity and momentum may be expressed in the dimensionless forms as follows:

Continuity equation

$$\frac{\partial u_i}{\partial x_i} = 0$$

Momentum equation

$$\frac{\partial u_i}{\partial t} + \frac{\partial (u_j u_i)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{1}{R_e}\frac{\partial^2 u_i}{\partial {x_j}^2}$$

The above equations are the non-dimensional form of continuity and momentum equations. The non-dimensional parameters are given as $x_i = \frac{x_i}{D}, u_i = \frac{u_i}{D}, p = \frac{p}{\rho u^2}$ where D is the characteristic length scale, U is the average inlet velocity scale, p is the pressure, ρ is the density and Re is the Reynolds number given by $R_e = \frac{\rho UD}{\mu}$ (μ is the viscosity of fluid).

Boundary conditions
The boundary conditions for the present problem are:

Inlet B.C: A uniform velocity has been prescribed at the inlet of the 2- D channel i.e u(y) = 1.0 and v = 0.

Outlet B.C: The outlet boundary condition should have such specifications that it would not affect the flow in the upstream. Therefore, the convective boundary conditions which were proposed by Orlanski [35] have been used:

$$\frac{\partial u_i}{\partial t} + u_c \frac{\partial u_i}{\partial x} = 0$$

where u_c , is the convective velocity in the above equation.
Confining boundaries: The confining boundaries (top and bottom boundaries) are modeled as the slip boundaries for example, at the transverse confining surfaces, the y = ± H/2, $\frac{\partial u}{\partial y} = 0$ and v=0.
Obstacle: No slip (u = 0, v = 0) boundary conditions are used for the velocities on square cylinder as well as on the splitter plate surface.

Assumptions
The phenomenological near-wake model describes a cylindrical object which translates with constant speed U through ambient fluid and has lateral dimension D. This model is based on three major experimental and analytical findings related to the geometry of the vortex street, the energy associated with the stream wise motion.

Problem formulation
The present study is aimed at controlling the formation of vortex shedding and wake region behind the square cylinder by using detached splitter plate. The flow has been taken from left side to right side of the two-dimensional channel. A splitter plate of length Lsp is used in order to suppress the vortex shedding, which is expected to have the effect of unsteady forces on the square cylinder. Figures 1 represent the flow structure of the present problem.

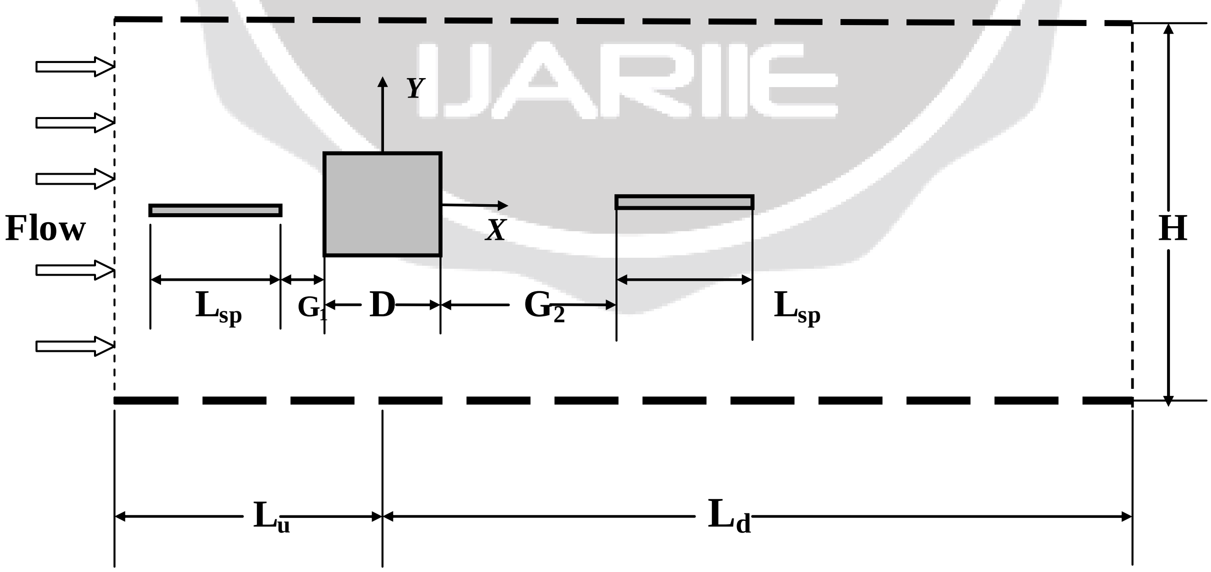


Figure 1: ***Flow domain for a square cylinder with a front and back detached splitter plate***

The length of the splitter plate is equal to the dimension of the square cylinder. i.e Lsp = D, where D is the one dimension of the square cylinder. The separation distance (G2) is measured from the rear surface of the cylinder to the leading edge of the plate and separation distance (G1) is measured from the front surface of the cylinder to the trailing edge of the plate. The thickness of the splitter plate is 4% of the dimension of square cylinder. The present study is done for only one case, by fix the distance of the rear end of the square cylinder to the leading edge of the splitter plate and fixes the distance of the front end of the square cylinder to the trailing edge of the splitter plate but the Reynolds number based on cylinder width. Therefore according to the corresponding gap, the grid domain is extended downstream, so that the distance between the leading edge of the square cylinder and the upstream computational domain is always same. Some of the important parameters that are considered in the present problem are Reynolds number ($Re = \rho UD / \mu$), drag coefficient ($Cd = F_D / 0.5\rho U^2 D$) and lift coefficient ($Cl = F_L / 0.5\rho U^2 D$). Uniform mesh is used for the present problem.

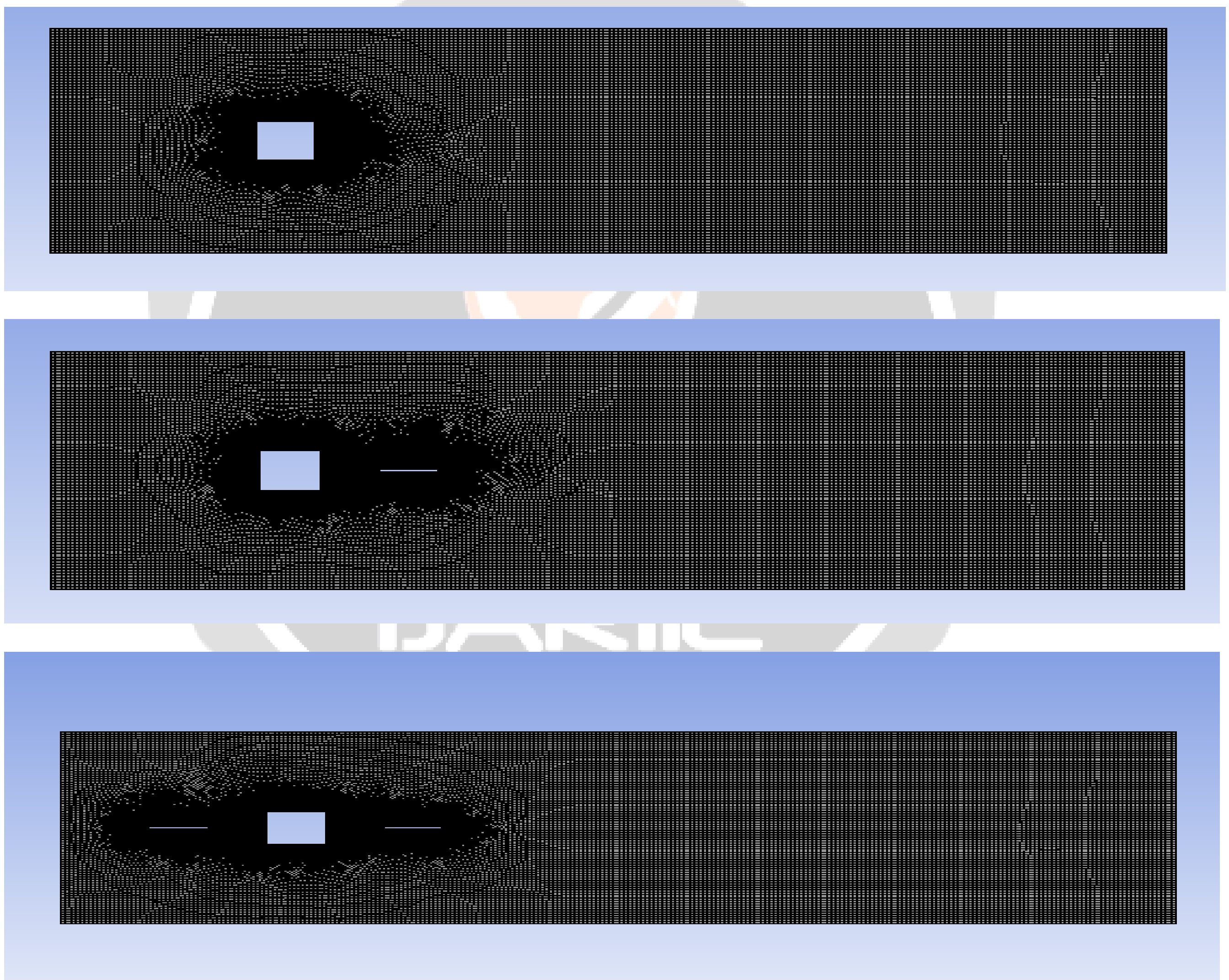


Figure 2: ***Two-dimensional uniform grid***

Code validation

Code validation of the present problem is done by validating the Navier-Stokes solver by considering the laminar flow past a square cylinder in 2-dimension channel. The Reynolds number based on the square cylinder width and the average inlet velocity considered in the study is 80 m/sec. The flow direction is from left to right of the domain. The relevant dimensions pertaining to the present study are: Lu = 5, Ld = 12, and H = 10. From the dimension, one can say that the blockage ratio is 4% and can be considered as the infinite media. For computation, the flow domain is divided into a number of rectangular cells. The mesh cell is uniform in both the directions The boundary conditions employed for the present validation are same as described above.

The drag coefficient is determined by integrating pressure on the forward and rear faces of the cylinder and the Strouhal number is obtained by the vortex shedding frequency.

Results and Discussion

The Reynolds number used for the present study is 150 and 200. The dimension of the square cylinder is same as that of the plate length. The structure of the flow is studied by using streamlines, velocity vector and vortices contours. Some useful physical quantities such as drag coefficient, Strouhal number and lift coefficient are computed in the present study. To keep the splitter plate at the same distance towards the front and back side of the square cylinder is to alter or suppress the vortex shedding phenomena. Aim of the present study is to find the drag coefficient; Strouhal number and lift coefficient fluctuation are minimum and also analysis the behavior of wake structure behind the cylinder due to detached plate.

Case I: Cylinder without front and back splitter plate

Figures 3.1 and 3.2 shows instantaneous velocity contours and corresponding streamline topology respectively if Reynolds number is 150 and Figures 3.3 and 3.4 shows instantaneous velocity contours and corresponding streamline topology respectively if Reynolds number is 200 .when the cylinder is without front and back splitter plate.

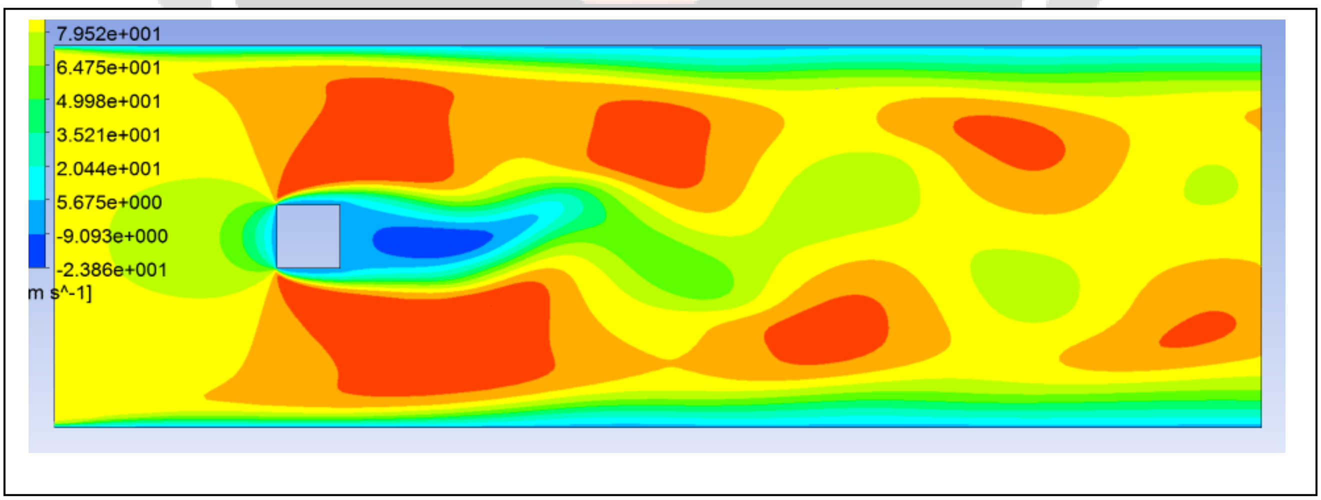


Figure 3.1: ***Instantaneous velocity contours*** Re=150

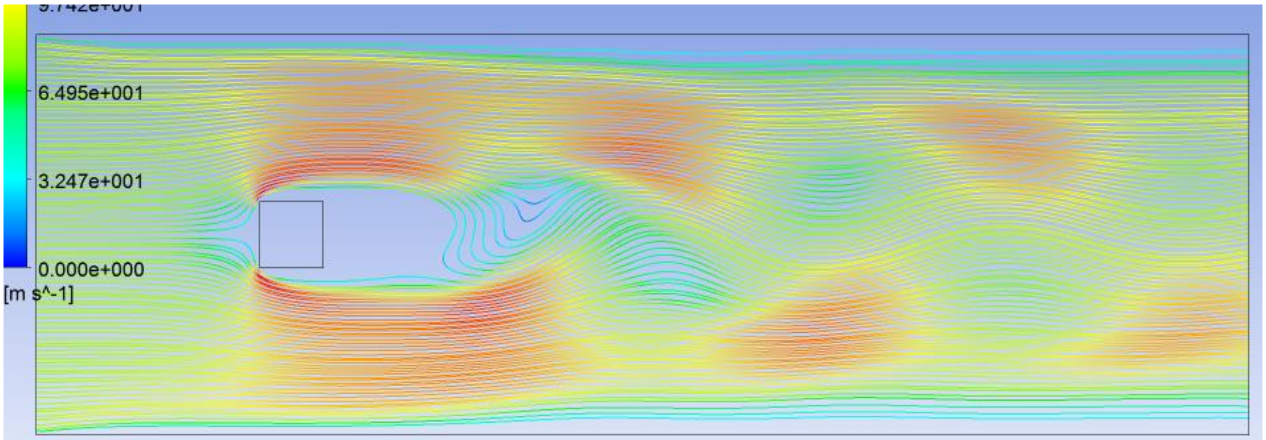


Figure 3.2: ***Streamline topology Re=150***

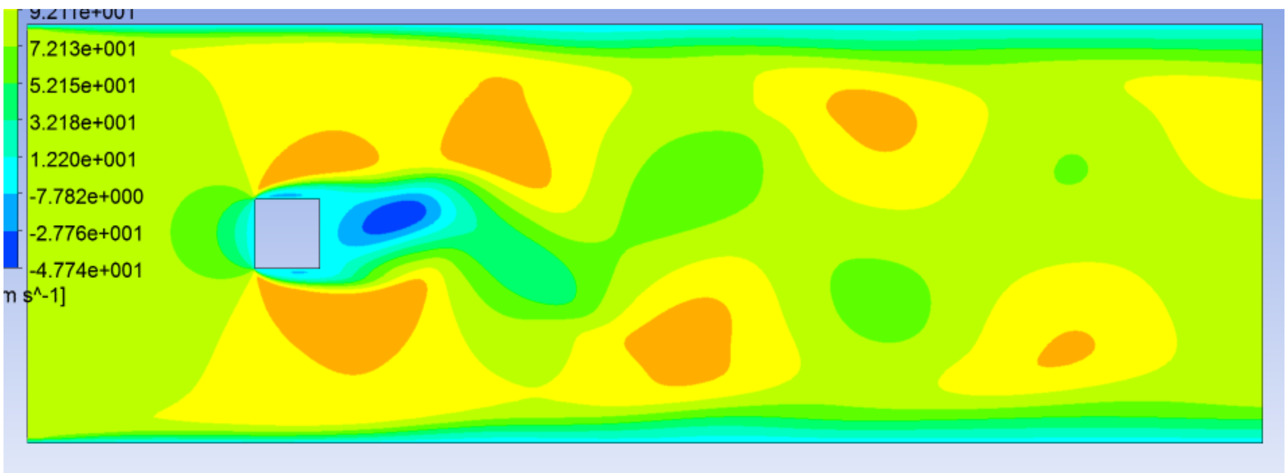


Figure 3.3: ***Instantaneous velocity contours*** Re=200

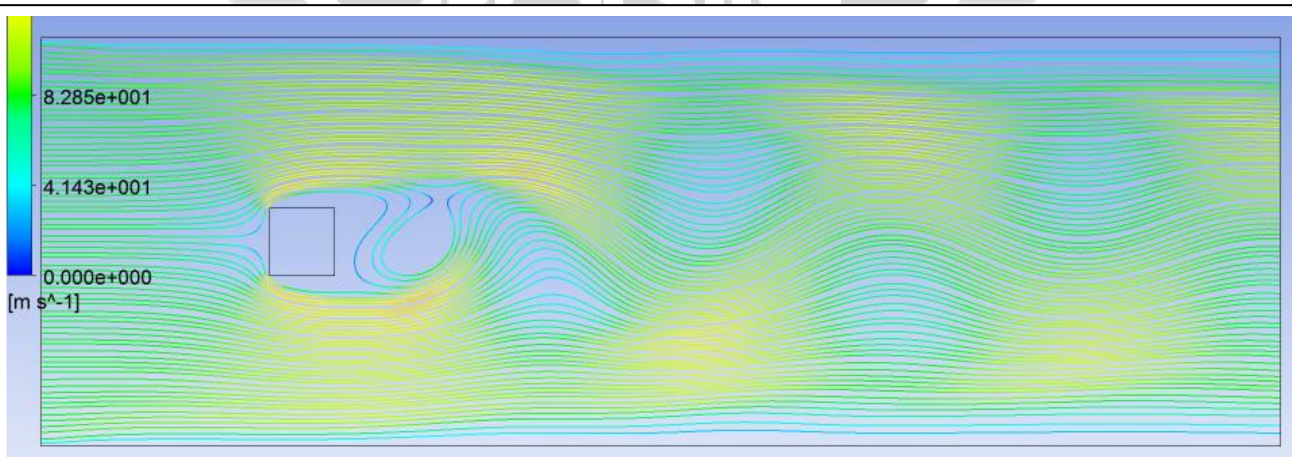
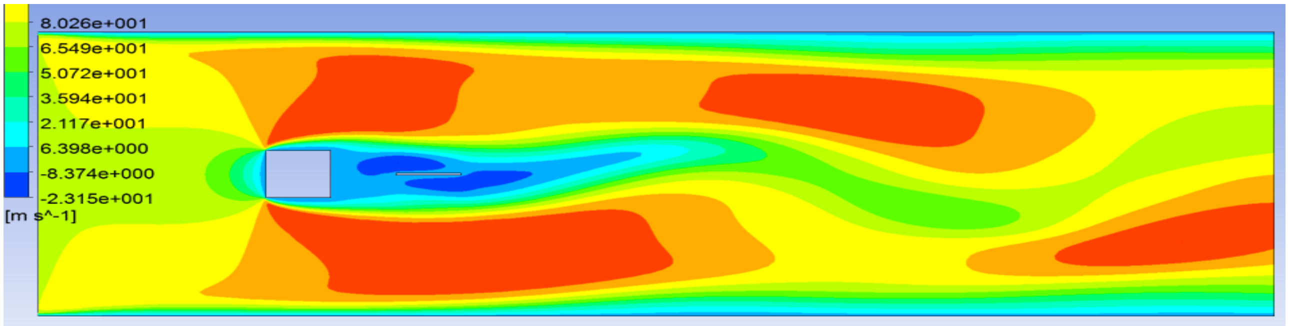
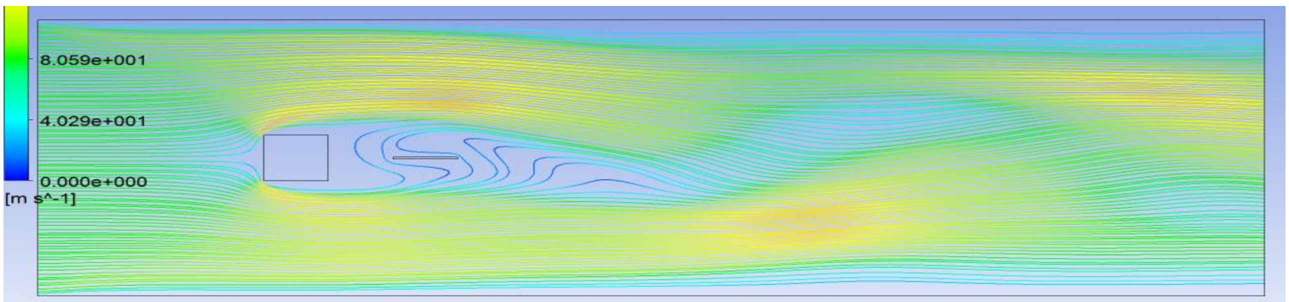


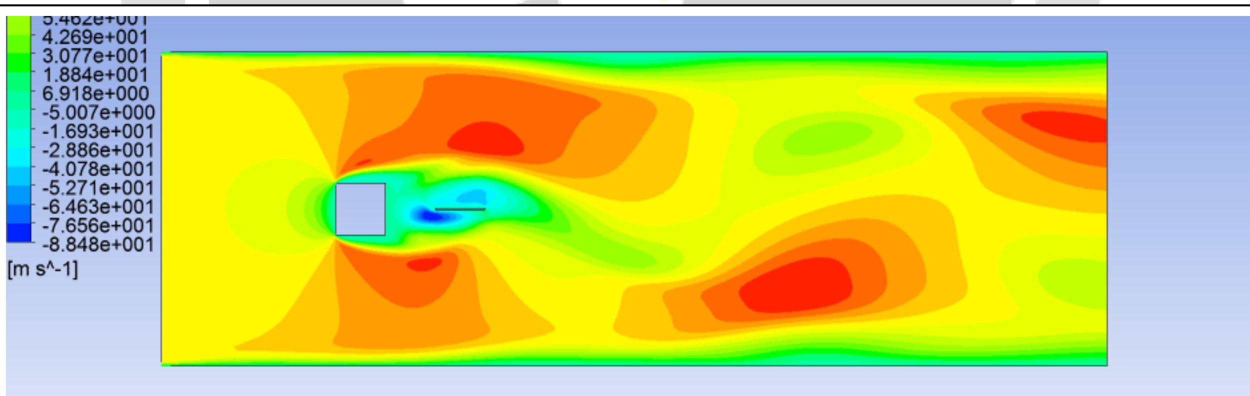
Figure 3.4: ***Streamline topology Re=150***

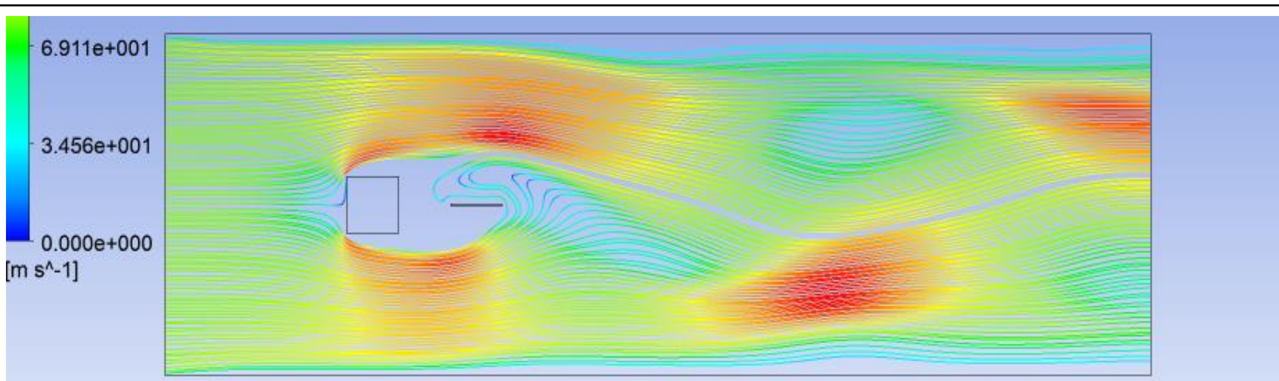
Case II: Cylinder with back splitter plate and without front splitter plate

Figures 4.1 and 4.2 shows instantaneous velocity contours and corresponding streamline topology respectively if Reynolds number is 150 and Figures 4.3 and 4.4 shows instantaneous velocity contours and corresponding streamline topology respectively if Reynolds number is 200 .When cylinder is back splitter plate and without front splitter plate.



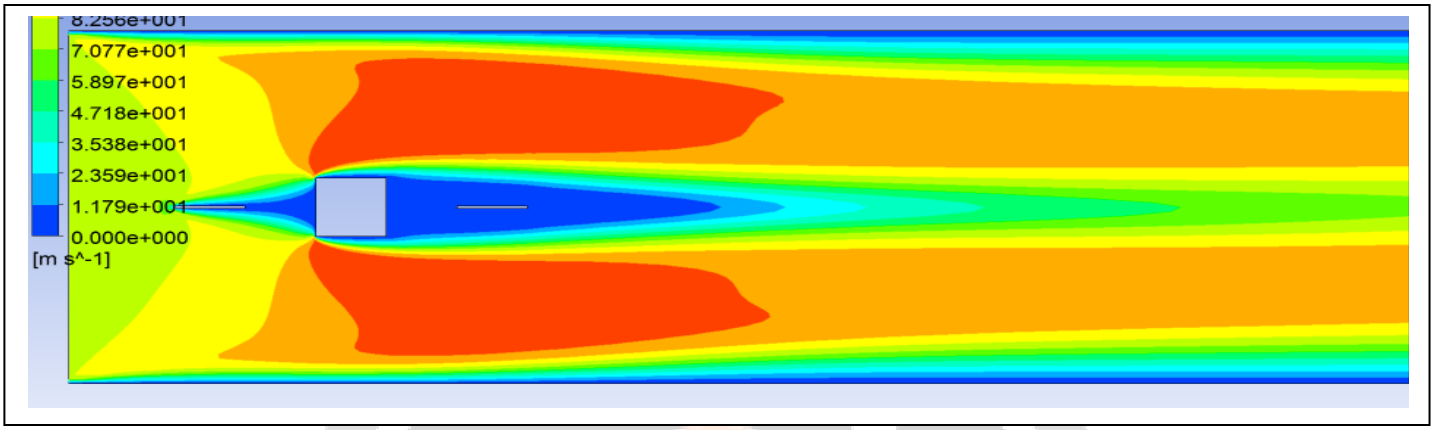


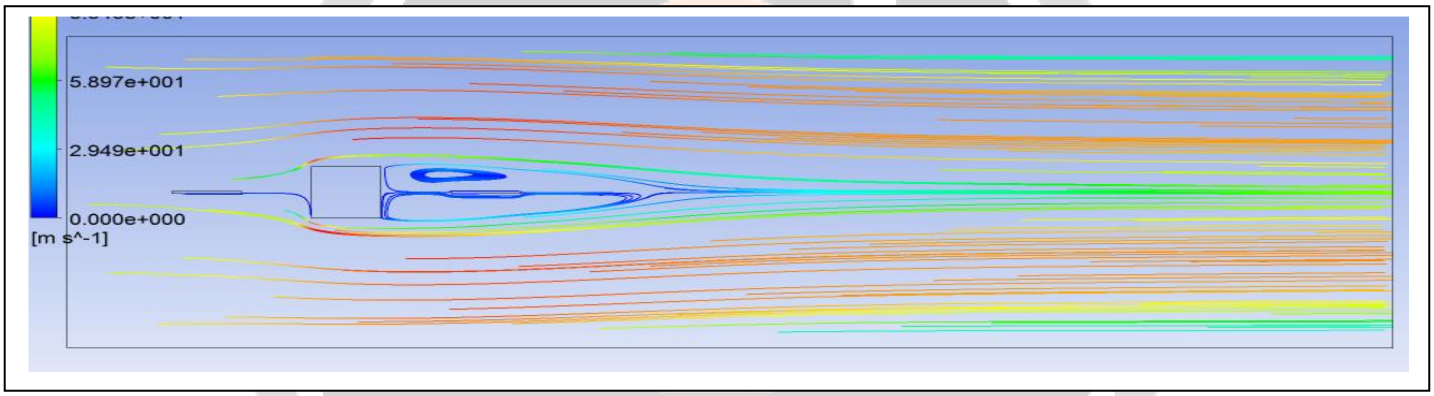


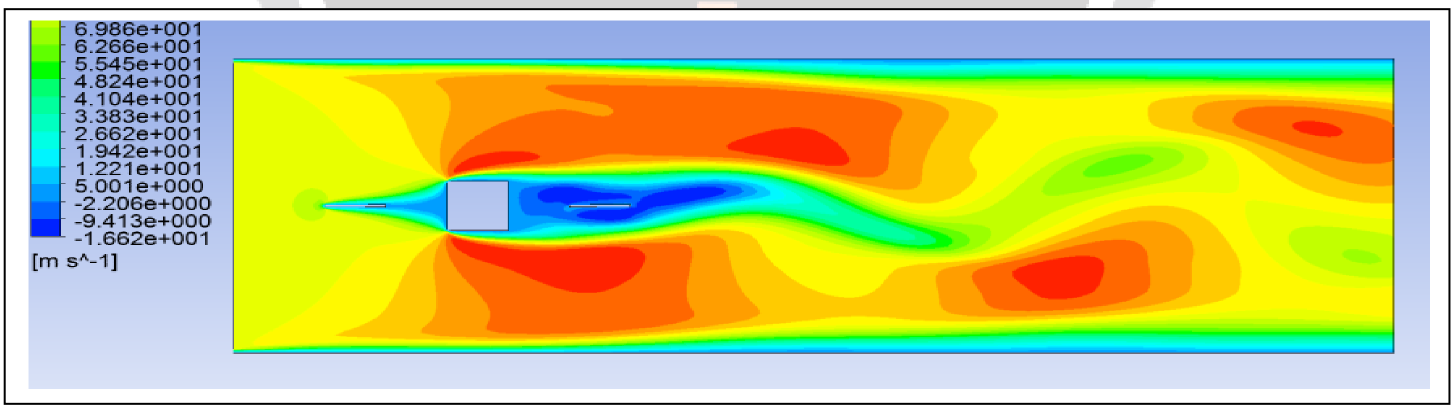


Case III: Cylinder with back splitter plate and front splitter plate

Figures 5.1 and 5.2 shows instantaneous velocity contours and corresponding streamline topology respectively if Reynolds number is 150 and Figures 5.3 and 5.4 shows instantaneous velocity contours and corresponding streamline topology respectively if Reynolds number is 200 .When cylinder is back splitter plate and without front splitter plate.







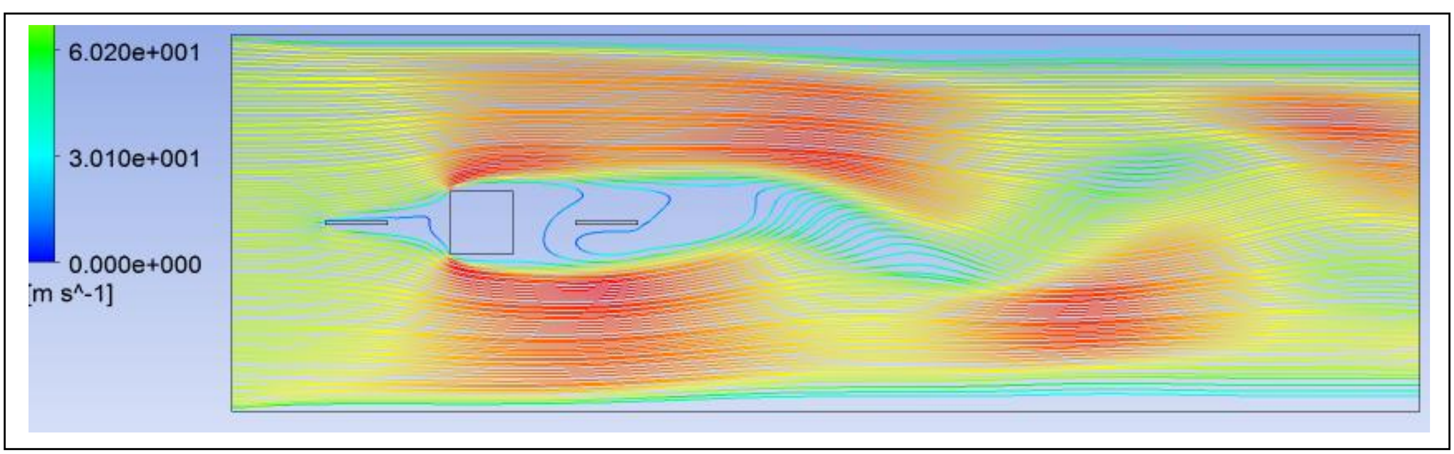


Table 1: *Variation of integral parameters with different Situation of cylender at Re=150 & Re=200.*

S.No.	Situation of Cylinder	Reynolds Number Re	Drag Coefficients C_{DMin}	Lift coefficients C_{lMax}	Strouhal Number S_t
1	Case I: Cylinder without front and back splitter plate	**150**	1.5733	0.1065	0.1608
		200	1.274	0.1767	0.1518
2	Case II: Cylinder with back splitter plate and without front splitter plate	**150**	1.5296	0.14779	0.086
		200	1.2055	0.18289	0.07882
3	Case III: Cylinder with back splitter plate and front splitter plate	**150**	1.4815	0.23776	0.0516
		200	1.1617	0.37639	0.099

CONCLUSIONS

The effects of downstream detached splitter plate on the suppression of vortex shedding have been numerically investigated at a Reynolds number of 150 and 200. Splitter plate having a thickness of 4% of dimension of square cylinder (D) is placed horizontally in the wake region and front side . The length of detached plate (L) is same as the dimension of square cylinder (D).

In the present study, The major conclusions are drawn as follows:

- The value of drag coefficients $\mathbf{C_{Dmin}}$ value is decreases if the situation of cylinder is changed .
- The value of lift coefficients $\mathbf{C_{lMax}}$ value is increases if the situation of cylinder is changed .
- The value of Strouhal Number St value is decreases if the situation of cylinder is changed .
- The value of Reynolds number is increases then the value of Strouhal Number St is also decreases.

REFERENCES

[1]. H. Sakamoto, H. Haniu, "*Optimal suppression of fluid forces acting on a circular cylinder*", J. Fluids Engineering 116 (1994) 221-227.
[2]. Harlow F.H and Welch, J.E., *"Numerical calculation of Time-Depentent Viscous Incompressible Flow,"* Phys. Fluids, vol. 8, p. 2182, 1965.
[3]. Evans MW, Harlow FH. "*The particle-in-cell method for hydrodynamic calculations*", Los Alamos National Laboratory Report LA-2139, 1957
[4]. Tome Murilo F. and Mckee sean, "*GENSMAC: A computational Marker and Cell Method for free surface flows in General Domains*"' J. Comput. Physc, vol. 110, pp.171- 186, 1994.
[5]. Chen et al., "*Velocity boundary conditions for the simulation of free surface fluid flow*", J Comput. Phys., vol.

116,pp. 262-267, 1995

[6].Nidhul K et al.," *Numerical Investigation of Flow Characteristics over a Square Cylinder with a Detached Flat Plate of Varying Thickness at Critical Gap Distance in the wake at Low Reynolds Number*", International journal of research in aeronautical and mechanical engineering issn (online): 2321-3051, Vol.3 Issue.1, January 2015. Pgs: 104-118

[7.] Jong-Yeon Hwang and Kyung-Soo Yang,"*Flow Control around a Circular Cylinder Using two splitter plates*".

[8.] Sohankar, A., Norberg, C., Davidson, L., *Simulation of three-dimensional flow around a square cylinder at moderate Reynolds numbers"*, Physics of Fluids 11, 288–306 ,1999.

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