NUMERICAL SIMULATION OF FLOW AROUND A SQUARE CYLINDER USING TWO SPLITER PLATE AT LOW REYNOLDS NUMBER

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ABSTRACT

Control of drag force on a square cylinder using multiple detached splitter plates is numerically studied for a laminar flow. The two splitter plates with the same length as the cylinder diameter are placed horizontally in the upstream of the cylinder and in the near wake region respectively. The drag varies with the two gap ratio, it has the minimum value at a certain set of gap ratio for each Reynolds Number 150 and 200.There positions are described by the gap ratio ($G_1/D,G_2/D$),where G_1 represents the gap between the cylinder stagnation point and the rear edge of the upstream of the splitter plate and G_2 represents the gap between the cylinder base point and the leading edge of the rear splitter plate. The upstream splitter plates decreases the stagnation pressure, while rear splitter plate increases the base pressure by suppressing vortex shading. This combined effect causes a significant drag reduction on the cylinder.

The 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 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. The thickness of splitter plate is 4% of the dimension of square cylinder.

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 shape 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.

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 minimum.

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 defined 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

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

Momentum equation

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

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 $\mathrm{R_e} = \frac{\rho \mathrm{UD}}{\mu}$ (μ is the viscosity of fluid).

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. Figure 1 represent the flow structure of the present problem.

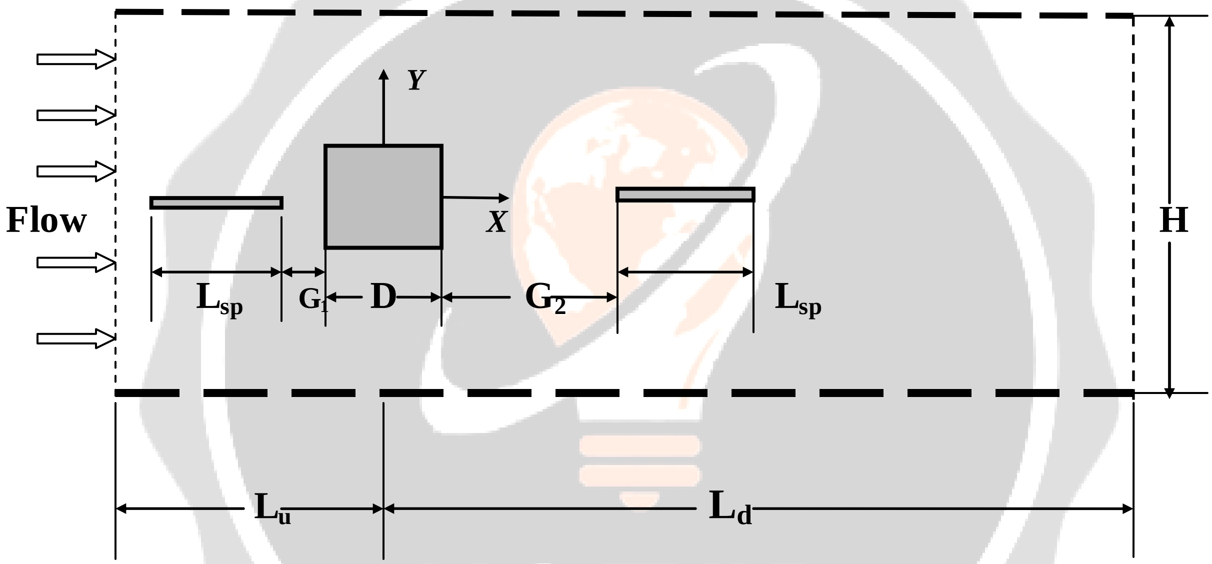


Figure 1:***Flow domain for a square cylinder with a front and back detached splitter plate***

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 (G_2) is measured from the rear surface of the cylinder to the leading edge of the plate and separation distance (G_1) 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 ($C_d = F_D / 0.5\rho U^2 D$) and lift coefficient ($C_l = F_L / 0.5\rho U^2 D$). Uniform mesh is used for the present problem.

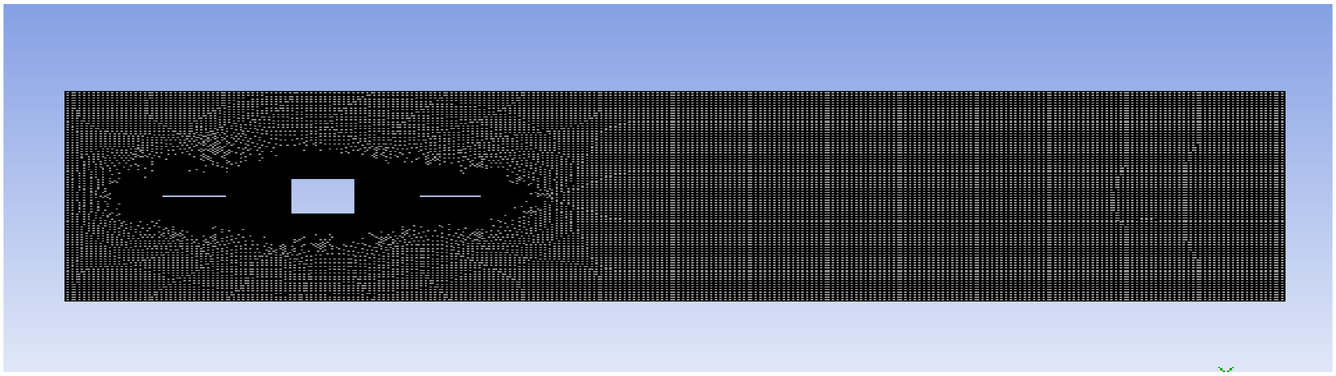


Figure 2: ***Two-dimensional uniform grid***

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. The value of St obtained by running the simulation at Re=150 and Re=200.Here the gap ratio (G_2/D) varies from 1 to 4 and the gap ratio ($G_1/D = 1$) is constant for all cases.

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. Some useful physical quantities such as drag coefficient, Strouhal number ,lift coefficient, drag force and lift force 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 drag force fluctuation are minimum and also analysis the behavior of wake structure behind the cylinder due to detached plate. The drag force, Strouthal number, lift force, drag coefficients and lift coefficients varies with the two gap ratio, it has the minimum value at a certain set of gap ratio for each Reynolds Number 150 and 200.There positions are described by the gap ratio ($G_1/D, G_2/D$).The upstream splitter plates decreases the stagnation pressure, while rear splitter plate increases the base pressure by suppressing vortex shading. This combined effect causes a significant drag reduction on the cylinder.

Effect of detached flat plate on vortex shedding

(a)Simulation was performed for a square cylinder at Re=150 with a detached flat plate of constant thickness along wake center-line at varying gap distance $D \leq G_2 \leq 4D$ and G_1=D. The velocity magnitude contours for each gap distance was obtained as shown in fig.3.

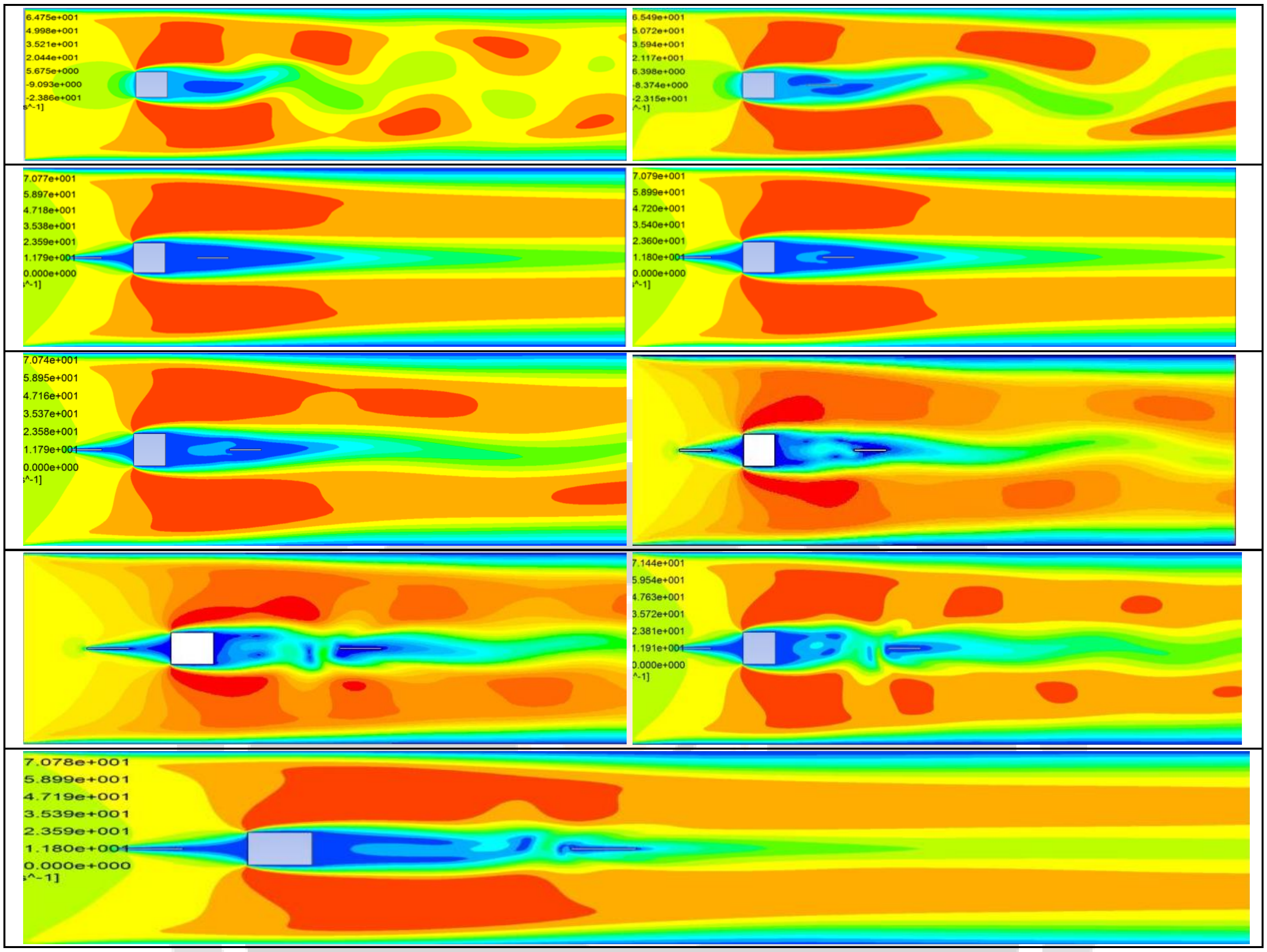
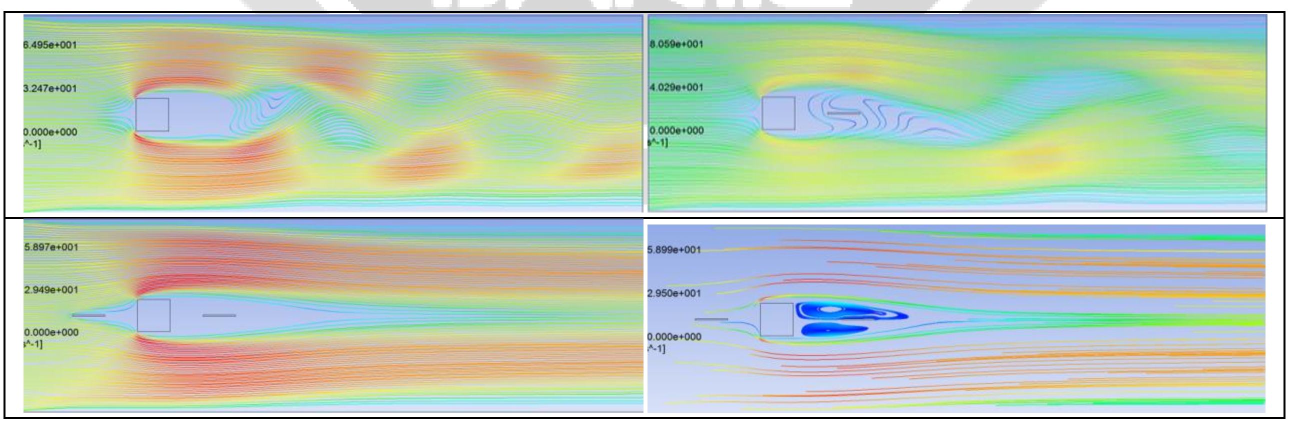


Figure 3: ***Velocity magnitude contours of square cylinder with detached plate at varying gap distances***

(b)Simulation was performed for a square cylinder at Re=150 with a detached flat plate of constant thickness along wake center-line at varying gap distance $D \leq G_2 \leq 4D$ and $G_1=D$. The Streamlines contours for each gap distance was obtained as shown in fig.4.



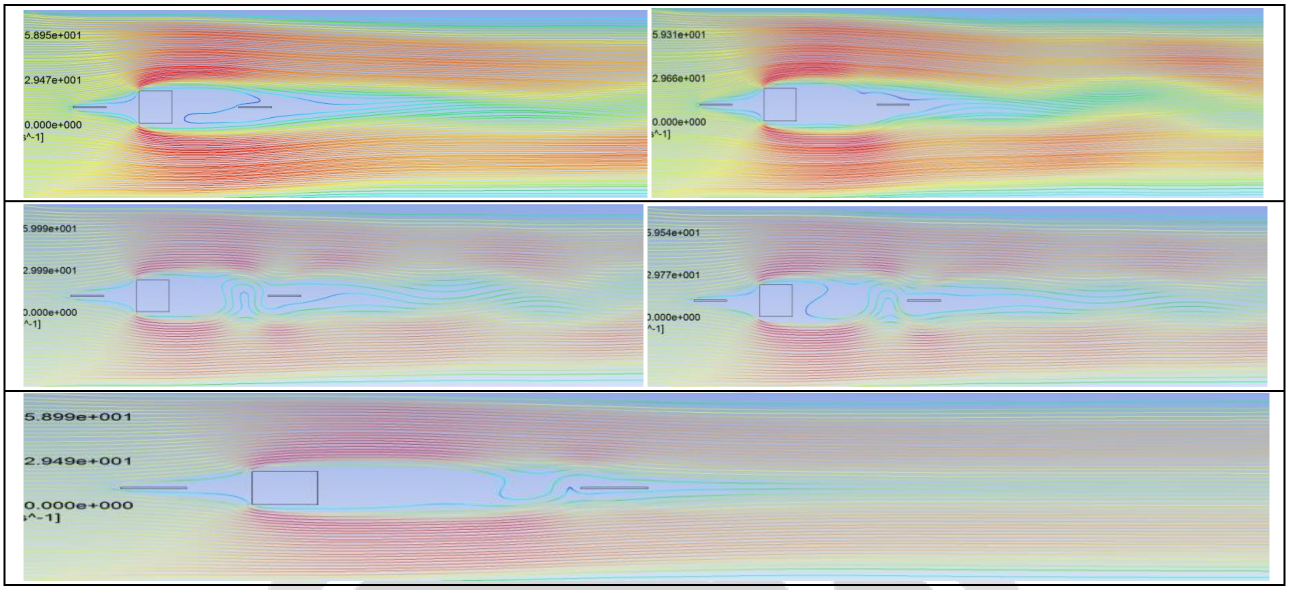
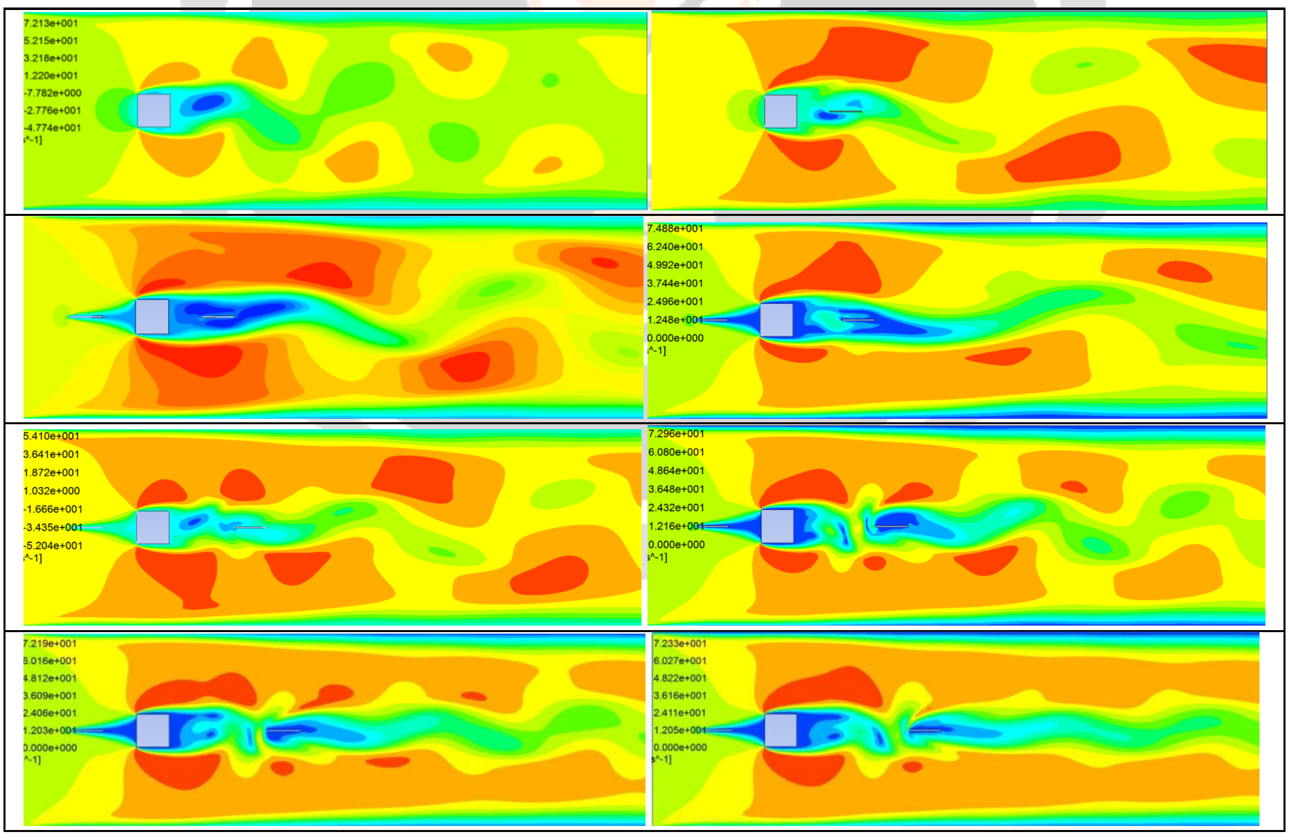


Figure 4: ***Streamlines contours of square cylinder with detached plate at varying gap distances***

(c)Simulation was performed for a square cylinder at Re=200 with a detached flat plate of constant thickness along wake center-line at varying gap distance $D \leq G_2 \leq 4D$ and G_1=D. The velocity magnitude contours for each gap distance was obtained as shown in fig.5.



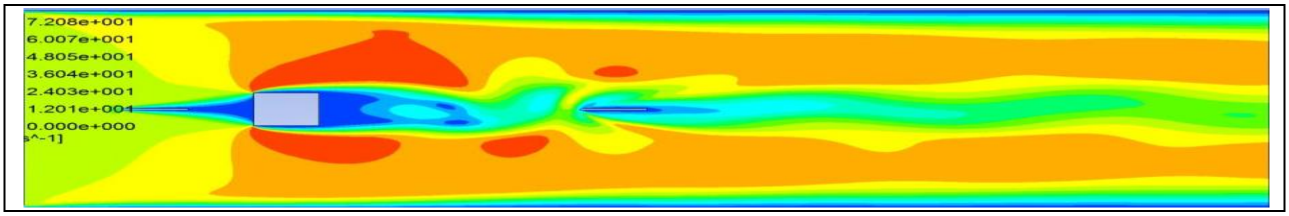


Figure 5: ***Velocity magnitude contours of square cylinder with detached plate at varying gap distances***

(d)Simulation was performed for a square cylinder at Re=200 with a detached flat plate of constant thickness along wake center-line at varying gap distance D ≤ G_2 ≤ 4D and G_1=D. The streamlines contours for each gap distance was obtained as shown in fig.6.

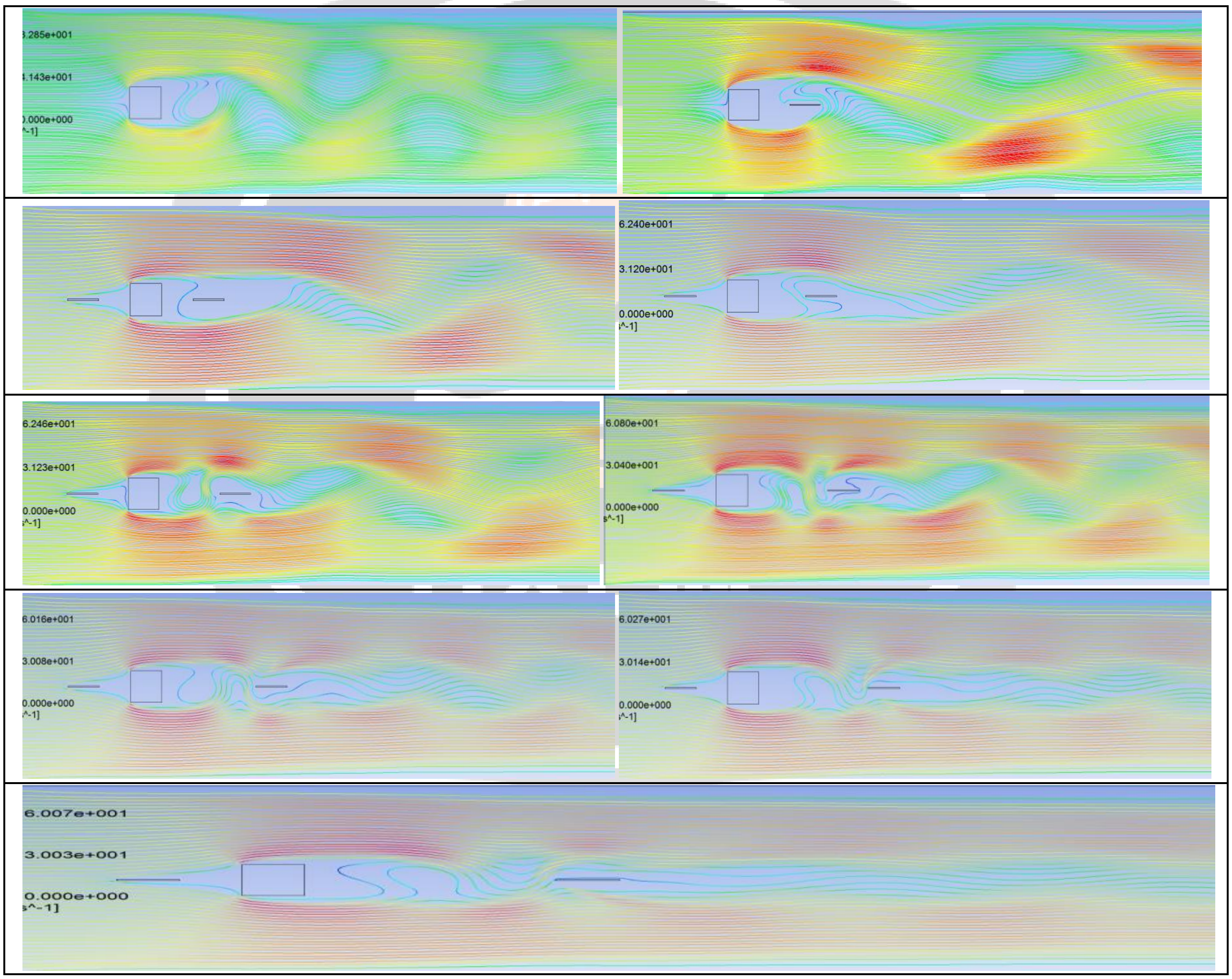


Figure 6: ***Streamlines contours of square cylinder with detached plate at varying gap distances***

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

S.No.	Position of Splitter Plate from the Cylinder	Re=150				
		Drag Coefficients C_{DMin}	Drag Force	Lift Coefficients C_l	Lift Force	Strouhal Number S_t
1	Case I: Cylinder without front and back splitter plate	1.5733	3287.567	0.1065	222.542	0.1608
2	Case II: Cylinder with back splitter plate and without front splitter plate ($G_2/D=1$)	1.5296	3196.252	0.14779	308.821	0.086
3	Case III: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=1.0$)	1.4815	3095.74	0.23776	496.82	0.0516
4	Case IV: Cylinder with back splitter plate and front splitter plate (G1/D=1,G2/D=1.5)	1.4387	3006.307	0.03812	79.65	0.02925
5	Case V: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=2$)	1.4126	2951.76	-0.07357	-153.73	0.092
6	Case VI: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=2.5$)	1.3894	2903.29	-0.10361	-216.48	0.127
7	Case VII: Cylinder with back splitter plate and front splitter plate (G1/D=1,G2/D=3)	1.4015	2928.57	-0.1007	-210.42	0.148
8	Case VIII: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=3.5$)	1.3975	2920.216	0.08835	185.869	0.1408
9	Case IX: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=4$)	1.3871	2898.48	-0.1225	-255.967	0.1838

Table 2: *Variation of integral parameters with different Situation of cylender at Re=200.*

S.No.	Position of Splitter Plate from the Cylinder	Re=200				
		Drag Coefficients C_{DMin}	Drag Force	Lift Coefficients C_l	Lift Force	Strouhal Number S_t
1	Case I: Cylinder without front and back splitter plate	1.274	1793.792	0.1767	248.793	0.1518
2	Case II: Cylinder with back splitter plate and without front splitter plate ($G_2/D=1$)	1.2055	1697.344	0.18289	257.382	0.07982
3	Case III: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=1.0$)	1.1817	1635.673	0.37639	529.957	0.099
4	Case IV: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=1.5$)	1.1174	1572.736	0.02554	35.904	0.079
5	Case V: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=2$)	1.1617	1635.673	-0.37389	-526.43	0.121
6	Case VI: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=2.5$)	1.0847	1527.257	-0.07693	-108.31	0.144
7	Case VII: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=3$)	1.1198	1576.678	-0.1863	-262.31	0.1608
8	Case VIII: Cylinder with back splitter plate and front splitter plate ($G_1/D=1, G_2/D=3.5$)	1.0639	1497.971	0.00963	13.559	0.1577
9	Case IX: Cylinder with back spliter plate and front spliter plate ($G_1/D=1, G_2/D=4$)	1.0926	1538.38	-0.17807	-250.624	0.1812

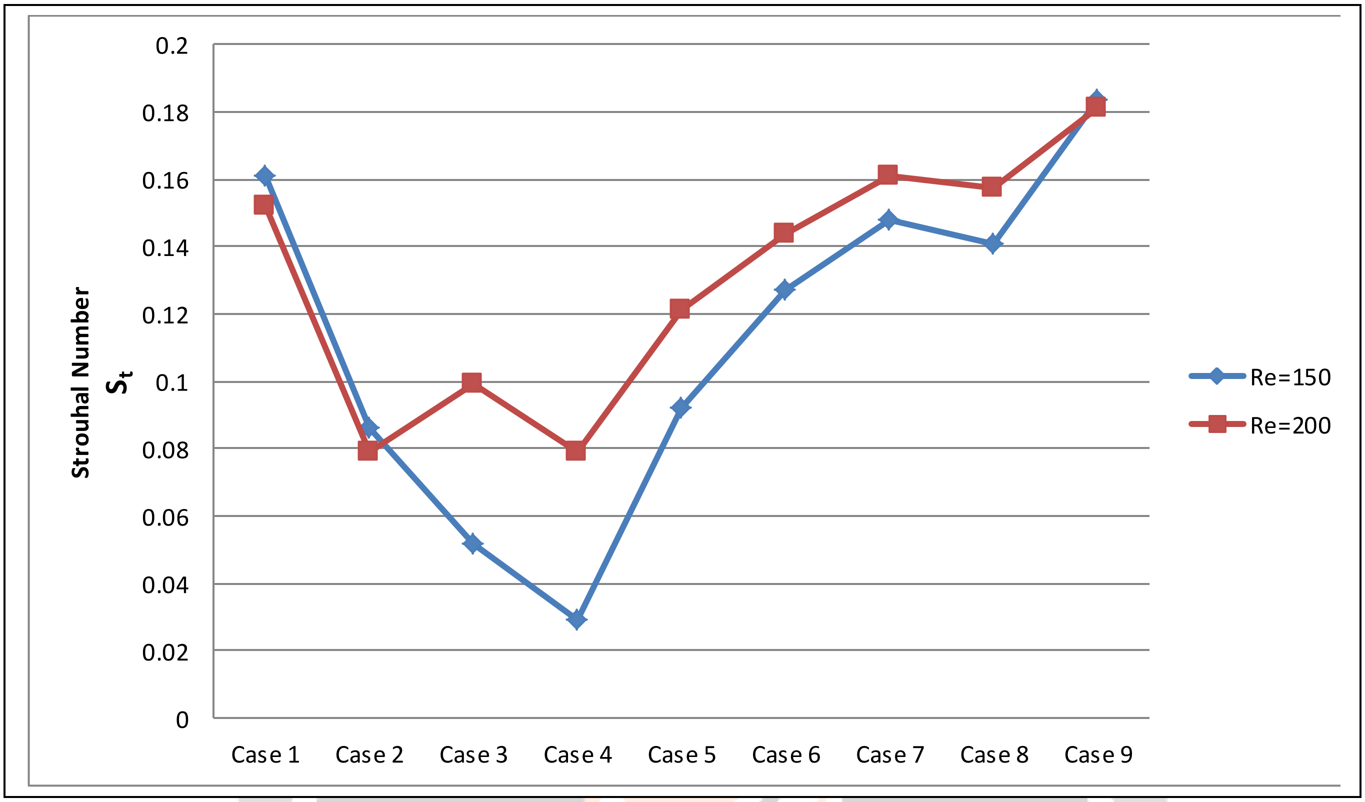


Figure 7: ***Strouhal number variation for varying gap distances***

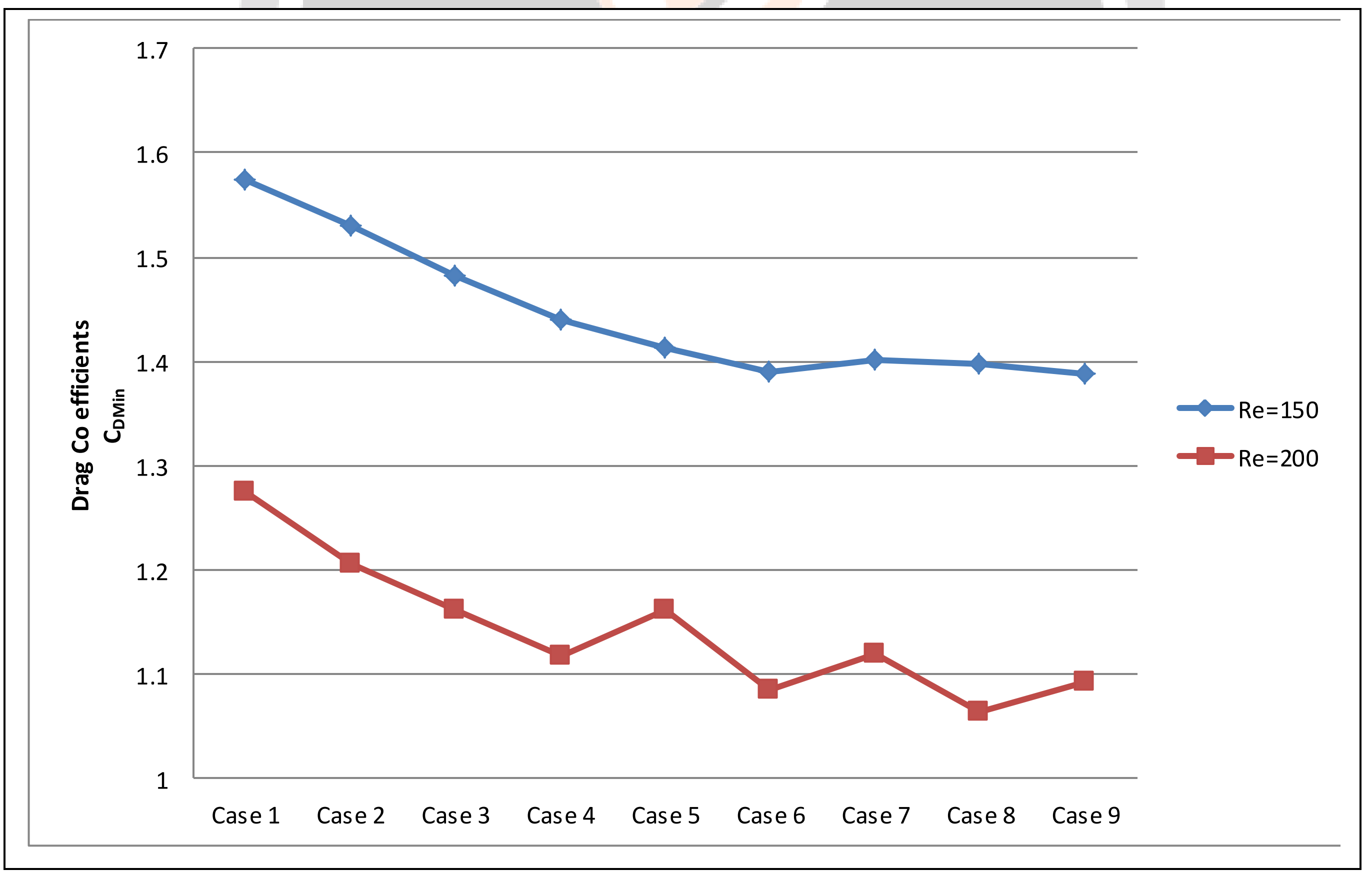
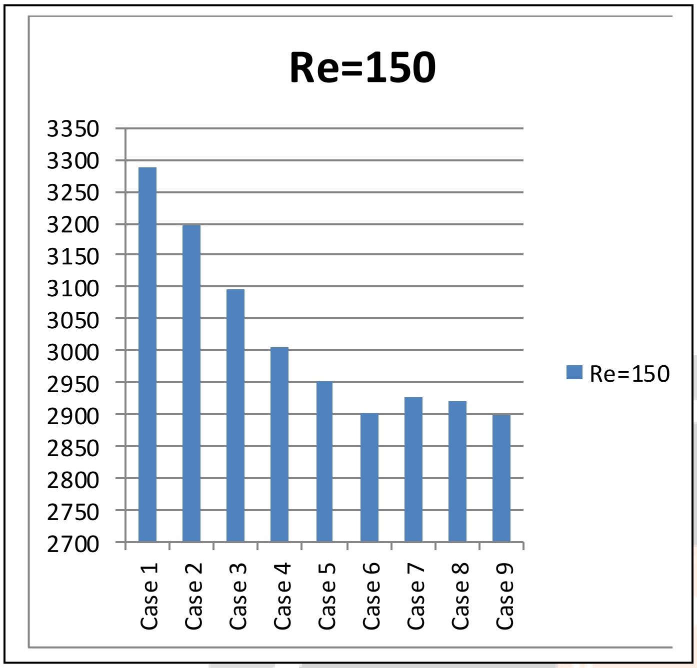


Figure 8: ***Coefficient of drag variation for varying gap distances***



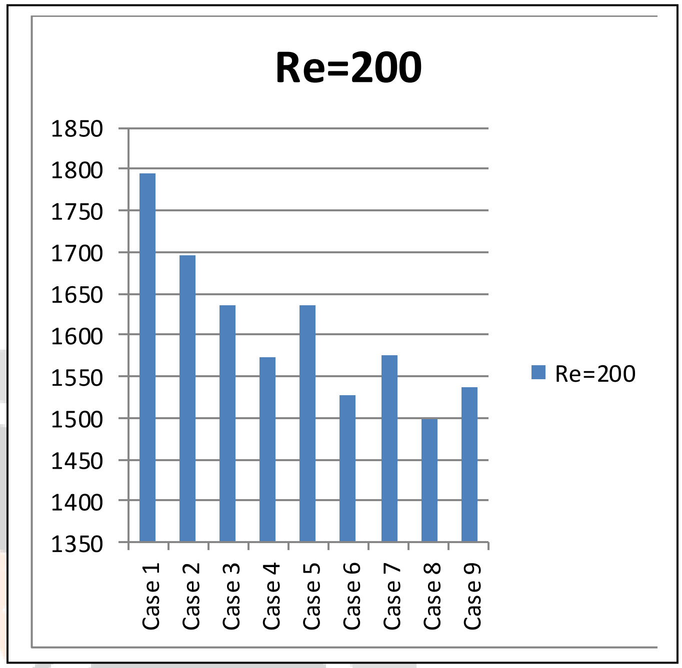


Figure 11: ***Drag Force variation for varying gap distances***

CONCLUSIONS

The major conclusions are drawn as follows:

- Detached flat plate suppresses the vortex shedding and reduces the flow induced forces by interrupting the regular vortex shedding. The Strouhal number for the flow around square cylinder greatly dependent on the position of the flat plate. The value of Strouhal Number St value starts decreases from case I to case IV (G_1/D=1,G_2/D=1.5) . For case IV point the value of strouhal number attain a minimum value beyond this point and during this the value of St is increases .This gap distance is called the Critical gap distance (G_{cr}) since beyond this gap distance, Strouhal number increases. The step increase in St beyond G_{cr} is due to accumulation of a secondary vortex on the leading edge of the flat plate at the both Reynolds numbers 150 and 200 .

- The flow induced force for the flow around square is cylinder greatly dependent on the position of the flat plate. As gap distance increases, the drag force decreases and reaches a minimum value at case IV (G_1/D=1,G_2/D=2.5) if Re=150 , and the minimum value of drag force at case VIII (G_1/D=1,G_2/D=3.5), if Re=200. Since beyond this gap distance Fd increases.

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