Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 2, Issue 13; October-December, 2015 pp. 77-81
© Krishi Sanskriti Publications
http://www.krishisanskriti.org/Publication.html

Low Reynolds Number Flow over a Square Cylinder in Vicinity of a Downstream Splitter Plate

Shubham Jain[1], Shubham Sharma[2] and Sudipto Sarkar[3]

[1,2]Undergraduate Students, School of Mechanical Engineering, Galgotias University, India
[3]School of Mechanical Engineering, Galgotias University
E-mail: [3]sudipto.sarkar@galgotiasuniversity.edu.in,

Abstract—*The vortex shedding of bluff bodies can be controlled effectively by introducing a downstream splitter plate of a very small thickness. This has been shown by Ali et al. [1] who have done their work at Reynolds number Re = 150 and indicated the existence of two flow regimes at Re in periodic vortex shedding regime: Regime 1, where splitter plate is placed within the critical gap distance and regime 2, where the plate is outside the critical gap. In the present study authors investigate the interaction of a square cylinder (side of the square = a) wake with the splitter plate (length = a, width = 0.1a) boundary layer by changing its position in horizontal direction. The gap-to-side ratio is maintained at G/a = 2.5– 4, where G is gap between cylinder and plate. The flow simulation is performed at Re = 100 with the help of Ansys Fluent for four different cases. The authors illustrate instantaneous flow visualization, aerodynamic forces, vortex shedding frequencies to understand the changes associated with wake of the cylinder when a splitter plate is kept downstream of it and outside of the critical gap ratio.*

1. INTRODUCTION

Bluff bodies are non-streamlined shapes objects which significantly resist the fluid flow and are characterized by negligible lift and high drag. This high drag experienced by bluff bodies has motivated many researchers to consider active and passive flow control to reduce the separation zone behind the cylinder. Control of vortex shedding both by active and passive ways can be found in the reviews of Zdravkovich [2] and Choi et al. [3].

A thin, flat, two dimensional plate, popularly known as “splitter plate” mounted behind the cylinder parallel to the flow to control the vortex shedding and separation region is one of the simplest passive flow control arrangement. The splitter plate has been used extensively for circular cylinder [4-8] and also for cylinders with square and rectangular cross-sections [1, 9-10]. This studies are mostly associated with the critical gap ratios (G/a, where G is defined as the distance between cylinder and plate up to which the vortex formation does not occur in between them).

The present simulation is mimicked the numerical investigation of Ali et al.[1] who investigated the flow behavior of a square cylinder wake with a detached plate in between $0 \leq G/a \leq 5$ for a Reynolds number in periodic vortex shedding regime. The flow field is divided in three different zones as per their observations. In zone I ($G/a < 2$), i.e. for short gap, the splitter plate is having maximum influence on the cylinder wake. The flow field transformed to a new mode of wake-plate interaction at intermediate gap (zone II, $2 \leq G/a \leq 2.5$). For long gap (zone III, $2.5 \leq G/a \leq 5$) the flow structure of the near wake region becomes unchanged with the gap. They concluded that the roll-up of vortices occurred only after the downstream of the plate for short gap ratios, whereas the shear layers started to roll-up within the gap for large gap ratios.

In the present study, the authors simulate flow around a square cylinder with a downstream splitter plate using Ansys Fluent for long gap ratios ($G/a \geq 2.5$). The flow physics have been understood with the help of vortex dynamics, aerodynamics forces and shedding frequencies. Appreciable changes in downstream flow field is seen when compare the result with the flow field of an unbounded cylinder.

2. COMPUTATIONAL DETAILS

To simulate the cylinder wake with a downstream splitter plate, computational fluid dynamics (CFD) tool is used. For this purpose the 2-D unsteady Navier-Stokes equations (governing momentum equation) is computed using Ansys Fluent 14.5. The geometry of flow domain is developed using Gambit 2.2.30, which also helps to impose the boundary conditions.

The stream wise and transverse directions are represented by x and y coordinates respectively and the corresponding velocities are denoted by u and v. Cartesian grid is used for the simulation considering the origin of the axes lies at the center of the downstream face of the square cylinder. The square cylinder is of side a and the dimension of the splitter plate is $a \times 0.1a$. The domain of the problem is extended up to $-8.5a$ towards inflow and $\pm 8a$ in flow normal direction from the origin and $27.5a$ towards outflow from the trailing edge of the splitter plate. The N-S equation is non-dimensionalized by considering U_∞ and a as unity. The boundary conditions for wake-splitter plate problem are set by velocity inlet ($u = U_\infty$), pressure outlet symmetry (free-slip boundary conditions) at upper and lower domain and wall boundary condition (no–slip boundary condition $u = v = 0$) both for cylinder and splitter plate. The schematic diagram of the flow geometry along with the boundary conditions is illustrated in Fig. 1 for better understanding of the flow problem.

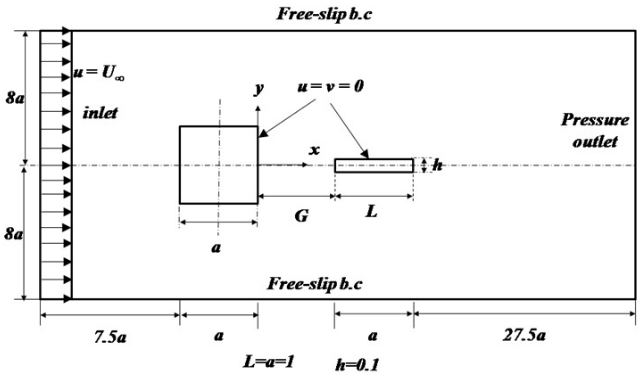

Fig. 1: Schematic diagram of flow geometry

Here, a grid of 328×208 points in the stream wise and flow normal direction are used for G/a=2.5. This grid has been chosen from Ref. [11] where a grid independent test is performing for a square cylinder in unbounded conditions. In detail for G/a = 2.5, a total of 132×80 uniform grid points are employed in an domain (size $5.5a \times 2a$) which covers both the square cylinder and the splitter plate away from the domain grid are slowly stretched out in all directions. For other 3 cases (G/a = 3, 3.5 & 4) no change in total grid point has been made in transverse direction; whereas the total number of grid are 340, 352 & 364 respectively in stream wise direction attributed to the increase in domain size.

The flow filled is then solved using Ansys Fluent 14.5, which is having an inbuilt SIMPLE algorithm to solve the Navier – Stokes equation. The N-S equation is non-dimensionalized by considering U_∞ and a as unity. The equation is descriptive by 2^{nd} order upwind momentum; accept for pressure term, which is solved by least square cell based pressure solver with 2a iterations at each time step. The non-dimensional spacing varies as Δx=0.042-0.265 and Δy= 0.025-0.01 in the near wake region (x/a = 3 to 15 and y/a = 0 to ± 3) for all G/a cases. These values are reasonably good to resolve the interaction of vortices with the splitter plate boundary layer. The time step is kept about t = 0.024 in non-dimensional unit (for G/a = 2) per flow-time in the time of computation. This value of time step helps to keep the Courant number below 1.0 for the entire simulation. The computation requires 3.125 microseconds/iteration/grid point, based on an i3 (Intel core) processor of 2.20 GHz.

3. RESULTS AND DISCUSSION

To visualize the vortex dynamics of a square cylinder in the presence of a downstream splitter plate during a shedding cycle, the snapshots of iso-countors of spanwise vorticity (ω_z) are presented in Figs. 2-5 for different gap-ratios (G/a = 2.5, 3, 3,5 and 4). The time period (T) of vortex shedding has been calculated with the help of the Strouhal number (St). For each case, six time-frames are drawn within a time period (t/T = 0, 0.2, 0.4, 0.6, 0.8 and 1). A brief description of the vortex formation from the cylinder, their downstream convection and interaction with the splitter plate are described.

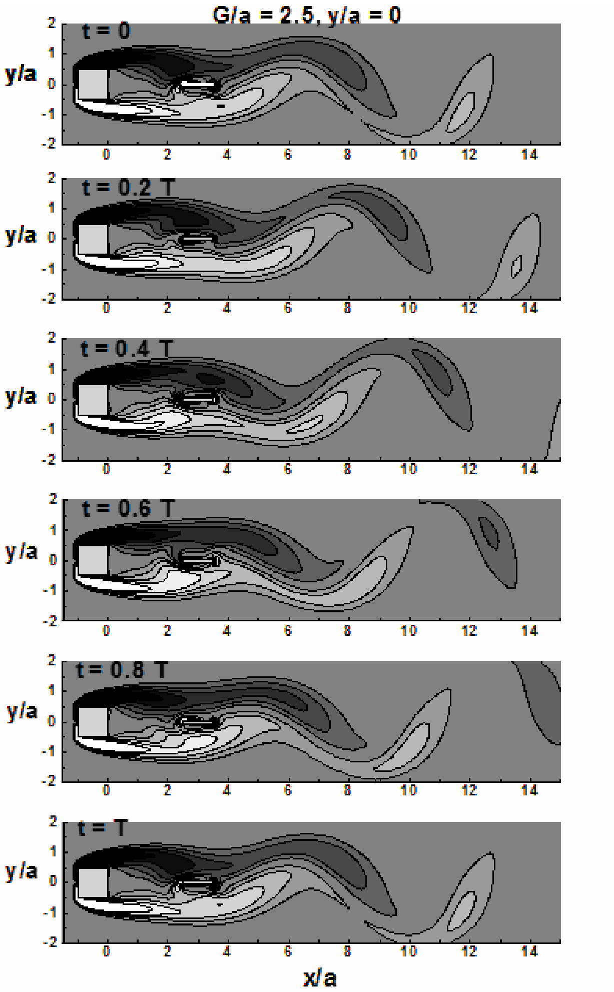

Fig. 2: Instantaneous vorticity contours at G/a = 2.5. A total of 10 non-diemnsional contours are considered in between -1 and +1.

The vortex shedding from the square cylinder is disturbed at G/a = 2.5 and 3 (just after critical gap-ratio). Highly stretched shear layers are seen from the cylinder at G/a = 2.5. The wake width in the downstream is also small.

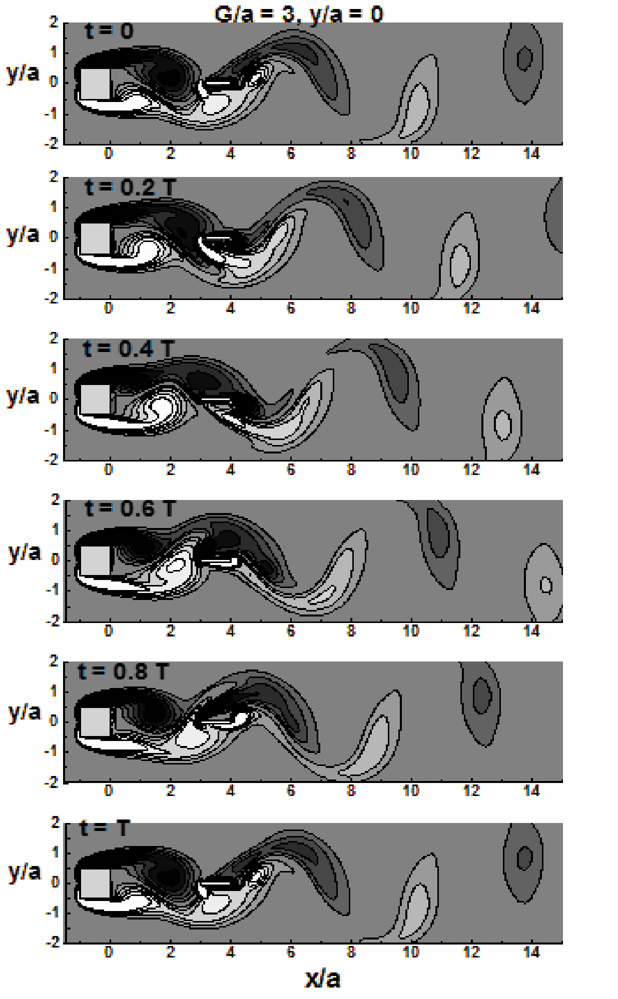

Fig. 3: Instantaneous vorticity contours at *G*/*a* = 3. For detail refer Fig. 2.

As the gap-ratio increases (*G*/*a* = 3.5 and 4, Figs. 4 and 5), the shear layers from the cylinder are able to roll-up and produce vortices much before the splitter plate. The interaction of these vortices is more with the splitter plate as compare to previous two cases. Due to this high interaction, the wake width in the downstream region is also increased.

The figures also reflect another significant difference in separation region for instantaneous flow field. This region is more for *G*/*a* = 2.5, 3 as compare to *G*/*a* = 3.5 and 4 cases attributed to the stretched shear layers in first two cases. From instantaneous vortex dynamics it can be concluded that the usefulness of the splitter plate reduces as *G*/*a* becomes more than 3. So it is highly recommended to use the plate before *G*/*a* = 3 to control the downstream separation region

Fig. 6 illustrates the instantaneous streamlines for all cases of *G*/*a* computed. The time instants for these figures are arbitrarily chosen. A total of 20 streamlines are equally distributed in between *y*/*a* = -1.5 to 1.5 to properly capture the flow physics captured by streamlines. The Fig. shows the disturbed vortex shedding at *G*/*a* = 2.5 and 3, where almost Karman like vortex street is observed at high gap-ratio (*G*/*a* = 3.5 and 4). The high deflection of vortices after interaction with the splitter plate at *G*/*a* = 3.5 and 4 is the reason for increase in wake-width downstream. This result validates the instantaneous vortex contours shown in Figs. 2-5.

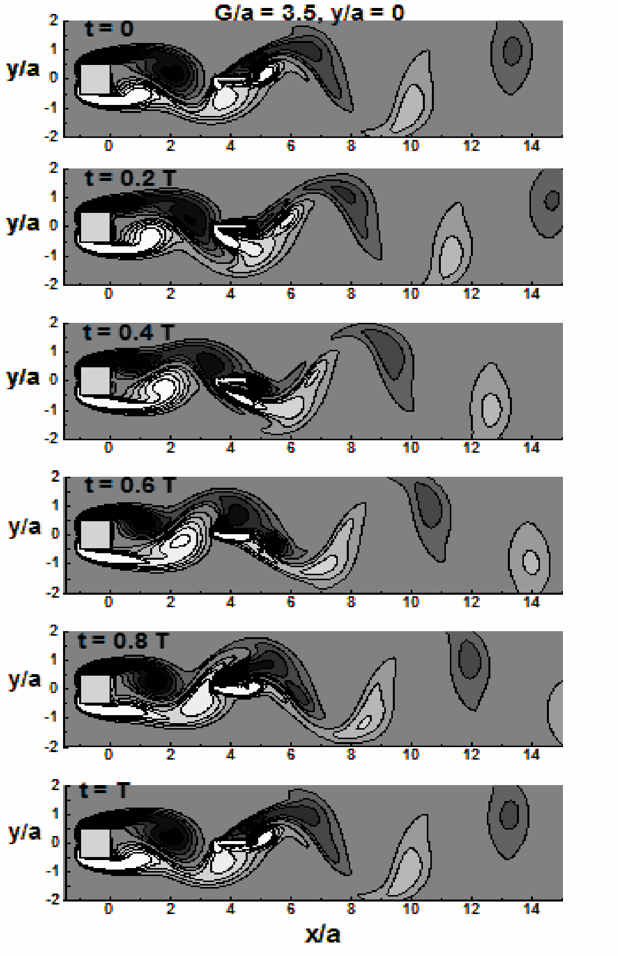

Fig. 4: Instantaneous vorticity contours at *G*/*a* = 3.5. For detail refer Fig. 2.

Time evolution of lift (C_L) and drag coefficients (C_D) for the cylinder is shown in the extreme two cases (*G*/*a* = 2.5 and 4) in Fig 7. These figures illustrate reduction in fluctuation of lift coefficient with the increase in gap-ratio, although the value fluctuation of drag coefficient rises with the increased gap. This difference in the behavior of aerodynamic coefficients are attributed to different physics associated with *G*/*a* = 2.5 and 4.

For better understanding of aerodynamic forces along with non-dimensional vortex shedding frequency, the value of C_L, C_D and Strouhal number ($St = fa/U_\infty$) are reported both for cylinder and splitter plate (Table 1). The value of mean lift coefficient ($\bar{C}_L$) is calculated as 0 in all *G*/*a* cases both for cylinder and plate. As *G*/*a* value

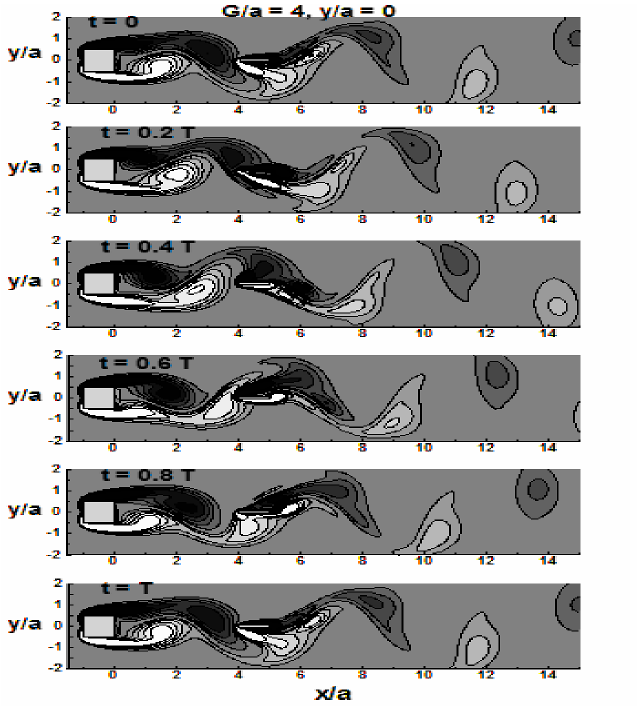

Fig. 5: Instantaneous vorticity contours at *G*/*a* = 4. For detail refer Fig. 2.

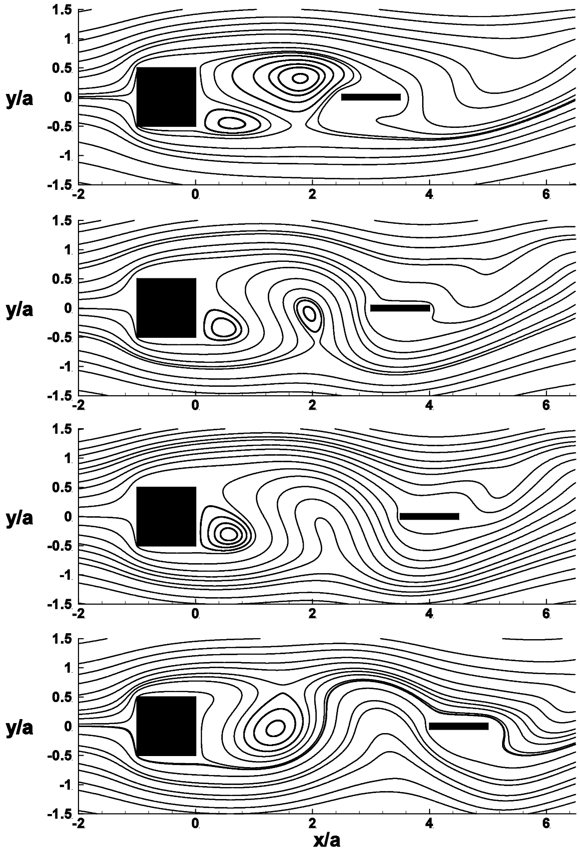

Fig. 6: Instantaneous streamlines for different gap-ratios (*G*/*a* = 2.5, 3, 3.5 and 4).

Table 1: Aerodynamic forces and *St* for different *G*/a

	Cylinder				Plate	
G/*a*	$\overline{C_L}$	C_L range	$\overline{C_D}$	*St*	$\overline{C_L}$	$\overline{C_D}$
2.5	0	0.124	1.427	0.124	0	-0.075
3	0	0.754	1.523	0.133	0	0.063
3.5	0	0.784	1.535	0.141	0	0.121
4	0	0.762	1.545	0.143	0	0.152

increases, the range of C_L spreads indicating better roll-up and vortex formation from the cylinder shear layer. The minimum value of C_D occurs at *G*/*a* = 2.5 illustrates the control power of splitter plate to reduce vortex formation get a setback when it is placed far downstream of the square cylinder.

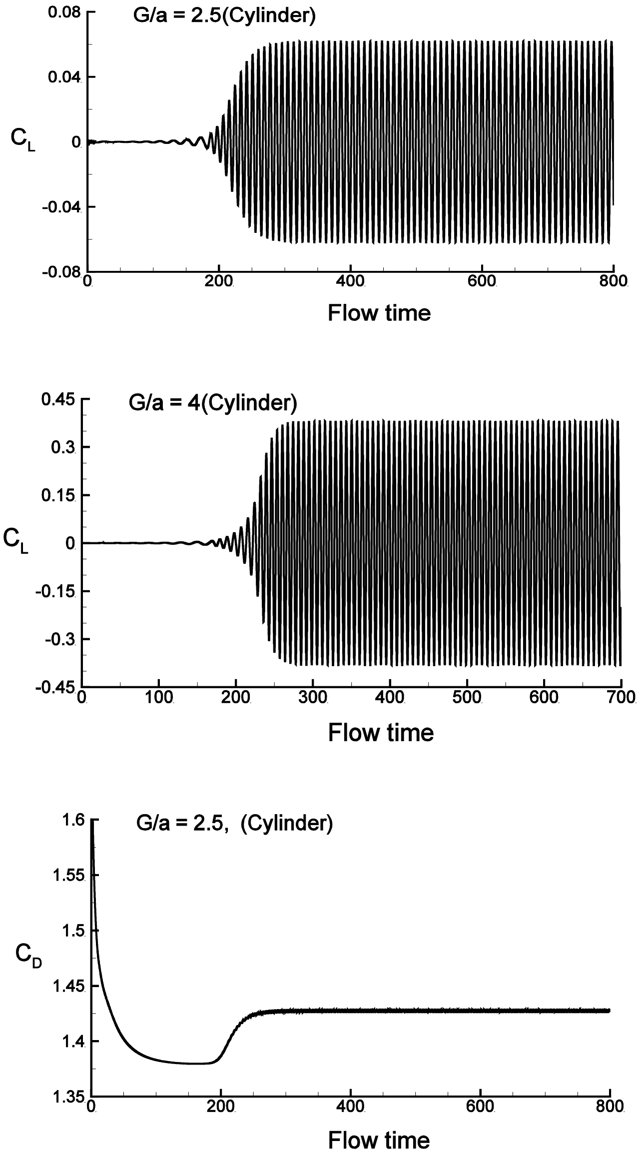

Fig. 7: Time evolution of C_L for *G*/*a* = 2.5 and 4.

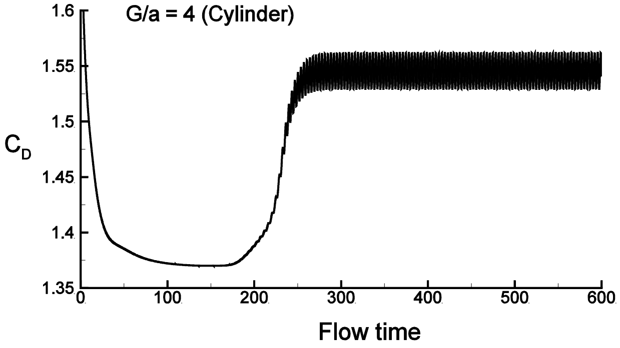

Fig. 8: Time evolution of C_D for *G/a* = 2.5 and 4.

The value of *St* for the square cylinder is minimum for *G*/*a* = 2.5 and maximum for *G*/*a* = 4. This reflects the vortex shedding rate enhances with the high gap ratio. Similar trend in the corresponding data are observed for the downstream splitter plate.

4. CONCLUSION

Flow analysis of vortex interaction with a downstream splitter plate has been carried out extensively at *Re* = 100 using Fluent. Four different cases have been considered (*G*/*a* = 2.5, 3, 3.5 and 4) at higher side of the critical gap ratio and detailed physics have been discussed from instantaneous flow visualization, aerodynamic forces and vortex shedding frequencies.

As expected it has been seen that as the gap-ratio increases, the vortex formation from the bluff body (square cylinder) comes close to an isolated cylinder and separation region reduces. The splitter plate's influence on the cylinder reduces significantly and vortex roll-up starts in the intermediate region between the cylinder and splitter plate. The quantitative values enlisted in the Table also explain the same physics.

REFERENCES

[1] Ali, M. S. M., Doolan, C. J., and Wheatley, V., "Low Reynolds number flow over a square cylinder with a splitter plate", *Physics of Fluids*, 23, 2011, 033602 (12 pp.).

[2] Zdravkovich, M. M., "Review and classification of various aerodynamic and hydrodynamic means for suppressing vortex shedding", *Journal of Wind Engineering and Industrial Aerodynamics*, 7, 1981, pp. 145–189.

[3] Choi, H., and Jeon, W. P., Kim, J., "Control of flow over a bluff body", *Annual Review of Fluid Mechanics*, 40, 2008, pp. 113–139.

[4] Roshko, A., "On the drag and shedding frequency of two-dimensional bluff bodies", *NACA TN* 3169, 1954.

[5] Roshko, A., "On the wake and drag of bluff bodies", *Journal of the Aeronautical Sciences*, 22, 1955, pp. 124–132.

[6] linder. Part 2. Control by splitter–plate interference", *Journal of Fluid Mechanics*, 190, 1987, pp. 513–529.

[7] Nakamura, Y., "Vortex shedding from bluff bodies with splitter plates", *Journal of Fluids and Structures*, 10, 1996, pp. 147–158.

[8] Mittal, S., "Effect of a 'slip' splitter plate on vortex shedding from a cylinder', *Physics of Fluids*, 15, pp. 817–820.

[9] Mansingh, V. and Oosthuizen, P. H., "Effects of splitter plates on the wake flow behind a bluff body", *AIAA Journal*, 28, 1990, pp. 778–783.

[10] Hasan, M. A. Z., Budair, M. O., "Role of splitter plates in modifying cylinder wake flows", *AIAA Journal*, 37, 1994, pp. 1992–1998.

[11] Srivastava, S. and Sarkar, S., "Wake interaction of a square cylinder with a splitter plate boundary layer at a low Reynolds number", *AJK2015-FED*, Seoul, 2015, 01793.