**OPTIMIZATION OF DRAG AND LIFT FORCES VIA POSITIONAL TUNING OF VERTICAL SPLITTERS UPSTREAM AND DOWNSTREAM AROUND A BLUNT OBJECT: A COMPUTATIONAL STUDY ON VORTICITY CONTROL**

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***ABSTRACT***

*This study presents a computational investigation into the passive control of hydrodynamic forces acting on a circular cylinder using vertical splitter plates strategically placed upstream, downstream, and in combined configurations. The simulations are performed at a laminar Reynolds number of 100 using the Finite Element Method to solve the incompressible Navier–Stokes equations. Key geometric parameters, including the height-to-diameter ratio, gap-to-diameter ratio, and vertical displacement, are systematically varied to optimize splitter plate positioning. The primary goal is to strategically position the plates to minimize the hydrodynamic forces acting on the cylinder, including lift and drag. The research shows how splitter plates change wake dynamics and flow separation, which in turn changes force distribution, by examining changes in lift/drag coefficients and vorticity patterns. The study shows that positioning vertical plates near a cylinder can effectively reduce hydrodynamic forces, with their efficacy heavily influenced by both their vertical and horizontal spacing from the obstacle. These results offer valuable guidance for refining splitter plate layouts in many engineering projects, such as those involving fluid dynamics management, while also advancing our grasp of how cylindrical structures interact with surrounding fluid flows. This combines contributions, bridges practical design optimization and fundamental fluid mechanics knowledge.*

***KEYWORDS***

*Splitter Plates, Passive Control, Drag & Lift, Finite Element Method*

**1. INTRODUCTION**

Modern engineering applications, such as advanced microelectromechanical devices (MEMS) and tall skyscrapers, depend on the suppression of hydrodynamic forces and mitigation of vortex-induced vibrations to maximize aerodynamic performance, maintain structural durability, and improve energy efficiency. Fluid flowing past a structure creates lift and drag forces that, over time, can cause wear, dynamic structural oscillations, and even catastrophic failure. These fluid-structure interactions can be attenuated without the need for external energy inputs by using passive flow control techniques like splitter plates, which are both economical and operationally dependable. The two main categories of flow control techniques are active and passive systems. Unlike passive methods like splitter plates, which are straightforward, static geometric changes that change wake behavior by interfering with vortex formation, active methods (such as artificial jets or plasma actuators) rely on external energy to control flow dynamics. Particularly useful for stabilizing near-wake dynamics and lowering drag coefficients are splitter plates, which are placed along the wake centerline of bluff bodies like cylinders [1–3]. These rigid, thin plates extend into the flow separation zone, reducing wake oscillations, delaying vortex shedding, and weakening the oscillatory lift and drag forces acting on the structure [4–7]. Their dual role in aerodynamic drag reduction and vortex shedding regulation has made them indispensable in cylindrical systems, including offshore risers, heat exchangers, and bridge pylons. By quantifying how splitter plates inhibit vortex shedding and decrease wake instabilities behind circular cylinders, Apelt et al.'s groundbreaking work [4] established crucial groundwork. Building on these discoveries, later research has investigated plate placement, dimensions, and how these interact with Reynolds numbers to improve design concepts.This research not only advances our understanding of fluid behavior, but it also offers engineers with concrete techniques for improving the design and efficiency of splitter plates in real-world engineering applications. It helps to design more effective solutions in sectors that rely on fluid flow management by connecting theory and practice.

Apelt and West's experimental studies [5] examined a plate with a length-to-diameter ratio of L/D, providing fundamental insights into splitter plate efficacy. D = 1 L/D = 1 firmly fastened to a cylinder's base. Their research, which was carried out at Reynolds numbers (Re) ranging from 10⁴ to 10⁵, showed that shorter splitter plates greatly reduce wake dimensions and stabilize boundary layer separation points. By promoting the systematic development of vortices along the plate's trailing edge, this stabilization successfully reduces the oscillatory forces that propel vibrations caused by vortices. Their results highlight how compact splitter plates might reduce aerodynamic instabilities in high Re flows that are common in large-scale engineering systems like industrial chimneys or offshore constructions. Kwon and Choi [6] conducted numerical studies on plate length effects for cylinder flows at lower Reynolds numbers (80 ≤ Re ≤ 160) to supplement this work. According to their analysis, increasing the length of the control plate reduces the frequency of vortex shedding and, with the right plate structure, may even totally suppress shedding. The impact of rigid splitter plates on blunt body wake areas under two-dimensional (2D) and three-dimensional (3D) flow conditions was methodically examined by Anderson and Szewczyk [7]. Although flexible, undulating, and hinged plate topologies have been studied in the past [8,9], the dynamics of non-flexible plates were the main emphasis of that research. Wu and Shu [8] used the boundary-lattice Boltzmann method to investigate flow control mechanisms at Re = 100 in order to supplement these investigations. Building on this foundation, Wu et al. [9] extended the investigation to oscillating plates, analyzing their effects on fluid dynamics and drag reduction. Through rigorous numerical simulation of flow around a stationary spherical cylinder with an oscillating plate, they systematically varied oscillation parameters (frequency and amplitude) and plate characteristics (length and flexibility). Their comprehensive analysis not only characterized fundamental flow patterns but also demonstrated significant drag reduction through controlled plate motion.

The application of splitter plates with square and rectangular cylinders has been the subject of numerous studies [10,11]. Experiments by Mansingh and Oosthuizen showed that adding a control plate to the flow increased base pressure by an average of 15% [10]. A splitter plate fastened to a square cylinder efficiently lowers drag and limits vortex shedding, according to Park and Higuchi's study [11], which used the vortex tracing method. In order to evaluate the effect of a solid plate on the flow around a bluff body, Rathakrishnan conducted experimental research [12]. It was discovered that the pressure differential across the body was the main source of high drag. Ali et al. [13] investigated flow over a square cylinder at low Rynold numbers by varying the splitter plate size 0.5 to 6 times the cylinder dimension, identifying three distinct flow regimes. In a separate study, Ali and colleagues [14] kept the Re constant (Re=150) and placed a detached plate downstream of a bluff body to analyze wake fluctuations.

They discovered two different flow regimes: one in the space between the main cylinder and the plate, and another slightly downstream of the splitter plate borders. Another numerical study on airflow over a square cylinder that generates noise [15]. The effects of a single control plate placed upstream and the effects of twin plates were also examined by Vamsee and colleagues [16], who focused on low Reynolds numbers. They demonstrated the importance of the upstream plate in reducing drag through numerical analysis. All things considered, these studies advance our knowledge of how splitter plates impact flow dynamics and reduce drag in square and rectangular cylinders. In order to minimize fluid forces, Barman and Bhattacharya [17] only optimized flat plate size and adjusted the Rynolds number (Re) in their computer simulations. Without taking gravity into account (g = 0), they used twin splitter plates. Meanwhile, Turki [18] used a control volume finite-element approach to study the effectiveness of control plates in both isolated and connected configurations for flow around a square-shaped object. In their work, Doolan examined how the flow pattern around a body changed as the control plate sizes were changed from L = 0.5 to 6 [19]. Furthermore, in order to reduce wake oscillations and vortices, Roshko [20] carried out experimental studies with a circular cylinder and a control plate. Both the drag force and the vorticity frequency decreased as a result of the plate's inclusion. Further studies on the application of removable rear splitter plates have been conducted. A DT with length L/D = 1 and positioned at G/D = 2.6 (where G is the gap distance) dramatically decreased lift variations and drag force, as demonstrated by Hwang et al. [21] by computational analysis. An arrangement including a circular cylinder and a splitter plate of the same size (L/D = 1) was investigated by Akilli et al. [22]. Their experimental findings demonstrated a steady decrease in the suppressing efficacy of the plate as the gap distance rose. After a crucial separation distance, the performance of the detached plate started to be affected by this phenomena, which Wang et al. [23] ascribed to vortex production in the intermediate gap zone. The computational investigations of Liang et al. [24] and Serson et al. [25], who noted comparable wake dynamics for a circular cylinder with a detached splitter plate, supported these conclusions.

Control plates placed either upstream or in pairs around an obstacle are less commonly mentioned in the literature than wake-mounted splitter plates, which have been studied more thoroughly. However, certain experimental and numerical studies have demonstrated their effectiveness. Chutkey et al.'s experiments [26] shown how an upstream 1D control plate may alter the flow and reduce drag by shifting the solid cylinder's boundary-layer separation point from 82° to 122°. In their numerical studies, Hwang and Yang [27] examined the impact of the separation between an obstruction and a detachable control plate. The effectiveness of these control plates was further confirmed by Qiu et al. [28] using wind tunnel testing, which produced results comparable to those of the previously mentioned numerical study.

Sooraj et al. [29] investigated the flow dynamics surrounding three nearby solid objects through an experimental investigation. Their results demonstrated that variations in the Reynolds number (Re) and the separation ratio had a considerable impact on the flow patterns. Ain et al. [30-34] used the FEM to examine how a downstream splitter plate affected the hydrodynamic forces operating on a circular cylinder. Their findings showed that while lift forces exhibited nonlinear behavior, the drag coefficient was considerably reduced by closing the space between the cylinder and plate.

In a recent study, Saraei et al. [35] examined the effects of a vertically oriented porous layered plate above a square obstruction on hydrodynamic forces. They found that raising the height of the plate and increasing the distance between it and the barrier decreased average drag and lift coefficients. This suggests that vertical plates in different configurations can effectively regulate flow forces. The main goal of this study is to investigate how vertical splitter plates, positioned upstream, downstream, and in combined upstream-downstream configurations, control vortex shedding and fluctuating hydrodynamic forces on a circular obstacle. The authors note a gap in the existing literature regarding detailed and comprehensive studies on laminar flow patterns managed by pairs of vertical splitter plates situated both upstream and downstream simultaneously.

This paper is structured as follows: The first section introduces the topic and reviews the relevant literature. The second section concisely describes the problem under investigation. The third section discusses the mathematical methods used in the study. The fourth section presents validation of the results for a bare cylinder by comparing them with established literature and includes a grid-independence test conducted on the computational domain. The fifth section provides a detailed analysis, focusing on the impact of vertical splitter plates of two different heights and examining various gap separation ratios upstream, downstream, and on both sides of the obstacle. The final section summarizes the conclusions drawn from the research.

**2. PROBLEM FORMULATION**

In this work, laminar flow past a circular cylinder is thoroughly investigated numerically. The flow control capabilities of vertical splitter plates in three different configurations upstream placement, downstream placement, and a novel dual-placement arrangement are specifically assessed. Key geometric parameters such as plate height-to-diameter ratios (L/D), gap-to-diameter ratios (G/D), and vertical displacement with respect to the channel centerline (α/D) are thoroughly examined in the study to determine their impact on hydrodynamic forces and vortex shedding processes. From attached configurations (G/D = 0) with L/D = 1 to different detached arrangements with different gap distances, the study examines a variety of plate positioning scenarios and compares the performance of single versus dual plate installations. The study simulates two-dimensional flow in a channel with a certain width (W) and height (H) at a constant Reynolds number (Re = 100) using the Finite Element Method (FEM). A thorough depiction of the problem geometry is given by the schematic diagram in Figure 1, which precisely defines all pertinent characteristics such as plate heights (L₁, L₂), upstream and downstream locations (Wu, Wd), and their spatial interactions. The study focuses on three main areas: measuring changes in drag and lift forces, examining vortex shedding suppression methods, and assessing how well various plate arrangements stabilize flow. The new dual-placement technique, which is a major development in passive flow control methods for bluff body applications, is given particular focus.

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| Figure 1. Vertical splitter plates upstream and downstream. |

**2.1. Mathematical formulation**

In this investigation, the study evaluates the effect of a rigid plate on laminar flow around a blunt body, which is close to the centerline of the enclosure. The flow field in the research is governed by the continuity and momentum equations [31].

Table 1 contains the boundary conditions used in this study. No-slip conditions are used to all solid surfaces, and a uniform flow profile is specified at the inlet. The dimensionless equations (1-3) are formulated using nondimensional variables which stand velocity, and time, respectively. The is expressed by where reference velocity , reference length is kinematic viscosity [31].

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| Table 1. Boundary conditions (B. C) | | |
| Inlet boundary |  |  |
| Outlet boundary |  |  |
| Side walls |  |  |
| B.C for cylinder |  |  |
| B.C for plates |  |  |
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The numerical simulations employ a finite element formulation of the governing equations (1)-(3), utilizing the inf-sup stable , with Newton's iterative method applied to linearize the discretized nonlinear systems. The PARDISO solver is employed to solve the linearized systems, which operate for the generic system . The computational solver employs an advanced LU matrix factorization approach coupled with optimized unknown reordering techniques to significantly enhance solution efficiency. This implementation demonstrates particular effectiveness in reducing the required number of iterations while maintaining robust convergence characteristics. A cross-wind stabilization approach has been implemented to achieve flow stabilization at higher Reynolds numbers (Re). The following quantities of interest have been identified in the post-processing stage:

Drag coefficient

* Lift coefficient

The dimensionless drag and lift forces are exerted on the circular obstacle.

**2.2. Validation of Results and Grid Independence**

In this section, the focus is on a circular cylinder of the laminar flow placed within a channel (see Fig. 2). The outcomes are compared with the corresponding numerical findings previously presented by Schafer et al. [36] and Ain et al. [31]. The comparison is summarized in Table 2. Additionally, Table 3 displays the variations in the values of concerning their respective values used in the reference works. In the current study, the width of the channel remains consistent with that mentioned in the previous work, and likewise, the diameter of the body remains the same. All simulations are performed at a Reynolds numberof 100.

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| Figure 2.Configuration without splitter plates**.** |

This study primarily focuses on controlling the hydrodynamic forces acting on a blunt body. The data in Table 4 validate the effects of changes made to the baseline configuration. The innovative design introduced in this research significantly influences the management of hydrodynamic forces. As shown in Tables 3 and 4, the computational model used in this study effectively predicts the flow patterns around an obstruction in a channel, illustrated in Figures 2 and 3, under conditions with and without vertical plates.

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| Table 2. Comparison for code validation. | | |
| Research |  |  |
| Schfer et al. [36] | 3.22245 | 0.96721 |
| Ain et al. [31] | 3.22234 | 0.96352 |
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| Table 3. Domain parameters comparison between the present and reference study configurations. | | | | |
| Configuration |  |  |  |  |
| Reference work |  |  |  |  |
| Present work |  |  |  |  |

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| Table 4.Comparison between the values of maximum drag and lift. | | |
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| Schfer et al. [36] | 3.2410 | 1.0100 |
| Present study |  | 1.0012 |
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**2.3. Grid Independence Test**

This study aims to establish the optimal number of grid sizes needed to attain grid independence. Table 5 presents an evaluation of three potential grid sizes. Drag coefficient () values are compared over a simulation duration of 4 seconds. Notably, the drag coefficient value at the L3mesh refinement level closely matches that of the even finer refinement level, indicating strong agreement between the two. As a result, the grid size comprising 32,224 elements is selected as the optimal grid size.

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| Table 5. Check for the grid independence for the novel configuration (Figure 1) at various refinement levels and | | |
| Refinement Levels | Number of Elements |  |
| L1 | 6540 | 2.761 |
| L2 | 13781 | 2.702 |
| L3 | 32232 | 2.709 |

**3. RESULTS AND DISCUSSION**

This section showcases the case results previously discussed in Section 2 (refer to Figure 1), highlighting the relationships among drag and lift coefficients ( and ) and vorticity contours. The analysis investigates the impact of vertical upward displacement relative to the channel centerline (), gap separation (), and height () of controlling vertical plates on flow patterns and hydrodynamic forces. In all cases examined within this study, the Reynolds number is consistently maintained at .

**3.1. Effects of the parameter on flow past over a circular cylinder installed with attached splitter plates.**

This section focuses on managing the energy cascade and mitigating the adverse effects of vortex shedding near the obstacle. A passive control strategy is implemented to suppress vortex shedding by incorporating attached splitter plates of lengths and . Introducing a control plate with and upstream of the circular body leads to the formation of vortices shedding from the top and bottom of the plate after the cylinder, as shown in Figure 3A. The frequency of vortex shedding changes once the plate is attached downstream. Figure 3B illustrates the visualization of the enhanced strength of vortices in the downstream flow.

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| A |
| B |
| Figure 3. Vorticity contours for (3A) upstream and (3B) downstream attached plate with and |

Figure 4 illustrates that placing a splitter plate with and near the body leads to separated shear layers, which greatly contribute to vortex generation, acting as carriers of energy. In Figure 4A, it is apparent that incorporating the upstream splitter plate with a shorter length near the circular cylinder increases the number of vortices. A similar observation can be made by comparing Figure 4B and Figure 3B for downstream plates and , respectively.

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| A |

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| --- |
| B |
| Figure 4.Vorticity contours for (4A) upstream and (4B) downstream attached plate with and |
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The simultaneous application of upstream and downstream splitter plates connected to the circular cylinder is also investigated to mitigate vorticity. Results from simulations for the scenario where plates of length are attached to the cylinder simultaneously in both upstream and downstream locations yield inconclusive findings. The examination for plates of length (which is less than ) is depicted in Figure 5. In this case, the strength of vortices is amplified compared to previous instances studied involving the introduction of a single attached plate at either an upstream or downstream location.

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| Figure 5. Vorticity contours for simultaneously upstream and downstream attached plates with and |

Table 5 provides the drag and lift coefficients for two distinct plates, and , positioned upstream (), downstream , and simultaneously at both upstream and downstream locations relative to the cylinder, with no gap separation (). The table illustrates the performance of these plates under different configurations. The maximum enhancement of the lift coefficient, (denoted as ), is observed for the upstream plate with and . Conversely, the maximum reduction of the drag coefficient, (referred to as ), is achieved for the same case. Notably, the effects of plate with and are also evident across all plate locations. The behavior observed for the downstream plate mirrors the outcomes obtained using plate . These results underscore the substantial influence of the length and vertical displacement of the attached vertical plate on both compared to the base case (refer to Table 2).

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| Table 6. Comparison of and for several adjustments of attached splitter plates in upstream, downstream, and simultaneously upstream and downstream flow. | | | | |
| Location of attached plate |  |  |  |  |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  |  |  | -1.68745 | |  |  |  |  | -0.76489 | |  |  |  |  | -0.96534 | |  | 2.83760 | 2.56535 | 0.89423 | -0.92481 | |  | 2.70838 | 2.56656 | 0.78617 | -0.82929 | | | | | |

To provide further clarity on the impacts of including a vertical plate with G/D = 0, an examination of the drag coefficients with time for the scenarios shown in Figure 1 are illustrated in Figures. 6-8. These coefficients are transiently periodic, and all of the cases under study exhibit fluctuation as a result of vortex shedding behind the obstruction. Changes can influence the intensity of the drag coefficient in the vertical plate's ratio Additionally, the results display that lowering the drag coefficient is caused by raising the value of .

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| A | B |
| C | D |
| Figure 6. Time trace visualizations of and for (6A and 6B) upstream and (6C and 6D) downstream attached plate with and | |

Figures 6A, 6B, 6C, and 6D show the drag and lift-coefficient variations for plate with at upstream and downstream locations, respectively. The periodic behavior of the drag and lift coefficients, using upstream and downstream plates of length with , is visualized in Figures 7(A-D).

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| --- | --- |
| A | B |
| C | D |
| Figure 7. Time trace visualizations of and for (7A and 7B) upstream and (7C and 7D) downstream attached plate with and | |

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| **A** | **B** |
| Figure 8. Time trace visualizations of (8A) and (8B) for simultaneously employed upstream and downstream attached plate with and | |

**3.2. Effects of height and gap separation of vertical plate present in upstream flow**

This section uses graphical and tabular representations to show how well the plate in the upstream flow controls vorticity, drag and lift forces. All results are obtained for fixed values and for the vertical upstream splitter plate at The splitter plate is no longer beneficial to the study, and the values are ineffective for meeting the desired objectives of the current study. The observed flow patterns in the case of an upstream splitter plate for different values of G⁄D are illustrated by the instantaneous vorticity contour visualization plots in Figures 9(A)–(C). In terms of the quantity of vortices, Figures 9A and B show five vortices downstream of the obstruction, respectively, by introducing an upstream plate at . However, as gap separation increases to , the plate causes the number of vortices to decrease to three. Figure 9C shows a variation in the vortex’s strength compared to Figures 9A and 9B.

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| A |

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| B |
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| C |
| Figure 9. Vorticity contours for upstream plate at (9A) (9B) and (9C) with fixed and |

Due to the Bernoulli effect, Table 6 demonstrates that the lift coefficient decreases as the distance b/w the plate and the obstruction increases. This decrease in lift coefficient results from reduced fluid pressure in regions with higher flow velocity. The situation with shows the most significant drop in the lift coefficient, whereas the case with offers a minor reduction. Additionally, the scenario with achieves substantial reductions in the drag coefficient. The gap separation ratio significantly impacts controlling not only the lift force but also the drag force.

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| Table 6**.** Comparison of and for several adjustments of splitter plates at different gap separation ratios in upstream flow. | | | | |
| Location of Plate |  |  |  |  |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | |  | 2.38158 | 2.32691 | 0.5243 | -0.55375 | |  | 2.15293 | 2.12972 | 0.2443 | -0.28147 | |  | 2.08001 | 2.06801 | 0.0675 | -0.11116 | | | | | |

The impact of upstream plate with fixed values and on the periodic behavior of drag and lift forces is visualized in Figures 10A-F. The figures showing graphical results for the drag coefficient depict a successful reduction by increasing the gap between the plate and the/obstacle. The minimum values of drag and lift coefficients are attained for the case with maximum gap separation, i.e.,

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| --- | --- |
| **A** | **B** |
| **C** | **D** |
| **E** | **F** |
| Figure 10.Time trace visualizations of and (10A and 10B) at , (10C and 10D) at and (10E and 10F) at upstream plate with fixed and | |

**3.3. Effects of height and gap separation of vertical plate present in downstream flow**

Simulations at are also used to examine the effects of the plate with fixed at the downstream location, used as a controlling device for various gap separations. To control hydrodynamic effects, practice employing a vertical scale in a position downstream of the cylinder is the focus of this section. Analyses of the gap separation's impact on downstream splitter plate utilization are conducted. Refer to the vorticity contours shown in Figures 11(A–C) to gain a better understanding of the application of vertical downstream plate . Figures 11A and 11B illustrate more significant vorticity suppression at G/D=0.5 and 1. On the other hand, Figure 11C shows stronger vortices when the value of G/D is increased to 1.5.

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| **A** |
| **B** |
| **C** |
| Figure 11. Vorticity contours for downstream plate at (11A) (11B) and (11C) with fixed and |

Table 7 compares the maximum drag coefficient , the minimum drag coefficient , the maximum lift coefficient , and the minimum lift coefficient for several adjustments achieved by implementing a downstream splitter plate to the problem shown in Figure 1. The variation in gap separation gives rise to the suppression of hydrodynamic forces. The maximum lift reduction is achieved at and the minimum at Whereas, at minimum drag reduction is recorded, and minimum gap separation the maximum drag reduction can be noticed by the value of .

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| Table 7. Comparison of and for several adjustments of splitter plates in downstream flow. | | | | |
| Location of plate |  |  |  |  |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | |  | 2.603608 | 2.480655 | 0.444668 | -0.4796 | |  | 2.477987 | 2.375349 | 0.320203 | -0.35256 | |  | 2.426383 | 2.280953 | 0.017468 | -0.1027 | | | | | |

Figure 12 provides a graphical interpretation of variations in the suppression mechanism of hydrodynamic forces. The drag coefficient’s periodic behavior is shown in Figures 12A, 12C, and 12E attained by mounting upstream plate at respectively. The amplitude is increasing for the case revealed in Figure 12A. The suppression of the lift coefficient is shown in Figures 12B, 12D, and 12F, which is the maximum for the last point.

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| **A** | **B** |

|  |  |
| --- | --- |
| **C** | **D** |
| **E** | **F** |
| Figure 12. Time trace visualizations of and (12A and 12B) at , (12C and 12D) at and (12E and 12F) at stream plate with fixed and | |

**3.4 Effect of novel employment of both upstream and downstream plates simultaneously**

The analysis for simultaneous upstream and downstream splitter plates attached () to the obstruction is done in section 5.1. The height of the containers and significantly impact how the flow separates. The separation of the flow is greatly influenced by the distance between the leaves and the cylinder, much like the height of the concurrent upstream and downstream containers. The current section demonstrates the impact of spacing for two concurrent upstream and downstream vertical splitter plates. Effective gap separation ratios are introduced to separate the plates from the obstacle. It is discovered that, at , only plates help analyze findings in the current section. The fascinating depiction of vortex-shedding/patterns can be seen in Figure 13. As shown in Figure 13A, the upstream splitter at G/D=0.5 caused scattered shear layers to reunite in the downstream flow. Following the downstream controlling plate, there are noticeable and distinct vortices shedding in the flow field. Additionally, vortex shedding was completely suppressed when the value of G/D was increased to 1. Figure 13B makes it clear that the flow zone lacks any discernible vortices.

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| **A** |
| **B** |
| Figure 13. Vorticity contours for combined upstream and downstream plates at (13A) and (13B) with fixed and |

Table 8 provides the results for the most effective strategy of using splitter plates . The effects of gap separation and simultaneous locations upstream and downstream of the circular cylinder are beneficial by noticing the attained values of maximum drag reduction and maximum reduction in lift coefficient. The values achieved for and at show the top drag and lift coefficients decrease, respectively. These reductions are more significant than all attained in other cases. However, the values achieved for the case depict a substantial reduction in drag and lift coefficients.

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| Table 8. Comparison of and for several adjustments of splitter plates in both upstream and downstream flow simultaneously. | | | | |
| Location of the plates |  |  |  |  |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | |  | 2.10670 | 2.08582 | 0.185029 | -0.21233 | |  | 1.89821 | 1.88873 | -0.01655 | -0.02568 | | | | | |

Figure 14 shows passive control visualization using splitter plate simultaneously at the upstream and downstream locations of the circular cylinder. Figures 12A and B show periodic suppression of the drag and lift coefficients at . The most desirable control using the same strategy at is attained successfully. A complete suppression can be visualized in Figure 12C for drag and lift coefficients in Figure 12D. The equilibrium states achieved for both reductions are observed after dimensionless time . These graphs are of great importance to make using a passive control device more reliable by introducing appropriate values of and the location of plates.

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| --- | --- |
| **A** | **B** |
| **C** | **D** |
| Figure 14.Time trace visualizations of and (14A and 14B) at , and (14C and 14D) at simultaneously employed upstream and stream plates with fixed and | |

**4. CONCLUSIONS**

The investigation involved direct numerical simulations of flow-induced vibration on a circular cylinder at a Reynolds number () of 100. The study scrutinized the effects of placing a splitter plate along with a pair of bilateral upstream and downstream splitter plates. The primary outcomes and conclusions of the study are as follows:

* The results obtained to analyze the effect of the parameter by introducing an attached splitter plate in upstream or downstream flow showed the hydrodynamical control difference between all cases. It is concluded that an attached upstream splitter plate with and effectively suppresses vortex shedding and controls hydrodynamic forces drag and lift. However, the implementation of attached double splitter plates (with and i.e., simultaneously in upstream and downstream flow generates vorticity of greater strength compared with the single plate configuration.
* The simulations for single plate with height 0.1 are ineffective in upstream and downstream configuration for all values of at
* The splitter plate with height 0.05 is a valuable passive control device in upstream and downstream configurations.
* It is determined that the employment of the plate in upstream flow at =1.5 is much more helpful in controlling hydrodynamic effects.
* The current work demonstrates novel positioning of vertical splitter plates with specific heights by implementing dual plates simultaneously in both upstream and downstream flow locations.
* The simultaneous use of upstream and downstream plates effectively controlled hydrodynamic effects when implemented with gap-to-diameter ratios of G/D = 0.5 and 1.
* The vortex shedding is completely suppressed at , making the use of this novel employment of double splitter plates of height 0.05.
* The equilibrium states for reduction of both hydrodynamic forces drag and lift are attained for the novel positions of vertical splitter plates for gap separation ratio equals unity.

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