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To cite this article: Sunakraneni Soumya and K Arul Prakash 2017 *J. Phys.: Conf. Ser.* **822** 012054

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# Effect of splitter plate on fluid flow characteristics past a triangular cylinder

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**Abstract.** In the present numerical investigation, the effect of splitter plate length on fluid flow characteristics past an equilateral triangular cylinder apex facing the flow configuration is studied. Simulations are carried out by using in-house solver based on Streamline Upwind/Petrov-Galerkin (SUPG) finite element method in laminar regime. The range of Reynolds numbers ( $Re$ ) based on side ( $b$ ) of the triangular cylinder is varied from 50 to 200 and the splitter plate length ( $L$ ) is varied from  $L/b = 0$  to  $= 6$ . The effect of splitter plate length on parameters like lift and drag are studied. It is observed that drag decreases with the attachment of splitter plate. In addition, vortex shedding suppression is observed for  $Re = 50 - 150$  whereas, for  $Re = 200$  vortex shedding suppression is not observed even for plate length of  $L/b = 6$ . The obtained results indicate that for a specific value of  $Re$  drag is minimized at a particular splitter plate length. The drag is minimized approximately from 9% to 57% based on  $Re$  by attaching a splitter plate to the triangular cylinder.

## 1. Introduction

Bluff bodies offer more resistance to the fluid flow and suffer oscillatory forces, and the fluid flow over bluff bodies is very complex. Moreover, the phenomenon of vortex shedding is observed in most of the fluid flows over bluff bodies. As a result, the forces acting on the body, and the transport mechanisms around the body are influenced by vortex shedding. The fluctuating periodic forces generated on the bluff body due to the vortex shedding leads to damage to the structure thereby shortening the life of the structure. As a consequence, techniques to suppress vortex shedding and reducing drag has remained a potential area for investigation. In one of the foremost experimental study by [1] it was found that a splitter plate length  $5D$  attached to the circular cylinder ( $D$  is cylinder diameter) suppressed the vortex shedding and reduced the pressure drag to approximately 63% of the the value for the plain cylinder. In addition, the effect of gap between the cylinder and splitter plate was also investigated by [1]. [2]



conducted experiments on different shapes of bluff bodies attached to the splitter plate to examine the vortex shedding characteristics and found that vortex shedding from bluff bodies with extended splitter plates is characterized by impinging-shear-layer instability. Numerical study done by [3] for fluid flow past circular cylinder attached with splitter plate found that for each  $Re$  there exists a critical length of the splitter plate where the complete suppression of vortex shedding is obtained. Drag is decreased with splitter plate attachment and there exists an optimum length for each  $Re$  where minimum drag is experienced. It is observed from the literature that the majority of studies carried out on the effect of splitter plate on laminar wakes of canonical body shapes such as circular and square cylinders ([3], [4]). In recent times fluid flow past non canonical shapes are getting more attention due to its novel flow features. The novelty of the present study is to find the critical splitter plate length where the vortex shedding disappears and minimum drag is obtained for each  $Re$ . To the best of authors knowledge, studies are not available on triangular cylinder attached with a splitter plate in low  $Re$  regime.

## 2. Problem definition

The problem under investigation is to study the fluid flow characteristics over an unconfined equilateral triangular cylinder attached with a thin rigid splitter plate of lengths ( $L/b$ ) varying from 0.0 to 6.0 (in steps of 0.5) with thickness ( $t_h/b$ ) = 0.1. The thickness of the splitter plate is constant throughout the study. Fig.1 shows the computational domain with boundary conditions of present study. In the present simulations side of triangular cylinder ( $b$ ) is taken as characteristic dimension and free stream velocity  $U_\infty$  is the characteristic velocity. The simulations are carried out for  $Re$  in the range of 50-200. The fluid flow is considered as two-dimensional, laminar and incompressible.

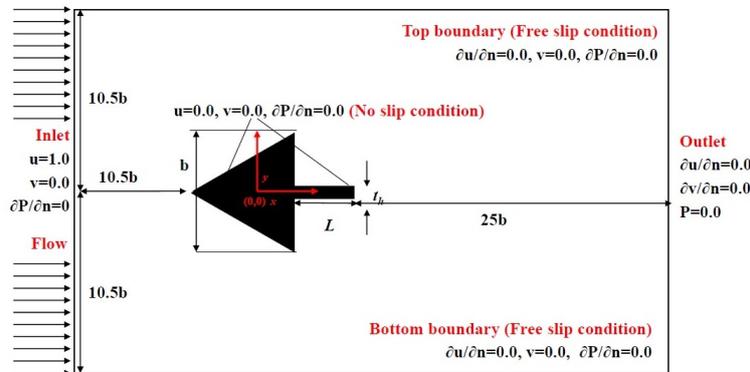


Figure 1: Computational domain with boundary conditions

### 2.1. Governing equations

The governing equations for unsteady, incompressible, laminar and two-dimensional flow with constant viscosity fluid in non-dimensional form are as follows.

Conservation of mass :

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

Conservation of momentum in x direction :

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

Conservation of momentum in y direction :

$$\frac{\partial v}{\partial \tau} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{\partial p}{\partial y} + \frac{1}{\text{Re}} \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (3)$$

In the above equations, geometrical parameters (x, y) are non-dimensionalized using side of triangular cylinder  $b$ , velocity is non-dimensionalized using free-stream velocity  $U_\infty$ , pressure is non-dimensionalized by  $\rho U_\infty^2$ , and time is non-dimensionalized by  $\frac{b}{U_\infty}$ . Here,  $\rho$  is density of the fluid, and  $\mu$  is the dynamic viscosity of the fluid. As depicted in Fig.1, the origin of the domain is located at the center of the cylinder. The outlet boundary is always maintained at a distance of  $25b$  from the trailing edge of the splitter plate. Hence, the downstream distance is adjusted in such a way that it varies with respect to the splitter plate length.

### 3. Numerical procedure and validation

Eulerian-Velocity correction approach is used to solve the governing equations iteratively and discretization is done by using SUPG based finite element method. To avoid node to node oscillations in the results when standard Galerkin method is applied to convection dominated flows, [5] proposed a method in which discontinuous weighting functions are used and the method is known as SUPG based finite element method. The details of the numerical formulation are given in [6, 7]. The present algorithm has been validated well with several experimental and numerical studies by [6].

Table 1: Comparison of various fluid flow parameters with available literature values for flow past a square cylinder at  $Re = 100$

Reference	$Cd_{p\_avg}$	$Cd_{avg}$	$Cl_{rms}$
[8]	1.441	1.4878	0.188
[9]	1.4436	1.4936	0.1922
[10]	-	1.64	-
[11]	-	1.61	-
[12]	-	1.8	-
[13]	-	1.47	0.156
[14]	-	1.44	0.152
[15]	-	1.47	0.159
[16]	-	1.5287	0.1928
[17]	-	1.542	0.1915
Present	1.464	1.534	0.189

Validation study of present scheme is done for fluid flow past a square cylinder. It

is evident from Table 1 that the drag and lift values obtained from present numerical algorithm are in good agreement with the literature values.

#### 4. Results and discussion

The performance of a splitter plate as a drag reduction device as well as a vortex shedding suppression device significantly depends on Reynolds number ( $Re$ ), cylinder shape and length of the splitter ( $L/b$ ). The combined effect of these parameters on fluid flow characteristics of an equilateral triangular cylinder is elucidated with the aid of instantaneous vorticity contours. Fig.2 depicts instantaneous vorticity contours.

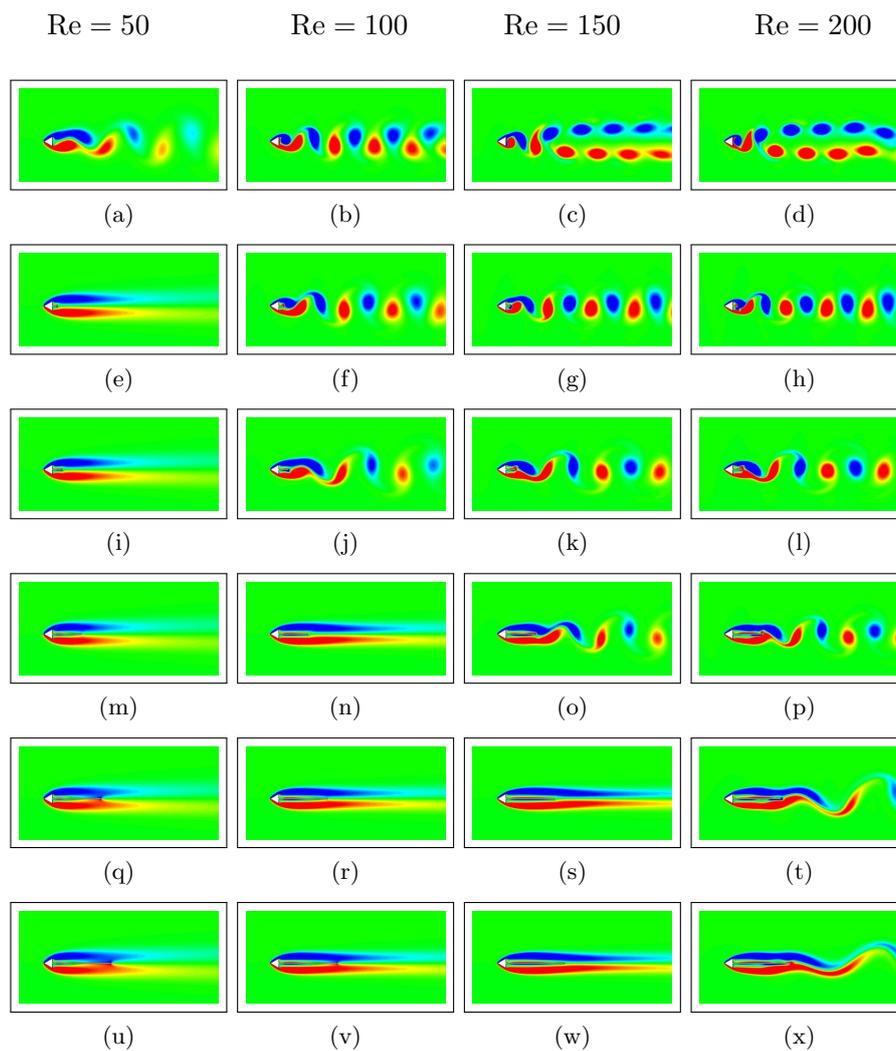


Figure 2: Instantaneous vorticity contours for an equilateral triangular cylinder attached with splitter plate of various lengths. (a-d)  $L = 0.0b$ , (e-h)  $L = 0.5b$ , (i-l)  $L = 1.0b$ , (m-p)  $L = 3.0b$ , (q-t)  $L = 5.0b$ , (u-x)  $L = 6.0b$

Wakes of all bluff bodies are similar in structure ([1]) as far as instabilities are concerned. From Fig.2 it is to be observed that when a small plate of length  $L = 0.5b$  is attached to the cylinder the separated shear layers are elongated and their point of interaction is located downstream in the wake region. A small-scale vortex is observed at the trailing edge of the plate. With the further increment of plate length the separated shear layers are convected more downstream and shedding occurs until  $L < L1_{cri}$ , and at  $L = L1_{cri}$  (example: Fig.2n) vortex shedding is suppressed.  $L1_{cri}$  is defined as the minimum plate length for which vortex shedding suppression is attained. From Fig.2 it is worth noticing that, for higher Re lengthier plates are required to obtain vortex shedding suppression. Further it is also observed that for  $Re = 200$  even with a plate length of  $L = 6.0b$  shedding is not suppressed but shear layers are elongated which results in reduction of vortex shedding frequency. The fluid flow is unsteady in nature for plate length of  $L < L1_{cri}$  whereas for  $L \geq L1_{cri}$  flow is steady in nature. These various flow patterns can be clearly identified from Fig. 3, which gives parametric space graph of various regimes depending on plate length ( $L/b$ ) and Reynolds number ( $Re$ ). From Fig.2 it is inferred that due to splitter plate attachment vortex formation process is altered, wake region is narrowed, vortex formation region is elongated.

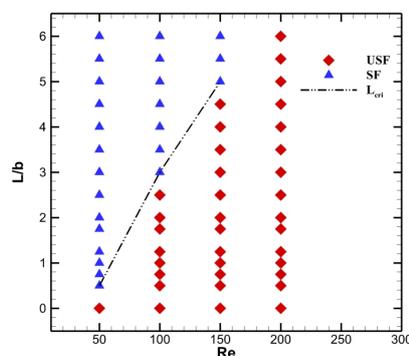


Figure 3: Parametric space graph of various fluid flow regimes

Figure 4 shows variation of viscous drag, pressure drag and total drag with splitter plate length. From Fig.4a it can be observed that skin friction drag decreases as the plate length increases upto certain length of the plate, and then with further increment of plate length skin friction drag increases, due to increased plate length causes additional frictional drag. From Fig.4b it is observed that pressure drag decreases almost monotonically as plate length increases upto  $L = L1_{cri}$ , beyond  $L1_{cri}$  pressure drag remains constant. Total drag is summation of skin friction drag and pressure drag, hence it shows the combined result of both. Fig.4c shows total drag variation with plate length. From Fig. 4 it is observed that for higher Re, significant drag reduction is observed when compared to lower Re. It is found that with the attachment of splitter plate reduction in total drag  $\simeq 9\%$  to  $\simeq 57\%$  is attained from cylinder without splitter plate.

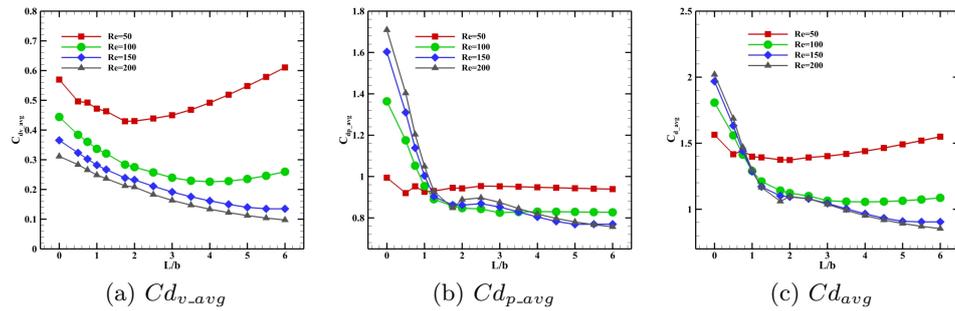


Figure 4: Effect of splitter plate length on drag

### 5. Conclusions

In the present numerical investigation, study has been carried out to notice the effect of splitter plate on equilateral triangular cylinder on fluid flow characteristics for low  $Re$ . From this study it is observed that vortex shedding suppression is observed for  $Re = 50 - 150$ . Decrease in drag is observed with splitter plate attachment.

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