

Aerodynamic and Acoustical Analysis of Flow around a Circular Cylinder in a Channel and Parametric Study on the Effects of a Splitter Plate on the Generated Vibration and Noise

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Abstract Generated noise of moving objects in different fluids is one of the most important subjects among scientists and researchers. Accordingly, in the present work, effects of splitters with different length and location on sound pressure level of circular cylinder are investigated by COMOSL software. Aerodynamic and aero-acoustic analyses are done in an air channel with Reynolds number 200. The analyses include 7 different cases of splitters. The obtained results indicate that splitters do not influence the frequency of lift force oscillation, but vibration force is reduced by about 99.6%. In the meantime, the SPL is increased 15.4 percent, when double splitters are located at the upper half of the cylinder. The best case scenario occurs when one splitter with a length equal to the diameter of cylinder is located at this position. In this situation, SPL is reduced by about 6.4 percent and lift force oscillation is increased by about 90.5 percent.

Keywords: cylinder, noise, splitter, lift

1. Introduction

Calculation of the sound of moving objects has always been an important issue for many researchers. considered in the world. Generally, there are two main methods for obtaining the noise. The first is experimental method and the second is numerical methods. Nowadays, more researchers use numerical methods for prediction of the noise. Pressure disturbance is the main reason of the sound generated from moving objects. This phenomenon can be produced from several sources such as: vorticity, shock, Therefore, acoustic pressure is computed in numerical methods. Some of these methods are as follow: solving Navier-stokes equations, Kirchhoff model and Ffowcs Williams and Hawkings model. In between these models solving Navier-stokes equations is the best for computation of the noise and the others are suitable for estimating the noise in far field but solving Navier-stokes equations are expensive. In this field different works are done that in continuation will be mentioned some of them.

In 1986, an effort has been done by Mori et al. [1], in order to generate symmetrical vortices which are induced by a cylinder in flow field. Using a splitter was one of the ways they tried beside wake heating and mesh number increasing. They showed with increasing the length of splitter the vortex shedding will come to be more symmetry. In other work Kawai [2] in 1990 shows that when the cylinder and splitter distance exceeds a critical

value the flow will roll-up. This parameter is highly depended on planes size when it is located normally to the flow, but in tangential case it is not so affected. Three years later a two dimensional high Reynolds vortex shedding and noise numerical simulation around an inclined plate with a splitter has been carried out by Kim and Konlisk [3] in 1993. They changed the plate's angle of attack, and the place of splitter which was located in the wake of plate in order to study the changes in downstream flow and induced noise field. They found that in case which splitter were placed $16c$ far from middle of plate the sound pressure level will decrease in contrast with case without splitter, which c is chord length and the angle of attack is 140° . In the same year, Miao et al. [4], studied experimentally the effect of splitter plate on suppression of induced vortex of trapezoidal cross-section cylinder in Reynolds number of 5×10^3 to 4.5×10^4 . They found twice maximum cylinder length is suitable for this purpose. Also they showed that stabilizing the vortices is highly depended on length of splitter. Boisaubert and Texier [5] in 1998, work on effectiveness of splitter plate on semi-circular cylinder shedding in near field in Reynolds number of 200 and 400. The splitter length was equal to the cylinder length and the distance between them were studied which caused to different phenomena. A 2D Study on a wake of fitted splitter plate to the bluff body with LES methods was carried out by Nakayama and Noda in 2000 [6]. They showed that they methods are well capable of simulating these flows. Five years later Akilli, Shahin and Tumen [7] in 2005, experimentally examined

the effect of splitter thickness and its distance from cylinder on suppression of circular cylinder's shedding in shallow water. They showed that in the distance of $2D$ from cylinder the effect of splitter plate is negligible. Also, Hwang and Yang [8] in 2007, succeed to reduce the Drag force on a circular cylinder using two splitter plates. These two cylinders which had same diameters, were located in front and behind of cylinder along its center line. An experiment work was done on wake study of bluff body with a rotating splitter hinged to it by Shukla, Govarhan and Arakeri [9] in 2009. They found splitter length to cylinder's diameter is an important ratio which effects oscillations. Sudhakar and Vengadesan [10] in 2011 studied the wake field of a circular cylinder attached to an oscillating splitter in Reynolds number 100. Three different shedding patterns were observed due to different plate frequency and amplitude which were normal shedding, chain once and splitter shedding. Also they found that inverse ratio between Strouhal number and vortex formation length is no longer confirmed in presence of oscillating splitter. In the same year Sukri, Doolan and Wheatly [11], use a thin flat plate as a splitter to reduce vortex induced noise of a square cylinder in Reynolds number of 150 and Ma. number of 0.2. In this numerically study the length of splitter which was attached to cylinder were studied in order to optimize the splitter length. This parameter were divided to three ranges up to $6D$ were D was cylinder's diameter. Different phenomena were observed in each regime. Also Gu et al [12] in latest of 2011 investigated the effect of free rotating splitter with different length on fluctuation force and vortex characteristics in different Reynolds number. They found that longer splitters have smaller amplitudes than short once and in case of very long splitters there is no difference in flow structure between fixed and rotating once. In 2012, Bao and Tao [13] used pair of plates to control the circular cylinder's wake field. They showed that the attachment angel is a vital parameter in Drag reduction control. Also they showed that the optimize range is between 40 and 50 degree. Oruc et al in 2012, [14] experimentally studied vortex shedding characteristics and flow field of dual cylinders located normal to the streamline with a splitter between them in shallow water, which splitter center line was along to cylinders bases. They found that in $L/D \geq 3$, the wake will be stable and symmetric. Malekzadeh and Sohankar [15] in 2012, tried to reduce the fluid forces and heat transfer of square cylinder in a cross flow, using a splitter as a controller. They found that $3W$ gap between cylinder and $.5W$ splitter arrangement will cause to maximum force reduction and minimum heat transfer, where W is the width of square cylinder. In the same year, Seyyedi [16] numerically studied the wake controlling of a square cylinder with the angel of 45, using a splitter in 2D channel. They showed that splitter place has important effect on downstream flow separation. Again in 2012, Sukri, Doolan and Wheatley [17] numerically investigate the effect of detached splitter plate on flow field around a square cylinder in Reynolds number of 150. They present a critical distance ($G=2.3D$) between cylinder and splitter which divides a flow in two regimes.

In this research effect of different splitters on the sound of circular cylinder are investigated in air and COMSOL software is used to obtain Navier-stokes solution and

sound pressure level. In next section numerical solution of this problem will be described.

2. Numerical Solution

Navier-stokes equations are solved for obtaining the pressure distribution and ultimately the sound pressure level (SPL). These equations include continuity equation and momentum equations as in

$$\int_{A_a(t)} \rho \bar{c} \cdot \bar{n} dA = 0 \quad (1)$$

$$\begin{aligned} \frac{d}{dt} \int_{V_a(t)} \rho \bar{U} dV + \int_{A_a(t)} \rho \bar{U} (\bar{c} \cdot \bar{n}) dA &= \\ &= \int_{A_a(t)} P \cdot \bar{n} dA + \int_{V_a(t)} \rho \bar{g} dA \end{aligned} \quad (2)$$

There are several methods for discretizing the given equations such as finite difference, finite volume and finite element. As mentioned earlier, for computation of acoustic pressure, COMSOL software is used, which is based on finite element method.

Once the acoustic pressure is determined, pressure sound pressure level is calculated by equation

$$SPL = 20 \log_{10} \left(\frac{P}{P_{ref}} \right) \quad (3)$$

where reference pressure for air is considered to be $2 \cdot 10^{-5}$ Pascal.

3. Problem Setup

In the present work, effects of splitters on the noise of circular cylinder in an air channel are investigated. Computational domain and boundary conditions are illustrated in Figure 1. Reynolds number for all the conducted analysis is considered to be 200.

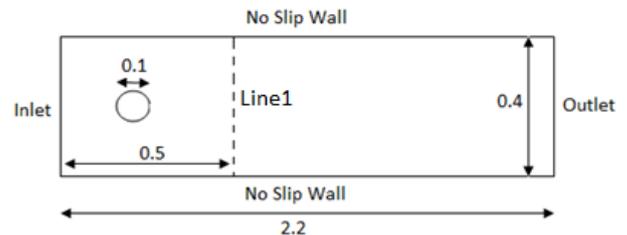


Figure 1. Domain and boundary conditions

As a first step, flow around the cylinder is analyzed alone then splitters are appended behind the cylinder in seven different conditions. Specifications and conditions of splitters are listed in Table 1.

Thickness of splitters in all cases is taken to be 0.01m. Analysis in each case is continued until lift force on the circular cylinder becomes stable. For evaluation of the generated noise, maximum acoustic pressure in the entire simulation is extracted at line1 (shown in Figure 1) and sound pressure levels are calculated and compared for each of the eight considered cases in Table 1. To obtain accurate results, around 3500 unstructured mesh are used to solve the problem.

Table 1. Cylinder conditions

Case	Length of splitter (m)	Vertical position of splitter from the center of cylinder (m)	Shape
1	-	-	
2	0.1	0	
3	0.075	0	
4	0.05	0	
5	0.025	0	
6	0.1	0.025	
7	0.1	0.05	
8	0.1	0.025	

4. Results and Discussion

Diagrams of the lift force exerted on the cylinder extracted by COMSOL software are presented in Figures 2 through 9.

Plots of lift forces, when splitters of different lengths are located on the symmetric axis of cylinder, are shown in Figures 3 through 6. Results illustrate that lift forces oscillate about the zeroth-line for these splitters. Also, it is shown that fluctuations of forces decrease, when the length of splitters increase. Meanwhile, it is demonstrated that longer splitters cause more uniform pressure distribution around the circular cylinder.

In Figures 7 through 9, lift forces associated with cases 6, 7 and 8 are displayed. In these cases, splitters aren't located on the symmetric axis of cylinder and lift forces oscillate about values different than the zeroth-line. Plots in the mentioned figures show that the last cases 6,7, and 8 have more effect on reduction of amplitude of lift force oscillation and among them; double splitters (case 8) seems to be the best, in this regard. Double splitters cause the necessary uniform pressure distribution around the cylinder.

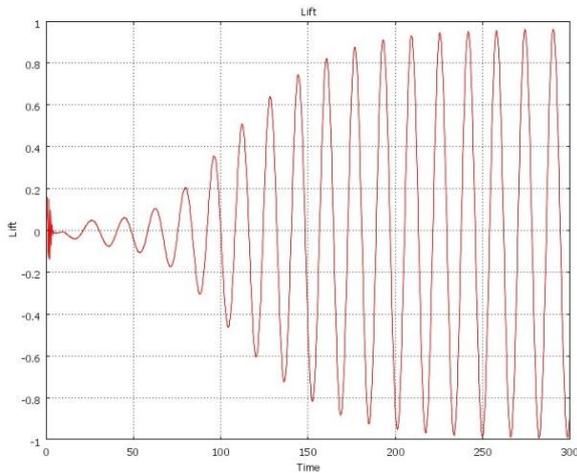


Figure 2. Lift force for case 1

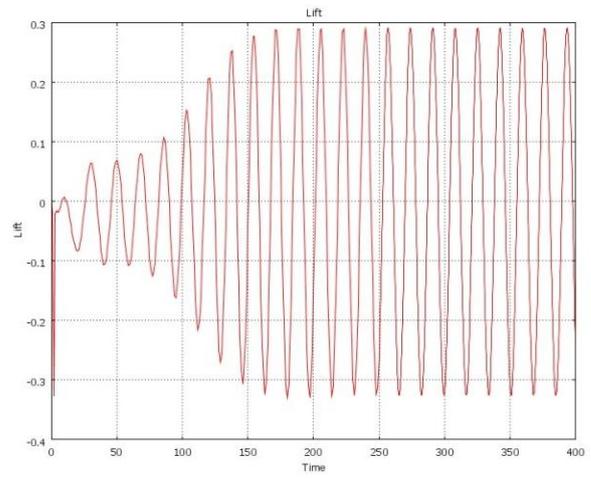


Figure 5. Lift force for case 4

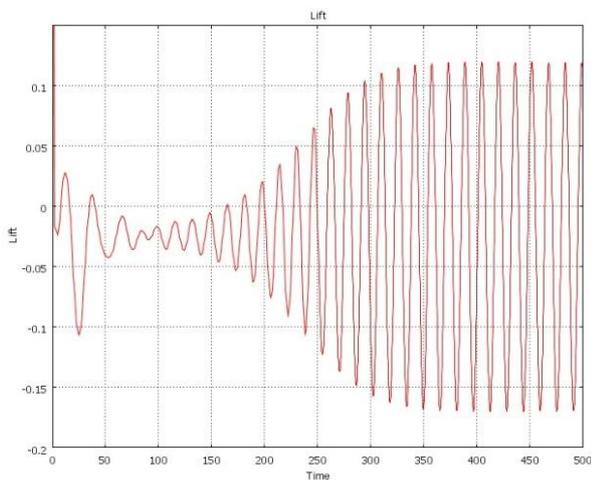


Figure 3. Lift force for case 2

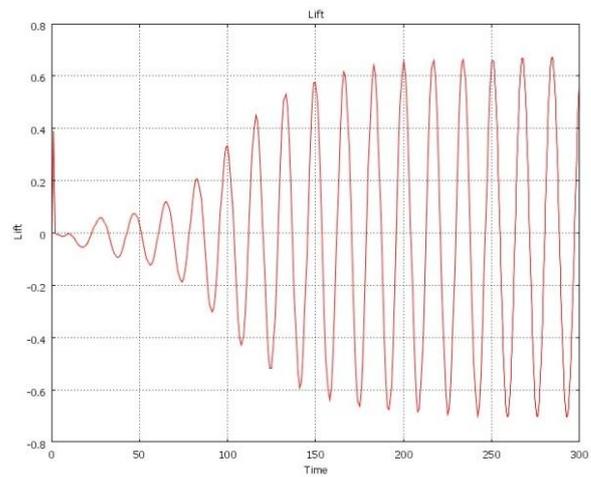


Figure 6. Lift force for case 5

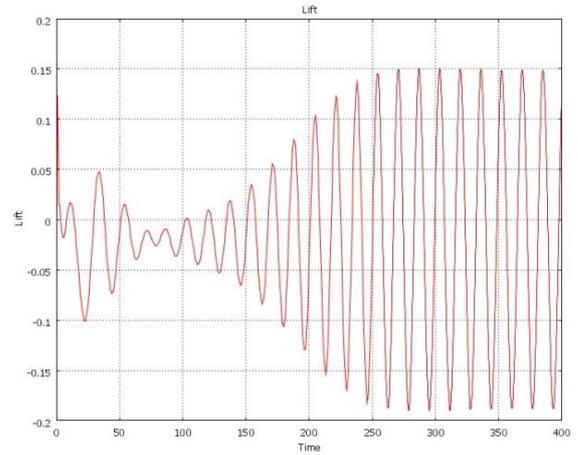


Figure 4. Lift force for case 3

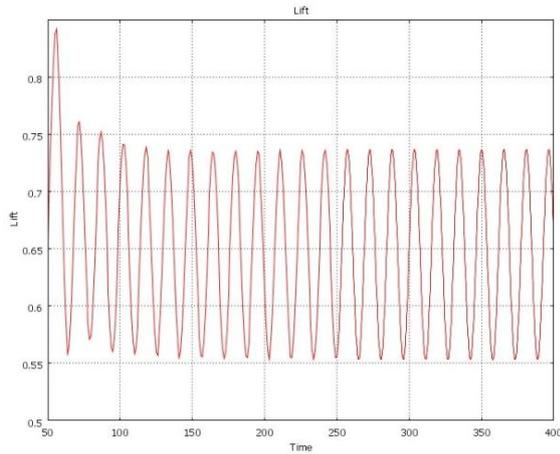


Figure 7. Lift force for case 6

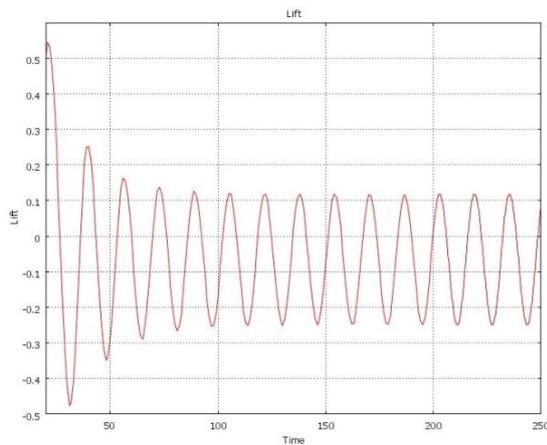


Figure 8. Lift force for case 7

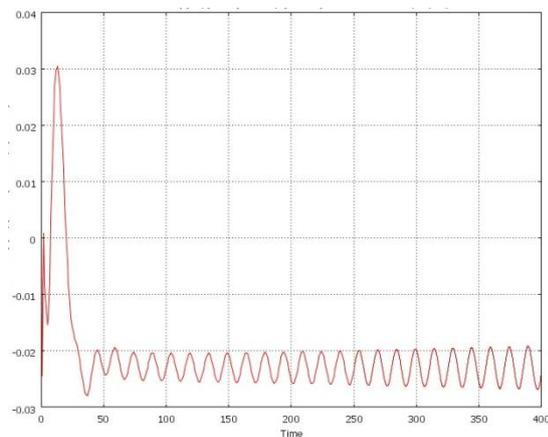


Figure 9. Lift force for case 8

Lift forces associated with the splitters have shown to have no effect on the frequency of lift oscillation, but interestingly do have influence on amplitude of the exerted force. Amplitude of the lift force in all cases analyzed is demonstrated in Figure 10, which display an eighty five (85%) reduction in amplitude by the splitter, when it has a length equal to the cylinder diameter and is positioned at the center of the cylinder. When the location of the splitted is moved by the amount of one radius about the centerline, the amplitude of lift force exhibits an 80 percent reduction, compared to a case without a splitter. In the meantime, when the position of splitter is at half radius of the cylinder, reduction of lift amplitude is about 90.5

percent. Furthermore, lift amplitude is decreased 99.6 percent, if double splitters are considered. Therefore, one may claim that double splitters reduce the lift oscillation on the cylinder quite significantly.

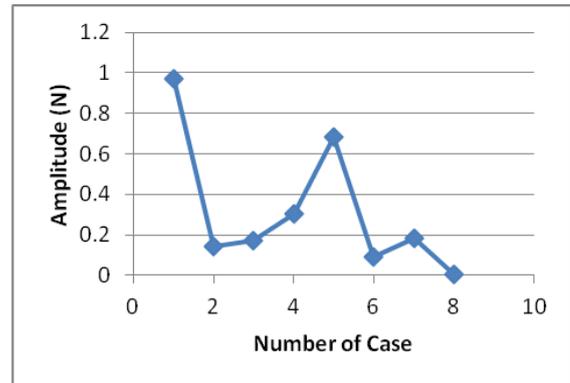


Figure 10. Amplitude of lift force

Afterwards, in the process of aerodynamic analysis of flow around circular cylinder, maximum sound pressure levels are computed at line 1. The obtained maximum value of SPL for each case is reported in Table 2.

Table 2. Maximum value of SPL.

Case	SPL (dB)
1	19.618239
2	20.214477
3	20.506117
4	20.595789
5	18.820285
6	18.360607
7	23.106721
8	22.64199

In case number 6, least maximum SPL is achieved, while in case number 7, the highest maximum SPL is obtained. Generally, reduction of sound pressure level happens in two cases of 5 and 6. Contour of acoustic pressure for cases 1, 5 and 6 are illustrated in Figures 11 through 13.

Figure 12 shows that fluctuation of acoustic pressure in case 5 is lower than that of case 1. Therefore, sound pressure level is smaller. Also, Figure 13 indicates that splitter in case 6 makes smooth acoustic pressure in air channel and based on the results listed in Table 2, this splitter generates the least noise.

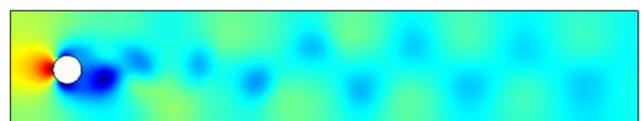


Figure 11. Contour of acoustic pressure for case 1

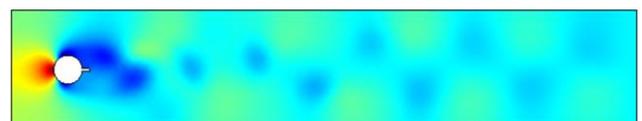


Figure 12. Contour of acoustic pressure for case 5



Figure 13. Contour of acoustic pressure for case 6

Comparison of results of all cases with splitter against that with no splitter indicate that reduction in amplitude of oscillation in case 8 is about 99.6 percent, but the obtained SPL is increased by about 15.4 percent. Also, in case 5, SPL is decreased about 4 percent, but reduction in lift oscillation is about 29.3 percent.

Finally, case number 7 is seen to be the best from viewpoints of aerodynamic and aero-acoustic. In this particular case, amplitude of lift force is reduced around 90.5 percent and reduction of the computed SPL is about 6.4 percent.

5. Conclusion

Computation the noise of moving objects is considered, Effect of different splitters on sound pressure level and lift forces have been investigated by COMSOL software.. The presented analyses have been conducted in an air channel at a Reynolds number of 200. The obtained results indicate that splitters do not have any effect on the frequency of lift force oscillation. When splitters are used in double form and positioned at a location half a radius of cylinder away from the centerline, lift force oscillation reduces by about 99.6 percent. However, for the same considered case, the sound pressure level (SPL) increases by about 15.4 percent. Finally, when one splitter is situated at the same designated location, the SPL is reduced by 6.4 percent and lift force oscillation also exhibits a 90.5 percent reduction.

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