Effect of Hole-uniformity of Shrouds on Vortex Shedding Suppression behind a Circular Cylinder

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Abstract. A passive flow control method over a circular cylinder using perforated shrouds was computationally investigated to manipulate the unsteady wake behind the circular cylinder for vortex shedding suppression. The perforated shrouds were of 33% porosity with uniform and non-uniform holes. The computation was performed at low Reynolds number (based on the circular cylinder diameter), Re=300. The objective of the study is to examine the effect of hole-uniformity of the perforated cylinders on the vortex shedding behind the circular cylinder. It was found that both perforated shrouds (uniform and non-uniform holes) significantly suppressed the vortex shedding behind the cylinder, although with an increased drag due to normalization according to cylinder diameter. The perforated shrouded cylinder with non-uniform holes has longer vortex formation length, suppressing vortex better than that of the uniform holes distribution. The intensity of vortices behind the shrouded cylinder wake with non-uniform holes was also considerably smaller than that of the uniform holes.

1. Introduction

Flow over circular cylinder is one of the most studied in fluid dynamics and relevant to many engineering applications. At critical Reynolds number, this flow is characterized by flow separations and vortex shedding behind the cylinder wake. The shedding of vortices results from the rolling up of the shear layers originated at the separation point. These vortices may lead to unwanted vibration when the shedding frequency matches the resonance frequency of the cylinder. This phenomenon is called Vortex induced Vibration (VIV). VIV can accelerate fatigue damage to the cylinder.

A number of passive control techniques have been explored and suggested to reduce drag, suppress fluctuating lift and mitigate vortex shedding from circular cylinders. These techniques include helical strakes, shrouds, splitter plates, guiding vanes and base bleed [1]. Passive control via perforated shrouds was first studied by Price [2]. Price demonstrated that VIV suppression could be achieved by the shrouds due to the delay in the formation of vortex street. Every et al. [3] reported that shrouds with the optimum dimension gave a 50% reduction in oscillations of a plain cylinder in suppressing flow induced vibrations. In the recent years, shrouds using screens have also been studied by researchers for VIV suppression [4, 5]. Interestingly, Huera-Huarte [6] found that about 95% VIV attenuation in addition to 20% drag reduction was achieved using wire meshes.

Mitigation in vortex shedding via shrouds also led to noise suppression. Ikeda and Takaishi [7] showed that suppression of Aeolian tone was achieved due to the jets emitted from the holes of perforated cylinder at regular interval. Boorsma et al. [8] discovered that the associated broadband

noise level is reduced remarkably by using perforated fairings due to the breakdown of the vortex shedding process.

In the turbulent wake regime, vortex shedding occurs in cells along the spanwise direction for Re>200 [9]. These cells are also out of phase, thus reducing the maximum resultant force acting on the cylinder. The average length of the cells may be termed the correlation length. Azmi et al. [10] found that a low correlation length was associated with small scale weak vortices indicating an enhanced three dimensionality in the flow. It is conjectured that by making the holes size of the perforated shroud non-uniform, a greater three dimensionality of the wake can be achieved, hence further suppressing the vortex shedding and reducing lift force. Therefore, this paper aims to investigate the effect of hole- uniformity of the shrouds on the vortex shedding behind a circular cylinder at low Reynold number. Two different porosity representing porosity lower than 50% and below 50% was studied, but only results for the 33% porosity are reported preliminary in this paper.

2. Methodology

The creation of model was done in the Ansys 16 Workbench. The model of the circular cylinder with the perforated cylinder (hereafter is referred to as perforated shrouded cylinder) is shown in Figure 1 and 2. The diameter ratio between the perforated cylinder and the circular cylinder, *D/d* was set at 2. The Reynolds number, *Re* was 300 based on the circular cylinder diameter, *d*. The computational domain was large to eliminate the effects of the blockage and outlet pressure. The streamwise spacing of 40D was chosen behind the cylinder and a 20D spacing was created on each side of the cylinder. Using the porosity definition, β = void area/ total area, the perforation area of the perforated cylinder was fix at an angle of 10° for the uniform holes while three different perforation angles of 5°, 10°, and 15° were used to model the non-uniform holes as shown in Figure 2. The simulation was performed for two different porosity values: 33% and 55%. However, only results using 33% porosity are presented in this paper.
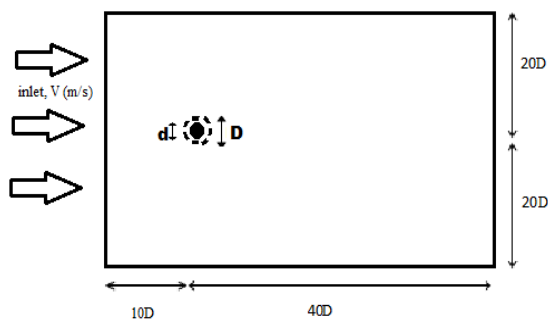

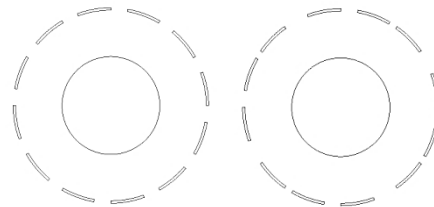**Figure 1.** Two dimensional flow over perforated shrouded cylinder.

Figure 2. 33% porosity perforated cylinder model (uniform and non-uniform holes).

Figure 3 shows the mesh used in the two dimensional 2-D simulation. The employed mesh was structural mesh. A grid independency study is conducted to ensure a grid–independent solution with high quality mesh. The study was done by increasing the numbers of cells and nodes of the mesh around the cylinder. The mesh elements and the results of Strouhal number and drag coefficients are summarized in Table 1. The grid convergence results reveal that M2 and M3 mesh provide similar outcomes in terms of the Drag Coefficient, however the Strouhal number is slightly changing. Therefore, mesh M3 is considered to give good grid resolution for the models. The grid independence study was only conducted for the shrouded cylinder of 55% porosity. A similar fine mesh scheme was used for the 33% porosity.
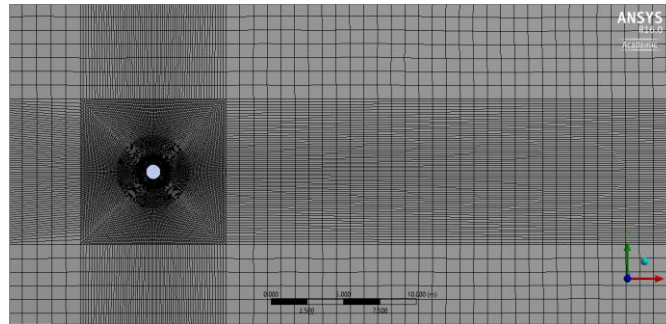
Figure 3. Mesh structure around perforated shrouded cylinder.

The simulation was performed using viscous laminar model with transient time for unsteady flow at Re=300. The wall and cylinder setup was no-slip condition and stationary wall boundary conditions. The second implicit solution was utilized. The simulation used hybrid initialization and the time step size was 0.001s for 1500 number time with 50 maximum iterations per time step to capture the flow structure at the wake region of the cylinders.

Table 1. Grid independence study

55% uniform perforated shrouded cylinder
Mesh	Nodes	Cells	Drag Coefficient, C_d	Strouhal Number, St
M1	38209	37808	1.35	0.080
M2	39454	39019	1.35	0.075
M3	42602	42114	1.36	0.070
55% non-uniform perforated shrouded cylinder
Mesh	Nodes	Cells	Drag Coefficient, C_d	Strouhal Number, St
M1	35591	35187	1.33	0.100
M2	36658	36214	1.33	0.090
M3	39383	38901	1.33	0.085

3. Results
Results are presented in terms of force coefficients, Strouhal number, velocity contours, velocity vector plot and vorticity contours. Comparison are made between the wakes of uniform and non-uniform holes shrouded cylinders on vortex shedding behaviour and suppression.

3.1 Model validation
The simulation was first validated by comparing result of the flow over a circular cylinder with experiment and other simulation. The validation was done to ensure the right simulation setup. Both simulation and experimental results were in good agreement with each other, a difference of between 1% and 10% as shown in Table 2.

Table 2. Strouhal and drag coefficient at Re=300

Circular cylinder		
	Drag Coefficient, C_d	Strouhal Number, St
2D- computation Mital and Balachandar, 1997 [11]	1.26	0.213
2D-Numerical simulation [12]	1.37	0.215
Experiment [13]	1.22	-
Experiment [14]	-	0.203

Present study	1.28	0.21
33% porosity perforated shrouded cylinder		
Uniform	1.43	0.10
Non-uniform	1.52	0.08

3.2 Drag and Lift Coefficient

Figure 4 shows the time history of the drag and lift coefficient, C_l and C_d, respectively for the circular cylinder and perforated shrouded cylinders (uniform and non-uniform holes). The periodic sinusoidal nature of the flow in the circular cylinder is obvious due to the presence of correlated vortex shedding. This is in contrast to the flow in the perforated shrouded cylinders where the oscillation are significantly damped signifying very low correlation of vortex, especially observed in that of the non-uniform holes. The drag coefficients for both shrouded cylinders are quite similar, with the non-uniform holes cylinder gives slightly larger value than that of the uniform-holes, but both values are about 20% higher than that of a circular cylinder as tabulated in Table 2. This is due to the normalizing the parameter based on the circular cylinder diameter.
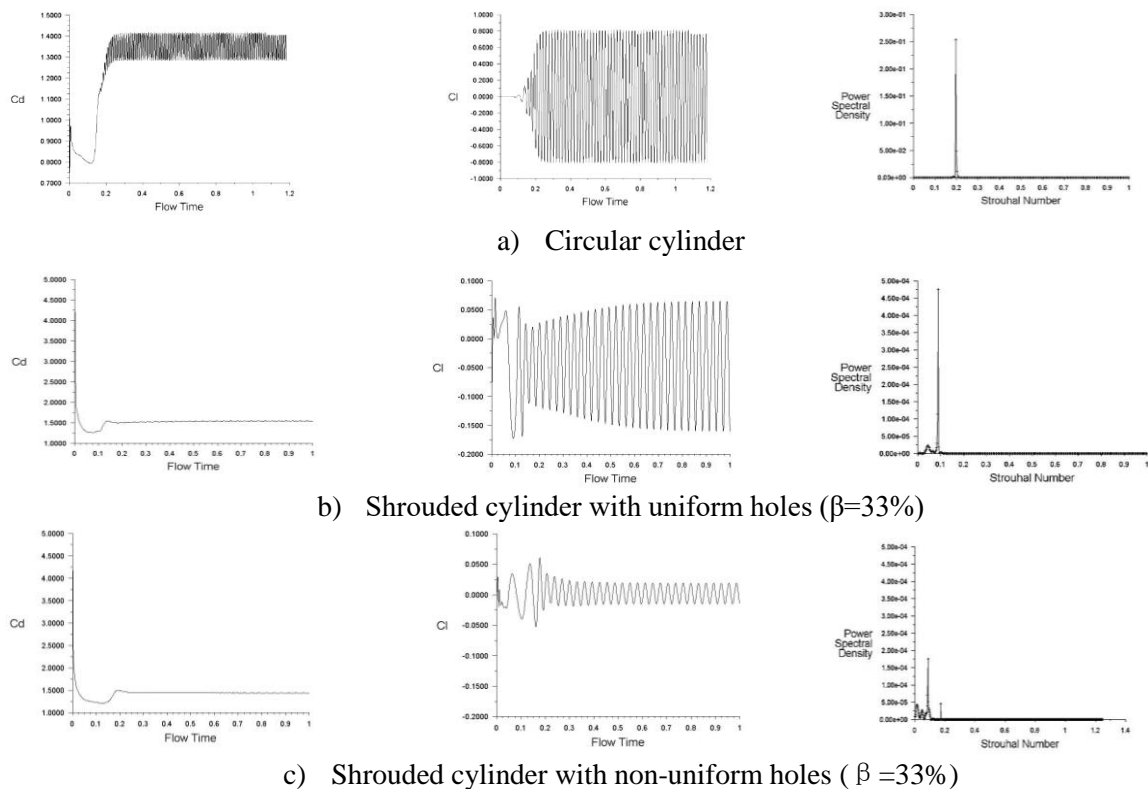

a)   Circular cylinder

b)   Shrouded cylinder with uniform holes (β=33%)

c)   Shrouded cylinder with non-uniform holes (β =33%)

Figure 4. Time history of Drag and Lift coefficient and Strouhal number for circular cylinder and perforated shrouded cylinder at Re=300.

3.3 Strouhal number

Figure 4 also shows the Spectral Analysis of Lift Convergence for the circular cylinder and perforated shrouded cylinder, obtained using Fast Fourier Transform. The amplitude spectrum of the Lift is plotted as a function of the dimensionless frequency. A sharp peak of large amplitude is observed for the circular cylinder wake at St=0.2, whereas several peaks of substantially low amplitude are evident for the shrouded cylinder wake with the highest peaks occur at St of around 0.1, indicating vortex has been suppressed. A considerably lower amplitude is observed by the non-uniform holes in comparison to that of uniform holes indicating the former suppress vortex better than the latter.

3.4 Velocity contour and velocity vector
Figure 5 shows the normalize velocity contour and velocity vector for the circular cylinder and perforated shrouded cylinders. The circular cylinder shows a reverse flow immediately downstream, circulating in the wake, whereas both the shrouded cylinders reveal that circulation is mainly observed in the annular region between the cylinder and the perforated cylinder. At the central region, region of significantly low velocity is observed clearly in both shrouded cylinder wakes. This region is elongated farther down the wake of the non-uniform holes in comparison to that of the uniform holes. It seems that this 'void' region prevents early interaction of the shear layers to form the large coherent vortices in the wake.
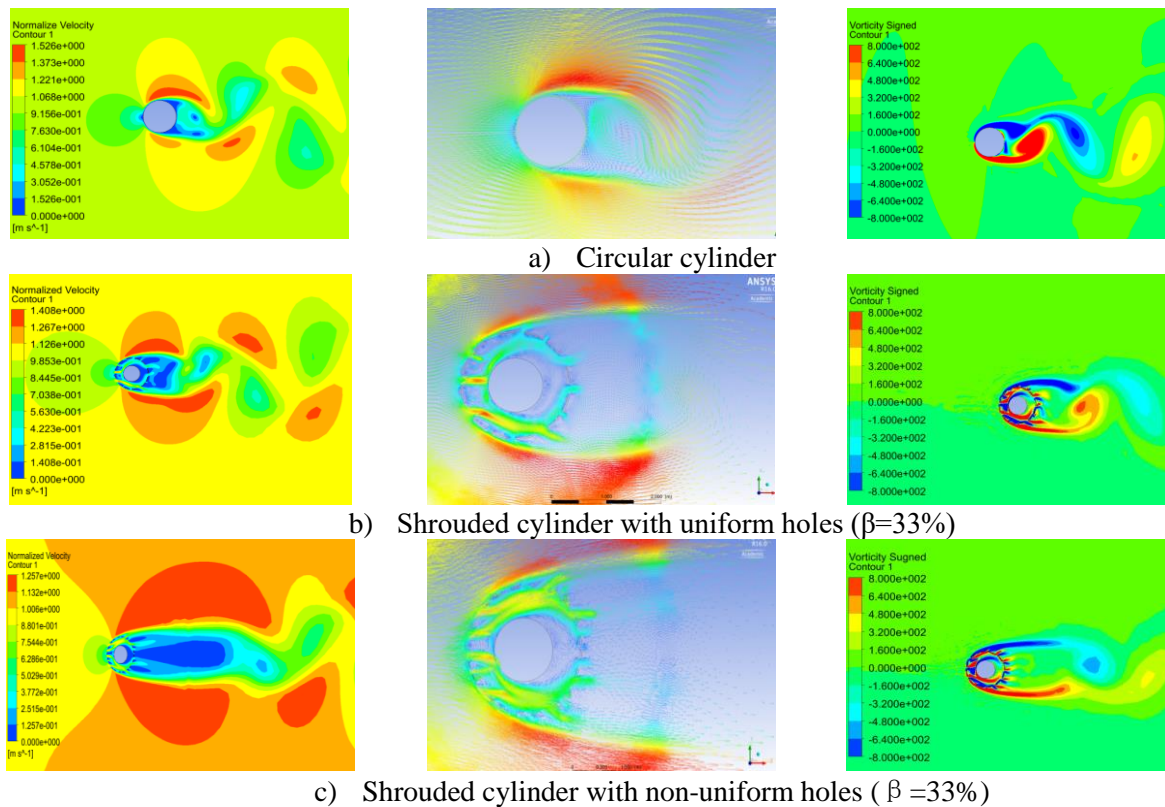
a)   Circular cylinder

b)   Shrouded cylinder with uniform holes (β=33%)

c)   Shrouded cylinder with non-uniform holes (β =33%)

Figure 5. Normalized velocity contours , velocity vectors and vorticity contours.

3.5 Vorticity contour
Figure 5 also shows the vorticity contour in the wake of all cylinders. The red color indicates clockwise vortices while the blue indicates counterclockwise vortices. Formation of vortices of high intensity occurs immediately behind the circular cylinder while low intensity vortices occurs quite a distance downstream in the wake of the shrouded cylinders. The vortex formation length for the shrouded cylinders is longer for the non-uniform holes in comparison to that of the uniform holes, consistent with the Lift, Strouhal and velocity contour results discussed previously.

4. Conclusion
Numerical simulations for two dimensional flow over perforated shrouded cylinders at Reynolds number of 300 were performed to understand the effect of hole-uniformity in controlling the wake behind a circular cylinder. Results showed that the shedding of vortex was controlled significantly in the wake of the circular cylinder using both perforated cylinders with uniform and non-uniform holes of 33% porosity, but superior suppression was achieved with that of non-uniform holes, indicated by the low intensity vortices and long vortex formation length. This suppression however, does not take

into account the effect in the spanwise direction which would further enhance the vortex suppression effect.

Acknowledgments

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