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Effect of local waviness in confining walls and its amplitude on vortex shedding control of the flow past a circular cylinder

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A R T I C L E I N F O

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Amplitude effect
Drag reduction

A B S T R A C T

Numerical investigation of vortex shedding control and its suppression due to flow past a circular cylinder has been carried out starting from the Reynolds number 20 and upto the appearance of first instability in the wake. A technique “local waviness” is used in the confining walls for the effective control of shedding. The local waviness with crest near the cylinder wake eliminates vortex shedding with reduced drag (Deepakkumar et al., 2017). Effect of amplitude of local waviness on vortex shedding characteristics are systematically carried out and presented in this article. It is found that local waviness with amplitude $A = 0.15D$ is an optimum value for effective vortex shedding suppression with reduced drag on the cylinder at $\mathrm{Re} = 200$. As the amplitude of waviness increases, the wake size is reduced significantly as compared with plain wall confined cylinder. The presence of crest closer to the cylinder in the downstream generates a favorable pressure gradient and prevents flow separation at Reynolds number 20. The pressure drag is controlled significantly by the trough region in the waviness, whereas the crest region affects both pressure and frictional drag. Also, the appearance of first instability in the flow is identified for different amplitude of waviness.

1. Introduction

Vortex shedding due to cross flow past a circular cylinder is a common phenomenon in many engineering applications. Flow over civil structure, submarines, offshore structures, pipelines in the sea bed, bridge piers, heat exchanger tubes are such examples. The rigidity of the structure on such situation depends on the flow Reynolds number, especially at higher Reynolds number it may fail due to flow induced vibration. Collapse of Tacoma narrow bridge (1940) is a well-known example. There are some remedial techniques to completely eliminate the formation of vortex, or to minimize the frequency and suppression of vortex shedding. It is well known that the active and passive controls are two commonly used techniques, where the passive technique of vortex shedding control requires no external power. Generally, when the cylinder is confined by a rigid wall, the shedding can be suppressed with some penalty in increase of drag on the cylinder. Strykowski and Sreenivasan, (1990), Mittal and Raghuvanshi, (2001) and Dipankar et al., (2006) have used a secondary small control cylinder in the downstream to suppress vortex shedding formation from primary main cylinder. They have identified that the suppression is achieved by the control cylinder which diverts a small amount of fluid into the wake of main cylinder. On the other hand, Shair et al., (1963), Chen et al., (1995), Sahin et al., (2004), Shaligram et al., (2006), Chen et al., (2013) and Singha and Sinhamahapatra, (2010) have used rigid plain wall confinement and effectively controlled the shedding, however reported increased drag on the cylinder.

Further, Sahin et al., (2004) have studied the effect of β on flow past circular cylinder and observed that for the values of $\beta < 0.5$, the vortex shedding characteristics were alike to that of the unbounded domain ($\beta = 0$). Hence, it is observed that in the case of wall confinement, confinement height (H) is a limiting factor on vortex shedding suppression. On the other hand, from the work of Wu et al., (2004), it was observed that the higher blockage ratio results in earlier separation and minifies the separation angle (measured from front stagnation point) due to the local acceleration of flow around the cylinder. However, Karman Vortex Street was found to be narrowed due to confinement and further increase in β ($\beta > 0.5$) leads to re-stabilized steady flow. The work of Anagnostopoulos and Iliadis, (1996) and Stansby and Slaouti, (1993), reported increased drag and Strouhal number due to confinement. Some of these effects are also observed from the work of Kanaris. et al., (2011). Thus, wall confinement leads to a stronger stream-wise alignment of vortices and results in coherent and sustained vortices in the downstream. Further, the interaction of vortices formed behind the cylinder

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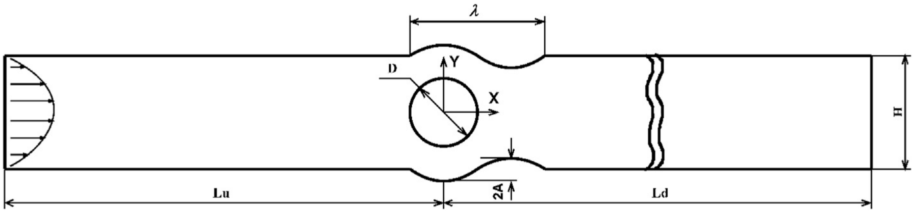

Fig. 1. Computational domain.

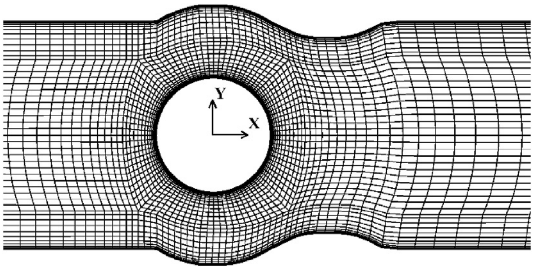

Fig. 2. Details of structured mesh around cylinder.

and those originated near the confining walls leads to an inversion of Von Karman vortices. Camarri and Giannetti, (2010) have also observed that the inversion of wake vortices does affect the nature of the instability. This inversion of vortices is reported by Singha and Sinhamahapatra, (2010) which is due to the interaction between the vortices from the channel wall and cylinder wake. In addition, they have studied the vortex shedding characteristics for various channel heights and observed that the Drag and Strouhal number increase with decreasing channel height, whereas lift decreases significantly.

Price et al., (2002) have experimentally studied the flow visualization around a circular cylinder near the confining rigid plain wall by varying gap between the cylinder and the plain wall. They have categorized the gap into four different ranges based on the formation of vortex shedding from both the cylinder and the plain wall. Sahin et al., (2004) have studied the β effect on vortex shedding characteristics and observed that at blockage ratios $\beta < 0.5$, the vortex shedding over the cylinder was quite similar to that of the unbounded case. They also found that the vortex street is shorter due to shear in the free stream, increasing value of β leads to re-stabilized steady flow. This effect is also observed from the work of Kanaris. et al., (2011) They have also observed that, even though the primary vortex core is absent in the far downstream of the confined cylinder, a stronger stream wise alignment of vortices is identified due to the wall confinement that result in coherency of hairpin vortices sustained for larger distance.

Experimental investigations on steady and unsteady confined flow past circular cylinder with aspect ratio, $\alpha = 30$ and blockage ratio, $\beta = 1/3$ was conducted by Rehimi et al., (2008) and the results were compared with unconfined flow. Von Karman instability, which occurs at $Re = 47$ for unconfined flow was delayed due to the confinement and found to occur at $Re = 108$. The delay in vortex shedding due to wall confinement was also observed and reported in the numerical study due to Shaligram et al., (2006). Semin et al., (2009) have studied the effect of confinement

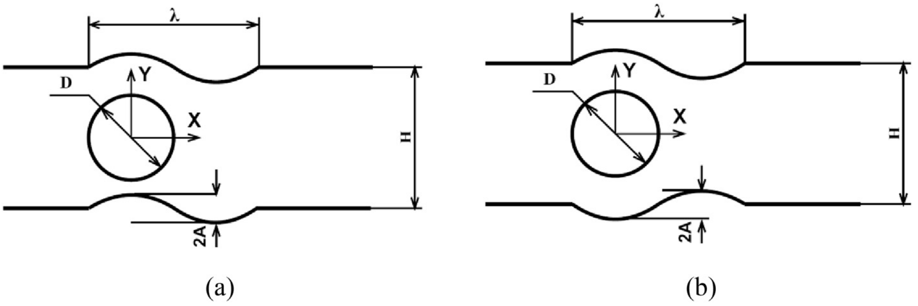

Fig. 3. Configuration of local waviness (a) IPC (b) OPC.

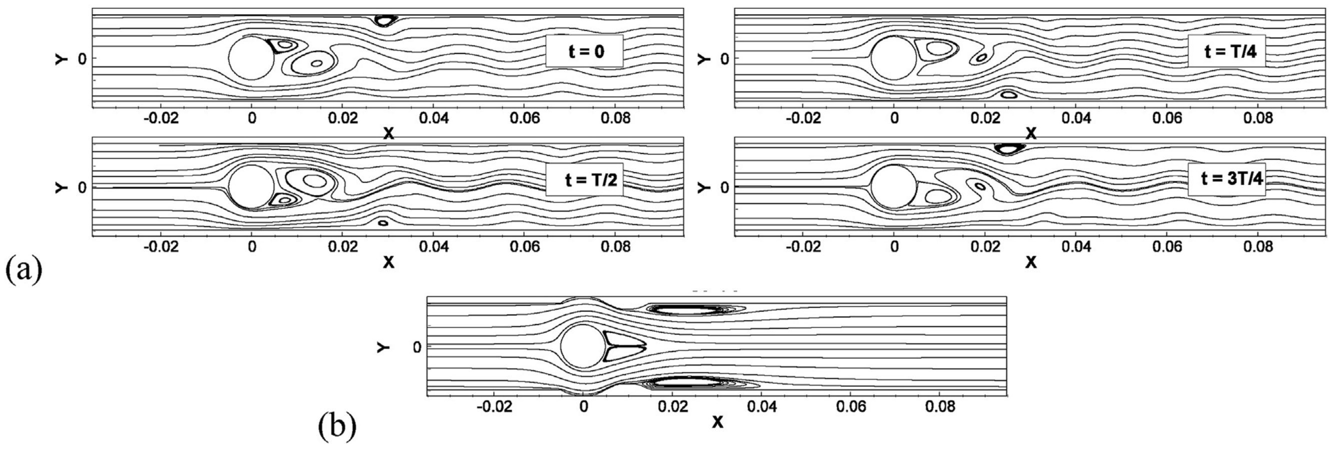

Fig. 4. Streamlines for (a) Plain-wall confinement (b) Wall with local waviness near the cylinder.