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Numerical Investigation of Vortex Shedding over a Circular Cylinder near a Plane Boundary

Mohammad Amin Salehi, Said Mazaheri and Mohammad Hossein Kazeminezhad
Ocean Engineering and Technology Research Center
Iranian National Institute for Oceanography and Atmospheric Sciences, Tehran, Iran

3-D RANS simulations are employed numerically to study flow characteristics around a near-wall circular cylinder for varying gap-to-diameter (G/D) ratios and range of Reynolds numbers from 100 to 6.5 x 10^4. Pressure distribution and other flow parameters were calculated and compared for all of the cases. The reciprocal effect of vortex shedding and flow characteristics on each other has been discussed. The occurrence of vortex shedding suppression is investigated via comparative parameters, through which the features like flow regime, wall presence, vortical activity, and balance between upper and lower vortex sheets can be taken into account.

INTRODUCTION

Flow around the circular cylinders near a plane boundary is a common issue both in aero/hydrodynamic theoretical studies and also engineering applications, such as flow around horizontal marine pipelines. Pipeline free spans can be formed as a result of local scour beneath the pipeline or irregularity of seabed. Vortex shedding phenomenon on a free span pipeline results in fluctuations in hydrodynamic forces acting on it. Vortex-induced vibration of a cylinder subjected to steady flow is highly influenced by fluctuating lift fluid forces, which damage the pipeline structure and the junctions due to fatigue. To ensure avoiding such a harmful effect on the pipelines, managing the occurrence of vortex shedding is attainable by realizing the characteristics of flow around a circular cylinder near a plane boundary.

Great efforts have been made by many researchers to describe the vortex shedding and suppression mechanism and its subsequent influence on the wake flow and gap flow in the presence of the wall. The assessment of the vorticity dynamics to inspect flow unsteadiness and the instability mechanism to investigate the vortex-induced instability was made by Dipankar and Sengupta (2005) as they studied how lift and drag coefficients are affected by the gap ratios of $G/D = 0.5$, 1.5 and $\mathrm{Re} = 1{,}200$. Physics of flow in the presence of the wall includes the shear layer transition, stretching, breakdown, and turbulence generation investigated by Sarkar and Sarkar (2010) for a Reynolds number of 1,440. They noticed that the suppression of vortex shedding and stretching of the shear layers occurs due to the strong coupling between the inner shear layer and the approaching boundary layer while the inner shear layer is submerged inside the boundary layer. Bimbato et al. (2013) suggested that moving ground can be utilized to avoid vorticity generation and inducing vortex shedding suppression on a bluff body. They demonstrated that the interaction between the upper and lower structures as a necessary condition for the detachment of vortex structures will be weakened due to Venturi inertial effects while gap ratio (G/D) decreases. Boghosian and Cassel (2016) presented a Vortex Shedding Mechanism, which leads to vortex splitting and subsequent shedding that is valid for 2-D incompressible, inviscid or viscous, and external or internal or wall-bounded flows. The criteria that are necessary and sufficient for a vortex splitting event require two conditions: (1) the existence of a location with zero momentum and (2) the presence of a net force having a positive divergence. Many researchers tried to find a measure for detection of vortex shedding suppression in the presence of a plane wall, particularly in terms of a critical gap ratio for a specified range of Reynolds numbers. Buresti and Lanciotti (1992) measured mean and fluctuating forces on a circular cylinder near a plane surface in cross-flow submerged in three different types of boundary layer on the plane, at a Reynolds number range of 0.86 to 2.77×10^5 and for various gap distances from 0 to 1.5. They found that vortex shedding persistence and suppression, regardless of boundary layer thickness on the plane, is a coherent feature of the flow unless the vertical velocity gradient becomes excessive. Experiments conducted by Lei et al. (1999) investigated the hydrodynamic forces and vortex shedding of a circular cylinder in different boundary layers at a Reynolds number range of 1.3×10^4 to 1.45×10^4. They suggested a quantitative method for identifying the vortex shedding suppression and observed that the critical gap ratio of the inception of vortex shedding suppression decreases as the thickness of boundary layer increases. Lei et al. (2000) identified a critical gap ratio versus Reynolds numbers up to 1,000. Price et al. (2002) visualized the flow around a circular cylinder near a plane wall for $1{,}200 < \mathrm{Re} < 4{,}960$ and $0 < G/D < 2$ and categorized the flow to four distinct regions based on the gap ratios, describing the status of vortex shedding in each region. Wang and Tan (2008) experimentally studied the flow characteristics in the near wake of a circular cylinder near a plane wall at the Reynolds number of 1.2×10^4 and for various gap ratios from 0.1 to 1. Their results showed that for the gap ratio $G/D \geq 0.3$, the flow is characterized by the periodic, Karman-like vortex shedding from the upper and lower sides of the cylinder, while for small and intermediate gap ratios ($G/D \leq 0.6$), the wake flow develops a distinct asymmetry about the cylinder centerline. Ong et al. (2010) investigated the onset of vortex shedding suppression numerically for flow around a circular cylinder near flat seabed at the Reynolds numbers of 1.31×10^4 and 3.6×10^6 considering the bed roughness effect. They reported the critical gap ratio between 0.1 and 0.15 in both cases but observed that the initiation of the vortex shedding occurs earlier when Re is larger. He et al. (2017), through PIV experiments, studied the dynamics of vortical structures in flow

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