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# The effect of arrangement of two circular cylinders on the maximum efficiency of Vortex-Induced Vibration power using a Scale-Adaptive Simulation model

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A B S T R A C T

The complex behaviour of an unsteady flow around two circular cylinders in tandem is of interest for many civil engineering applications across a wide range of aerospace, mechanical and marine applications. The present paper analyses Vortex-Induced Vibration (VIV) for the flow around two circular cylinders. It has been shown that the amount of kinetic energy which can be captured by VIV is a function of the arrangement of the two cylinders. The upstream cylinder is fixed while the downstream is mounted elastically with one degree of freedom normal to the mean flow direction. The efficiency of the VIV power obtained from downstream cylinder is compared for different arrangement of the cylinders. For this purpose, the longitudinal and lateral distances between the cylinders were varied and the Reynolds number was kept constant. Scale-Adaptive Simulation (SAS) and Shear Stress Transport (SST) CFD models are utilized to analyse the validity of the SAS turbulence model. The results indicate that both turbulence models predict the flow characteristics around the cylinders with reasonable precision; however, the predictions from SAS were more accurate compared to the SST. Based on this comparison, SAS model was chosen as a tool to analyse the VIV response of the downstream cylinder. The location of the downstream cylinder has been altered in the wake of upstream one in order to obtain the optimum efficiency of the VIV power. The results reveal that the arrangement of the cylinders can significantly change the efficiency. It is also observed that cylinders offset from one another show a higher efficiency compared to cylinders with their centres aligned.



## 1. Introduction

In regards to the abundance of water sources in the world, it is obvious that harnessing hydrokinetic energy can be a considerable source of energy for future generations. Hydropower energy can be extracted from different sources such as rivers, waves, tides, thermal and salinity gradients (Bernitsas et al., 2008). Güney and Kaygusuz (2010) compared different hydropower energy sources and predicted the global increasing demand on hydrokinetic energy generation in the near future. They expected that hydropower energy production, including ocean sources, will provide 200 GW of installed production capacity by 2025 (Fig. 1). Therefore, hydropower energy can be recognized as a significant source of electricity

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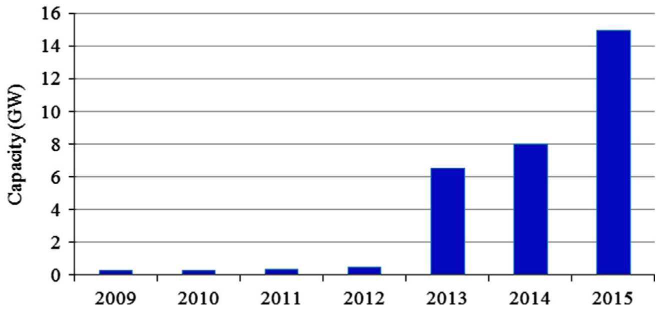


**Fig. 1.** Prediction of global hydrokinetic energy capacity between 2009 and 2015 (based on Güney and Kaygusuz (2010)).

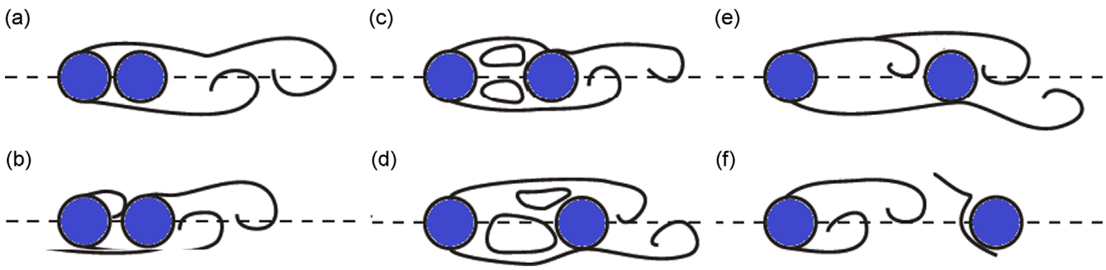


**Fig. 2.** Flow patterns around two stationary circular cylinders as a function of streamwise separation (a-f) (based on Igarashi (1981)).

production. This objective has encouraged the scientists and engineers to develop refined methods to harness the maximum available energy from the oceans and other source of water using different methods such as wave energy (Khan et al., 2009).

Vortex Induced Vibration (VIV) arises from the interaction of a moving fluid with an elastic structure. The number of publications on VIV is extensive (Bearman, 1984; Blevins, 1990; Khalak and Williamson, 1996, 1997; Zdravkovich, 1997; Govardhan and Williamson, 2000). Khalak and Williamson (1997) investigated the dynamic response of a circular cylinder and the effect of the mass ratio on the VIV mechanism. In their research, the displacement amplitude of a circular cylinder for very low mass and damping ratios has been categorized into three types; known as *initial*, *upper* and *lower* branches. In the initial category, the oscillation of the cylinder begins to build up and in the upper one resonance occurs with the maximum obtainable amplitude ratio. Finally, at the lower amplitude response, the oscillation of the cylinder is damped. Williamson (1996) also conducted a series of experimental studies to define the instability of the Strouhal number at low Reynolds numbers flows, $120 \leq Re \leq 260$. In addition, a comprehensive review of the flow around a circular cylinder has been undertaken by Williamson (1996), comparing previous numerical and experimental work which had focused on the wake of a circular cylinder.

Recently, it has been shown that the VIV mechanism has the potential to produce renewable energy and a great deal of attention has been devoted to research in this field (Bernitsas and Raghavan, 2004; Bernitsas et al., 2008, 2009; Chang et al., 2011; Lee et al., 2011; Raghavan and Bernitsas, 2011). In contrast to the more common turbine systems, the VIV mechanism can be categorized into a non-turbine system (Khan et al., 2009). For a turbine system the maximum theoretical efficiency is defined by the Betz limit which is equal to 16/27 or approximately 59.3% for a single and open free blade (Van Kuik, 2007). However, the efficiency of mechanical or electrical processes reduces the overall output with a total actual efficiency of the system ranging between 20% and 55% (Vries, 1983). In contrast to the turbine system, the theoretical efficiency of a VIV as a non-turbine system was calculated 37%, while the efficiency from experiments has been measured 22% (Bernitsas et al., 2008). The efficiency achievements of researchers investigating energy production from VIV suggest that further study is warranted.

For two aligned cylinders in tandem, the wake of the upstream cylinder is highly dependent on the streamwise separation between the cylinders and the resulting flow may be categorized into six different patterns (Igarashi, 1981). This tandem configuration has been studied experimentally and numerically by Zdravkovich (1987) and Carmo (2005), respectively. Fig. 2 illustrates the flow patterns of the unstable shear layers as a function of the distance between two cylinders (patterns A to F). In the case where the distance between cylinders is less than 1.5$D$, where $D$ is the diameter of the cylinder, the vortices have no interaction in the wake area (patterns A and B). By increasing the separation of the cylinders to $1.5 < x/D < 3$, (patterns C and D), two recirculation regions appear in the wake of the upstream cylinder. Initially, the vortices are symmetric and later they alternate to the asymmetric reattachment of shear layers. Therefore, it can be concluded that a mean value of the sinusoidal lift force of the upstream cylinder is equal to zero (Assi, 2009). For larger spacings between the cylinders, the shear layers begin to roll up in the wake and finally a fully developed vortex street is formed behind the upstream cylinder.