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ORIGINAL

Numerical study of convective heat transfer and fluid flow around two side by side square cylinders using $k-\omega-\overline{\upsilon^2}-f$ turbulence model

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Abstract The effect of spacing between two identical square cylinders placed side by side on the fluid flow and heat transfer is numerically investigated using $k-\omega-\overline{\upsilon^2}-f$ turbulence model. The present study is performed at $Pr = 0.7$ and $Re = 10{,}000$, 21,000 for different scaled gap spacing between cylinders in the range of $Gl = 0.5$–6. It should be noted all geometrical lengths such as Gl are scaled with cylinders side. In order to show the accuracy of $k-\omega-\overline{\upsilon^2}-f$ model, part of the results such as various flow patterns (flip-flop, in-phase and anti-phase) and global quantities are compared with the available numerical and experimental results and also a Large Eddy Simulation study of the present work. Based on this comparison, a close agreement is observed. The local and averaged flow and thermal quantities are also compared for two side by side square and circular cylinders and some significant similarities and differences are presented. Progressive increasing and decreasing of the distance between cylinders indicates that the hysteresis phenomenon appears for the gap spacing in the range of $Gl = 1$–2.5. In the hysteresis range, two different patterns are observed for each distance in the aforementioned range. Also in this range, two different values are found for different quantities such as lift and drag coefficients, Strouhal number and Nusselt number.

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1 Introduction

The flow over two- and three-dimensional cylinders with different arrangements, (tandem, staggered and side by side) are always recognized as the relevant objects in various industrial applications. In spite of their simple geometry, the formation of flow around this type of geometries contains the main flow characteristics such as separation and reattachment, wake, shear layer instabilities and vortex shedding.

So far, some studies have been conducted for the flow over cylinders with side by side arrangement with circular [1–8] or square [9–15] cross section in various ranges of the Reynolds numbers (*Re*) and gap spacing between cylinders (*G*). Based on the references mentioned and the gap spacing of the cylinders, generally two main flow patterns occur. In the first one, the wake created behind the cylinders is asymmetric and with no orderly pattern. This flow pattern is recognized as the "flip-flopping" or bi-stable flow regime (see Fig. 1a). The second one is known as the "synchronized" regime where, the vortex shedding from the cylinders occurs with either in-phase or anti-phase patterns (see Fig. 1b, c). In both in-phase and anti-phase patterns, two distinct vortex streets separate from the cylinders. For the in-phase pattern, the vortex pairs rotate around each other at the downstream and leads to a single large wake at downstream while, in anti-phase pattern the vortices can stably proceeds to the far downstream wake zone.

Before presenting a literature review of various numerical and experimental studies on side by side circular and square cylinders for different ranges of Reynolds numbers, it should be noted that the scaled cylinder spacing is defined as the distance between the center to center of the cylinders in some reported works, *G*, while in the