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Numerical Analysis of Flow Past Four Circular Cylinders

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ABSTRACT

The complex phenomenon of flow past a single circular cylinder is analysed for different Reynolds number. Drag coefficient, Lift coefficient, Strouhal number, streamlines and vortex shedding is observed for $60 \leq Re \leq 80$. As Reynolds number increases drag coefficient decreases while lift coefficient increases. Strouhal number also increases with increase in Reynolds number. When more than one cylinder are present in the flow regime their vortex shedding affect each other depending upon surface spacing ratio (s/d) between cylinders. Therefore, we also analysed the complex phenomenon of flow behaviour over four circular cylinders which are arranged in square configuration with different spacing. As the spacing decreases, consequently reattachment and shielding type of flow patterns are observed. As the spacing changes, time signal of coefficient of drag and lift also differ; at larger spacing only vortex shading frequency appears in the signal; cylinders behave independently, and there is no interaction between the wakes of the cylinders.

Keywords— Reynolds number,Strouhal number,S/D,Wake,Numerical Analysis of Flow.

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I. INTRODUCTION

In spite of extensive experimental and numerical studies almost over a century, flow around a circular cylinder still remains a challenging problem in fluid mechanics, where intensive investigations are continued even today to understand the complex unsteady dynamics of the cylinder wake flow.Translational flow past a three-dimensional circular cylinder is a widely studied phenomenon since this problem is of interest with respect to many technical applications.In scientific terms, the flow around circular cylinders includes a variety of fluid dynamics phenomena, such as separation, vortex shedding and the transition to turbulence.The present report concerns with fluid flow over four circular cylinders. Cylinders arrange in a square format such that each cylinder is at each corner of square with different surface spacing ratios between cylinders. There are many investigations done on a pair of cylinders in side by side, tandem and staggered arrangement to justify flow pattern at different Reynolds number and spacing with respect to streamline. But the cause of different flow pattern generate around the cylinder are discussed here using four cylinders to clearly understand the physics of flow behind the cylinder. When there are more than one cylinder in flow, the vortex shedding behind the cylinder affects each other and form different flow regions with respect to spacing between them. So here the stimulations of flow past four cylinders spaced at different surface spacing are analysed. The structured Cartesian quadrilateral grid is used for flow regime is fine near the cylinder and coarse at a far distance while fine structure quadrilateral grid is formed around the circular cylinder. All cylinders of equal diameter (d) and equal surface spacing (s) between the cylinders is used. The non-dimensional parameter surface spacing s/d and Reynolds number, $Re=U_{\infty}d/\nu$ are important parameters on which flow behaviour depends. We analysed results of flow behaviour past four cylinders with different surface spacing ratios between cylinders.Experimental study of the flow around a circular cylinder has identified regions where significant patterns of flow occur as the Reynolds number changes, especially when the flow changes from laminar to turbulent state. Generally, the following regimes have been identified from experiment

$40 < Re < 150$	stable range
$150 < Re < 300$	transition range
$300 < Re < 200{,}000$	Irregular range

Vortex shedding behind the cylinder is affected when one or more than one circular cylinder comes near to it in given flow. The vortex shedding of each cylinder is also affected by transverse spacing between the cylinders. Time signals of lift and drag coefficient also varies as spacing changes between the cylinders.To investigate flow past four circular cylinders with different spacing ratios, this study includes effect of Reynolds number, Re = 100 and Re = 150 and gap between cylinders on flow pattern, vortex shedding, effect of Reynolds number, Strouhal number.

II. RESEARCH ELABORATION

A. STUDY OF FLOW PAST A CIRCULAR CYLINDER

Analysis of shedding process and flow behaviour behind a single circular cylinder would greatly help to understand the flow characteristics of four circular cylinders in square pattern.

The lift and drag coefficient, Strouhal number and Reynolds number are defined as follows:

$$C_L = \frac{F_L}{\frac{1}{2}\rho A u^2} \qquad C_d = \frac{F_D}{\frac{1}{2}\rho A u^2} \qquad St = \frac{f\ d}{v_o}$$

$$Re = \frac{\rho d U_o}{\mu}$$

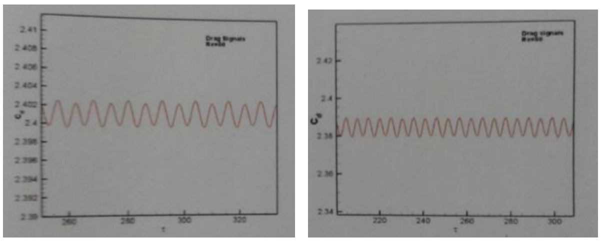
Where F_L and F_D denote lift and drag force, respectively. St is the non-dimensional form of vortex shedding frequency, called Strouhal number where, d is cylinder diameter and f is the frequency of vortex shedding, which can be calculated from oscillation frequency of lift force. The simulation result of flow past a stationary circular cylinder are presented for mean drag coefficient, root mean square value of list coefficient and Strouhal number and these are compared with other numerical and experimental results.

B. DRAG COEFFICIENT

In fluid dynamics, the **drag coefficient** is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment, such as air or water. It is used in the drag equation, where a lower drag coefficient indicates the object will have less aerodynamic or hydrodynamic drag.

For a given work drag coefficients are computed for various Reynolds numbers ranging from 60 & 80. From this analysis it can be observed that as Reynolds number increases the amplitude of drag coefficient decreases.

The flow depends strongly upon Reynolds number. When the Reynolds number are small(1 and below) the flow behaves like a potential flow. There is no separation. The drag is all due to skin friction. As the Reynolds number is increased this drag deceases. At Reynolds numbers around 2-30, there is a separation of boundary layer, but the wake is of a limited length. The eddies formed seem fixed behind the cylinder. For Reynolds numbers close to 40-70, there is a periodic oscillation of the wake. For higher Reynolds number the eddies break off from the cylinder. As the Reynolds number is increased, the eddies are continuously shed from the cylinder and washed downstream. Two rows of vortices are formed called the Vortex Street.



(a) (b)

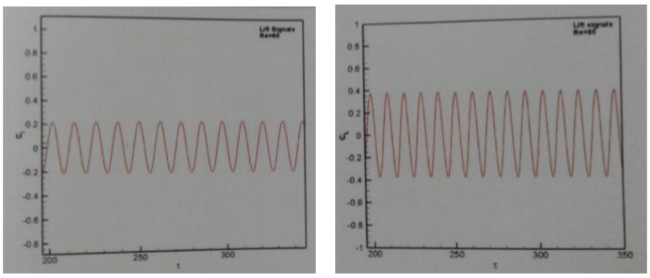
Fig. Drag coefficient for stationary circular cylinder (a) Re=60, (b)Re=80

C. LIFT COEFFICIENT

The lift coefficient can be approximated using the lifting-line theory,[4] numerically calculated or measured in a wind tunnel test of a complete aircraft configuration.

For a given work lift coefficients are computed for Reynolds numbers Re=60& Re=80

From this analysis it is observed that as the reynolds number increases amplitude of lift coefficient decreases.



(a) (b)

Fig. Lift coefficient for stationary circular cylinder (a) Re=60, (b)Re=80

D.STREAMLINES AND VORTICITY CONTOURS

Streamlines are a family of curves that are instantaneously tangent to the velocity vector of the flow. These show the direction a mass less fluid element will travel in at any point in time. Different streamlines at the same instant in a flow do not intersect, because a fluid particle cannot have two different velocities at the same point.

Streamline equation can be stated as follows:

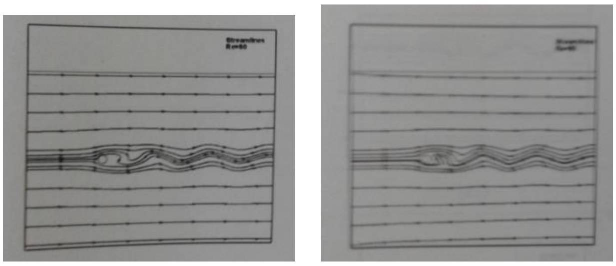
$$\frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w}$$

Vorticity dynamics is the natural paradigm for the field of complex motion of fluid. Therefore, vorticity contours are obtained by determining the vorticity at all the grid points in the computational domain.

Vorticity is defined as the curl of the fluid velocity. It can be considered as the circulation per unit area at a point in the fluid flow field. For two dimensional flow fields, the vorticity vector is perpendicular to the plate. Mathematically vorticity is given as

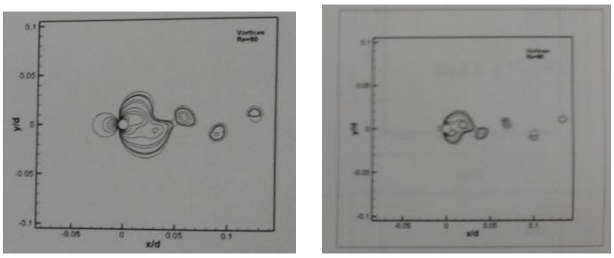
$$\frac{dv}{dx} - \frac{du}{dy}$$

The streamline pattern of given results for circular cylinder follows its vortex shedding as vortex shed from upper half portion of the cylinder which is pointed downward, same time the streamline goes downward and as the vortex shed from lower half portion of the cylinder pointed upwards, the streamline waves follows the same form.



(a) (b)

Fig. Streamlines for stationary circular cylinder (a) Re=60, (b)Re=80



(a) (b)

Fig. Vorticity contours for stationary circular cylinder (a) Re=60, (b)Re=80

III. ANALYSIS OF FLOW PAST FOUR CIRCULAR CYLINDERS

For this work mean drag coefficient and root mean square value of lift coefficient are computed for different spacing(s/d=1,2) at Re=100. From this analysis it is observed that both coefficient are largely affected by the spacing between cylinders.

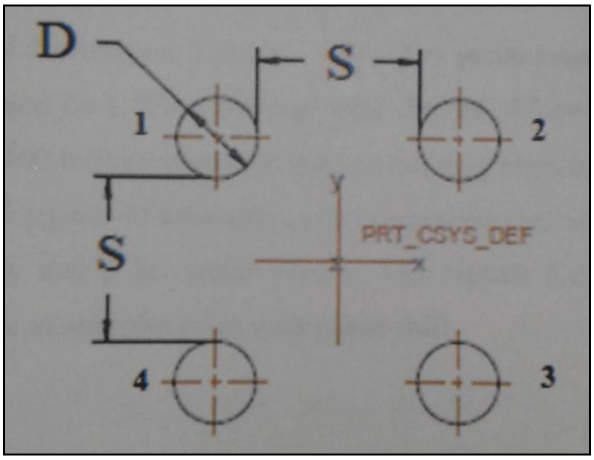
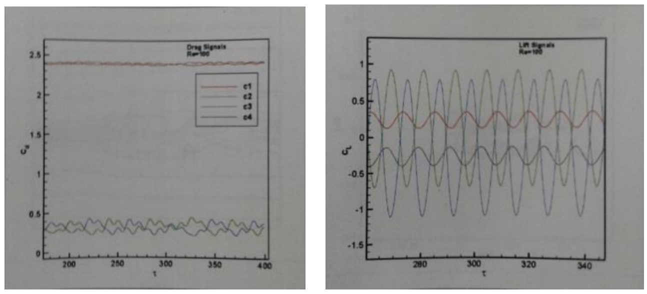


Fig. Geometry of Four Cylinders in Square Configuration

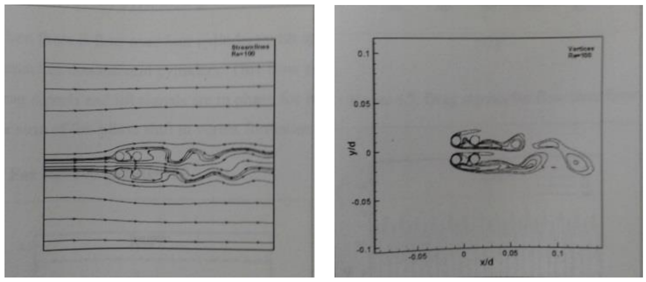
Generally the force coefficient of upstream cylinders and those of downstream cylinders are almost same due to the flow symmetry of x-axis.

RESULTS FOR S/D= 1

When spacing ratio between cylinders is 1, they are closely places which cause wake interaction of upstream and downstream cylinders. The flow pattern may be called as chaotic flow or shedding flow.



(a) (b)

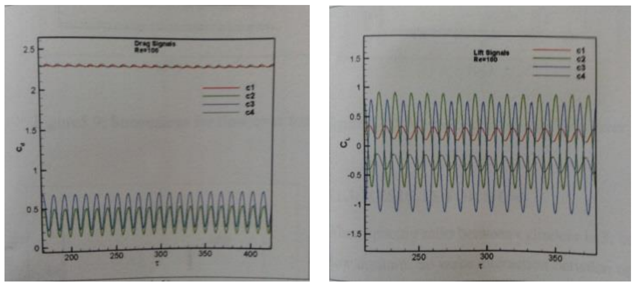


(c) (d)

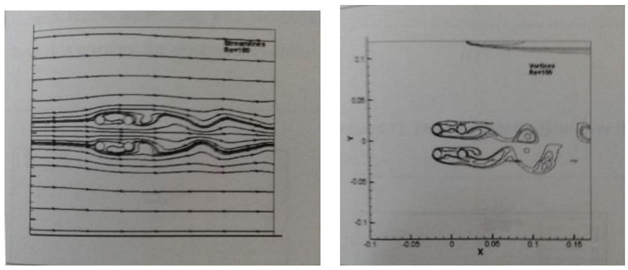
Fig. Drag signals(a),lift signals(b),Streamlines(c),Vorticity contours(d) for flow over four cylinders with (S/D)=1 at Re=100.

RESULTS FOR S/D= 2

hen there is flow over four cylinders with spacing ratio 2, shear layer from upstream cylinders reattaches downstream cylinders. This flow pattern may be called as reattachment flow regime



(a) (b)



(c) (d)

Fig. Drag signals(a),lift signals(b),Streamlines(c),Vorticity contours(d) for flow over four cylinders with (S/D)=2 at Re=100.

IV. SCOPE OF WORK

Computational Fluid Dynamics (CFD) calculates numerical solutions using the equations governing fluid flow. The flow past circular cylinders has been extensively studied due to its importance in many practical applications, such as Heat Exangers, Chimneys, and Hydrodynamic loading on ocean marine piles and offshore platform risers and support legs

V. Conclusion

A numerical simulation of flow over cluster of four circular of four circular cylinders in square configuration is an object of study carried out using ANSYS CFD and finite volume method for different surface spacing ratio ($1 \leq S/D \leq 2$) and for Reynolds number of 100.

The result of flow over circular cylinder at different Reynolds number ($60 \leq Re \leq 80$) is very well analyzed. We analyzed that, as Reynolds no. increases drag force on a circular cylinder decreases. Drag coefficient decreases from 2.413 to 2.392 for $60 \leq Re \leq 80$, whereas lift force increases with Reynolds number. Lift coefficient increases from 0.1365 to 0.1397 for $60 \leq Re \leq 80$.

The aim of this project is to understand the physics of flow around one and four circular cylinders interacting in flow field. The flow pattern for different spacing ratio $1 \leq S/D \leq 2$ changes from different kinds of flow patterns is observed. It can be seen that flow near downstream cylinder 2 oscillates due to influence of wake of upstream cylinder 1. Moreover drag force acting on cylinder 1 should be much larger than that on the downstream cylinders since cylinder 2 are completely shielded by the upstream cylinders.

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