

Flow around Two Cam Shaped Cylinders in Tandem Arrangement

Arash Mir Abdollah Lavasani and Hamidreza Bayat

Abstract—In this paper flow around two cam shaped cylinders had been studied numerically. The equivalent diameter of cylinders is 27.6 mm. The space between center to center of two cam shaped cylinders is define as longitudinal pitch ratio and it varies in range of $2 < L/D_{eq} < 6$. Reynolds number base on equivalent circular cylinder varies in range of $50 < Re_{eq} < 300$. Results show that drag coefficient of both cylinders depends on pitch ratio. However drag coefficient of downstream cylinder is more dependent on the pitch ratio.

Keywords—Cam shaped, tandem cylinders, numerical, drag coefficient.

I. INTRODUCTION

THE Spatial arrangement of two cylinders can be classified into three categories, namely, aligned with the direction of the main flow (in tandem), placed side-by-side, and placed in a staggered arrangement. In the tandem arrangement, the flow field and heat transfer depend highly on the configuration and the spacing of the cylinder pair due to both wake and proximity-induced interference effects.

There are many experimental and numerical studies [1]–[4] devoted to the flow and heat transfer over two circular cylinders with different arrangement. As it is clear from the previous studies [5], [6] drag coefficient of circular tube is more than streamline cylinder. There are some studies about flow around tandem streamline cylinder.

Flow around two elliptic cylinders in tandem arrangement was experimentally investigated by Ota and Nishiyama [7]. The elliptic cylinders examined had an axis ratio of 1:3 and they were arranged in tandem with an identical angle of attack. The angle of attack was ranged from 0 to 90 deg and the nondimensional cylinder spacing L/C from 1.03 to 4.0, where L denotes the distance between the cylinder centers and C is the major axis. It has been found that the flow characteristics vary drastically with the angle of attack and also the cylinder spacing.

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Nishiyama and Ota [8] studied experimentally heat transfer characteristics of two elliptic cylinders having an axis ratio 1:2. They were placed in tandem arrangements and their angles of attack to the upstream uniform flow were identical. The testing fluid was air and the Reynolds number based on the major axis length C ranged from about 15,000 to 80,000. The angle of attack was varied from 0 to 90 deg at 30 deg intervals and the nondimensional cylinder spacing L/C from 1.25 to 4.0. It has been found that the heat transfer features vary drastically with the angle of attack and also with the cylinder spacing.

They were also found that, at narrower cylinder spacing and smaller angles of attack, the heat transfer capacity of the elliptical cylinders considered here is comparable to that of inline circular cylinders.

The aim of characterizing its features or developing reduced-order models that predict the induced drag forces on it. So, the purpose of this study is to numerically investigate the flow characteristics of two cam shape cylinders of equal equivalent diameter in tandem arrangements subject to cross flow of air.

II. PROBLEM DESCRIPTION AND GOVERNING EQUATIONS

The cross section profile of the cylinder comprised some parts of two circles with two line segments tangent to them. The cylinder have identical diameters equal to $d=11$ mm and $D=22$ mm with distance between their centers, $l=13$ mm, (Fig. 1). Characteristic length for this tube is the diameter of an equivalent circular cylinder, $D_{eq}=P/\pi =27.6$ mm, whose circumferential length is equal to that of the cam-shaped cylinder.

The typical solution domain and the cylinder boundary definition and nomenclature used in this work are shown in Fig. 2. The inlet flow has a uniform velocity U_{∞} . The velocity range considered only covers laminar flow conditions. The solution domain is bounded by the inlet, the outlet, and by the plane confining walls, AB and CD. These are treated as solid walls, while AC and BD are the flow inlet and outlet planes.

In order to decrease the effect of entrance and outlet regions, the upstream and downstream lengths are $15D_{eq}$ and $50D_{eq}$, respectively and for neglecting the wall effects on cylinders the distance between walls is $30D_{eq}$.

Equations are written for conservation of mass and momentum in two dimensions. Cartesian velocity components U and V are used, and it has been assumed that the flow is steady and laminar, while the fluid is incompressible and Newtonian with constant transport properties.

Furthermore, the effect of viscous dissipation is neglected. The governing equations consist of the following three equations for the dependent variables U, V and P are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

$$\rho \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = -\frac{\partial P}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \quad (2)$$

$$\rho \left(u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial P}{\partial y} + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (3)$$

Equations (1) to (3) are the conservation of mass, x and y direction momentum equations, respectively. The boundary conditions used for the solution domain shown in Fig. 2 are uniform inlet velocity, fully developed outflow and no-slip cylinder surface boundary. The total drag coefficient for a cam shaped cylinder is

$$C_D = \frac{F_D}{0.5 \rho U_\infty^2 D_{eq}} \quad (4)$$

Where, F_D is the total drag force exerted by the fluid on the cylinder per unit cylinder length.

III. NUMERICAL METHOD

This problem considers a 2D section of a cam shaped cylinder. For the simulations presented here, depending on the geometry used, fine meshes of 150000 to 200000 elements for $L/D_{eq}=2$ to 6 were used. The computational grids used in this work were generated using the set of regions shown in Fig. 3.

In this domain quadrilateral cells are used in the regions surrounding the cylinder walls and the rest of the domain. In all simulation, a convergence criterion of 1×10^{-6} was used for all variables.

The governing equations with appropriate boundary conditions are solved using finite volume approach based in Cartesian and coordinate systems.

The second order upwind scheme was chosen for interpolation of the interpolation of the flow variables. The SIMPLEC algorithm [9] has been adapted for the pressure velocity coupling.

IV. RESULTS AND DISCUSSION

For the purpose of the validation of the solution procedure, it is essential that CFD simulations be compared with experimental data. Fig. 4 compares the drag coefficient circular cylinder with the results of Zhukauskas [10]. There is a difference of about 8 percent between the present results and the results of Zhukauskas. It can therefore be concluded that the CFD code can be used to solve the flow field for similar geometries and conditions.

The effect of the longitudinal pitch ratio from 2 to 6 over total drag coefficient presented in Fig. 5 and for cam shaped cylinders.

However, the drag coefficient for the downstream cylinder increases about 56 percent as the pitch ratio increase from 2 to 6 but the drag coefficient for upstream cylinder will be more like single cylinder in cross flow.

Fig. 6 and Fig. 7 represent CDP and CDF. As the pitch ratio increase from 2 to 6, CDP and CDF increase about to 61 and 47 percent respectively.

V. CONCLUSION

In this study flow around two cam shaped cylinders had been investigated. The dependency of the drag coefficient for cam shape cylinders on the longitudinal pitch ratio is quite clear from the results.

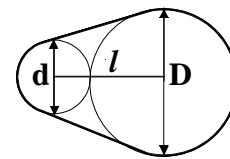


Fig. 1 Schematic of a Cam Shape Tube

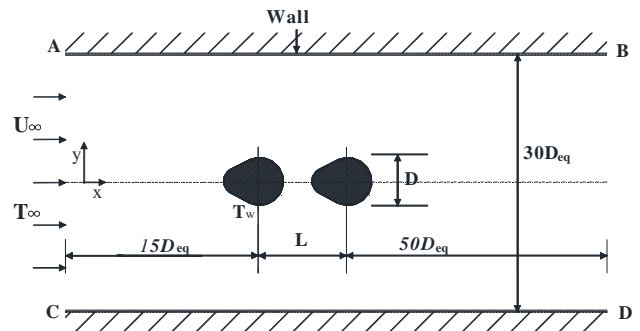


Fig. 2 Solution Domain

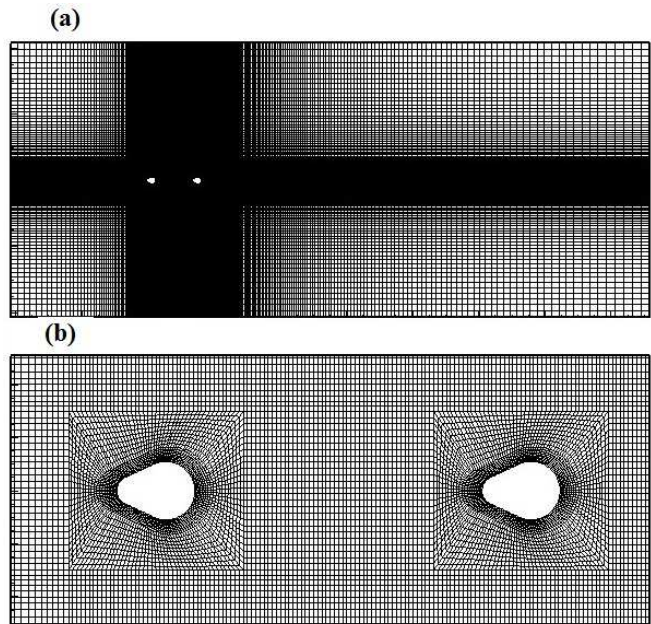


Fig. 3 Computational grid: (a) entire computational domain, (b) closer view around cylinders

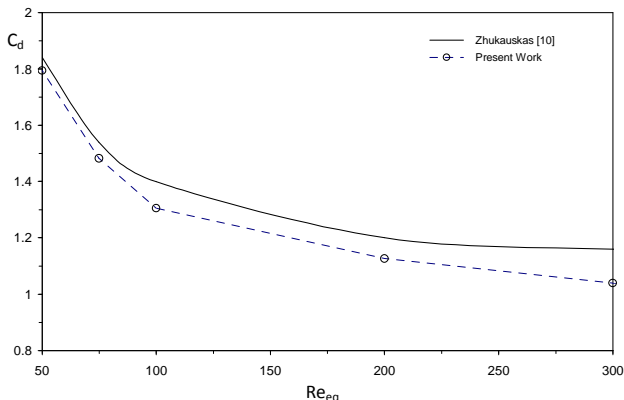


Fig. 4 Comparison of experimental and numerical drag coefficient

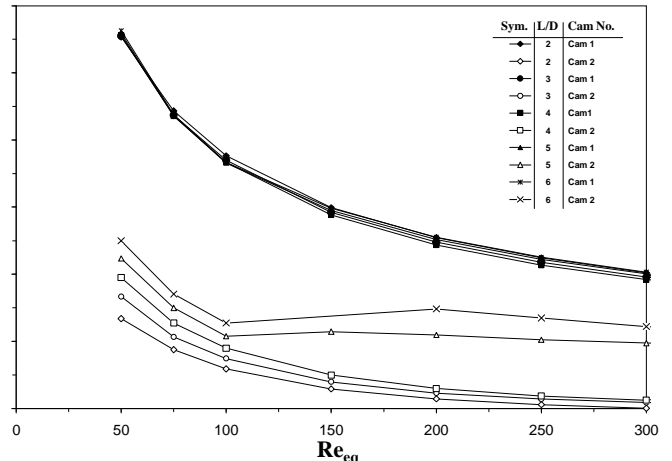


Fig. 7 Variation of CDF with Reynolds number and pitch ratio

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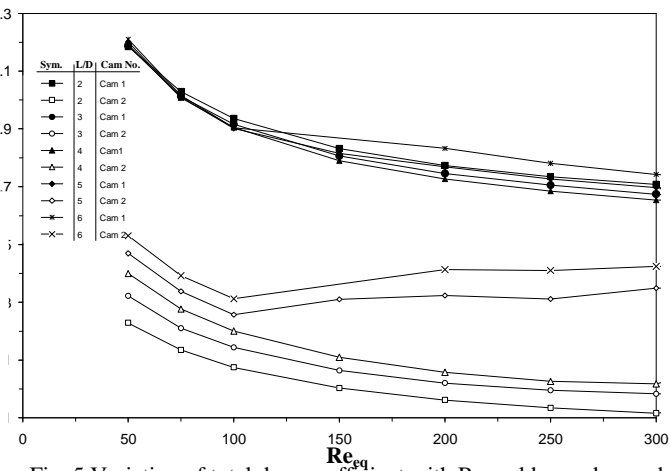


Fig. 5 Variation of total drag coefficient with Reynolds number and pitch ratio

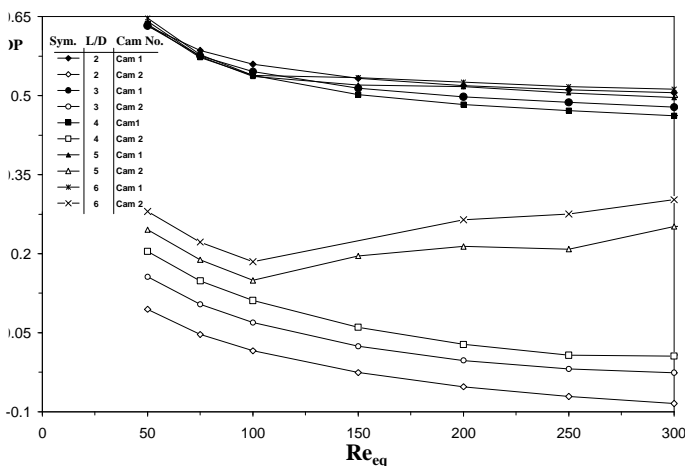


Fig. 6 Variation of CDP with Reynolds number and pitch ratio

NOMENCLATURE

- d Small diameter
- D Large diameter
- L Distance between centers of two cam cylinders
- l Distance between centers
- P Pressure, circumferential length
- Re Reynolds number, $U_x D/n$
- U x-direction velocity
- V y-direction velocity
- X Distance between stagnation point and every Point on circumferential length

(i) Greek

- ρ Density
- μ Kinematic viscosity

(ii) Subscripts

- Cam Cam-shaped cylinder
- Cir Circular cylinder
- eq Equivalent
- ∞ Free stream

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