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Heat Transfer from Two Cam Shaped Cylinders in Tandem Arrangement

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***Abstract*—**Heat transfer from two cam shape cylinder in tandem arrangement had been studied numerically.

The distance between the centers of cylinders (L) is allowed to vary to change the longitudinal pitch ratio (L/D_{eq}). The equivalent diameter of the cylinder (D_{eq}) is 27.6 mm and longitudinal pitch ratio varies in range $2<L/D_{eq}<6$. The Reynolds number based on equivalent circular cylinder are within $50< Re_{eq} <300$. Results show that Nusselt number of second cylinder increases about 5 to 33 times when longitudinal pitch ratio increases from 2 to 6.

***Keywords*—**Cam Shaped, tandem Cylinders, Numerical, Heat Transfer.

I. Introduction

THE convection heat transfer around multiple bluff bodies has wide engineering applications such as heat exchangers, space heating, cooling towers, oil and gas pipelines, electronic cooling and so on.

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 and heat transfer 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.

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It has been found that the flow characteristics vary drastically with the angle of attack and also the cylinder spacing.

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 spacings and smaller angles of attack, the heat transfer capacity of the elliptical cylinders considered here is comparable to that of in-line 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 convection heat transfer 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, Deq=P/π=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 Figure 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, momentum and energy 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 thermal and transport properties. Furthermore, the effects of buoyancy and viscous dissipation are neglected. The governing equations consist of the following four equations for the dependent variables U, V, P and T:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

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

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

$$\frac{\partial}{\partial x}(uT)+\frac{\partial}{\partial y}(vT)=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

Equations 1 to 4 are the conservation of mass, x and y direction momentum and energy equations, respectively. The boundary conditions used for the solution domain shown in Figure 2 are uniform inlet velocity, outflow and no-slip cylinder surface boundary. The Nusselt number for a cam cylinder is respectively as follows:

$$Nu=\frac{q\,D_{eq}}{A\,k\,\Delta T} \tag{5}$$

Where q is the total rate of heat transfer to the fluid and A is the total surface area of tubes. The temperature of the cylinders wall is 400 K and the bulk temperature of the cross-flow air is 300 K and ΔT is the difference between these temperatures.

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 Figure.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 numerical simulations be compared with experimental data. Figure.4 compares the Nusselt number of circular cylinder with the results of Zhukauskas [11]. There is a difference of about 3 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 effects of the longitudinal pitch ratio on the velocity distribution outside the boundary layer for Re=200 are shown in Figure 5.

Effects of the increasing longitudinal pitch ratio from 2 to 6 over total heat transfer of the first and second cam shaped cylinders presented in Figure 6. By comparing the heat transfer from single cam shape cylinder with the first cylinder in this study it can be seen that the effect of longitudinal pitch ratio on Nusselt number for the first cam shape cylinder is about 0.3 to 7 percent for 2<L/Deq <6 .However longitudinal pitch ratio has considerable effect on Nusselt number of the second cylinder. Results show that by increasing pitch ratio from 2 to 6 Nusselt number of second cylinder increase about 5 to 33 percent.

Figure 7 shows the relations between Nusselt number with drag coefficient and Reynolds number for various pitch ratio of first cylinder.

V. Conclusion

In this study heat transfer of two cam shaped cylinders in tandem arrangement had been investigated. The dependency of the Nusselt number for cam shape cylinder on the longitudinal pitch ratio is quite clear from the results. The heat transfer from the first cylinder is similar to single cylinder when pitch ratio increases more than $4D_{eq}$. However the results show that pitch ratio has more effect on heat transfer from second cylinder, by increasing the pitch ratio from 2 to 6 Nusselt number increases about 5 to 33 percent.

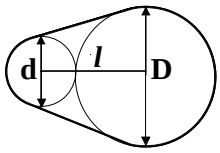

Fig. 1 Schematic of a Cam Shape Tube

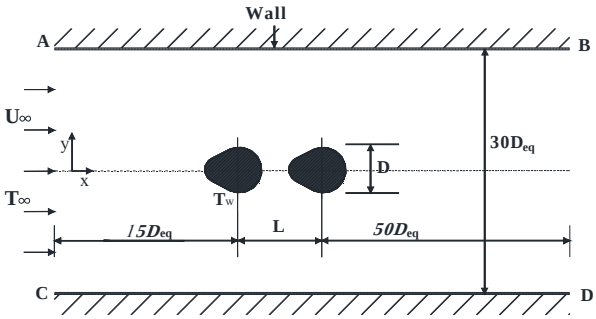

Fig. 2 Solution Domain

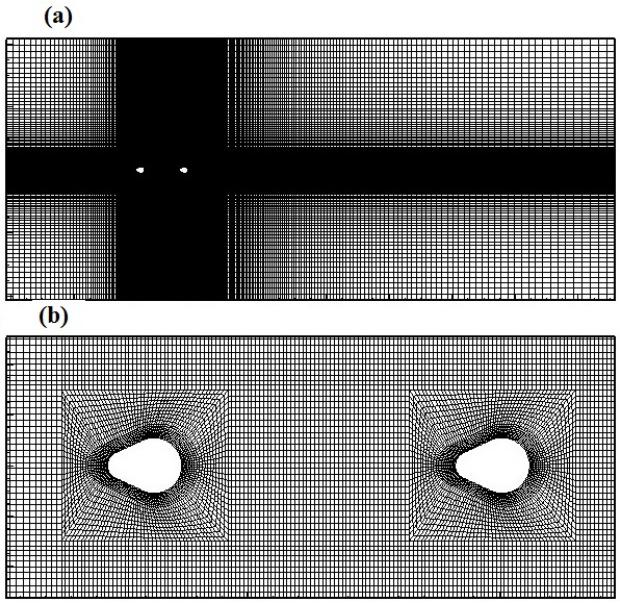

Fig. 3 Computational grid: (a) entire computional domain, (b) closer view around cylinders

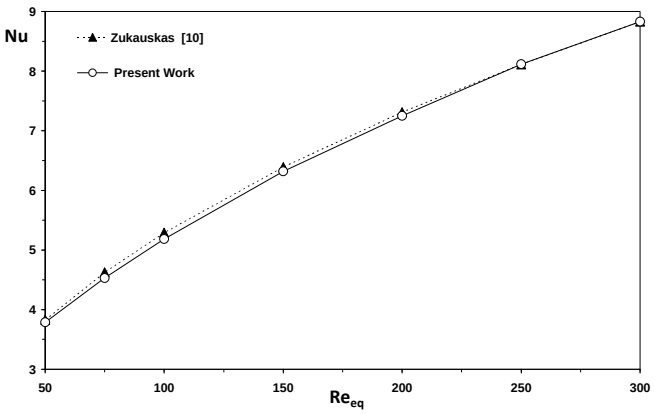

Fig. 4 Comparison of experimental and numerical heat transfer

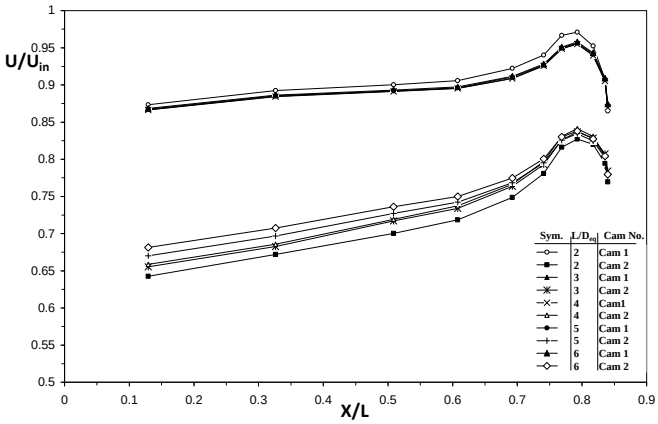

Fig. 5 Effect of longitudinal pitch ratio on velocity distribution for Re_{eq}=50

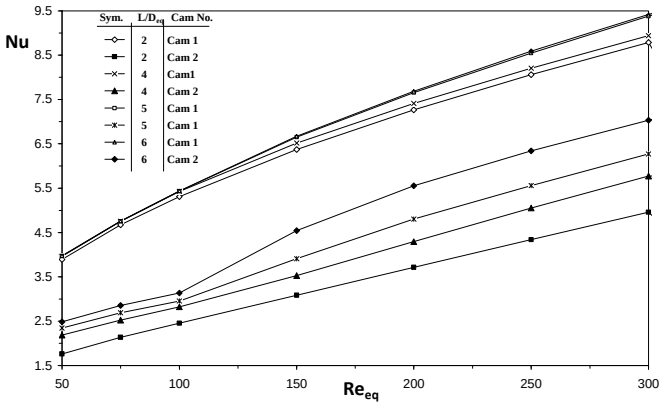

Fig. 6 Variation of Nusselt number with Reynolds number and longitudinal pitch ratio

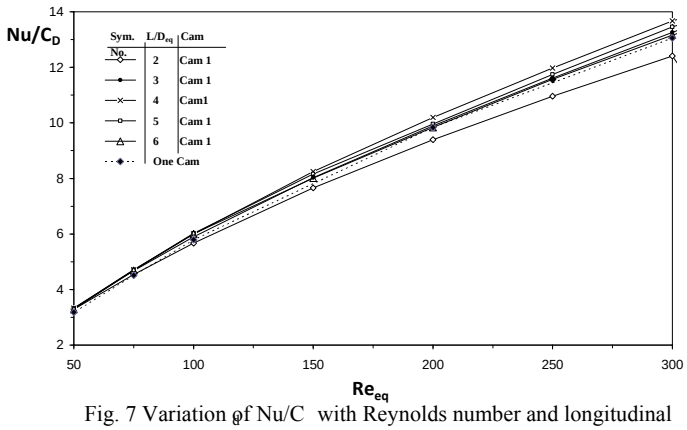

Fig. 7 Variation of Nu/C_D with Reynolds number and longitudinal pitch ratio

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, $U_\infty D/n$
St	Stanton number, Nu/(Re.Pr)
T	Temperature
U	x-direction velocity
V	y-direction velocity
X	Distance between stagnation point and every Point on circumferential length

(i) Greek

r	density
n	kinematic viscosity

(ii) Subscripts

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

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