Flow over three circular cylinders in lateral arrangement with different diameters

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***Abstract*: Flow over a circular cylinder is quite complex to study. Since the cylinder has symmetrical shape, wake formations are quite low and affect the flow stream. Several problems involving the flow of fluid around submerged objects are encountered in the various engineering fields. Such problems may have either a fluid flowing around a stationary submerged object, an object moving through a large mass of stationary fluid or both the object or the fluid being in motion. In the analysis and design of such objects, the knowledge of forces exerted on them by the fluid is of great significance. The following study involves analysis of wake and proximity interference effects which will be determined. We will review the current understanding of the flow around two circular cylinders with varying distances between them. The flow visualization parameters, the Strouhal numbers, and drag and lift coefficients will be comprehensively presented and compared for different cases in order to reveal the effect of the Reynolds number and gap spacing on the behavior of the flow.**

I. INTRODUCTION

Several problems involving the flow of fluid around submerged objects are encountered in the various engineering fields. Such problems may have either a fluid flowing around a stationary submerged object, an object moving through a large mass of stationary fluid or both the object or the fluid being in motion. Some of the examples which may be quoted are the motion of very small objects such as fine sand particles in air or water, very large objects such as airplanes, automobiles, submarines, etc., moving through air or water and the structures such as buildings, bridges, etc. which are submerged in air or water. In the analysis and design of such objects, the knowledge of forces exerted on them by the fluid is of great significance. When the free-stream velocity exceeds a certain critical value in flow past a bluff body, vortex shedding occurs due to the flow instability in the near wake, resulting in periodically oscillating drag and lift forces. Such fluctuating forces may cause structural vibrations, acoustic noise and resonance, which in some cases can trigger structure failure or enhance mixing in the wake. Therefore, it is very important to appropriately control vortex shedding in practical engineering environment.

Singh et al 1998 [1] numerically studied steady and unsteady periodic mixed convection heat transfer for flow of air around a hot/cold circular cylinder in a vertical adiabatic channel, with parabolic inlet velocity profile at Re = 100, -1 < Ri < 1 and a blockage ratio of 25%. They found the ''breakdown'' of Karman vortex street at Ri = 0.15. All the work discussed above on the channel-confined mixed-convective flow is for the circular cylinder.
The Flow around two cylinders is more complex than wake from single cylinder. When s/d < 5, the two wakes interact in a rather complicated manner resulting in a variety of flow patterns. When s/d > 5, there were no wake interaction is observed by Le Gal P et al. [2] and Williamson CHK [3].

Kim et al. [4] conclude that the changeover between synchronized and flip-flop for circular cylinders occurs at s/d = 1 and is accompanied by a drastic change in flow properties. Spivak [5]found that the shedding frequencies behind one cylinder were greater than the other in this state.

Ishigai and Nishikawa [6] experimentally investigated the flow downstream of five side by-side circular cylinder for $\mathrm{Re} = 4000 - 33000$, along with other configuration not of interest here. They used the Schlieren technique with special attention to dependence of the vortex formation region and the Coanda effect on the gap flow. The Strouhal number is almost double when the spacing reduced from $s/d = 1.5$ to 0.2.

The objective of this review is to study the effect of surface spacing ratio at low Reynolds number of 100 and to analysis the flow behaviour beyond the above observation. To examined the jet form between cylinders and their effect of dynamics of wake. To brief out the combined effect of Reynolds number, spacing ratio, mean drag coefficient and root mean square of lift and vortex shedding.

II. PROBLEM STATEMENT

The physical model considered here is three different circular cylinders arranged in row shown in Fig.1.1. Let the cylinder diameters (d_1,d_2 and d_3) and the incoming flow velocity Uo be the non-dimensional characteristic length and velocity respectively. The non-dimensional horizontal surface distance between each two cylinders s/d is used to recognize geometrical configuration, where's' is the surface distance between two cylinders. The coordinate origin is located at first cylinder's centre, and the x-axis is the mean flow velocity direction, while y-axis velocity is kept zero. Initial condition of x-velocity to start the simulation considered as a zero. The differential equation governing incompressible, viscous, unsteady and 2d-fluid flow comprises the continuity equations which are written as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (2.1)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+\frac{1}{Re}\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right] \qquad (2.2)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial y}+\frac{1}{Re}\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right] \qquad (2.3)$$

Where u and v are the velocity components, , the dynamic viscosity of the fluid and is the fluid density. The density is assumed to be constant in calculation due to the incompressibility of fluid. Air is used as fluid medium. As Flow is incompressible with =1.225 and throughout the current study. The flow configuration is shown in Figure 1.1. Three fixed two-dimensional circular cylinders with diameter d_1=0.01m ,d_2=0.015 m and ,d_3=0.02m which is also characteristic length scale, are exposed to constant and uniform velocity Uo. The Length of computational domain in streamwise direction is taken to be $L_x = L_u + d + L_d$, where L_u is the upstream length and L_d the downstream length from the origin. In this case L_u = 7d and L_d =10d are used for the computational domain. The number of points along the lateral direction is L_y = (3*(8d+s)), where s is the spacing between two cylinders. Using above two formula of Lx and Ly the different boundary dimension are created for s/d=0.05 m to s/d=0.15 m. At the inlet of the flow field, the boundary condition are applied (u= Uo=0.22 m/s, v=0) where Uo is the free stream velocity, and at the outlet the pressure P=0. Symmetric condition is applied on top and bottom boundary. No-slip boundary condition is imposed on all the cylinder surfaces.

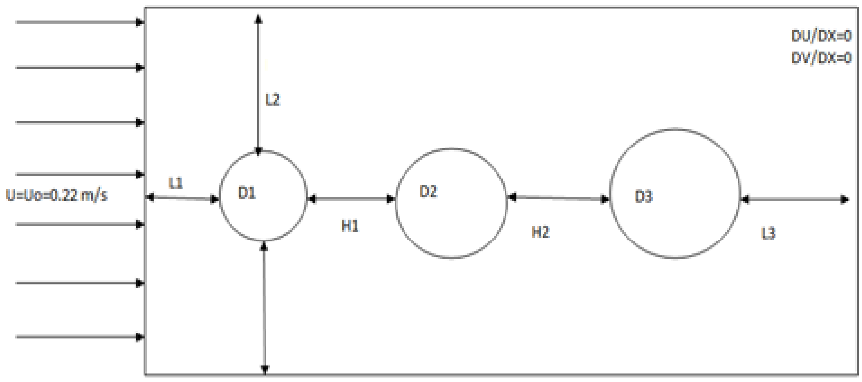

Figure No. 1. Basic Geometry

z	S/D=1	S/D=2	S/D=4	S/D=5	S/D=6
L1=7D1	700mm	700mm	700mm	700mm	700mm
L2	500mm	500mm	500mm	500mm	500mm
L3	1000mm	1000mm	1000mm	1000mm	1000mm

H1	10mm	20mm	40mm	50mm	60mm
H2	10mm	20mm	40mm	50mm	60mm
D1	10mm	10mm	10mm	10mm	10mm
D2	15mm	15mm	15mm	15mm	15mm
D3	20mm	20mm	20mm	20mm	20mm

Table 1. Dimensions

III. SIMULATION WORK

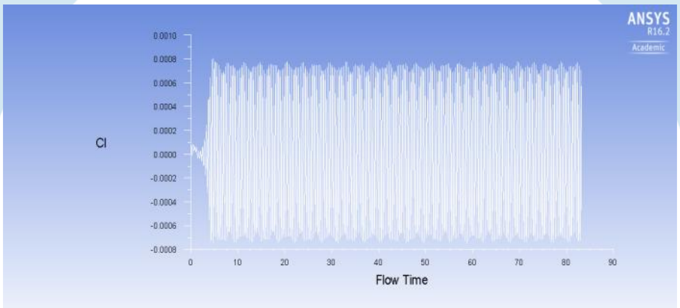

Figure 2. Coefficient of Lift for s/d=6

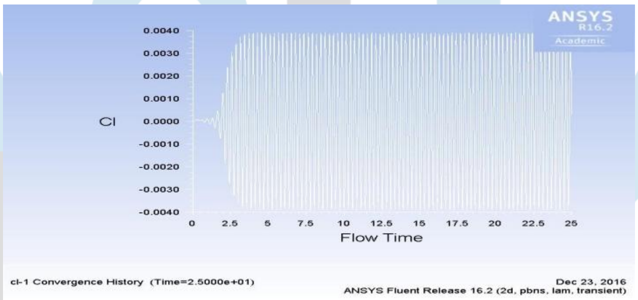

Figure 3. Coefficient of Lift for s/d=5

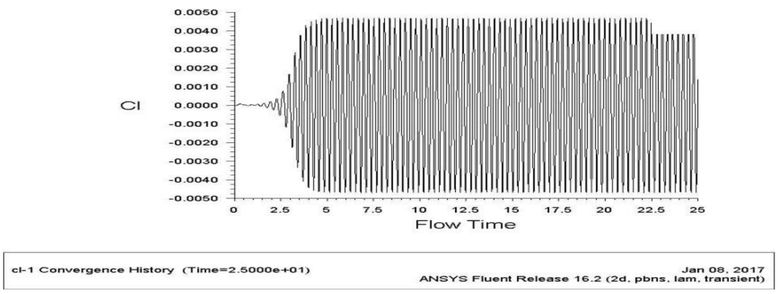

Figure 4. Coefficient of Lift Convergence History for S/d=4

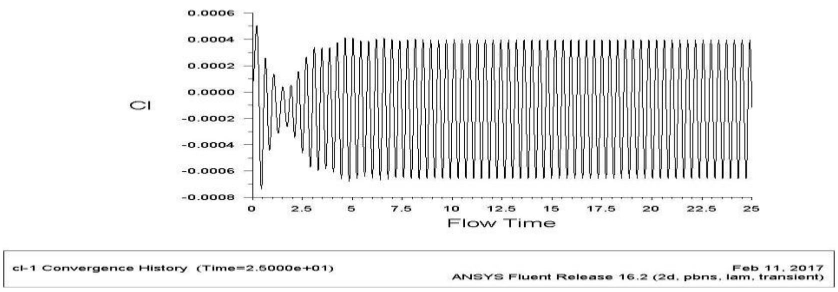

Figure 5. Coefficient of Lift, Convergence History for S/d=2

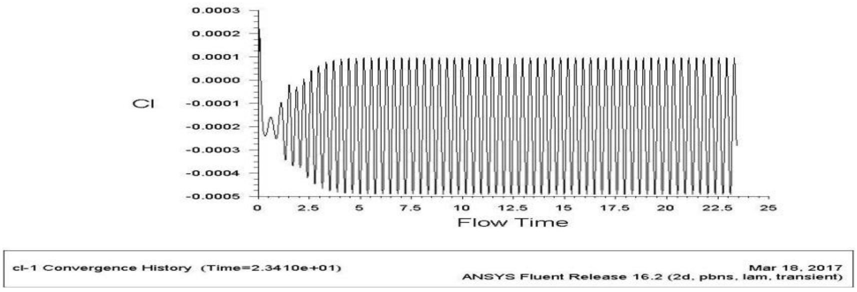

Figure 6. Coefficient of Lift for s/d= 1

From the above figures we can see that, as time goes forward, the transient initial solution reaches a steady state and oscillating nature of the lift coefficient takes a constant form. The decaying lift coefficient highlights the role of viscosity in diminishing the unsteady behavior and turning it into a steady one.

3.1 S/D=6

Simulations are first done at s/d=6 and the spacing is kept constant. The result for s/d =6 but with cylinders of different diameters are not similar and only notable observations are made. For these spacing, almost no interaction are occurs between the flow behind adjoining cylinders. The only way to confirm it is by starting the simulation with different phase lags in vortex shedding from cylinders. However, this is not done because it is tedious and the same result can be obtained by examining the mean C_d and St. Because of no significant interaction between the wakes, little investigation is done at those separation ratios. When s/d $\leq$6.0, the wakes behind the cylinders are interacts in a rather complicated manner resulting in variety of flow patterns. The flow pattern is followed over several vortex shedding cycles before making conclusion about them. All the results presented below are after the initial transients have died out.

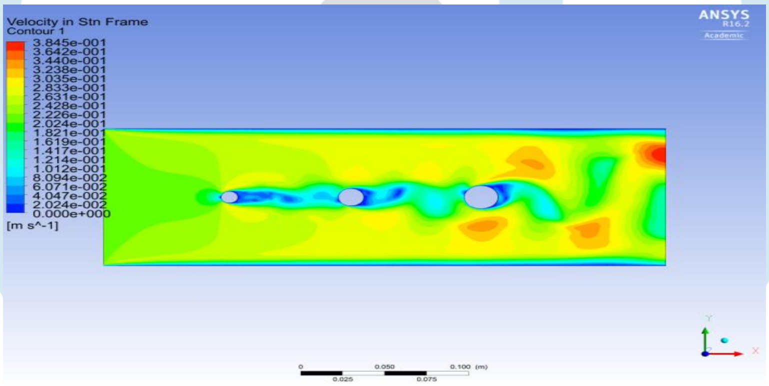

Figure7. Velocity in Stn Frame (Contour 1)

For Configuration with s/d=6.0, vortices shed from any cylinder have constant frequency with vortices shedding from other cylinders. Williamson (1985) further noted that the vortex configuration keeps its form for a large downstream distance. For s/d= 6.0 vortex shedding of cylinder neither in in-phase nor anti-phase. From above figure, cylinders C1 and C2 and cylinder C3 is shedding in in-phase while cylinder C2 and C3 are in antiphase mode. In this case, the vortices remain distinct throughout the computational domain, unlike other regimes present later. This is probably because of weak interaction due to large spacing between the cylinders.

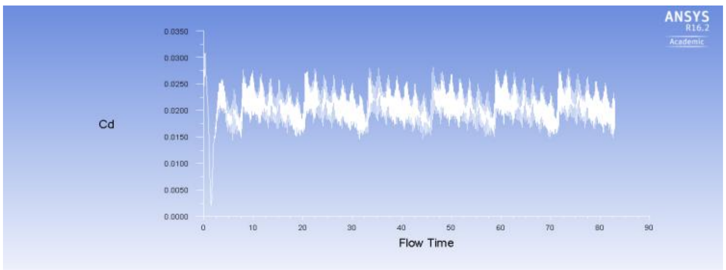

Figure 8. Coefficient of Drag for First Cylinder

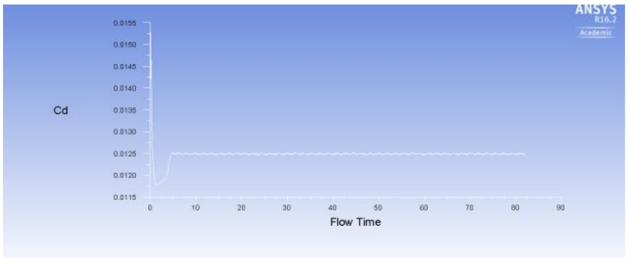

Figure 9. Coefficient of Drag for Second Cylinder

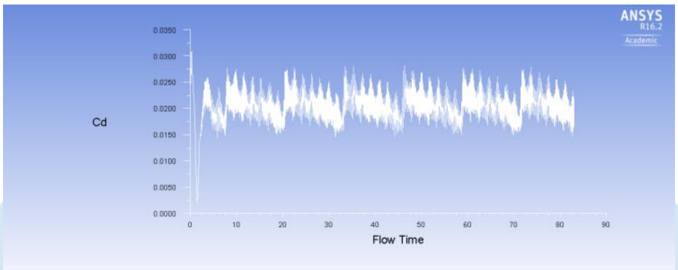

Figure10. Coefficient of Drag for third Cylinder

3.2 S/D= 5

In this arrangement we have reduced the distance between two successive cylinders to 50 mm. the graphs regarding the same are displayed below.

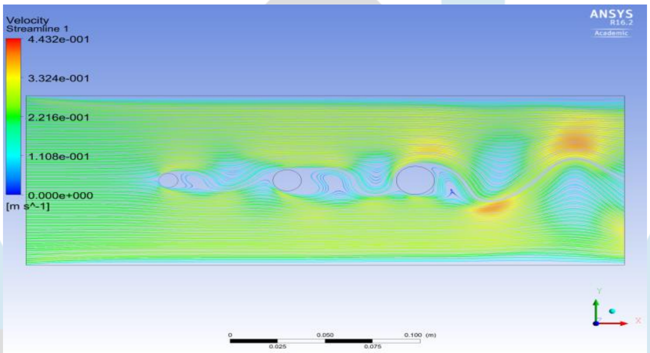

Figure11. Streamlines

We observe from the above streamline diagram that almost similar to the observations in S/D=6 each cylinder here behaves almost singularly without affecting the next cylinder much. Each cylinder acts as an individual cylinder. There is very little interference between the wake formations and the vortex formations of two successive cylinders..The graphs regarding the same are given below.

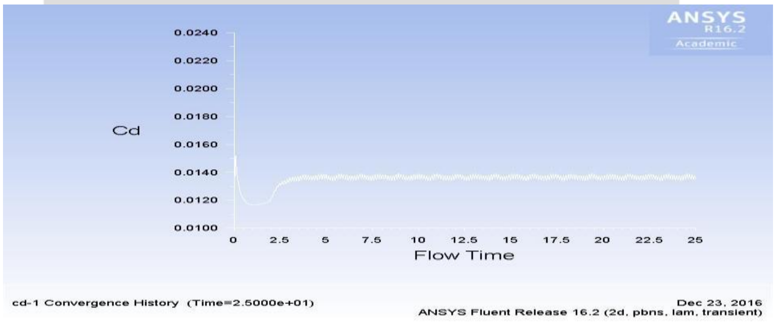

Figure12. Coefficient of Drag for 1st Cylinder

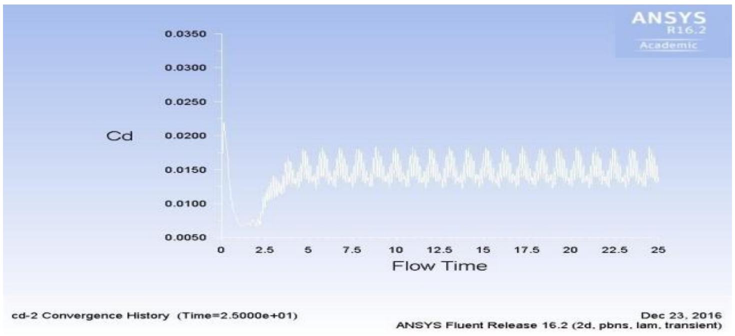

Figure13. Coefficient of Drag for 2nd Cylinder

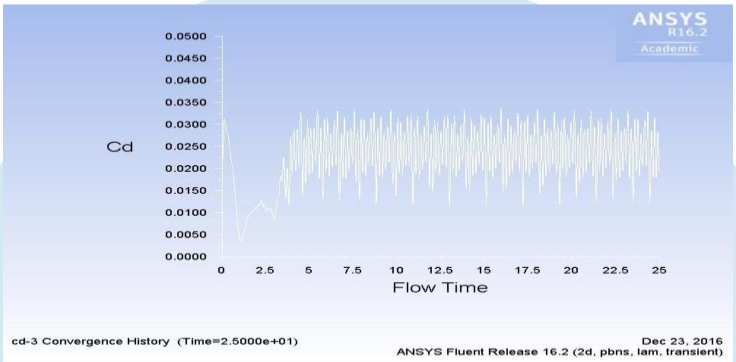

Figure 14.Coefficient of Drag for 3rd cylinder

We ignore the graphs for lift coefficient (Cl) as the effect of lift in this particular arrangement is negligible.

3.3 S/D=4

The distance between two successive cylinders is now reduced to 40 mm. The velocity profile for the same is given below.

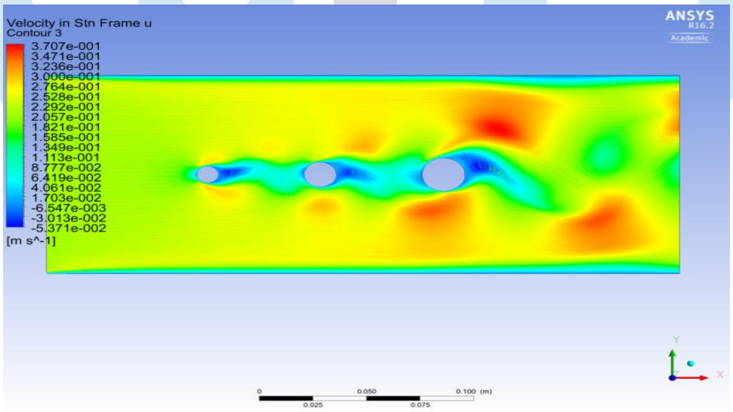

Figure 15. Velocity in Stn Frame

In this figure we can see the wake formations behind each cylinder. The wake formations are dependent on the diameter of the cylinder but here the upstream cylinder hardly affects the downstream cylinder. The pressure difference around the downstream cylinder is also not affected by the upstream cylinder. The graphs for the same are given below.

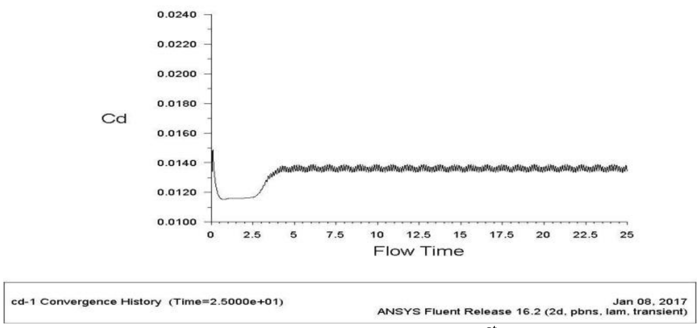

Figure 16 Coefficient of Drag for 1st cylinder

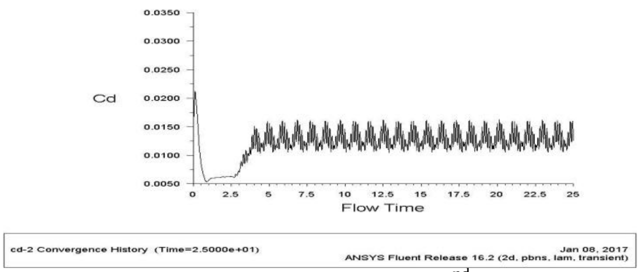

Figure 17 Coefficient of Drag for 2nd cylinder

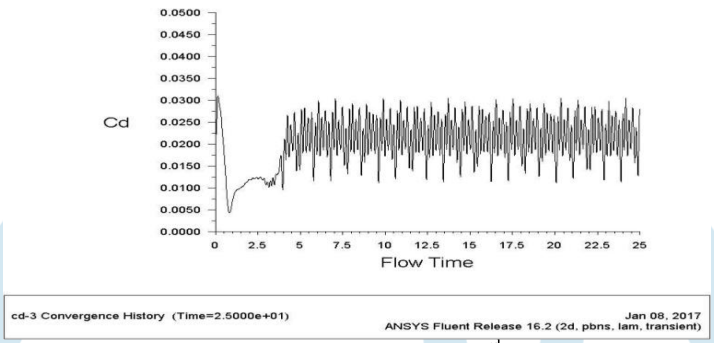

Figure 18 Coefficient of Drag for 3rd Cylinder

3.4 S/D=2

We have reduced the distance between successive cylinders from 40mm to 20mm. Here we observe sharp changes in the wake and vortex formations. The wake of the upstream cylinder interferes with the flow characteristics of the downstream cylinder. It is also observed that, the downstream cylinder undergoes a negative drag due to full submergence in the relatively low pressure wake region behind the upstream cylinder. The presence of the downstream cylinder leads to the pressure increase in this region, causing a reduction in upstream cylinder drag force.

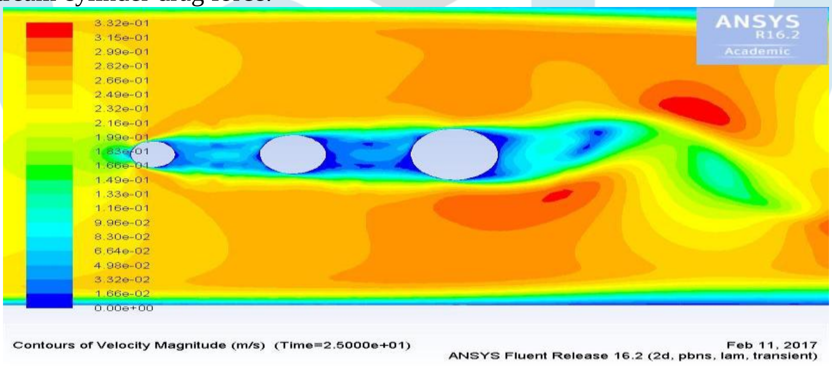

Figure 19 Contours of Velocity Magnitude

Also, due to the dominance of wake interference effect for the small spacing, downstream cylinder experiences more live oscillations than for the upstream one. A low-pressure region is formed in front of the first cylinder and behind the second and the third cylinders it becomes higher than its front but still has small negative values.

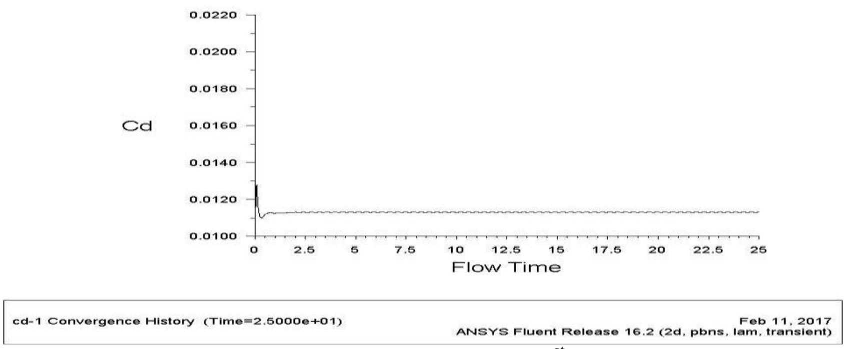

Figure 20 Coefficient of Drag for 1st Cylinder

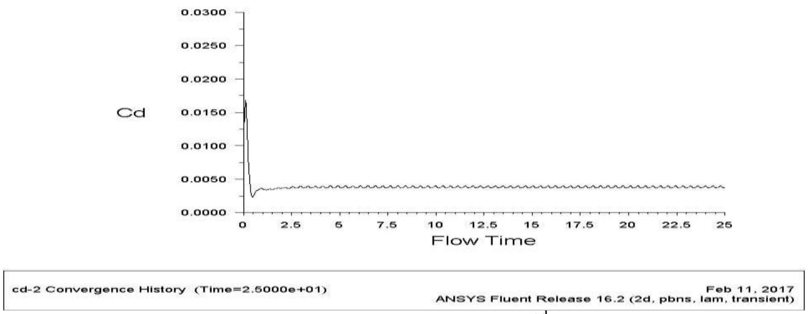

Figure 21 Coefficient of Drag for 2nd Cylinder

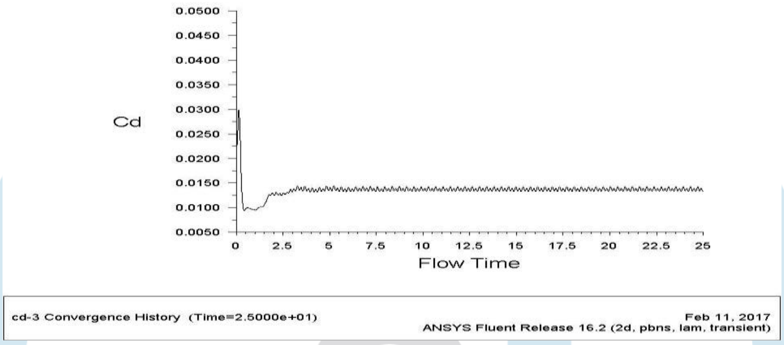

Figure 22. Coefficient of Drag

3.5 S/D=1

We have now reduced the distance between two successive cylinders from 20mm to 10mm. The interference between the fluid characteristics of each cylinder with other further increases. The presence of the downstream cylinders leads to the increase of pressure before them and causing a reduction in the upstream cylinder drag force. This saves the upstream cylinder from damage but the downstream cylinders are severely affected.

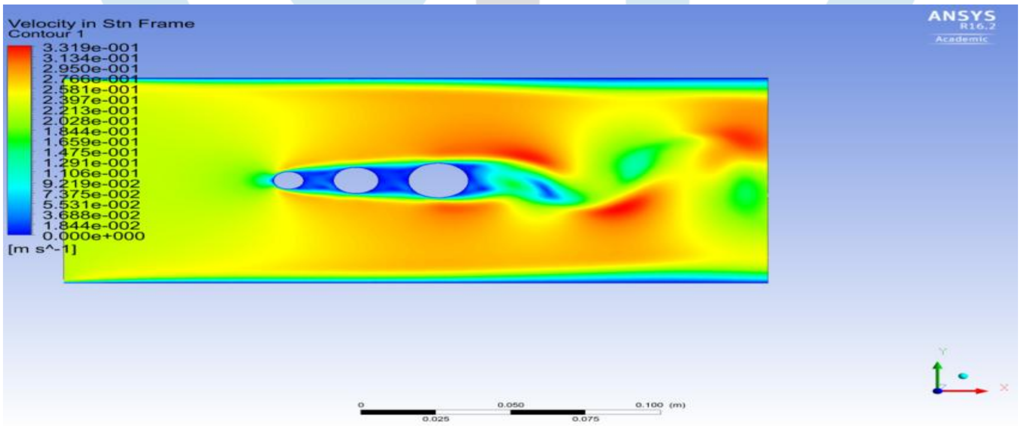

Figure 23. Velocity in Stn Frame

Here we see how the upstream cylinder affects the downstream cylinder with the third cylinder affected the most. The flow pattern behind downstream cylinder shows a steady behavior because no vortex is impinged onto the downstream cylinder from the upstream one

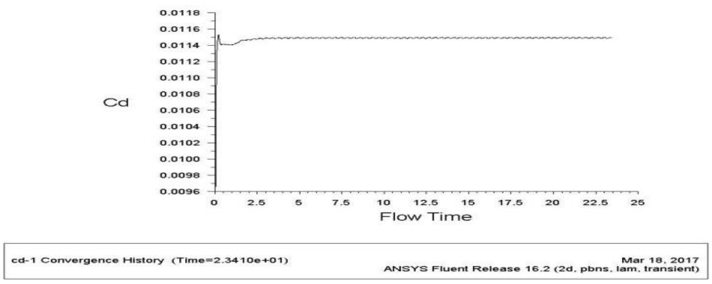

Figure 24 Coefficient of Drag for 1st Cylinder

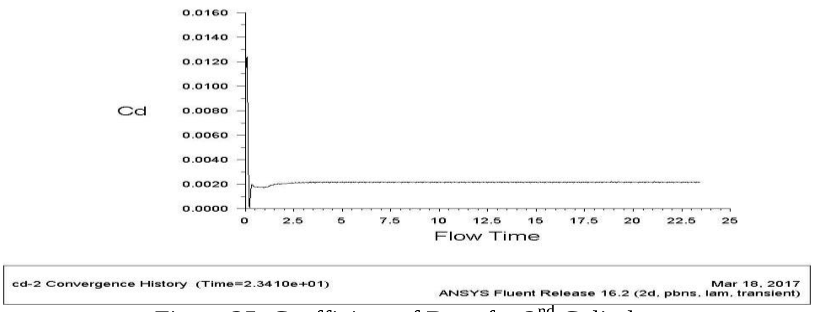

Figure 25. Coefficient of Drag for 2nd Cylinder

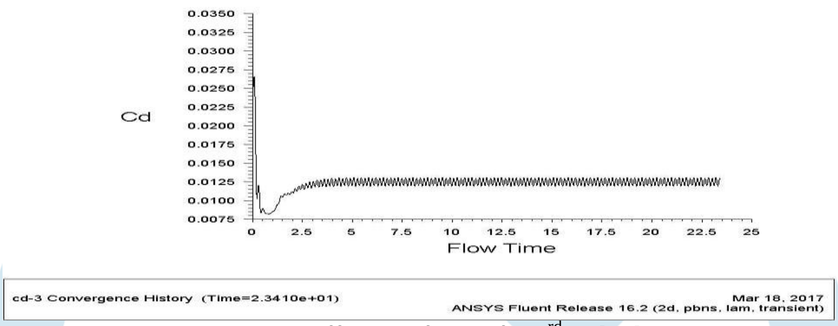

Figure36. Coefficient of Drag for 3rd Cylinder

Noticeable from these simulations is the similarity among the force attributes of the upstream cylinder at S/D=5 to those of a single cylinder while downstream cylinder shows unsteady behavior due to the impingement of shed vortices from upstream cylinder. This implies that by increasing the gap, the wake interference effects due to the presence of the downstream cylinder decreases. However, lying in the full wake of the upstream cylinder, the downstream cylinder will bear significant changes in its force coefficients. At S/D=5, as a result of vortex shedding from all three cylinders, the variations of hydrodynamic forces follow an oscillating trend with large amplitude with respect to the case of S/D=1. The drag of the downstream cylinder becomes positive, connoting that the pressure field created by the upstream cylinder is intensified.

IV. CONCLUDING REMARKS

A Numerical simulation of flow over cluster of three circular cylinders in side-by-side as an object of study carried out using ANSYS/CFD finite volume method were performed for different surface spacing ratios: S/D=6,5,4,2,1 and Reynolds number of 100. Comparing to other methods, it has advantage of higher accuracy. The aim of this project to understand the physics of flow around more than one circular cylinders interaction in flow field, the flow pattern for same spacing ratio but with cylinders of different diameters have been studied numerically, and several new flow patterns with respect to time signal have been found. The present result of circular cylinder is compared with square cylinder for Re=100.

(1) At S/D = 1 and 2, the upstream cylinder shed no vortices and the separated shear layers from this cylinder reattached onto the surfaces of the downstream cylinders. The lift coefficient shows a decaying trend due to the role of viscosity in stabilizing the flow. On the other hand, drag force took negative values showing full submergence of downstream cylinders in the wake of the upstream ones.

(2) Increasing the gap to S/D=4,5,6 leads to more unstable behavior of flow, especially behind the downstream cylinders. This shows that as in this case the upstream cylinders also shed vortices, the impingement of these vortices onto downstream cylinders caused more lift fluctuations for it and also highly disturbed the flow behind this cylinder. Vortices are shed counter wise from both cylinders and are not synchronized.At Re=100, it is evident that as the gap between cylinders increases, the upstream cylinder shows the same behaviors as a single cylinder and its lift and drag time histories have confirmed this.

V. SCOPE FOR FUTURE WORK

A complete understanding of the fluid dynamics for the flow around a circular cylinder includes such fundamental subjects as the boundary layer, separation, the free shear layer, the wake, and the dynamics of vortices.

Air flow and heat transfer around chimney stacks and cooling towers, heat losses from tall buildings and heat transfer in heat exchangers and boilers are just some of the applications. Measurement of aerodynamic forces acting on a body like automobile or flying object is very important and effective in design and manufacturing processes.

Examples of its various applications in practical engineering areas include: offshore platforms, transmission cables, cooling towers, heat exchanger tubes, chimney stacks and marine risers.Since many high-rise buildings are affected by other nearby buildings, their design must consider the aerodynamic forces acting on the structures. It is also important to investigate the characteristics of vortex shedding caused by the flow interference of other structures since this may be connected to structural vibration problems.

Cylinder-like structures can be found both alone and in groups in the designs for heat exchangers, cooling systems for nuclear power plants, offshore structures, buildings, chimneys, power lines, struts, grids, screens, and cables, in both air- and water-flow.

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