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# Numerical Study of Unsteady Laminar Flow around a Circular Cylinder

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**ABSTRACT:** In this paper, numerical study of incompressible and unsteady flow around a circular cylinder with Reynolds number=150 has been studied at different alternative vortex times. Flow has been studied via solution of Navier-Stokes and continuity equations with using of finite volume method. Flow Parameters including drag and lift coefficient, Strouhal number, velocity contours, pressure contours, pressure coefficients and vorticity contours are calculated in this work and were compared with other numerical and experimental results that show good agreement. Results have shown that flow in entrance boundary after passing cylinder is completely unsteady in spite of steady flow and also results have shown changes periodically and have minimum value in symmetry line in the computational domain.

**Keywords:** Unsteady flow- Finite Volume Method- Circular Cylinder- Strouhal number- Drag and Lift coefficient

ORIGINAL ARTICLE

## INTRODUCTION

Many issue related to aerodynamics and hydrodynamics are placed in category of incompressible flow and in many applications, flow is unsteady and a wide range of flow conditions such as Reynolds number is considered.

For this reason, the analysis of these types of flow is important. Flow around objects such as circular and square cylinders are widely used in engineering. Tall buildings, chimneys, cooling towers and heat exchange tubes are examples of these applications. In recent decades many researches on the flow around cylinders with variety of geometries have been done. In each of these studies, according to researchers' point of view, flow around the cylinders has been investigated from a certain perspective including pressure distribution, force coefficients, vortex shedding, flow patterns and Strouhal number. Most of these researches have been carried out through numerical methods or wind tunnel Experiments and only limit number of these studies carried out from the measurement of actual scales.

Flow behind a circular cylinder has been a major research topic in fluid mechanics, not only because of the geometric simplicity but also because of the practical importance in engineering.

At a very low Reynolds number $Re = \frac{U_{\infty} d}{\upsilon} \leq 1$ flow around a circular cylinder is steady and symmetrical upstream and downstream. As the Reynolds number increase, the upstream and downstream symmetry disappears and two- attached eddies appear behind a cylinder. These eddies become bigger with increasing Reynolds number. For Re>45, unsteadiness arises spontaneously even though all the imposed conditions are being held steady and vortex shedding appears behind a circular cylinder [1]. Accordingly flow quantities on the cylinder surface significantly change as the Reynolds number increase. For example when vortex shedding occurs behind a circular cylinder, drag on the cylinder increase and the body suffer from a periodic forcing in the normal direction to the main stream.

Bai and Li [2] simulated hydrodynamic characteristics of circular cylinder in two dimensional unsteady flows with FLUENT software. The pressure distribution, drag and lift coefficient and Strouhal number in Re=200 have been investigated in this simulation [2].

Rajani [3] focuses on the analysis of two- and three-dimensional flow past a circular cylinder in different laminar flow regimes. In this simulation, an implicit pressure-based finite volume method is used for time-accurate computation of incompressible flow using second order accurate convective flux discretisation schemes. The computation results are validated against measurement data for mean surface pressure, skin friction coefficients, the size and strength of the recirculation wake for the steady flow regime and also for the Strouhal frequency of vortex shedding and the mean and RMS amplitude of the fluctuating aerodynamic coefficients for the unsteady periodic flow regime. The complex three dimensional flow structure of the cylinder wake is also reasonably captured by the present prediction procedure [3].

Igor M. Kozlov et al. [4] simulated two dimensional flow past a circular cylinder for Re=5-200 via RES .In this method, fast Fourier transformation (FFT) is used for solving the Poisson equation in rectangular meshes with complex geometries [4].

Park [5] investigated past flow around circular cylinder in Reynolds numbers more than 160 numerically and earned flow quantities through numerical simulation

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and compared with previous experimental and numerical results [5].

Ding et al. [6] used conventional finite difference (FD) and mesh free least square-based finite difference (MLSFD) methods for numerical simulation of Steady flow in Re=10, 20, 40 and unsteady flow in Re=100, 200 around a circular cylinder respectively [6].

Gera et al. [7] had been investigated two dimensional unsteady flows around a square cylinder with Reynolds number of 50 to 250 via finite element method [7].

We have some research in this field in Reynolds number other than Re=150 that investigated in this work and also investigated and calculated flow field parameters in four different times of vortex period.

**Meshes and computational boundary condition:**

In this work, we use unsteady two dimensional laminar flow for free stream simulation around circular cylinder with Re=150. For improving accuracy of stimulation results, 176403 quadrilateral elements are used near the cylinder. Fig.1 shows elements around the cylinder.

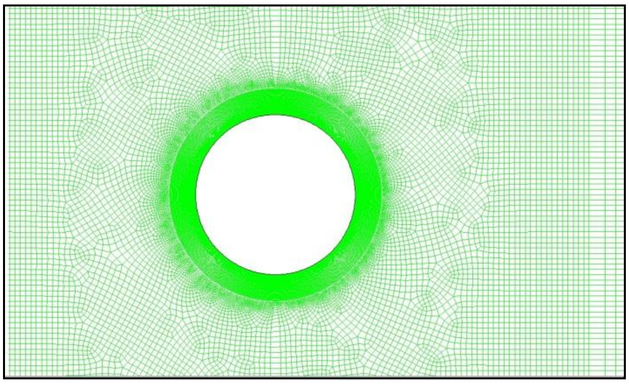


**Figure 1.** Meshes and computational boundary condition around a circular cylinder

For being discrete of Navier Stokes equations, we used Presto method for pressure parameter and second order upwind for momentum equations and for pressure and velocity coupling, Piso method has been used.

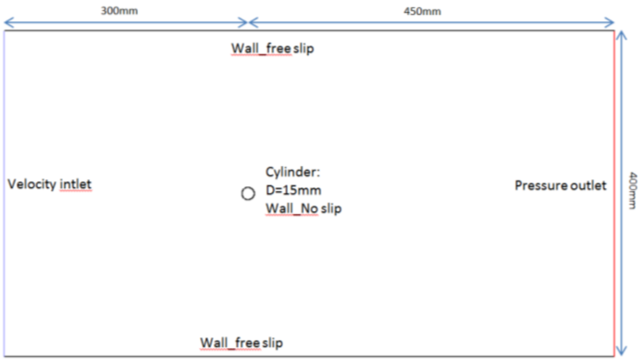


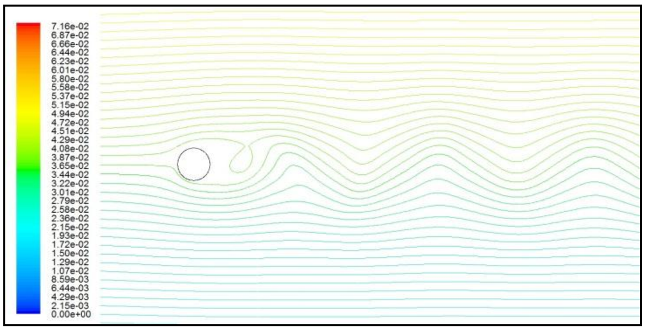

**Figure 2.** Boundary conditions and flow geometry

Boundary conditions and flow geometry is shown in fig.2. Velocity in entrance was equal to 0.1460735m/s and gauge pressure in output is equal to zero. Pressures are obtained relatively with placing operation condition equal to zero.

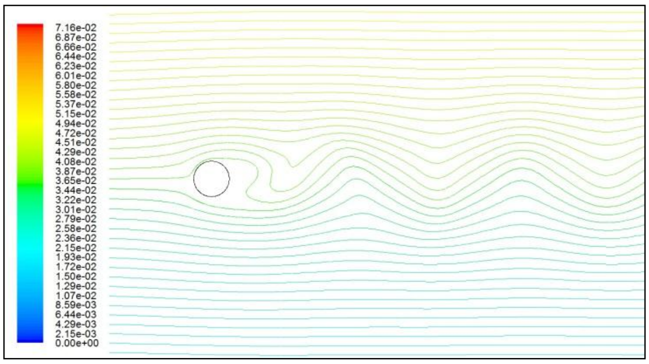
**RESULTS**

To analyze the time dependent vortex shedding for a cycle, the streamline are calculated for a cycle of t=T. Fig 3 shows the periodic vortex shedding at various time intervals between t=0 and t=T.

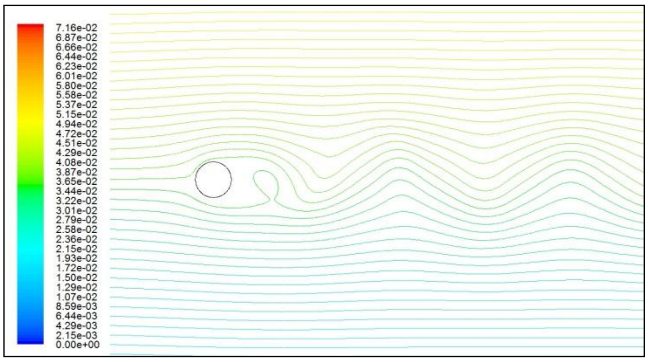
The dynamic of the flow behind the cylinder and the changes in the vortex shedding pattern within a cycle can be easily observed from Fig 3.



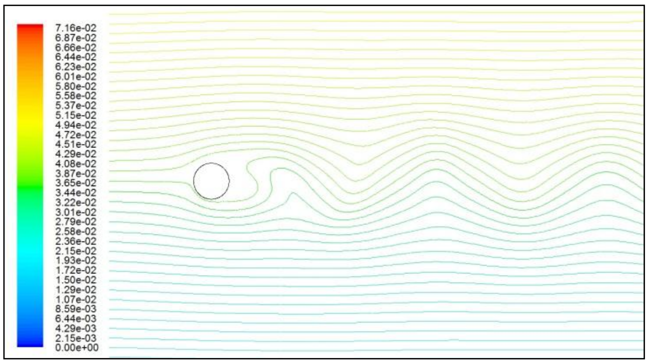
t=0/4T



t=1/4T



t=2/4T



t=3/4T

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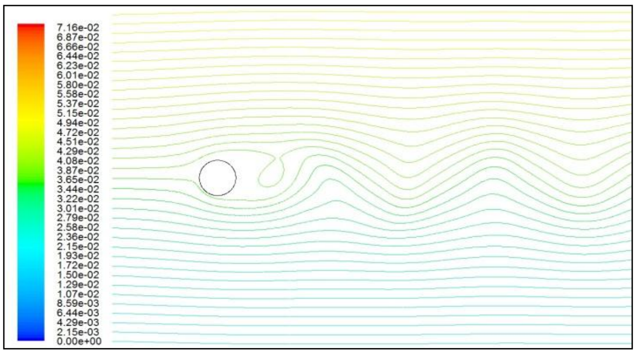

t=4/4T

**Figure 3.** Time development of vortex shedding streamlines past a circular cylinder, Re=150

It can be observed from study of streamline that flow has steady behavior in entrance, just prior to contact cylinder and becomes unsteady after contacting with cylinder.

Fig 4 that lift and drag coefficients show obvious periodic oscillations for Re=150. This implies the periodic variation of flow field. From fig 4, it can also be found that the lift coefficient oscillates with larger amplitude than the drag coefficient; the drag coefficient varies twice as fast as the lift coefficient. The reason lies on that the drag coefficient is affected by vortex shedding process from both sides of the cylinder

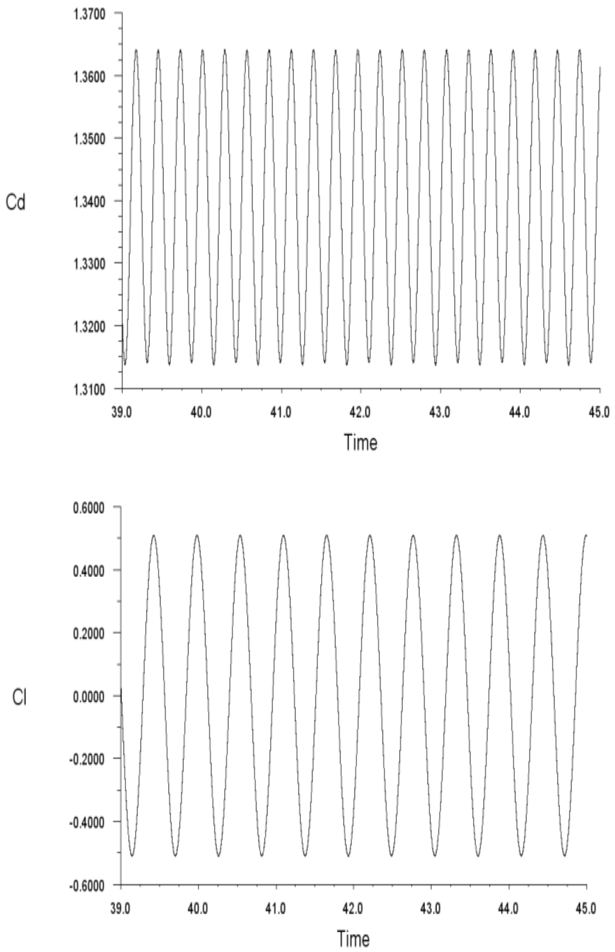


**Figure 4.** The time-evolution of lift and drag coefficient for Re=150

It can be observed that results of drag and lift coefficient in this work have completely agreement with results of Ding works [6].

The ϴ orientation angle, illustrated by Fig. 5, varies from 0 to 180, between the two stagnation points.

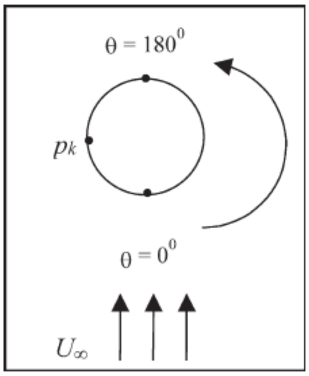


**Figure 5**. Schematic illustration of the angle

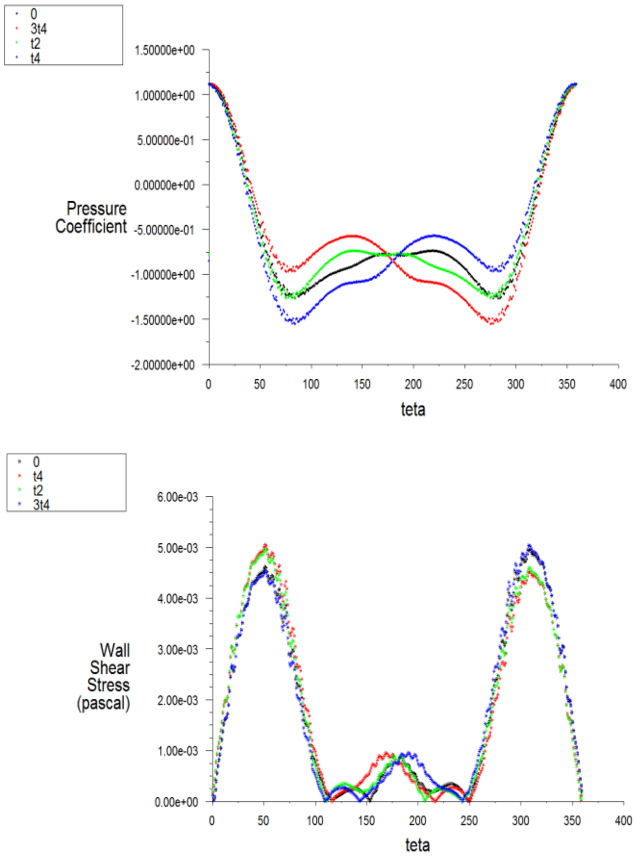


**Figure 6**. Pressure coefficient and wall shear stress distribution at different vortex times, between the stagnation point (ϴ=0) and (ϴ=360): Re=150

Fig. 6 shows the pressure coefficient and wall shear stress at zero and 180 at different vortex times have the same figure and it does not change at different times. And indicates the flow in a straight line between zero and 180 has a fewer changes. But the pressure coefficient and wall shear stress at other angles change with different times.
It can be seen from Fig.6 that velocity gradient eventually became zero in $\mu \frac{\partial u}{\partial y} \uparrow_{y=0}$ which is named separation point. In this point, flow momentum near the surface is

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not sufficient to overcome pressure gradient and continuing movement in downstream became impossible, because progressive stream prevent flow to return and boundary layer separation should be occurred. In this condition boundary layer separated from surface and wake will be created in the downstream. Flow in this area is associated with vortex formation and is highly irregular [8].

And also it can be observed that pressure coefficient and wall shear stress in 0 and 180 angles have a fewer changes in various vertex times and can be ignored, but in the other angles changes will be occurred by time.

**Table 1.** Computed stagnation angle, stagnation pressure, base pressure and drag coefficient, Strouhal number for flow past smooth cylinder Re=150

| t | 0 | T/4 | T/2 | 3T/4 |
|---|---|---|---|---|
| Separation angle | 116.5 | 116.5 | 110.7 | 109.4 |
| $Cp_0$ | 1.11 | 1.11 | 1.109 | 1.12 |
| $Cp_b$ | -0.78 | -0.85 | -0.78 | -0.85 |
| $C_{dp}$ | 1.029681 | 1.069048 | 1.029394 | 1.06924 |
| $C_{df}$ | 0.289590 | 0.289171 | 0.289481 | 0.28908 |
| Cd | 1.319272 | 1.358220 | 1.318876 | 1.35833 |
| Strouhal number | 0.187225 | | | |

Table 1 shows the computed values of the separation angle, the front (ϴ=0) stagnation pressure ($C_{p0}$) the base pressure ($C_{pb}$) at the back (ϴ=180) of the cylinder, and also the total drag coefficient ($C_d$ ) along with its pressure ($C_{dp}$) and friction ($C_{df}$) components and strouhal number at Reynolds number=150.

It can be seen from Table 1 that at various times of the vertex, separation angle changes with time and the range of this changes is equal to 7.1 degree.

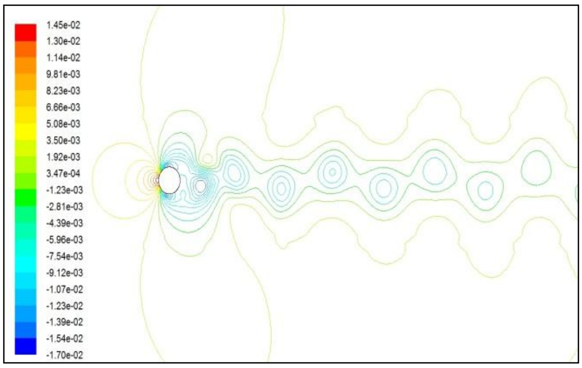

**Figure 7.** Static pressure contour

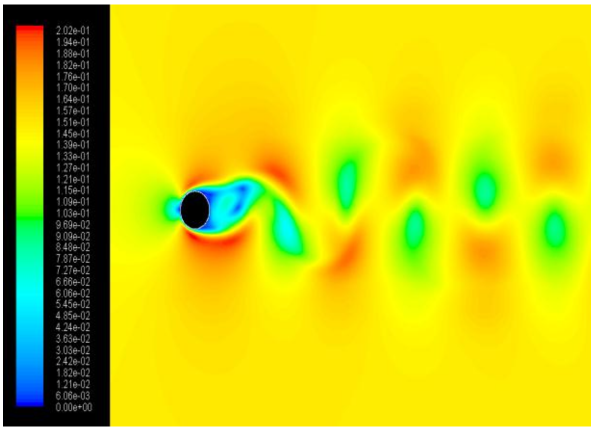

**Figure 8.** Velocity magnitude contour

Fig. 7 and 8 show static pressure and velocity magnitude contours respectively. It can be observed from Fig.7,8 that vortex initially grown in one side of cylinder and then separated and grown again in other side of the cylinder. As a result ,position of separated vortex from the cylinder sides are seen in opposite phases.

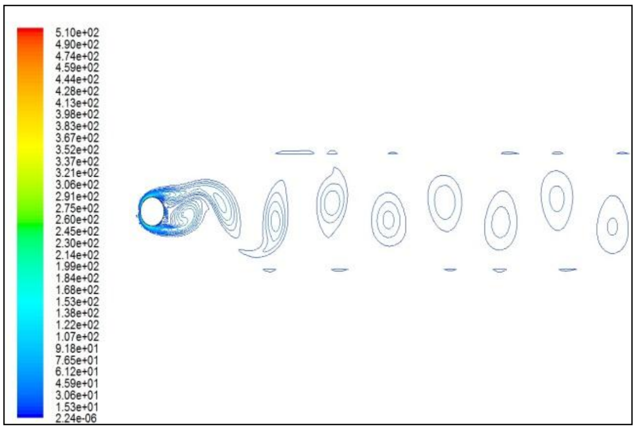

**Figure 9.** Vorticity contour

In Fig.9, vortex formed in the upper side of the cylinder and separated and is growing in the lower side of the cylinder. It can be observed that as the vortex growing in the lower side its growth in the upper side limited and the vortex will start its growth in opposite side as soon as vortex separation.

## CONCLUSION

In this paper, flow behind around a circular cylinder simulated via FLUENT software. Flow parameters such as drag and lift coefficient, Strouhal number, separation angle and pressure and velocity contours are investigated in this paper. Strouhal number and drag coefficient for circular cylinder in Re=150 are 0.187225 and 1.3192723 respectively. And also it was shown that flow parameters in 0 and 180 degree have a fewer changes in vortex period times and also it was shown that the amplitude of the oscillation of lift coefficient is more than that of drag coefficient but the frequency of the oscillation of drag coefficient is as twice as that of lift coefficient.

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