Simulation of Unsteady Laminar Flow around a Circular Cylinder

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Abstract
In this paper, unsteady laminar flow around a circular cylinder has been studied. Navier-stokes equations solved by Simple *C* algorithm exerted to specified structured and unstructured grids. Equations solved by staggered method and discretization of those done by upwind method. The mean drag coefficient, lift coefficient and strouhal number are compared from current work at three different Reynolds numbers with experimental and numerical values.

Keywords: Laminar flows, circular cylinder, lift, drag, Strouhal number.

1. INTRODUCTION

External flows past objects have been studied extensively because of their many practical applications. For example, airfoils are made into streamline shapes in order to increase the lifts, and at the same time, reducing the aerodynamic drags exerted on the wings. On the other hand, flow past a blunt body, such as a circular cylinder, usually experiences boundary layer separation and very strong flow oscillations in the wake region behind the body. Fornberg [1] did a numerical study of steady viscous flow past a circular cylinder at Reynolds numbers up to 300. Kim and Lee [2] investigated the flow around a circular cylinder under the influence of an electromagnetic force. The numerical results predict that the Lorentz force applied in the circumferential direction on the cylinder moves the separation point rearward, and reduces the drag. Catalano et al. [3] studied the flow around a circular cylinder at high Reynolds numbers using LES method. They showed that the LES solutions are more accurate than the RANS results. Hishida et al. [4] studied the dependency of Strouhal frequency with drag and lift on the non-dimensional pitch of square-pitched circular cylinder array. Alam and Zhou [5] presented the effect of the diameter of a cylinder and Reynolds number on time-averaged drag, rms drag, rms lift and Strouhal in the wake of a downstream cylinder. Behara and Mittal [6] investigated the transition of the wake of a circular cylinder via a stabilized finite element method for $150 < Re < 350$. They showed that the transition from mode-A to mode-B vortex structure is gradual and not hysteric.
The present work aims to study the unsteady laminar flow around a circular cylinder using the commercial software FLUENT. The mean drag coefficient, lift coefficient and strouhal number are compared from current work at three different Reynolds numbers with experimental and numerical values.

2. GOVERNING EQUATIONS

The most important equations such as conservation of mass and momentum used by the software's solver are listed as follows:
Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla . \rho v = 0 \qquad (1)$$

Conservation of momentum:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_j}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu \frac{\partial u_i}{\partial x_j} \right) \qquad (2)$$

3. RESULTS

The non-dimensional parameter describing the flow around a circular cylinder is Reynolds number:

$$Re = \frac{UD}{\nu} \qquad (3)$$

where D is the diameter of the cylinder, U is the flow velocity, and ν is the kinematic viscosity. The computational domain of the flow is shown in Figure 1.

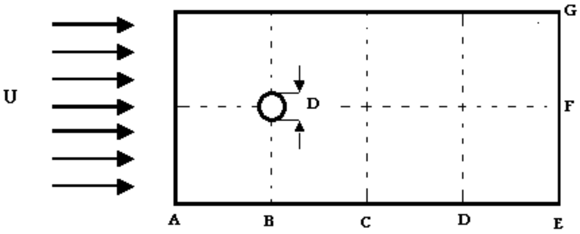

Figure 1. Computational domain of the flow (2D). AB=BC=CD=DE=EF=FG=10D

The cylinder was modeled in the software package GAMBIT. The geometry of the cylinder has been shown in figure 2 (two dimensional) and figure 3 (three dimensional). A fine mesh is needed in the closer regions of the cylinder.
The presence of the fluid viscosity slows down the fluid particles very close to the solid surface and forms a thin slow-moving fluid layer called a boundary layer. The flow velocity is zero at the surface to satisfy the no-slip boundary condition.

The flow regimes experienced with increasing the Reynolds number. In present work, we can see three regimes: *i*) Re < 5: no separation creeping flow. The separation first appears when *Re* becomes 5. *ii*) 5 < Re < 40: a fixed pair of symmetric vortices (figure 3). The length of this vortex formation increases with *Re*. *iii*) 40 < Re < 200: laminar vortex street (figure 4). The shedding is essentially two-dimensional.

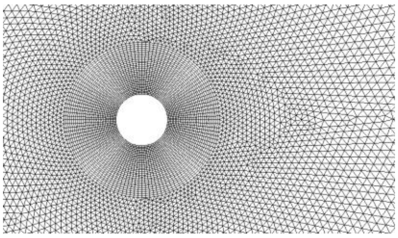

Figure 2. Geometry of the circular cylinder (2D).

The hydrodynamic driving forces exerted on a cylinder will be resolved into two components. The first is the drag force, which acts in the direction of the motion of the fluid. Drag is only force component that acts on a cylinder below Re = 40 because all flows in that regime are symmetrical with respect to the direction of the flow. Vortex instability and shedding in the regime: Re > 40 gives rise to an additional force component called lift, which is normal to both the flow direction and to the axis of the cylinder. The drag force is steady until vortex instability begins. Then it oscillates either periodically or randomly about zero.

Drag force refers to force which acts on a solid object in the direction of the relative flow velocity. This force can be determined using the following equation:

$$Drag = \frac{1}{2}\rho U^2 A C_d \tag{4}$$

Lift force is the component of the surface force that is perpendicular to the oncoming flow direction. This force can be determined using the following equation:

$$Lift = \frac{1}{2}\rho U^2 A C_L \tag{5}$$

Strouhal number can be determined using the following equation:

$$s = \frac{f_s d}{U_\infty} \tag{6}$$

f_s is frequency of the oscillation of the lift curve.

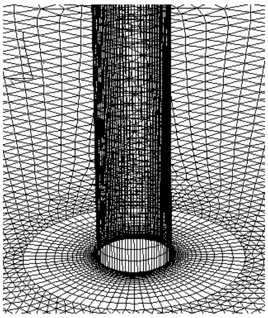

Figure 3. Geometry of the circular cylinder (3D).

In table 1, the mean drag coefficient, lift coefficient and strouhal number are compared from current work at three different Reynolds numbers with experimental values ([7]). The agreement with the measurements of Norberg [7] is reasonably good.

Table 1. Drag coefficient at three different Reynolds numbers

Re		Present work 3D	Present work 2D	Experimental results [7]	Numerical results [7]
40	C_D	1.4	1.5	1.4	1.5
100	C_D	1.48	1.6	1.2	1.29
	C_L	0.286	0.45	0.5	0.12–0.52
	S	0.18	0.18	0.18	0.17
500	C_D	1.4	1.52	1.06	1.25
	C_L	0.545	1.25	0.9	0.55 – 0.7
	S	0.203	0.227	0.21	0.21

4. CONCLUSIONS

In this paper, unsteady turbulent flow around an airfoil has been studied. Navier-stokes equations solved by Simple *C* algorithm exerted to specified structured and unstructured grids. The present work aims to simulate the flow around circular cylinder using the commercial software FLUENT. The mean drag coefficient, lift coefficient and strouhal number are compared from current work at three different Reynolds numbers with experimental and numerical values. ([7]). The agreement with the measurements of Norberg [7] is reasonably good

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