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CONTROL OF WAKE AND VORTEX SHEDDING BEHIND SOLID CIRCULAR OBSTACLE BY MAGNETOHYDRODYNAMICS

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ABSTRACT

Control of vortex shedding leads to a reduction in the unsteady forces acting on the bluff bodies and can significantly reduce their vibrations. In this paper, the finite volume method (FVM) is used to simulate the flow around and through two-dimensional circular obstacle. An external magnetic field is applied to control the wake behind the obstacle and also to suppress the vortex shedding phenomena. Maxwell equations are applied to provide the coupling between the flow field and the magnetic field. The range of Stuart (N) and Reynolds (Re) numbers are 0-10 and 1-200, respectively. The effects of magnetic field on control of wake structure behind the obstacle are investigated in details. It is found that for higher Stuart number (i.e. N=5), drag coefficient increases rapidly by using magnetic field.

INTRODUCTION

The investigation of wake structure and vortex shedding behind the bluff bodies and the prediction of flow separation from them have been intensely studied for a long time because of their fundamental significance in flow physics and their practical importance in aerodynamic and engineering structures applications. Examples of such applications are vibration of pipelines lying on the sea-bottom under the effect of sea-currents, pipelines and bridges, off-shore marine structures, heat exchangers, skyscrapers, chimneystacks, structures in the atmospheric boundary layers, etc.

A review of previous published works in this field is necessary to classify them. Control of vortex shedding behind a circular obstacle for low Reynolds numbers has been done by Mittal and Raghuvanshi [1]. They used a control obstacle in the near wake of the main obstacle to suppress the vortex-shedding behind the main obstacle. Their results revealed that the proper placement of the virtual obstacle can lead to a complete suppression of the vortex shedding behind the main obstacle.

The effects of uniform suction and injection through the walls of a square obstacle on the vortex shedding and wake structure are studied by Sohankar et al. [2]. They employed suction on the top and bottom walls and injection is used on the front and rear surfaces of the obstacle. They found that the lift and drag fluctuations decreases by this method and the maximum reduction on the drag force is 72% for Re = 150. Valipour et al. [3] controlled the fluid flow behind a porous obstacle by changing Darcy number. Their results indicate that the wake vanishes in the narrow range of Darcy numbers. In another study, Rashidi et al. [4] controlled the flow behind a porous diamond obstacle by changing apex angles of the obstacle. They found that the critical Reynolds number to onset of the re-circulating wake decreases with increasing apex angles.

The effects of streamwise and transverse magnetic fields on physical interpretation of flow around an obstacle embedded in a porous medium have been studied by Rashidi et al. [5]. Their study indicated that the effects of transverse magnetic field on flow structure are more than that of the streamwise magnetic field. Also, Rashidi et al. [6] applied the streamwise magnetic field for controlling the flow parameters around a square obstacle in a rectangular channel. They reported that the Strouhal number decreases linearly with increasing the strength of the magnetic field.

The potential influence of magnetic field on the control of the vortex shedding behind circular obstacle is the aim of the present research.

PHYSICAL MODEL

The physical model is considered a two dimensional, viscous, unsteady and incompressible fluid flow with the parabolic inlet velocity and constant fluid properties past an obstacle. The obstacle is placed in a channel. The channel height is H and the upstream and downstream distances of the obstacle are L_1 and L_2, respectively. The geometric parameters are shown in Fig.1.

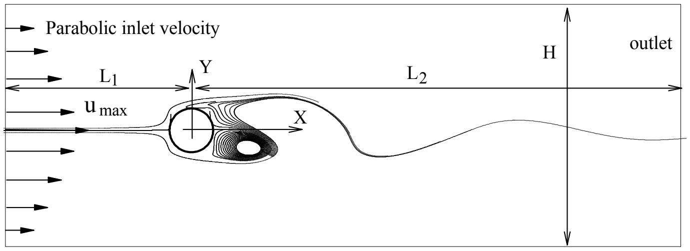

Fig 1. Schematic representation of the problem and coordinate system

With the above description, the following assumptions are considered to make the model amenable to numerical simulations.

- The fluid is considered as a conductor of electricity.
- For minimizing the effects of inflow and outflow boundaries, the outflow and inflow lengths of channel were set to 37.5D and 12.5D, respectively.
- The magnetic field is exerted in horizontal direction (streamwise magnetic field).

GOVERNING EQUATIONS AND BOUNDARY CONDITIONS

Governing equations (momentum and continuity equations) are derived to simulate this problem. The governing equations are made dimensionless by using the following dimensionless variables [7,8]:

$$r = \frac{r*}{R},\ \theta = \theta^*,\ u = \frac{u*}{U_0}, v = \frac{v*}{U_0}, P = \frac{P*}{\rho U_0^2}, Re = \frac{\rho U_0 H}{\mu},\ N = \frac{\sigma B^2 H}{\rho U_0} \tag{1}$$

where superscript "*" denotes dimensional variables. Also, N and Re are the Stuart and Reynolds number, respectively. In unsteady, the equations of conservation are given as follows:

Mass conservation equation:

$$\frac{\partial}{\partial r}(ru) + \frac{\partial v}{\partial \theta} = 0 \tag{2}$$

u and v are the components of the fluid velocity in the r and θ directions, respectively.

Momentum conservation equations

$$\left(\frac{\partial u}{\partial t} + \frac{v}{r}\frac{\partial u}{\partial \theta} + u\frac{\partial u}{\partial r} - \frac{v^2}{r}\right) = \frac{2}{Re}\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} + \frac{1}{r^2}\frac{\partial^2 u}{\partial \theta^2} - \frac{2}{r^2}\frac{\partial v}{\partial \theta} - \frac{u}{r^2}\right) - \frac{\partial p}{\partial r} - u\frac{N}{2} \tag{3}$$

$$\left(\frac{\partial v}{\partial t} + \frac{v}{r}\frac{\partial v}{\partial \theta} + u\frac{\partial v}{\partial r} + \frac{uv}{r}\right) = \frac{2}{Re}\left(\frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} + \frac{1}{r^2}\frac{\partial^2 v}{\partial \theta^2} + \frac{2}{r^2}\frac{\partial u}{\partial \theta} - \frac{v}{r^2}\right) - \frac{1}{r}\frac{\partial p}{\partial \theta} \tag{4}$$

Boundary conditions

INLET:

$$u = U_0(1 - \left(\frac{2y}{H}\right)^2) \quad v = 0$$

OUTLET:

$$\frac{\partial u}{\partial u} = \frac{\partial v}{\partial x} = 0.$$

WALL:

$$u = v = 0$$

As the initial condition, there is no flow inside the computational domain at the beginning time (t=0).

VALIDATION:

A view of the grid resolution in the vicinity of the circular obstacle as a sample mesh is shown in Fig. 2. A two-dimensional square mesh has been used. Also, this mesh is refined near the obstacle and channel walls, where the velocity gradients vary quickly. A test on the mesh was conducted to insure that the results are independent of the grid size. A number of nodes 2000×320 were passed. More details about this test are available at Bovand et al. [9].

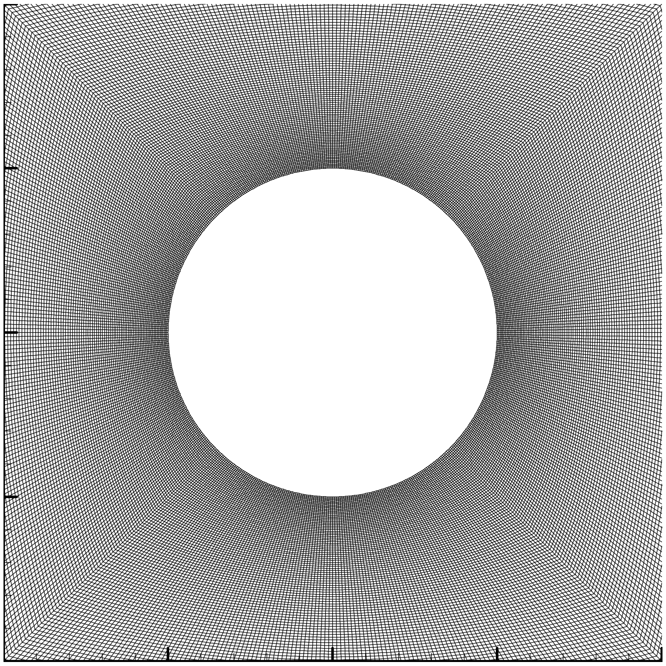

Fig. 2. Sample mesh around the obstacle

Validation of numerical simulations is also important. The model used for the validation is the square obstacle that is placed in the channel. The drag coefficient is calculated and presented in table 1. It indicates that the results agree well with the results reported in the literature.

TABLE 1 COMPARISON OF THE PRESENT RESULTS AND THE PREVIOUS RESEARCHES

Re	C_D Present study	C_D Breuer et al. (2000)	*Error*
55	1.55	1.53	1.3 %
165	1.34	1.32	1.5 %
235	1.43	1.40	2.1 %

RESULTS AND DISCUSSION

A numerical study has been done in this research to investigate the effects of a streamwise magnetic field on suppression of vortex shedding and controlling the destructive behavior of the flow behind the circular obstacle. The simulations are performed for the Reynolds number from Re=1 to 200, Stuart number from N=0 to 10 and the fixed blockage ratio (S=D/H) equal to 0.8. Note that N=0 represents the absence of magnetic field.

Figure 3 shows the temporal evolution of streamline behaviors for the flow over the obstacle at various Stuart numbers and Re=100. As shown in this figure, a periodic vortex shedding is visible at N=0 because the flow is time-dependent. Lorentz force is generated by exerting magnetic field in horizontal direction. This force always acts to the negative vertical direction (y direction) in this problem that magnetic field is in the horizontal direction (see Eq. 3). Therefore, this force tends to retard the motion of the fluid. It can be seen that for N=0.1, the boundary layer thickness on the obstacle increases and this leads to decrease in vortex strength. Also, the vortex street generated in the wake region is elongated in the horizontal direction with decrease in vortex strength [10]. The flow is stabilized and changes its distribution from the time-dependent

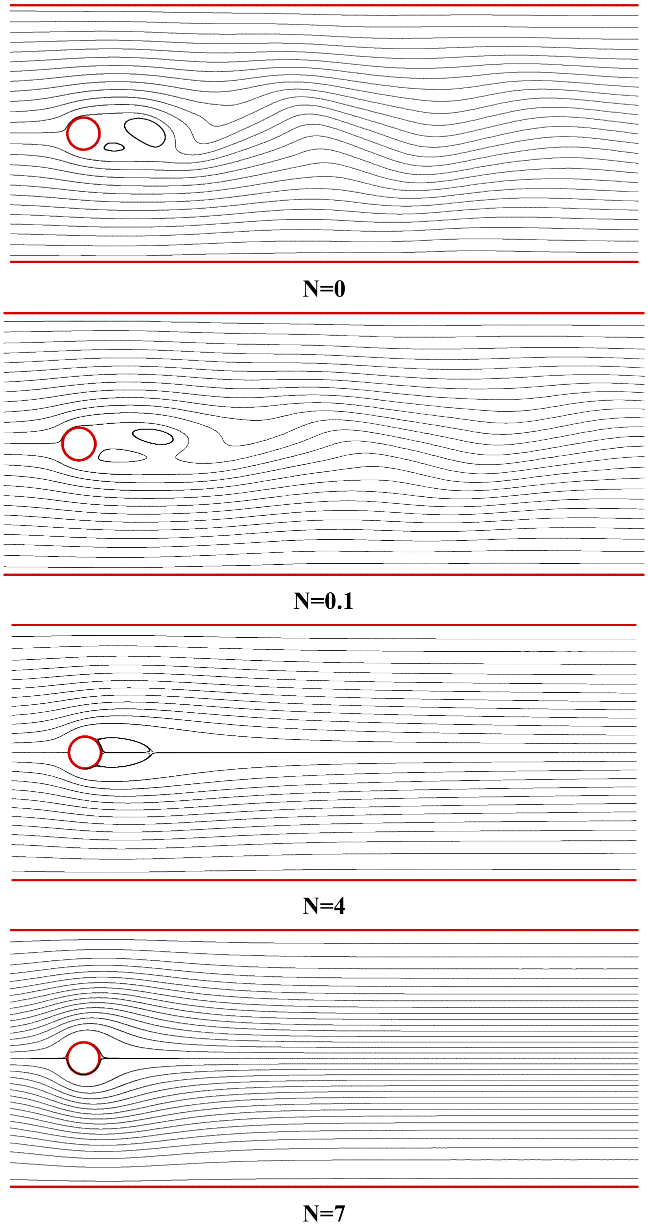

Fig. 3. Temporal evolution of streamline behaviors for flow over the obstacle at various Stuart numbers and Re=100

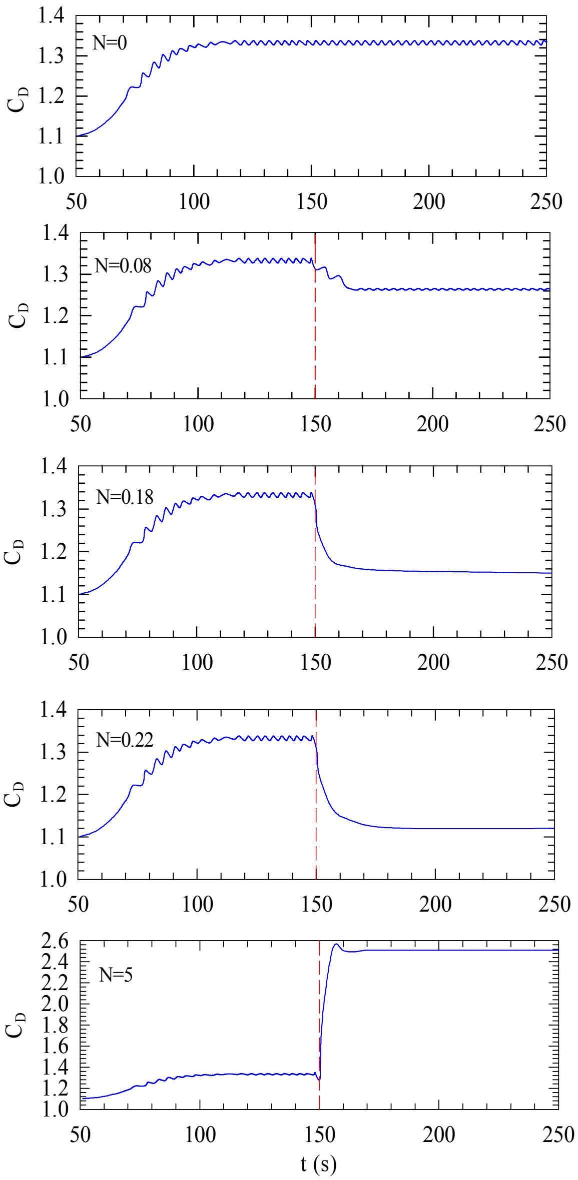

Fig. 4. Variation of drag coefficient versus time at different Stuart numbers for circular obstacle at Re=100

pattern with vortex shedding to the steady state with a symmetric shape along the centerline for higher Stuart number (i.e., N=4). Two counter-rotating vortices are available at N=4 about the centerline. These vortices are vanished by more increase in Stuart number (i.e., N=8).

The variations of the time evolution of the drag coefficient at various Stuart numbers are presented in Fig. 7. The vertical line refers to the activation of the magnetic field at t=150. This figure shows that for low Stuart number, (N<0.22), the drag coefficient reduces slowly by exerting the magnetic field. Within this range, the shear stress forces decreases monotonically with Stuart number. It can also be seen that the fluctuations in drag coefficient are reduced and the diagrams have a smooth behavior by using magnetic field. Also, for higher Stuart number (i.e. N=5), drag coefficient increases rapidly by using magnetic field. Note that for low Stuart number that the flow is still time-dependent, exerting magnetic field leads to decrease in unsteady-flow fluctuations and drag coefficient. At high Stuart number, the flow behavior changes from the time-dependent pattern to the steady state and exerting magnetic field leads to suppress the velocity field and this shows up as an increased viscous drag coefficient. Also, the difference between upstream and downstream pressures increases by using magnetic field and this leads to an increase in pressure drag coefficient.

CONCLUSION

This work focuses on the effects of a magnetic field on suppression of vortex shedding. The numerical model is based on the general equations of conservation of mass (continuity) and the momentum equations. The important findings of this research are listed as follows:

- The flow is stabilized and changes its distribution from the time-dependent pattern with vortex shedding to the steady state with a symmetric shape along the centerline for higher Stuart number (i.e., N=4)
- For low Stuart numbers, (N<0.22), the drag coefficient slowly reduces by exerting the magnetic field.
- For higher Stuart number (i.e. N=5), the drag coefficient increases rapidly by using magnetic field.

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