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Analysis of flow over a circular cylinder fitted with helical strakes

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Abstract

The effectiveness of the helical strakes in suppressing the vortex-induced vibration (VIV) of a rigid cylinder is investigated by providing a three start helical strakes around a circular cylinder at two Reynolds numbers (100&28000). While the effect of helical strakes on suppression of vortex shedding has been studied extensively, the mechanism of VIV mitigation using helical strakes is much less well documented in the literature. In the present study, a rigid circular cylinder of diameter d=40mm attached with three-strand helical strakes of dimensions of 10d in pitch and 0.15d in height was tested by simulation. To numerically simulate vortex shedding, CFD is used to calculate the unsteady flow that arises from a fluid moving past an obstruction. A computational grid independence study has been done for flow over the circular cylinder and the grid resolution in which there is faster recovery of coefficient of lift is taken for the simulation. The contours of static pressure, velocity magnitude and vorticity magnitude and the hydrodynamic coefficients Cd and CL are obtained. It is found that, as expected, the straked cylinder has a higher drag coefficient in comparison with a smooth bare cylinder. The helical strakes can reduce VIV by about 99%.

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*Keywords:*Helical strakes; Vortex induced vibration (VIV); Hydrodynamic coefficient

1. Introduction

Vortex shedding behind bluff bodies is of concern for many engineering applications. Bluff bodies are structures with shapes that significantly disturb the flow around them, as opposed to flow around a streamlined body. Fluid flow past a circular cylindrical object generates vorticity due to the shear present in the boundary layer. This vorticity in the flow field coalesces into regions of concentrated vorticity known as vortices on either side of the cylinder. When vortices are shed from a bluff body, the latter is subjected to time-dependent drag and lift forces. The lift force oscillates at the vortex shedding frequency while the drag force oscillates at twice the vortex shedding

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frequency. If the cylinder is not rigid enough, these forces may induce vibration of the cylinder. The lift force may induce cross-flow vibrations and the drag force may induce in-line vibrations. This phenomenon is called vortex-induced vibration (VIV). Vortex-induced vibration of bluff structures is one of the key issues in riser and pipe line designs. This is because VIV will increase not only the dynamic load to the structures but will also influence the structural stability. The vibrations may cause structural failure or accelerate the fatigue failure. The above factors may result in an increase in capital investment of the structures and the expenses for maintenance and replacement.

As a result, this subject requires investigation, particularly when the cylinder is fitted with helical fins commonly known as helical strakes, so that a comprehensive understanding about behaviours of the flow for a wide range of conditions can be obtained. Thus the fluid flow around a cylinder, because of complicated phenomena such as vortex shedding and flow separation behind the cylinder, has been studied by many researchers and scientists. They applied some methods and devices to control this flow. Methods are classified in three groups: (1) passive control, (2) active control and (3) compound control. Passive control techniques do not need any external energy. Additional devices in the fluid flow or changing the geometry of the bluff body such as fins, splitter plate and roughness are applied in this method. Active control techniques such as EHD actuators and vibrators need external energy to affect the fluid flow. In compound control method, both active and passive techniques are applied simultaneously.

Inoue et al. [1] constructed a non-uniform mesh but divided the computational domain into three regions, each with a different grid ratio. The smallest cell was located along the edges of the square cylinder with the value of h/D = 0.01. Doolan [2] investigated the grid convergence for three different grid resolutions on DNS around a square cylinder and found that the solution converged when the smallest cell size along the square cylinder edge was h/D = 0.0167. Shuyang Cao et.al.[3] investigated the shear effects on flow around circular and square cylinders. One interesting finding is that the direction of the lift force depends on the body shape, i.e., the lift force acts from high velocity side to low velocity side for the circular cylinder while it is in the opposite direction for the square cylinder. By conducting a numerical investigation Md. MahbubarRahman [4] found that 2-D finite volume method is very much prospective for turbulent flow as well as laminar flow.

T. Zhou et al [5] experimentally investigated the vortex-induced vibration of a cylinder with helical strakes. A rigid circular cylinder attached with three-strand helical strakes of dimensions of 10d in pitch and 0.12d in height was tested in a wind tunnel. It was found that unlike the bare cylinder, which experiences lock-in over the reduced velocity in the range of 5–8.5, the straked cylinder does not show any lock-in region.

Shan Huang [6] , Andy Sworn conducted experiments on two fixed circular cylinders fitted with helical strakes at various staggered and tandem arrangements. It is found that, the straked cylinder has a higher drag coefficient in comparison with its smooth counterpart. It is further found that whilst the strakes reduce the fluctuating forces on the upstream cylinder, the reduction is significantly smaller for the down-stream straked cylinder.

Lee KeeQuen [7] et al. investigated the effectiveness of helical strakes in suppressing VIV of flexible riser. He found that the most effective configuration of strakes in terms of the dynamic responses is p = 10 D and h = 0.15 D model. However, model of p = 10 D and h = 0.10 D performs better in reducing the hydrodynamic forces. The CFD results of two flexible straked risers [8] have also shown that the upstream riser had very little motion than the downstream riser.

Shan Huang [9] found that the helical grooves were effective in suppressing the vortex-induced cross-flow vibration amplitudes with the peak amplitude reduced by 64%. Drag reductions of up to 25% were also achievable in the sub-critical Reynolds number range tested in that study for the fixed cylinders.

Over the last twenty years, a vast amount of studies has been conducted to increase the understanding of different transition processes of the flow past a circular cylinder as well as rectangular cylinders experimentally, numerically and theoretically. By contrast, there are very few similar studies found on flow past circular cylindrical structures provided with helical projecting fins commonly known as helical strakes, at moderate Reynolds numbers.

2. Numerical Simulation Procedure

2.1. Flow field formulation

The governing equations on the flow field are the continuity and momentum equations (Navier–Stokes equations), which can be written as follows:

$$\frac{\partial \rho}{\partial t} + div(\rho V) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho u) + div(\rho V u) = -\frac{\partial p}{\partial x} + div(\mu\, grad u) + B_x \tag{2}$$

$$\frac{\partial}{\partial t}(\rho v) + div(\rho V v) = -\frac{\partial p}{\partial y} + div(\mu\, grad v) + B_y \tag{3}$$

$$\frac{\partial}{\partial t}(\rho w) + div(\rho V w) = -\frac{\partial p}{\partial y} + div(\mu\, grad w) + B_z \tag{4}$$

Where 'ρ' is the fluid density, 'μ' is the fluid viscosity, 'V' is the velocity vector of the flow field, 'p' is the pressure, and u, v and w are the velocity components in the x, y, and z-directions,respectively. B_x and B_y are also the body forces per unit volume, which are negligible in the present study. The fluid is assumed to be incompressible, and its properties has been taken as ρ=998.2 kg/m^3 and μ=1.003×10^{-3} kg/m s.

A circular cylinder with a diameter 'd' of 40mm and a length 'L' of 400mm was used either as a bare cylinder or after the installation of the helical strakes, as a straked cylinder. It contains three-start strakes helically wound on the surface of the structural member in a definite fashion. The strakes are rigid and has dimension of 10d pitch & 0.15d height, is tested.

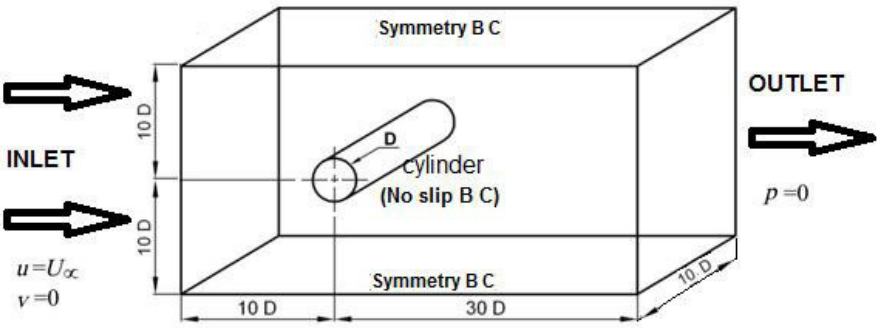


Fig.1 Domain for a circular cylinder (not to scale).

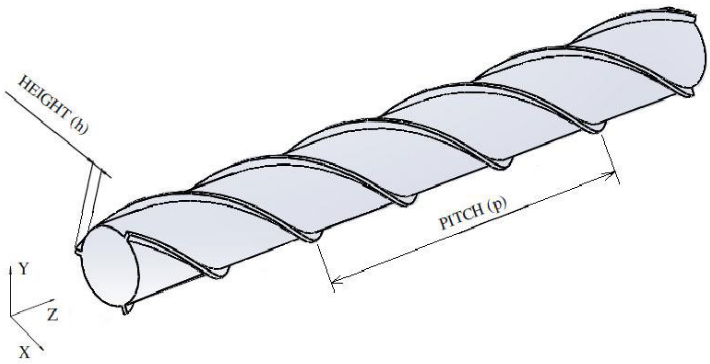


Fig. 2 Circular cylinder fitted with helical strakes

2.2. Discretization Method

The governing equations have been discretized using the finite-volume method on a fixed Cartesian-staggered grid with non-uniform grid spacing. The grids in the region of the embedded boundaries are sufficiently fine in order to achieve the reasonable accuracy. The temporal discretization has been done in conformity with the fully implicit scheme. For the spatial discretization, the Hybrid scheme has been employed.

The PISO (Pressure-implicit with splitting of operators) procedure was applied to calculate the flow field variables.

2.3. Grid Independence

Within the scope of predicting the flow field around a circular cylinder using numerical analysis, many similar investigations have been made, but the results always show small discrepancies even though the overall global trends are similar. One of the reasons for these discrepancies is the difference in the construction of the mesh.

The coefficient of lift on the cylinder is shown in figure 3. Five different 3D grids are used.

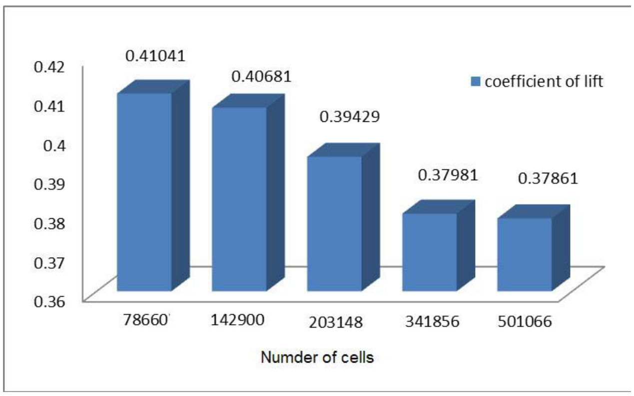


Fig. 3 Coefficient of lift on the cylinder

The results of this case show a certain dependency on the grid resolution for the grids used. Lift force has been obtained for each case and plotted as shown in figure 2. It is observed that there is a change in value of lift force with increase in number of cells up to 3 lakh cells. Beyond that the lift force is approximately the same in all runs.

3. Results and discussion

Preliminary simulations have been carried out in order to define adequate computational domains to assure grid independence. With different refinements, both uniform and non-uniform meshes have been tested.

In the present study, simulation analyses of 2 cases i.e., for bare circular cylinder and for circular cylinder fitted with helical strakes at two Reynolds numbers (Re 100 & 28000) are included.

3.1. Case:1 Flow Over A Circular Cylinder

As a preliminary analysis, the flow over a circular cylinder was simulated at a low Reynolds number. The aim of this is to obtain the flow structure, pressure and velocity near the cylinder and in the downstream wake region. Also obtain the frequency at which the vortex shedding taking place.

As the fluid flows past the circular cylinder, due to the adverse pressure gradient on the downstream surface of the cylinder, at some point the boundary layer separates from the cylinder. The separation takes place alternatively from top and bottom of the cylinder surface. This causes an alternate shedding of vortices in the downstream side as shown in vorticity magnitude contour in fig 4.

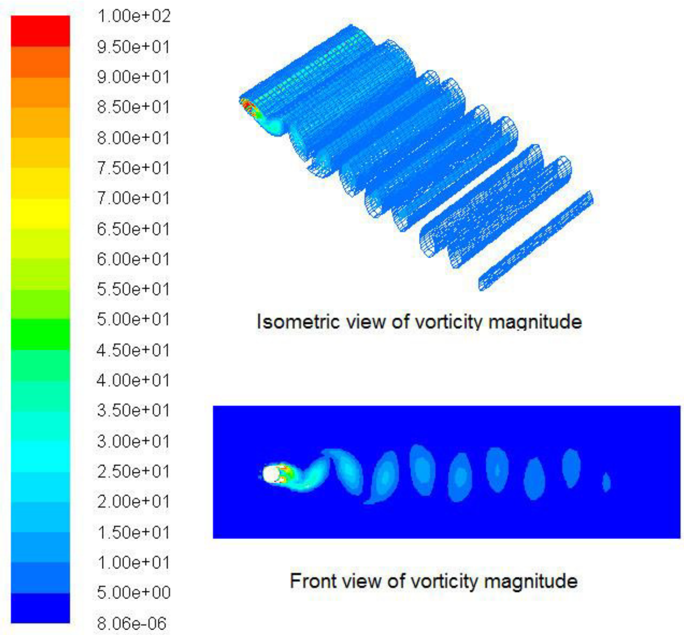


Fig. 4 Contour of vorticity magnitude

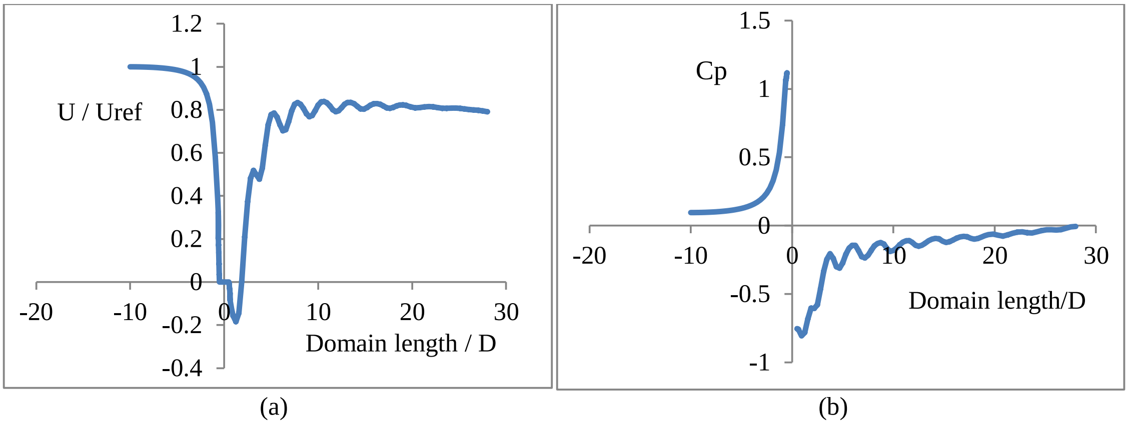


Fig. 5 (a) Mean axial velocity along the centre plane,(b)Variation of coefficient of pressure with domain length

Fig-5b shows variation of pressure in the wake region of cylinder. The contours obtained and the variation of coefficient of pressure indicates that the numerical scheme, domain size, mesh resolution, and other parameters have been adequately chosen to capture the complex wake behaviour.

3.2. Case:2 Flow Over Circular Cylinder Fitted With Three Start Helical Strakes

3D simulation was performed for a circular cylinder fitted with helical strakes of pitch 10d and height of 0.15d in order to study its effects and changes in the flow characteristics in the wake region of the cylinder.

If the fluid flows past the cylinder fitted with helical strakes, these strakes will break the flow and produces vortices at different points along the cylinder. These vortices are out of phase with one another and due to partial cancellation of the out-of-phase lift forces at different span wise position, the lift coefficient for the straked cylinder is much smaller than that of a bare cylinder. Fig-6 shows the velocity vector at 3 planes along the length of the straked circular cylinder.

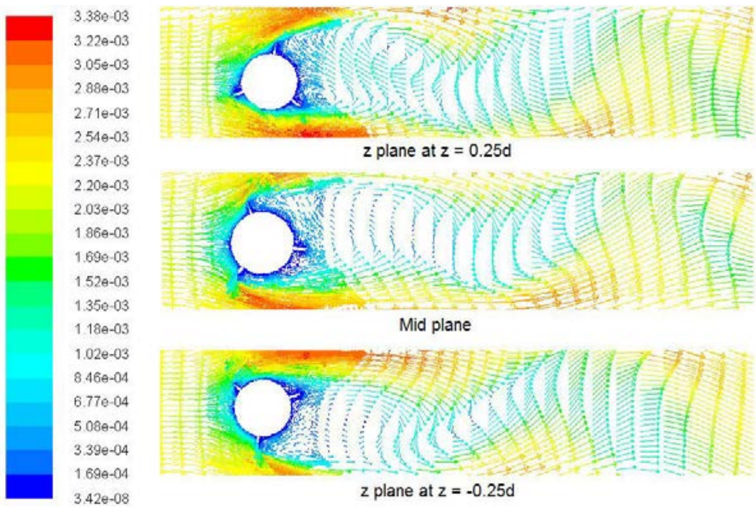


Fig. 6Velocity vector at different z planes (spanwise planes) for a staked cylinder

The helical pattern of the projecting fin induces a span wise motion for the fluid while it flows around the straked cylinder. This will produce a swirling motion in the wake region and disrupt the spanwise vortex formation.

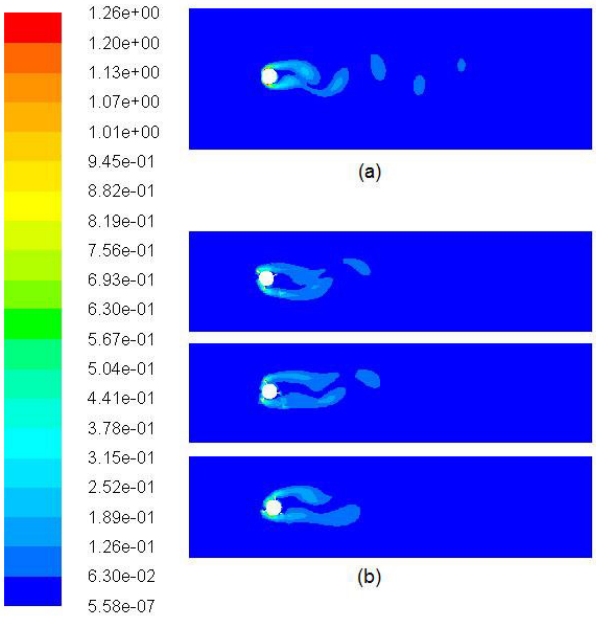
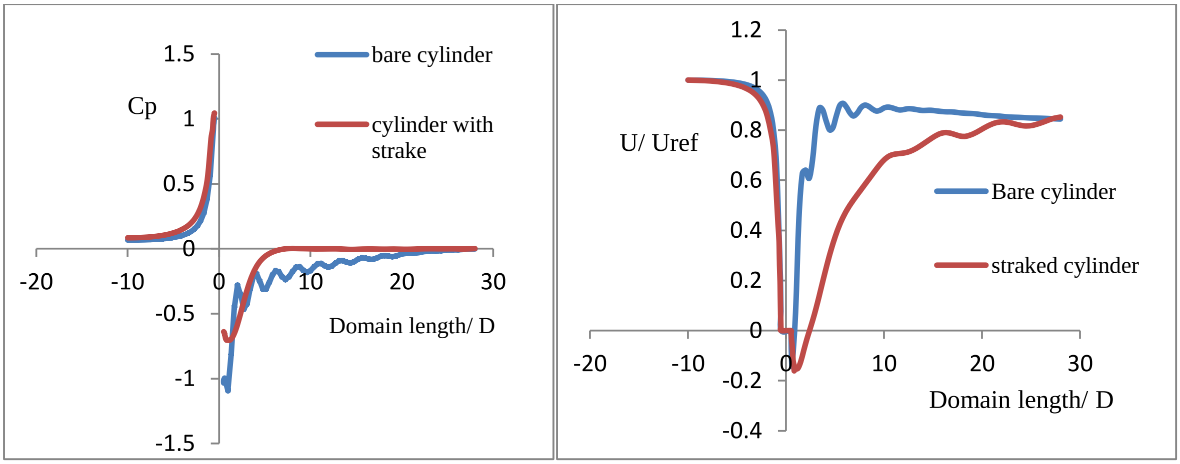


Fig. 7Contours of vorticity magnitude at Re = 100 :(a) bare cylinder; (b) straked cylinder at 3 spanwise sections

Contour of vorticity magnitude indicates that there is a close interaction between the two shear layers and results in an oscillating wake for the plain cylinder. If the cylinder is provided with helical strakes, the strake height will control the shear layer separation & they interact at a farther distance from the cylinder body than the bare cylinder case.

The helical strake has a main effect on the pressure distribution downstream of the circular cylinder. This is shown in fig.8(a).



(a) (b)

Fig. 8 (a)Variation of coefficient of pressure for a bare cylinder and a straked cylinder; (b) Mean axial velocity on the centre plane of the cylinder with and without helical strakes

For strake cylinder wake, the two shear layers do not interact with each other, resulting in the absence of the oscillating wake in the downstream region of the cylinder.

Table 1.A comparison between bare cylinder and straked cylinder

Reynolds Number	Parameter	Bare cylinder	Straked cylinder (pitch=10d, height=0.15d)
100	C_L	0.36	0.3
	C_d	1.41	1.61
	St	0.17	0.15
28000	C_L	1.01	0.01
	C_d	1.1	1.3
	St	0.189	0.142

As shown in the table-1, the strakes reduce the lift force acting on the cylinder and strouhal number. Strouhal number is a non-dimensional parameter which relate the frequency of vortex shedding to the incident fluid by St=fD/U. where D is the diameter of cylinder, f is the vortex shedding frequency and U is the incident velocity. As expected the drag force increases with the addition of strakes.

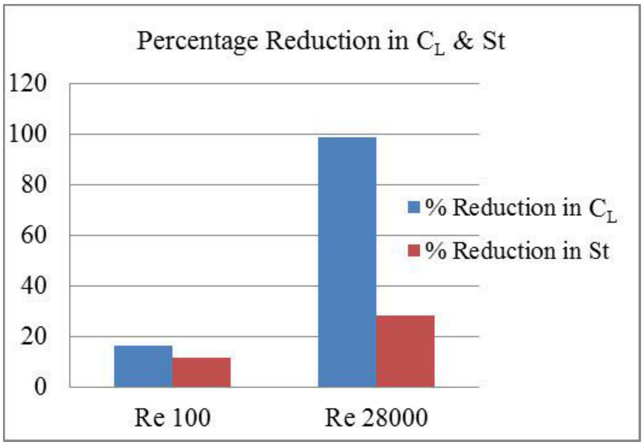


Fig. 9Percentage reduction in coefficient of lift (C_L) &Strouhal number (St)

4. Conclusion

A numerical investigation of the flow around circular cylinder with and without the helical strakes at Reynolds numbers 100&28000 has been presented. The simulation performed after grid refinement allowed observation of the vortex generation process over the circular cylinder and its wake region.

The helical strakes are very effective in suppressing the vortex shedding from circular cylinders and can reduce the strength of vortex shedding by about 99%. At low Reynolds number flows, since the boundary layer thickness is high, the same helical strake of 0.15d in height is not given the same effectiveness in reducing the vortex shedding. A maximum of 19% reduction is possible at Low Reynolds numbers.

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