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Effect of Upstream Cylinder on the Wake Structure and Evolution of Flow over a Finned Circular Cylinder

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ABSTRACT

This paper reports the results of Computational Fluid Dynamics (CFD) simulations to investigate the effect of an upstream cylinder on the wake structure and evolution of flow over a finned circular cylinder evenly attached with rectangular ribs around its circumference and identifying the near-wall vortex structure are formed. Also examined the effect of the number of ribs ($n=3, 5$) in a low Reynolds number range of 60–180. The main concern in the aerospace domain is the vortex induced vibrations. It is necessary to find ways to reduce the fluid forces and stabilise the flow wake either actively or passively. Therefore, be it in the field of aerodynamics and in offshore wind turbines. The near-wall vortices and their evolution are sensitive to *Re* as well as n. The evolution of flow around the cylinder with 3 ribs ($n = 3$) *QS* are formed in the corners over which the boundary layers stride. The subordinate vortices disappear at $Re=60$, possibly attributed to the relatively great viscous force at such lower *Re*. The evolutions of flow over the finned cylinder with 5 ribs at three representative *Re* cases are compared. The number of Sub created in accompany with a main vortex grows with the increase in Re. and then generates the main vortices behind the associated ribs

INTRODUCTION

One of the main concerns in the domain of aerospace is the vortex induced vibrations (VIV). H. Zhu and J. Yao (2015) investigated that it is necessary to find ways to reduce the fluid forces and stabilise the flow wake either actively or passively. Passive control techniques are easier and less costly to be implemented in practice without the requirement of external energy input. Therefore, be it in the field of aerodynamics or in offshore wind turbines it is usually studied with maximum solicitude. A great understanding of flow over a finned circular cylinder with the variable number of ribs and the associated flow characteristics of wake structure in the downstream of a circular cylinder in a lower Re range is of utmost need. The fluctuating fluid force exerted on the finned circular cylinder can cause VIV and thus lead to fatigue damage. This can affect the lifetime of the structure. The main motivation of this research is to find a structure which is simpler and can be practical. A sufficiently large size of surface roughness is required to trip the boundary layer, and the effect depends on the Reynolds number. The VIV suppression is typically attained at the cost of increasing drag force. As the name near wake stabiliser indicates, a dummy cylinder is placed in the wake of a finned circular cylinder. The cylinder stabilised the flow wake and delayed the vortex shedding at a subcritical Reynolds number.

To design the computational domain of a rectangular region with an upstream as well as a downstream finned cylinder in ANSYS WORKBENCH 2021 using designer modeller. To perform low Reynolds number (Re) simulation (60-180) on finned cylinder to identify the flow structures with changes in number of fins and Re. To address how the flow structures involve an upstream cylinder. These were the main objectives focused on this project. The wind tunnel experiment conducted by Nigim and Batill

(1997) illustrates that the mean drag and vortex shedding frequency are closely related to the near-body flow field, which is significantly altered by the small circular rods evenly attached to the cylinder as surface perturbations. Semi-circular ribs were employed as perturbations in the experiments performed by Skeide (2020), it demonstrated that the height and spacing of ribs affect the drag coefficient and the critical *Re* for drag reduction. Zhang (2016) numerically evaluated the performance of perturbations with polygonal and ridged cross section and found small vortices are generated in between the ridges due to the local separations. Kimura and Tsutahara (1991) reported that a groove on the cylinder surface influences the boundary layer separation point, and the effect of drag reduction depends strongly on the groove location and *Re*, which is confirmed by Yamagishi and Oki, Fujisawa and Lee (2005) for a circular cylinder covered with triangular groove, arc groove, and V-shaped groove rib lets. Canpolat(2015) pointed out that the Karman vortex shedding frequency is also associated with the groove size and a sufficiently large groove can create the shear layer instability with additional frequencies.

LITERATURE REVIEW

Hongjun Zhu and Wenli Liu (2021) reported the results of a numerical investigation into the flow over a circular cylinder evenly attached with rectangular ribs around its circumference and the associated near-wall vortex structure as well as the evolution of wake flow. The effect of the number of ribs (*n*) ranging from 1 to 12 is examined in a low *Re* range of 60–180. Five kinds of near-wall vortices are identified with the presence of rectangular ribs, including quasi-stagnation vortices, subordinate vortices, inter-rib vortices, inter-rib quasi-stagnation vortices, and dynamic inter-rib vortices. These near wall vortices and their evolution are sensitive to *Re* as well as n. With the introduction of ribs, each boundary layer experiences multiple separations that increase from 2 to 4 as n increases from 1 to 12.The biofouling contributes to the occurrence of naturally roughed cylinders immersed in the water current, which is widely encountered in daily life and engineering practice. As the two dimensional-to-three-dimensional wake transition behind a circular cylinder occurs when $Re > 180$, a two-dimensional numerical simulation is considered in the present study for *Re* range of 60–180.

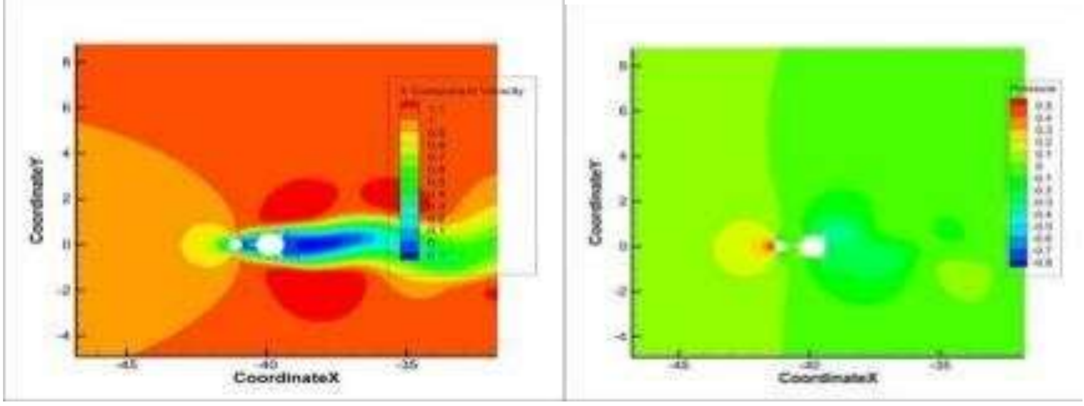
Hongjun Zhu and Tongming Zhou (2019)studied the effect of two symmetrically distributed fin-shaped strips on hydrodynamic forces and flow structures of a circular cylinder is numerically investigated at low *Re* of 60–180.It is observed that the boundary layer separation is tripped by the strips, altering the pressure distribution and forming a recirculation region behind the strips. As a result, the drag and lift coefficients have increased significantly. Both experimental measurements and numerical simulations have confirmed that the instability of the flow wake behind a circular cylinder occurs when *Re* is higher than 47. The vortex shedding identified by definite frequencies leads to time dependent drag and lift forces acting on circular cylinders. Consequently, vibration, known as vortex-induced vibration (VIV), is induced over a range of *Re*. In this work, fin-shaped strips are proposed with the intent of increasing the hydrodynamic forces and altering the vortex shedding. The primary aim is to examine the effects of fin shaped strips on fluid forces, flow structure and vortex shedding at low *Re* range of 60–180 to get further insight into the interaction between fluid and structure under a controlled situation. It is expected that numerical simulations at low*Re* can provide detailed flow structures in the boundary layers of the cylinder surface, which is difficult to measure experimentally. This knowledge is invaluable in explaining the effect of control on the flow structure. The fin-shaped strips trip the boundary layer and alter the pressure distribution around the cylinder surface. A recirculation region is formed behind the strips. Moreover, this region at $\theta = 30°$ and $40°$ is separated by the reattached boundary layer flow from the flow wake, leading to an obvious turning point after the pressure recovery. When the strips are placed at $40°– 80°$, the reduction of base pressure becomes larger as *Re* increases, and hence the uplift in drag force. The minimal base pressure occurs at $\theta = 60°$, resulting in the maximal drag.

RESEARCH METHOD

The finned cylinder with *n* ranging from n=3 and =5 denotes the number of fins evenly distributed around the circular cylinder. Each fin is a rectangular rib with a height of h= 0.25D and a thickness of t= 0.1D. In the examination of the influence of ribs' number, there is always a rib installed in the front stagnation point of the circular cylinder while increasing n=3 and n=5. The methodology involved designing the computational domain in a rectangular region measuring 90D in the stream wise direction as well as adding distance between the upstream and downstream cylinder. Then generating fine mesh using face meshing and edge sizing in Ansys Fluent 2022. The mesh in a fluent CFD solver was set up. The boundary conditions, calculation activities and solution animations to get velocity and pressure contours for the computational rectangular domain were specified. Run two dimensional simulations and export solution data history from fluent for plotting streamlines in Tecplot 350 EX 2020 R2.

Flow field analysis when the velocity of 1 m/s is applied at the inlet. The velocity palette and the pressure palette are displayed below. For Re 60

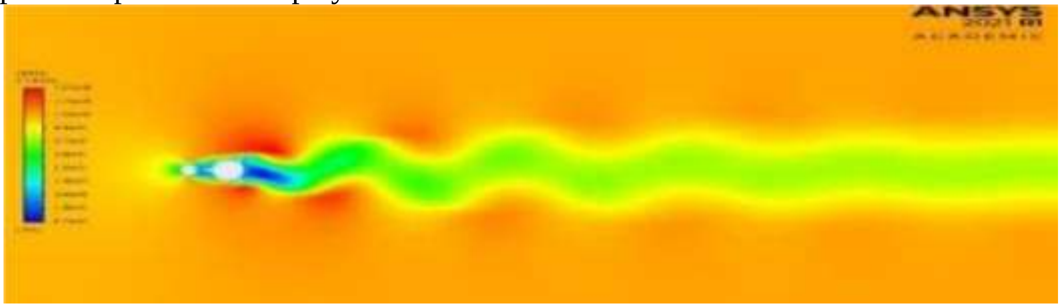
Flow field analysis of velocity palette of range -0.1 to 1.1 where the exit velocity is 0.9 to 1. As velocity is the driving force, the pressure is almost negligible at the inlet and then it slowly begins to increase as the flow moves downstream of the finned cylinder. The maximum velocity of 1.1 is observed at the point where the boundary layer separation occurs in the upstream and downstream cylinder.



(a) Velocity contour at *Re* 60 (b) Pressure contour at *Re* 60

Pressure palette of range -0.8 to 0.5 bar is shown. As pressure is initialised at the inlet, the point of maximum pressure will be at the inlet and as the flow develops, it will decrease in the downstream cylinder until ambient condition is achieved at the exit.

Flow field analysis when the velocity of 1 m/s is applied at the inlet. The velocity palette and the pressure palette are displayed below. For Re 180



(a) Velocity contour at *Re* 180 where d=0.5D

(b) Pressure contour at *Re* 180 where d=0.5D

RESULTS AND DISCUSSION

The effect of the number of ribs (n) ranging from 3 and 5 in a low *Re* range of 60–180. Five kinds of near-wall vortices are identified with the presence of rectangular ribs, including quasi-stagnation vortices, subordinate vortices, inter-rib vortices, inter-rib quasi-stagnation vortices these near-wall vortices and their evolution are sensitive to *Re* as well as n. The evolution of flow around the cylinder with 3 ribs (*n* = 3) *QS* are formed in the corners over which the boundary layers stride. The existence of a *QS* indicates that the boundary layer separates from the structure surface (rib or cylinder) upstream the corner and then reattaches the structure surface downstream the corner. The boundary layers finally separate from the top of the ribs symmetrically distributed in the cylinder's rear surface and roll up to generate main vortices. Consequently, the vortex shedding occurs in an alternate manner between the two sides of the finned cylinder with three ribs

The subordinate vortices disappear at *Re=60*, possibly attributed to the relatively great viscous force at such lower *Re*. As *Re* increases from 90 to 180, the size of Sub enlarges gradually, signifying the influence of the amplification of inertial force on the near-wall flow

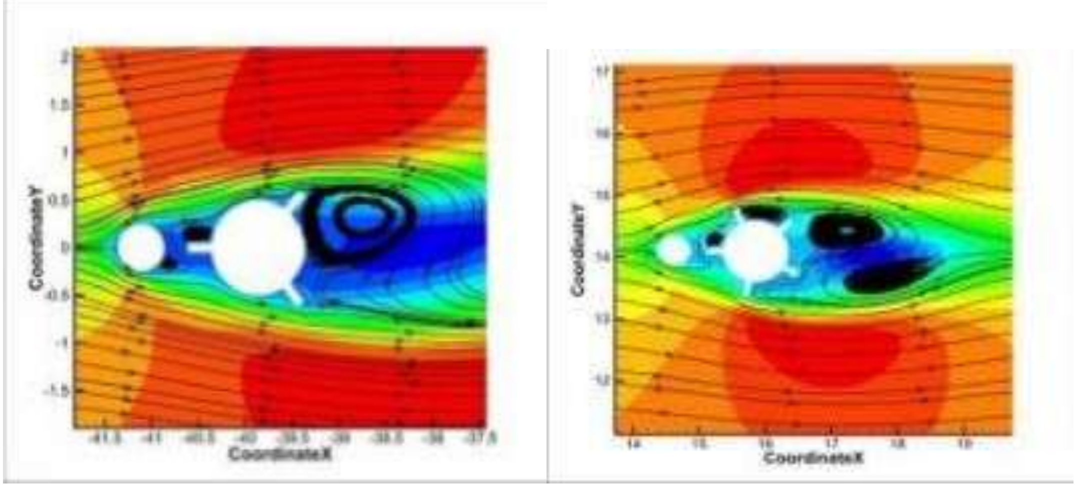


Fig. Tecplot graph for dummy and finned cylinder at *Re* 60 (n=3, 5)

n=3, Subordinate vortex is formed behind the bare cylinder and the main vortex in the downstream cylinder. n=5, formation of inter rib vortex is observed and wake width of subordinate vortex accompanying main vortex is increased.

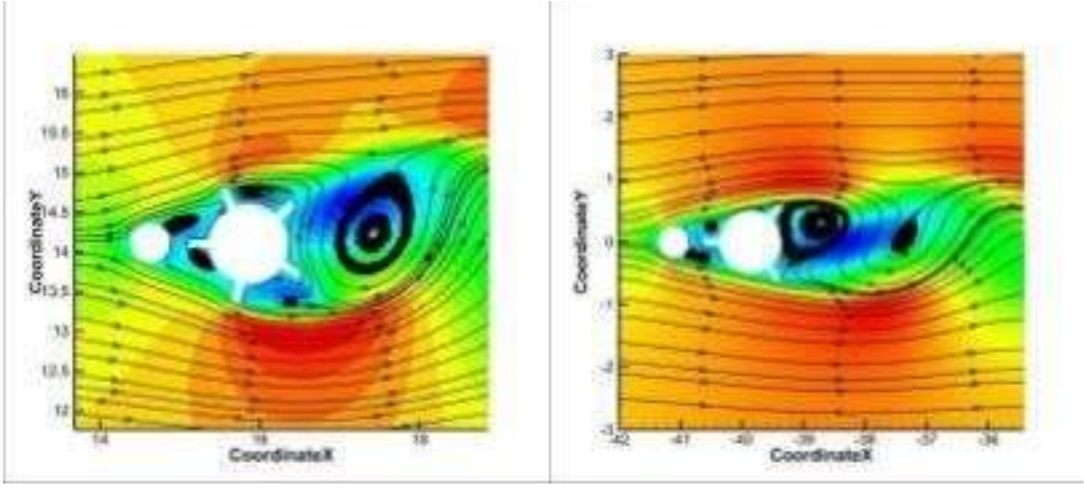


Fig. Tecplot graph for dummy and finned cylinder at *Re* 180 (n=3, 5)

n=3, Quasi stagnation and subordinate vortex is observed behind the dummy cylinder and the main vortex is not found behind the downstream cylinder but a subordinate vortex is observed behind the downstream cylinder. n=5, with fewer subordinate vortices, the size of quasi-stagnation vortices increased. Main vortex reduced due to decrease in sub ordinate vortex. The evolutions of flow over the finned cylinder with 5 ribs at three representative *Re* cases are compared. The number of Sub created in accompaniment with a main vortex grows with the increase in *Re*. and then generates the main vortices behind the associated ribs. At *Re*, when a clockwise main vortex is formed behind the rib, a subordinate vortex emerges behind the downstream rib. Two subordinate vortices are created near the cylinder wall in accompaniment with the formation of two main vortices during one shedding cycle for this finned cylinder with five ribs at *Re=90*. At *Re=120*, apart from the appearance of Subordinate vortex, another subordinate vortex occurs at the root of the lower rib. Vortices accompanied with two pairs of subordinate vortices are formed near the cylinder surface during one shedding cycle at *Re=120.* When *Re* further increases to *180*, the formation ofone main vortex is accompanied by three subordinate vortices, located behind the rib downstream the main vortex and the two sides of the rib across the wake. In other words, a main vortex and three subordinate vortices merge into one vortex during a half shedding cycle at *Re=180*. It implies that the enlargement of inertial force withincreasing Re possibly contributes to the rise of the number of subordinate vortices.

CONCLUSION

Due to the fatigue damage caused by VIV, a variety of control methods have been proposed to stabilise the flow wake and hence suppress VIV. With the introduction of an upstream cylinder, the boundary layers develop along the cylinder before attaching on the cylinder surface, while the vortex shedding is delayed and flow wake is narrowed as compared to the bare cylinder, contributing to the vortex-induced vibration suppression. The structure becomes more streamlined resulting in the smaller wake width. Four kinds of near-wall vortices were introduced in the presence of the dummy and the fin cylinder. Quasi stagnation vortices (*QS*) are formed in the root of ribs due to the boundary layer separation from cylinder (or rib) surface followed by a reattachment on rib (or cylinder) surface. Subordinate vortices (*Sub*) are generated along with the main vortices because of the obstruction of ribs. The subordinate vortices are finally merged into the main vortices. Inter rib vortices (*I*) are produced in the grooves between ribs. *VIV* suppression is typically attained at the cost of increasing drag force. The near-wall vortex is strongly dependent on *Re* and number of fins. The subordinate vortices increase with increase in number of fins and *Re*. The subordinate vortices disappear for *Re* 60 and it gradually increases from 90 to 180.

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