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Numerical investigation of fluid-structure interaction of a detached flexible plate behind a circular cylinder

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ABSTRACT: Fluid-structural interaction is one of the most challenging phenomena observed in the surrounding environment, which can play a major role in increasing heat transfer, reducing drag and lift coefficients, energy dissipation, and reducing pressure drop. By inspiration from similar phenomena in nature, the dynamic behavior of flexible structures that interact with fluid is recognized as a novel application in industrial processes such as marine equipment, heat exchangers, and fluid transports. So, this phenomenon should be considered as a way to increase efficiency, eliminate defects, and prevent possible damage in industrial issues on a smaller scale. In this study, the effect of a detached flexible plate, which is placed at a specific distance from a circular cylinder, on aerodynamic and thermal parameters is investigated. This study is simulated by the finite volume method and the finite element method, simultaneously, and also kw-SST model is considered as the turbulent flow model. The fin is placed at different distances of 0.5D, 1D, and 1.5D in upstream and downstream of the circular cylinder, where D is the diameter of the cylinder. The results show that placing the fin at a distance 1D from cylinder downstream increases the Nusselt up to 5%. Moreover, the maximum reduction of the drag coefficient is obtained in this situation.

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1- Introduction

Fluid-structure interaction (FSI) is important in engineering because when fluid flows over a bluff body, it can change shape and affect the flow. This makes studying fluid flow for engineering devices complicated. There have been many experimental and numerical studies on the effect of an attached and detached rigid/flexible plate on a circular cylinder. for the detached flexible plate, it was found that placing a flexible splitter plate upstream, downstream, and on both sides of the cylinder reduced drag significantly [1-3]. On the other hand, it is observed that aerodynamic forces caused the plate to move vertically [5], and the maximum oscillations of a flexible plate occurred where the vorticity structure was fully formed [6]. The plate in the wake of the circular cylinder or square cylinder had the benefit of harvesting more energy [7]. This article studies the impact of fin flexibility on heat transfer in turbulent flow, using rigid support to bind the fin in fluid flow. It also discusses the effect of Young's modulus on heat transfer, drag coefficients, and cylinder drag.

2- Methodology

In this study, a fin behind a cylinder with a supporter in the wake of a circular cylinder is investigated (See Fig. 1). The fin length and the thickness are D and 0.02D (where D is the diameter of the cylinder), respectively. The distance between the beginning of the fin and the closest point to the cylinder is equal to 0.5D, 1D, and 1.5 D.

The stress and strain for linear and isotropic elastic behavior based on Poisson's ratio, Young's modulus, and Kronecker's delta are considered for the structure part.

Also, the *k-ω SST* (Shear Stress Transport) model is used for turbulent flow simulation. This model, which uses the k-ε model and the k-ω model for free-shear layers and near the surface, can predict the beginning and the amount of the flow separation under adverse pressure gradient conditions.

This study assumes constant pressure at the outlet and constant velocity and temperature at the inlet. Non-slip and high-temperature conditions are applied to the bluff body boundaries and symmetry conditions for the upper and lower boundaries. This study utilized the ANSYS workbench with the Arbitrary Lagrangian-Eulerian ALE method and SIMPLE scheme to pressure-velocity coupling while discretizing convection terms with the second-order upwind scheme. The time step for integration is 5-10 based on the courant number. The Reynolds and Prandtl numbers and Poisson's ratio are Re=14400, Pr≈0.74, and 0.35, respectively. The convergence criterion is 10^{-6} for motion, energy, and continuity equations and 10^{-8} for structure equations.

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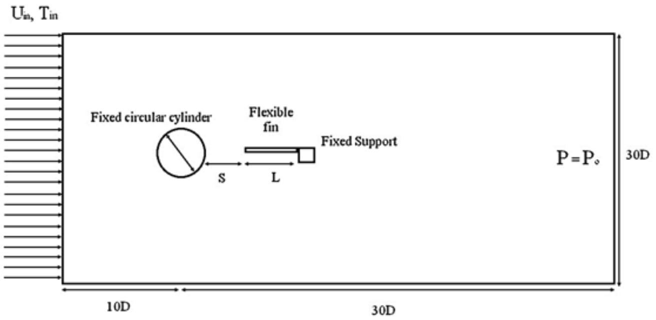

Fig. 1. Schematic of the current geometry and computational domain

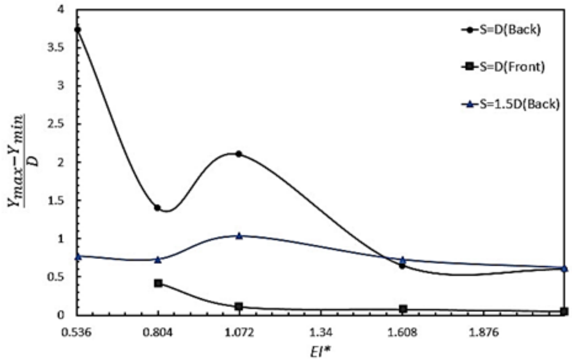

Fig. 2. Comparing the effect of the distance of the fin from the cylinder on the Y-displacement of the fin end

3- Discussion and Results

In this section, we present numerical simulation results for different distances of the flexible fin from the cylinder and various values of Young's modulus (*0.54<EI*<2.14*).

According to Figure 2, At EI*>1.5, the fin displacement is farthest downstream from S=D. For EI*<1.5, displacement stays constant despite Young's modulus increase at all distances. Displacement at S=0.5D is minimal and insignificant in front of the cylinder.

Based on Figure 3, The lowest drag coefficient for the fin is observed when placed at a distance S=D upstream of the cylinder. This value increases for EI*<1.63. Comparing different distances of fin placement in the downstream flow, it can be seen that at distance S=D, where displacement of the fin is more remarkable than distance D=1.5, the reduction of the average drag coefficient is the greatest. Comparing the flexible state of the fin with its rigid state at distance S=D, the value of this coefficient is higher for EI*>1/1 for the flexible state but decreases significantly with the increase of Young's modulus compared to the rigid case. At a distance D=1.5, the value of the average drag coefficient in the EI*>1.63 range is higher for the flexible state than for the rigid case. However, there is not much difference between the two cases.

According to Figure 4. The average Nusselt number decreases at *EI*=1.6* for all fin positions. But it increases for *EI*>1.6*. Also, the average Nusselt number is higher downstream for *S=D* due to the fin's displacement. Increasing Young's modulus and reducing fin displacement improves the average Nusselt number for the upstream fin position until *EI*=1.6*. *S=1.5D* shows a higher Nusselt number for *EI*<1.1* and less fin displacement, while *S=D* has a higher Nusselt number for *EI*<1.096* due to more fin displacement for Young's modulus *EI*<1.1*. Flexible fin downstream of the cylinder has a higher average Nusselt number than rigid fin with EI*<1.1. But for EI*>1.096, rigid fins have better conditions for the average Nusselt number.

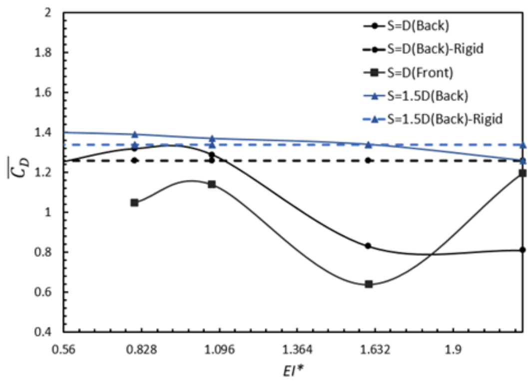

Fig. 3. Averaged-drag coefficient at different distances for Rigid and Flexible cases

4- Conclusion

In this research, the effects of fluid-structure interaction on heat transfer, drag, and lift coefficients were studied. A flexible fin at a different distance from a rigid cylinder with varying values of Young's modulus was analyzed. Results demonstrate that the distance between the fin and cylinder, Young's modulus, and the position of the fin affect flow pattern, forces on the cylinder, and heat transfer.

A fin near a cylinder causes vorticity to elongate while displacement is minimal. As the fin moves away, vorticity shedding becomes complex. Also, Young's modulus affects drag reduction at low fin distances. EI* increases and reduces the lift coefficient range when the fin is behind the cylinder, but the effect is different when the fin is in front. Flexible fins can reduce hydrodynamic forces but may not increase heat transfer significantly compared to rigid fins (up to 5%). In fact, they may even decrease it by up to 20% in some cases. Therefore, the use of a detached flexible fin is effective in reducing hydrodynamic forces but ineffective in increasing

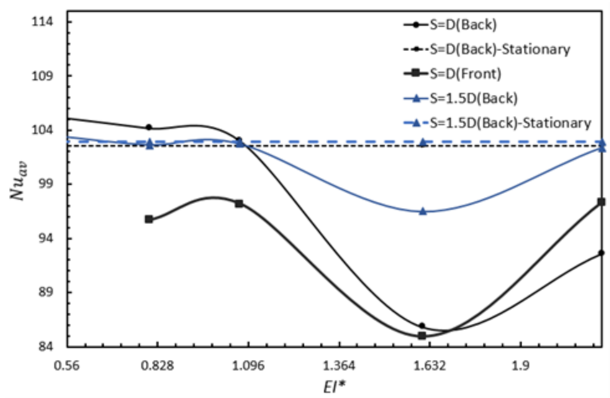

Fig. 4. Averaged-Nusselt Number versus Young Modulus at different distances of the fin from the cylinder for Rigid and Flexible cases

heat transfer.

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