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Numerical Analysis of the effect of fluid-structure interaction on Heat Transfer in the square cavity using OpenFOAM

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The present study discusses the effect of FSI (Fluid-Structure Interaction) in a square cavity with a top wall oscillating i.e. sinusoidal variation of the velocity of the top wall. Due to this varying motion of top plate, fin (flexible fin) start oscillating in the transverse direction of the fin length. Due to flexible plate motion, fluid motion also gets disturbed. Because of this it can increase or decrease the heat transfer rate of the hot wall. For checking the effect of the fin, flexible plate is set on the left, right and bottom wall. It is observed that, incorporation of flexible flap on any wall decreased the heat transfer rate.

***Keywords*:** FSI, sinusoidal, flexible fin.

1. Introduction

In a lid-driven cavity heat transfer is mainly due to air circulation by moving wall. To increase the heat transfer rate of the heated wall is a matter of concern and also it has some engineering application i.e. cooling of microelectronic devices, flat-plate solar collectors, cooling of the electrical component. Abdalla et.al. [1] studied the fluid-structure interaction of mixed convection heat transfer with the flexible bottom in a lid-driven cavity. It is observed that with respect to bottom rigid wall flexible bottom is having a higher heat transfer rate.

Flow-induced deformation of a flexible thin structure as a demonstration of an increase in heat transfer, investigated by Atul et.al [2]. Authors concluded that cylinder with a flexible flap having the highest heat transfer rate as compared to a cylinder with no flap and cylinder with a rigid flap is having least heat transfer because it reduces the vortex shedding. Sameer et.al. [3] investigated the heat transfer and mixing enhancement by free elastic flap oscillation and found that flow through the channel with rigid flap is having less transfer rate with respect to flexible flap. This all the study motivate the current research, where square cavity with flexible flaps are installed on various walls to check the heat transfer rate.

2. Methodology

For numerical simulation, authors used C++ based open source CFD toolkit OpenFOAM as a platform. Finite Volume Method base fsiFoam solver is modified to simulate the present test case. Unsteady incompressible form of Navier-Stokes equation governs is considered. An Arbitrary Lagrangian-Eulerian Approach (ALE) is used to solve the governing equation:

Continuity equation:

$$\nabla . u_f = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial u_f}{\partial t} + \left(u_f - u_{m,f}\right). \nabla u_f = -\frac{\nabla P}{\rho_f} + \vartheta_f \nabla^2 u_f \tag{2}$$

Energy equation:

$$\frac{\partial T_f}{\partial t} + (u_f - u_{m,f}).\nabla T_f = \alpha \nabla^2 T_f \tag{3}$$

Here, u_f = velocity of fluid, $u_{m,f}$ = mesh motion velocity in fluid domain, α = thermal diffusivity, ϑ_f = kinematic viscosity of fluid, T_f = temperature of fluid.

The equation of motion for an elastic adiabatic solid structure can be described from a Lagrangian viewpoint as:

$$\rho_s \frac{\partial^2 d_s}{\partial t^2} = F_\vartheta + \nabla \sigma \tag{4.}$$

ρ_s = density of solid structure, d_s = displacement of solid structure, F_ϑ = resultant body force.

2. 1. Simulation Details

Fig1(left) shows the geometrical and boundary condition details of the considered case. The length of the fin is 15 percent the domain length (a = 1). The oscillating velocity ($U = 1 - \cos\left(\frac{2\pi t}{7}\right)$) is applied on the top wall of the cavity having temperature of 300K . All other boundaries are fixed wall having fixed temperature of 301K. To finalized grid distribution within computational domain, various grid of size 100x100, 120x120, and 140x140 are considered and after comparing the Nu of left wall it is observed that grid size of 120x120 (Fig 1(right)) gives satisfactory results. The selected mesh has 0.001 element size near to all the walls and that gives better quantification of heat transfer. All the simulations are performed for a fixed Reynolds number of 250.

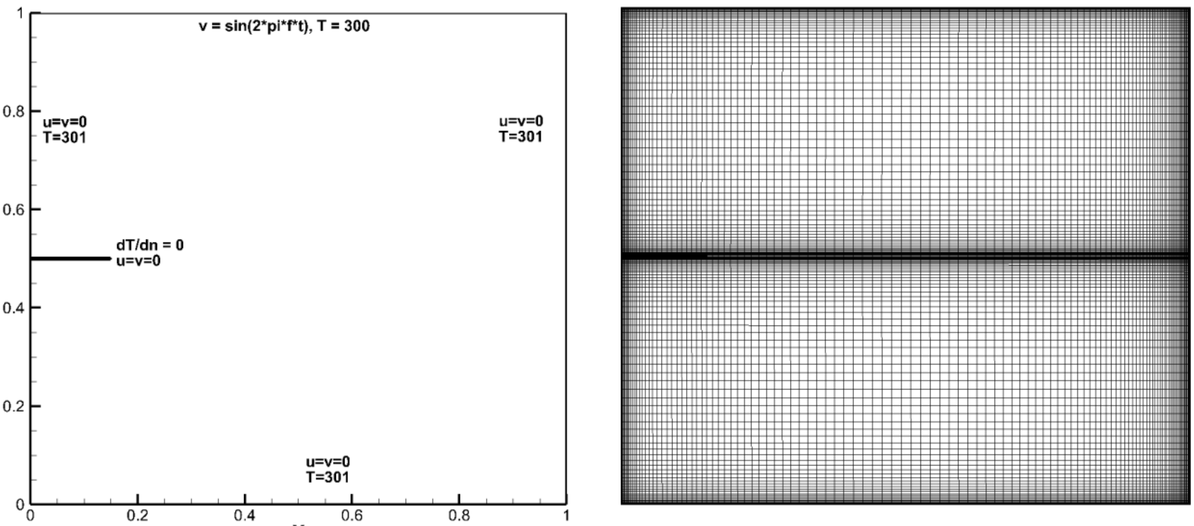
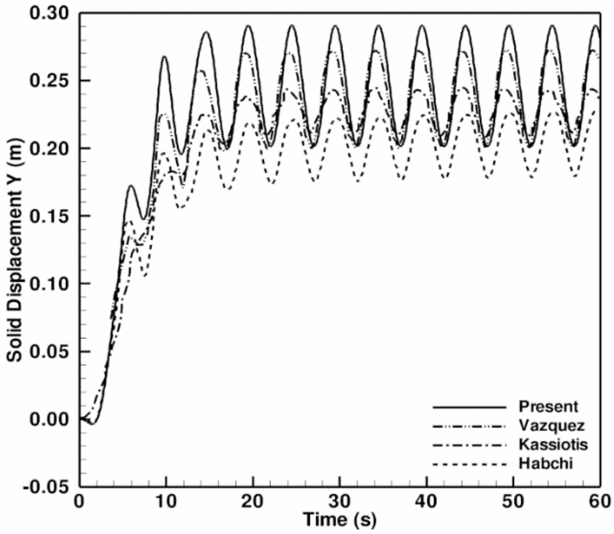


Fig1.Boundary condition and mesh of the test case for simulation

Validation

As a validation study, a square cavity with a flexible bottom and the oscillating top wall is considered. All the geometric detail and boundary condition have taken from Hubchi et.al. [4]. Fig2. shows the mid-point displacement of the flexible bottom wall with respect to time. Present results shows good agreement with the data of Hubchi et.al. [4].



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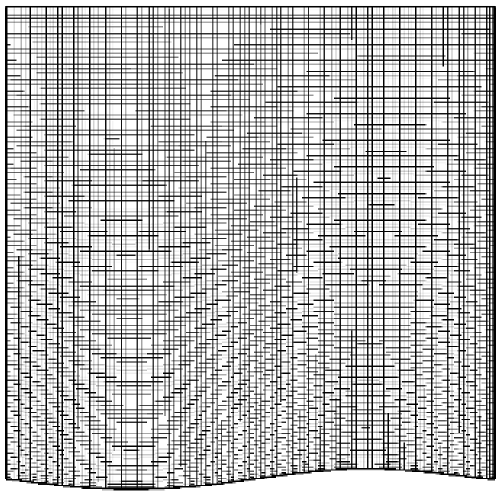

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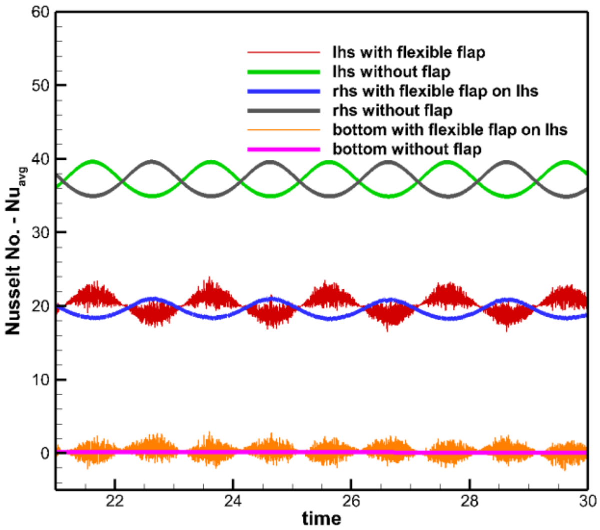
Fig1. (a) Displacement of mid-point on flexible bottom-wall w.r.t time, (b) mesh diagram of the geometry.

3. Results and Discussion

The effect of the fin (flexible plate) placement on the increase or decrease of heat transfer of all hot wall are discussed below.

3. 1. Effect of flexible plate

In the square cavity, the top wall is at a lower temperature and other three walls have isothermally heated with higher equal temperature and stationary. Due to oscillation of top wall the fluid inside the cavity start circulating in the enclosure in the clockwise and anticlockwise direction depending upon the direction of velocity.



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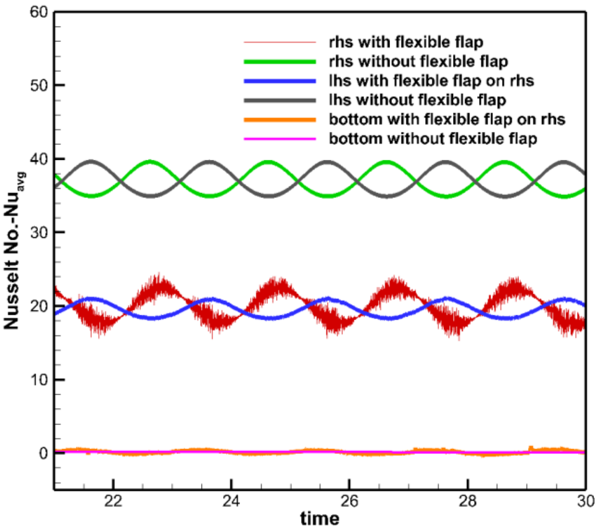

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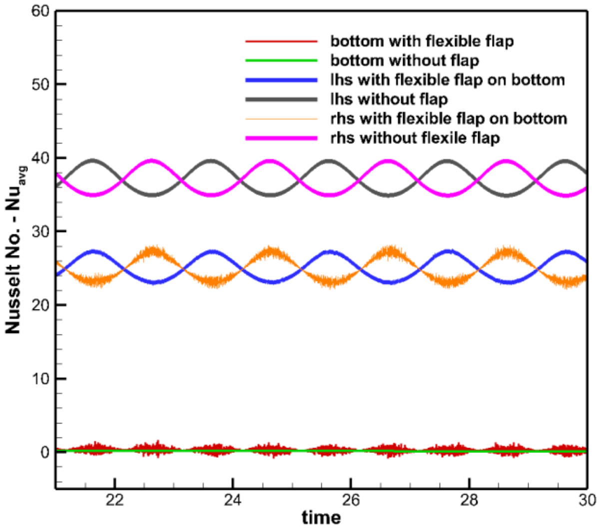
Fig3. Variation of average Nusselt number for left, right and a bottom wall with time (left) flap on the left wall (a), (right) flap on the right wall (b), and comparison with square cavity without a flap.

Fig3 and 4 illustrate the effect of placement of flexible flaps on the Nusselt Number. In Fig 3(left) and 3(right) flap is on the left and right wall respectively and compared the Nusselt Number with without any flap case. Nusselt Number of left and right wall with flexible flap is less as compared to the case of without flap. In square enclosure without any flap, the oscillating movement of top wall disturbs the formation of the boundary layer over the stationary wall and subsequently Nusselt number increases in turn which increases the heat transfer. However, with flap either on left of the right wall, motion of it obstructing the fluid movement within cavity and the heat transfer decreases. However, the oscillation of the top wall do not have that much effect on the bottom wall and therefore the Nusselt number of the bottom wall is least.



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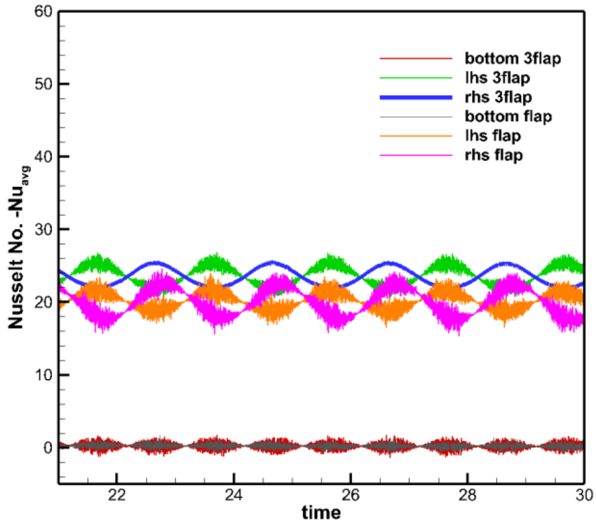

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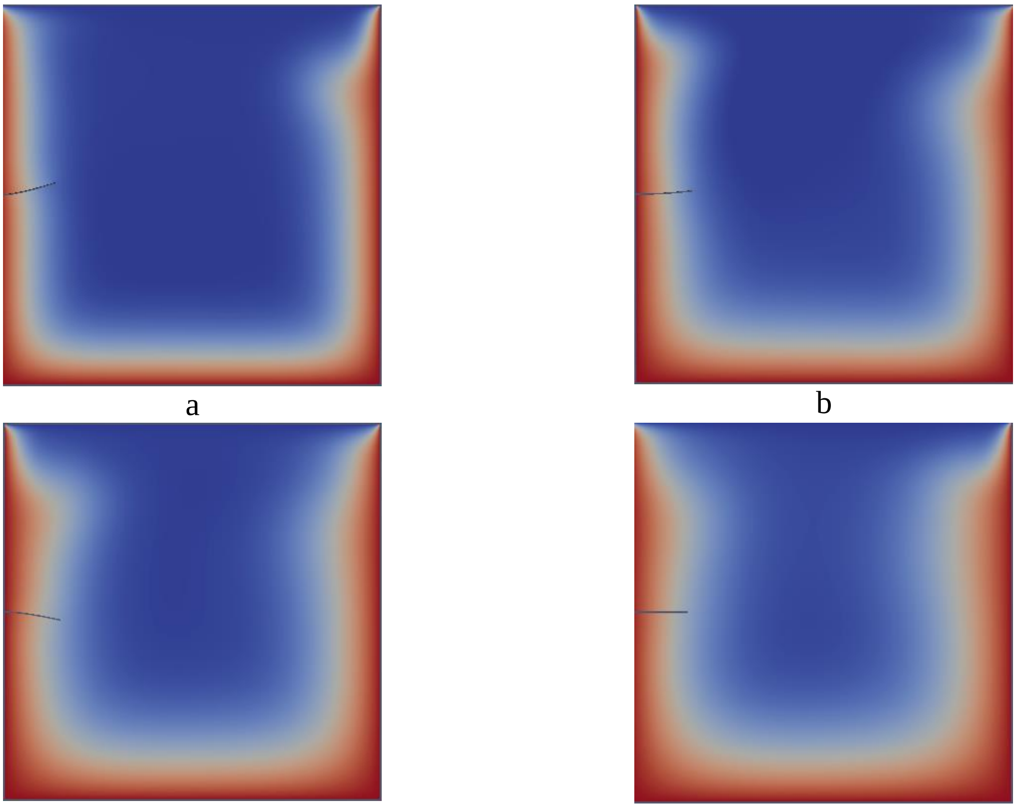
Fig4. (a) Variation of Nusselt Number for the flap on the bottom wall w.r.t square cavity with no flexible plate. (b) Variation of Nusselt number with 3 flaps on the left, right and bottom wall of the cavity compared with the cases of a single flap on an individual wall.

There is not much variation in the Nusselt number of bottom wall with the flap as observed in Fig4 (left). In Fig4 (b) three flap attached inside the square enclosure on the left, right and bottom walls. The result has compared with the moving flap on an individual wall of different cases. With the three flap, heat transfer increases for left and right wall however, still its Nusselt number is lesser than the case of the square cavity without a flap. Fig5 shows the flap movement due to the top wall oscillation. It is observed that, as the top wall oscillate in the horizontal direction, the flexible flap start oscillation in the vertical direction and change the fluid movement within cavity.



a b

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Fig5. Showing the flapping motion of flexible fin due to oscillation of the top wall.

4. Conclusion

In the present study, FSI analysis is performed for square cavity with oscillation top wall and a flexible flap attached to all other three walls. The open source CFD toolkit OpenFOAM is considered as a platform to simulate the proposed test case. It is observed that Nusselt number distribution over left, bottom and right walls are lower for wall with flexible flap as compared to the cavity wall without and flexible flap. However, the fluid motion considerable alter due to the presence of the flexible flap.

References

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