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VORTEX FORMATION IN UNSTEADY FLOW OVER NACA 4412 AND NACA 4424 AIRFOILS

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ABSTRACT

Over the years, the effects of vortex formation on the aerodynamic performance of airfoils have served as motivation for many research studies. This study takes into account NACA 4412 and NACA 4424 which are cambered airfoils. The simulations performed involve low Reynolds number air flow over the airfoils at several angles of attack. Main attention is given on the separation bubble and vortex shedding phenomena, and the effects of vortex formation on airfoils' aerodynamic performance as represented by lift and drag coefficients. Apparently, the vortex-influenced velocity curl shows alternating vortex formation along the airfoils' surfaces and at down streams. Also, the angles of attack influence such formation by developing specific separation bubbles with contrasting fixed points, in particular those along the airfoils' surfaces.

Keywords: vortex shedding, separation bubble.

1. INTRODUCTION

A kind of oscillating flow is vortex shedding which takes place when a fluid such as air or water flows past a bluff body at certain velocities, depending on the size and shape of the body [1], [2]. Once developed, vortex will continue to grow and move circularly from its connected shear layer just before it is strong enough to draw opposing shear layer across the near wake. The theory regarding the stability of vortex sheet was first suggested by Von Karman where vortex shedding phenomena is possible to stabilize if the vortices are shed alternately [3] [4].

Observation of separation bubble, vortex shedding and reattachment is possible in time-dependent flows [5]. They could, under certain conditions, affect surface fluctuations [7]. Numerical simulations of such phenomena can be validated against well-established experiment data in, for instance, [5] and [6].

We aim at the formation of vortex over airfoils. We consider aerodynamic properties of 2-dimensional incompressible viscous flow [8], [9], [10], [11]. The numerical simulations are carried out with the use of ANSYS Fluent. The geometries of interest are the cambered airfoils (i.e. NACA 4412 and NACA 4424).

It is a must that the aerodynamic properties of the flow over the airfoils are at least theoretically correct.

2. FLOW COMPUTATIONAL DOMAIN

The geometry of the cambered airfoils is shown in Figure-1. Respective grid, computational domain and boundary conditions are shown in Figure-2.

3. TOPOLOGICAL OVERVIEW

In this study, both vortex shedding and reattachment information is gained by means of topological overview of the flow. The flow development would show the velocity curl profile over the airfoils in unsteady condition towards the end of normalized time t.

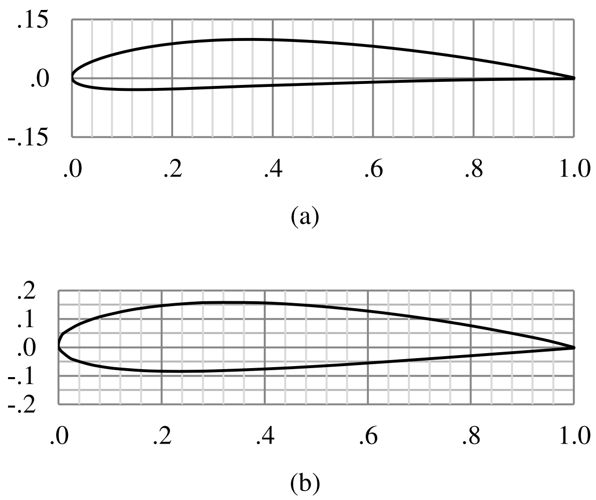

Figure-1. Geometry of cambered airfoils (a) NACA 4412 (b) NACA 4424.

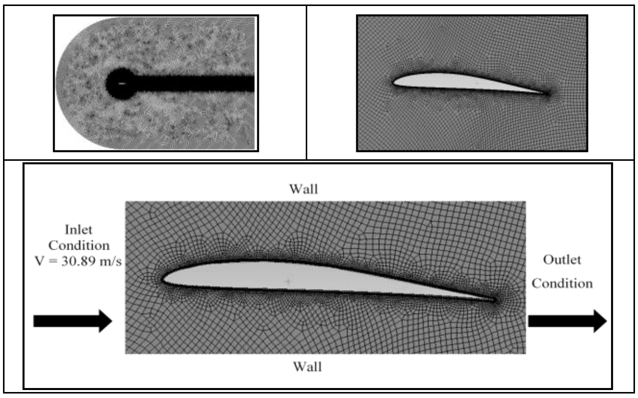

Figure-2. Grid, domain and boundary conditions.

In the case of NACA 4412, the vorticity-induced velocity curl profile begins to occur as early as at 0° angle of attack (see Figure-3). When α = 4°, 8°, 10°, 12°, as

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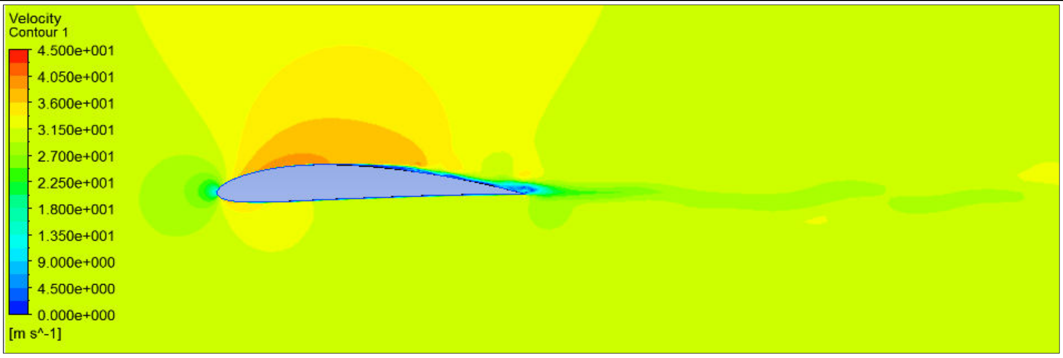
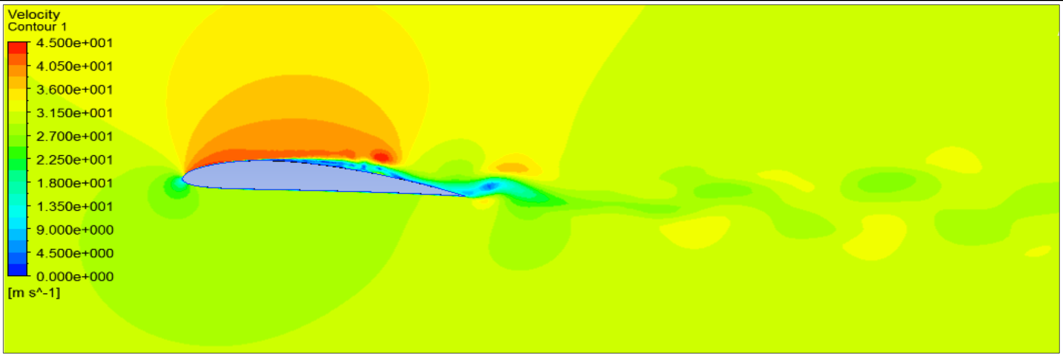
shown in Figure-3(b) to Figure-3(e), the velocity curl profile is obvious.

The vorticity-induced velocity curl profiles in the case of NACA 4424are significant even atα = 0°; in general, the vortex sheddings at various α as shown in Figure-4(a) to Figure-4(e) are more obvious than those which occur in the case of NACA 4412.



(a)



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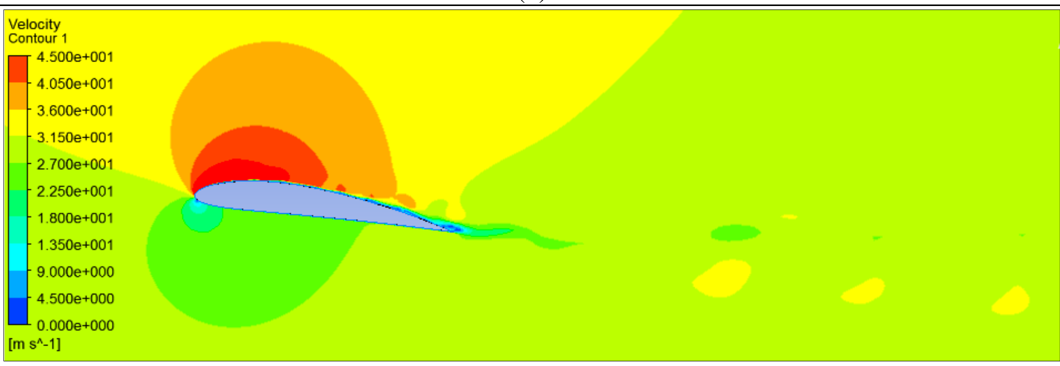

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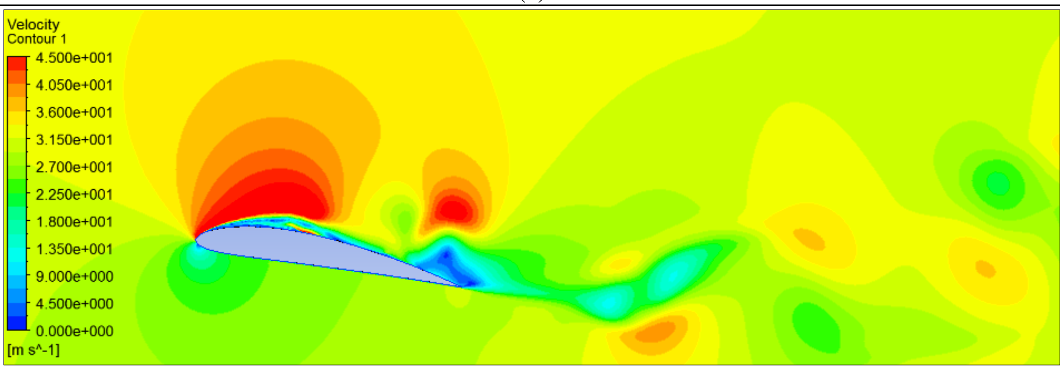

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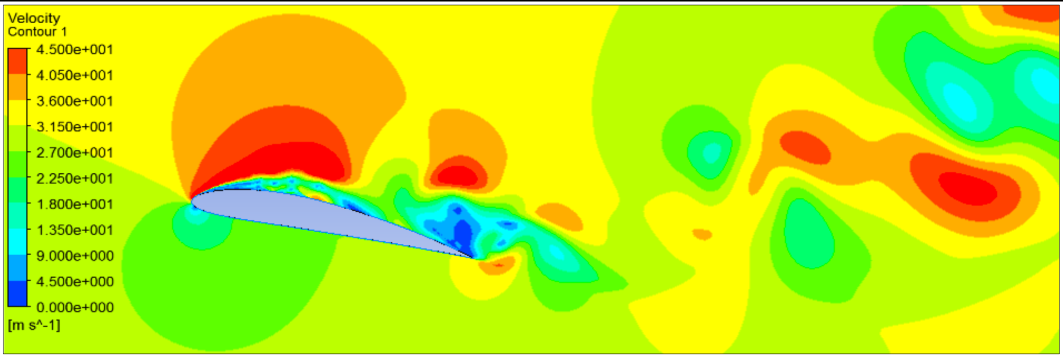
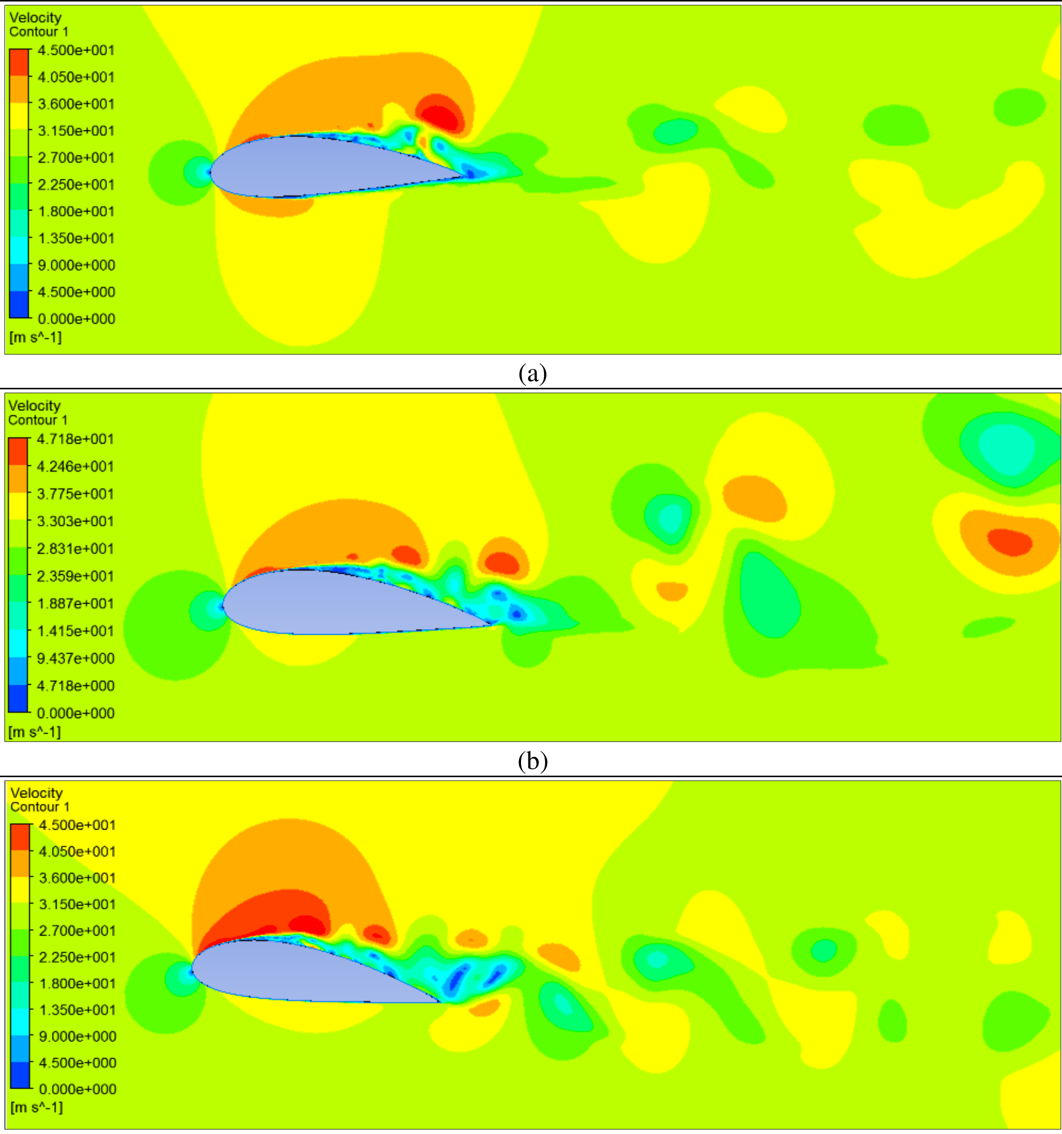


(e)

Figure-3. Vorticity map of low Reynolds number flow with Re = 60,000 over NACA 4412 airfoil at t = 1.0 (a) $\alpha = 0°$ (b) $\alpha = 4°$ (c) $\alpha = 8°$ (d) $\alpha = 10°$ (e) $\alpha = 12°$.



(c)

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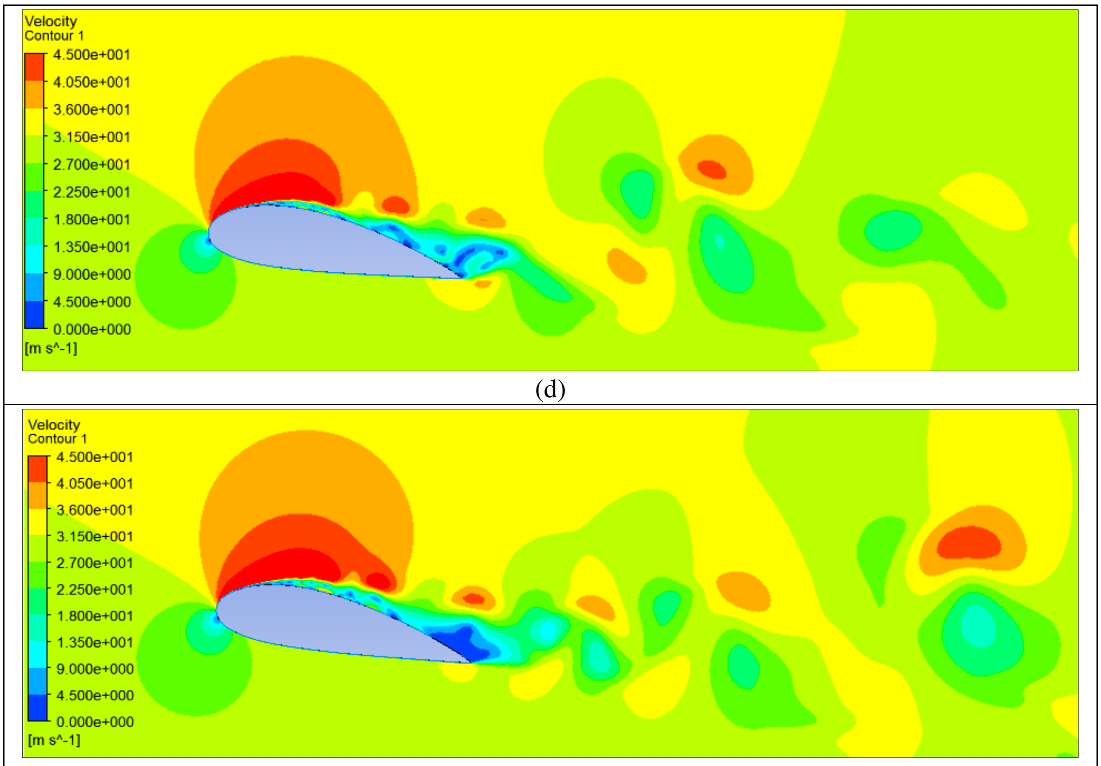

(e)

Figure-4. Vorticity map of low Reynolds number flow with *Re* = 60,000 over NACA 4424 airfoil at $t = 1.0$ (a) $\alpha = 0°$ (b) $\alpha = 4°$ (c) $\alpha = 8°$ (d) $\alpha = 10°$ (e) $\alpha = 12°$.

4. LIFT AND DRAG PROFILE

In general, the lift profile in the case of NACA 4412 is greater than that of another, except when $\alpha = 0^{\circ}$. Moreover, the airfoil's stall angle of attack α_{stall} is relatively bigger.

However, the trends of drag profile show quite the opposite; NACA 4412 experiences lower drag in comparison to NACA 4424 at allα of interests.

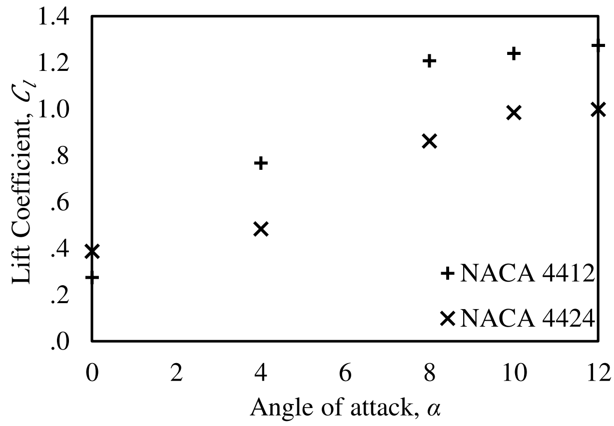

Figure-5. Lift coefficient vs angle of attack results at *Re* 6 x 10^4.

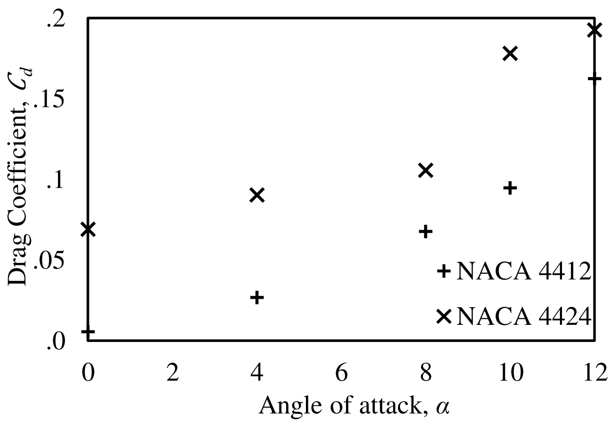

Figure-6. Drag coefficient *vs* angle of attack at *Re* 6 x 10^4.

5. SEPARATION BUBBLE DEVELOPMENT

The identification of the separation bubble formation over airfoilas well as the vortex shedding are done by denoting Δ and ▼ as elliptic fixed point and hyperbolic fixed point, respectively.

As Figure-7(a) transitions to Figure-7(b) in the case of NACA 4412, H1 and H2collide, creating a new vortex centered on point E2. In the transition from Figure-7(b) to Figure-7(c), H3 and H4 collide and separate from the airfoil's surface, creating a new hyperbolic fixed point just on the left of the shed vortex.

More interesting development of separation bubble over NACA 4424 can be seen in Figure-8. As Figure-8(a) transitions to Figure-8(b), H1 and E1 collide

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and destroy each other, resulting in a reverse saddle-node bifurcation. Consequently, anew vortex gets separated from the separation bubble. Within the next transition from Figure-8(b) to Figure-8(c), H2 and H3collide and separate from the airfoil's surface, creating a new hyperbolic fixed point just below the shed vortex.

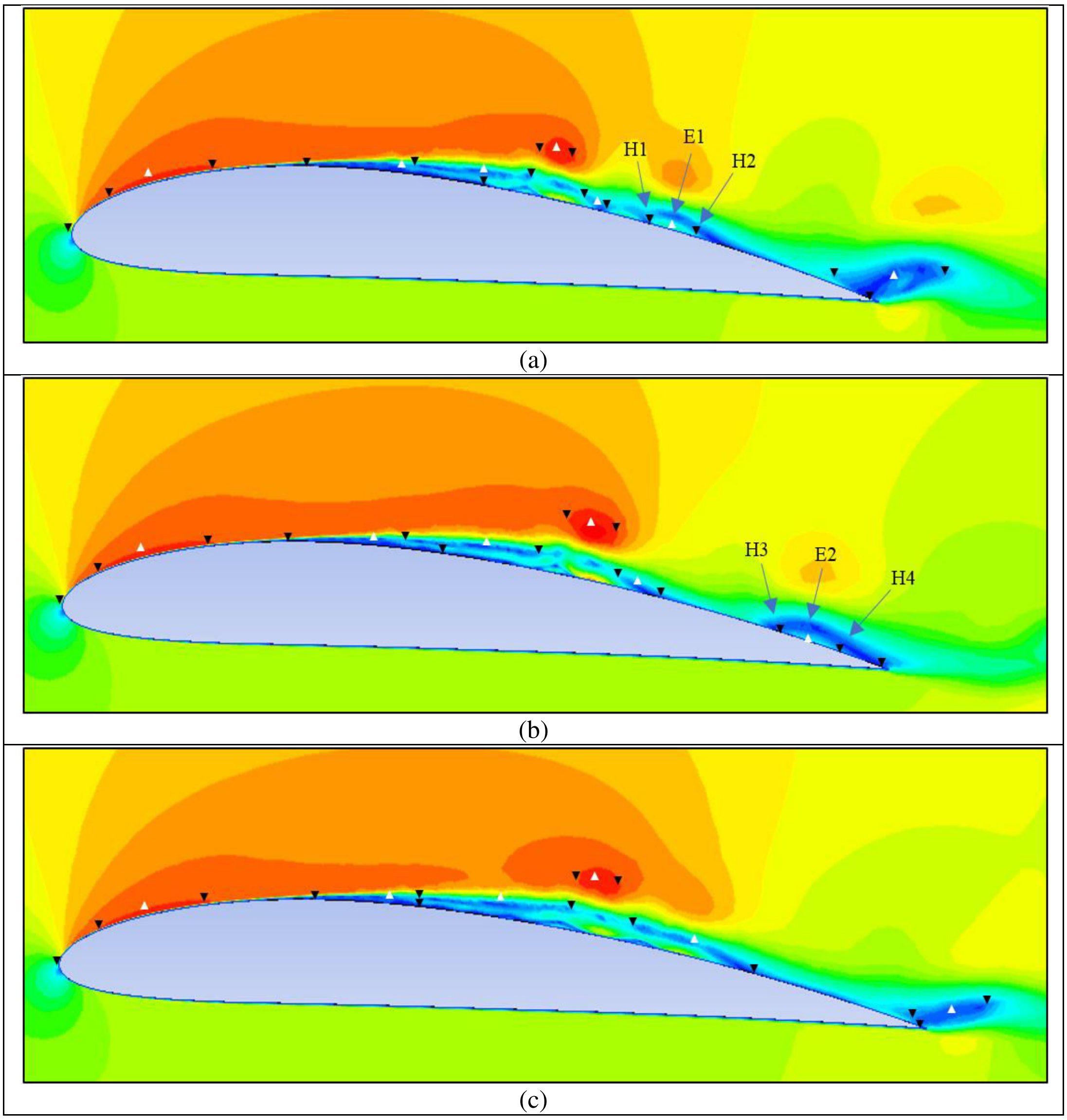

Figure-7. Development of separation bubbles over NACA 4412 airfoil where α=4°, *Re* = 60,000 at three representative times. (a) $t_1 = 0.5$ (b) $t_2 = 0.8$ (c) $t_3 = 1.0$

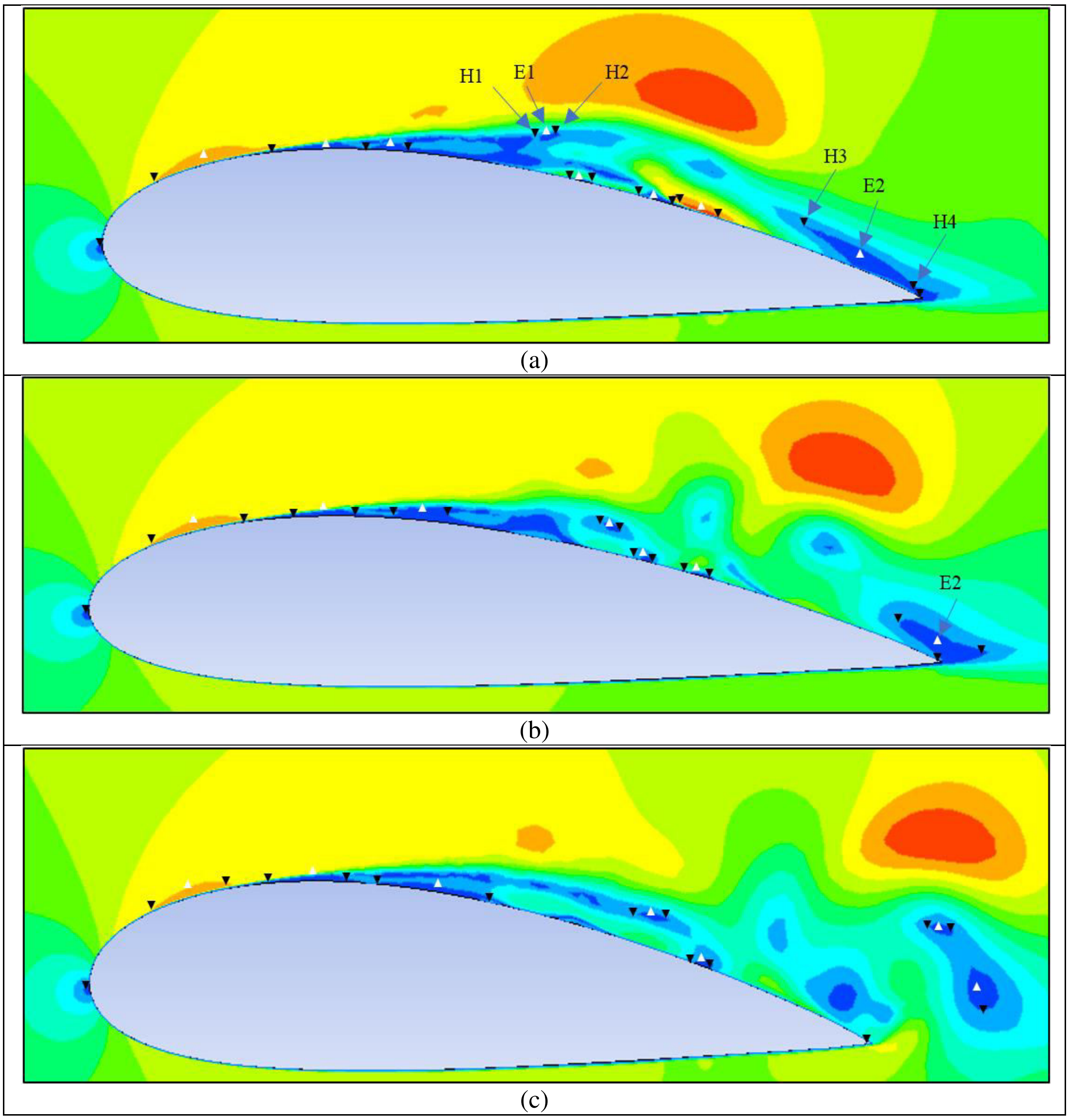

Figure-8. Development of separation bubbles over NACA 4424 airfoil where $\alpha=4^{\circ}$, Re = 60,000 at three representative times. (a) $t_1 = 0.5$ (b) $t_2 = 0.8$ (c) $t_3 = 1.0$

6. CONCLUSIONS

The numerical experiments succeed in highlighting formation of vortex over airfoils of interest. The evolution of the invariant manifolds during vortex shedding have been discussed above. The transient development of fixed points and separation bubble at 4° angle of attack have also been discussed accordingly.

At zero angle of attack, vortex formation in the flow over NACA 4424ismore significant than that over another airfoil. Even when angle of attack increases, such formations generally more significant in the flow over the former airfoil. The phenomena (i.e. that of vortex formation) makes the study of fixed point's development across airfoils possible.

In addition, the occurrence of vortex shedding seems to have direct effect on the performance of airfoil, as far as the lift and drag are concerned; such occurrence degrades the performance.

The extension of this study would be, for example, the study of vortex formation in the case of airfoils experiencing ground effects [12], [13], as well as that of compressible flow over airfoils [14].

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