VOL. 14, NO. 22, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

STUDY OF VORTEX BEHAVIOR IN UNSTEADY FLOW OVER NACA 0012 AND NACA 0024 AIRFOILS

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ABSTRACT

The effects of vortex behaviour on the aerodynamic performance of airfoils have been widely discussed over the years and serve as motivation for many research studies. This study takes two symmetrical airfoils into account, namely NACA 0012 and NACA 0024. Computational fluid dynamics simulations carried out involve low Reynolds number air flow over the airfoils at several angles of attack. The attention is given mainly on the separation bubble and vortex shedding phenomena, and the effects of vortex behaviour on airfoils' aerodynamic performance as represented by lift and drag coefficients. The results show that the vortex-influenced velocity curl shows alternating vortex behaviour along the airfoils' surfaces and at downstreams. The angles of attack influence such behaviour by developing specific separation bubbles with contrasting fixed points, in particular those along the airfoils' surfaces.

Keywords: vortex shedding, separation bubble.

1. INTRODUCTION

Vortex shedding is an oscillating flow that 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].

Separation bubble, vortex shedding and reattachment can be observed 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].

This study aims at the formation and behavior of vortex over airfoils. We consider aerodynamic properties of 2-dimensional incompressible viscous flow [8],[9], [10], [11]. The numerical simulations are conducted with the use of ANSYS Fluent. The geometries of interest are the symmetrical airfoils (i.e. NACA 0012 and NACA 0024).

The aerodynamic properties of the flow over the airfoils should be at least theoretically correct.

2. GEOMETRY, GRID AND DOMAIN

The flow of interest is that over the symmetrical airfoils. The geometry of the airfoils are shown in Figure-1. Respective grid, domain and boundary conditions are shown in Figure-2.

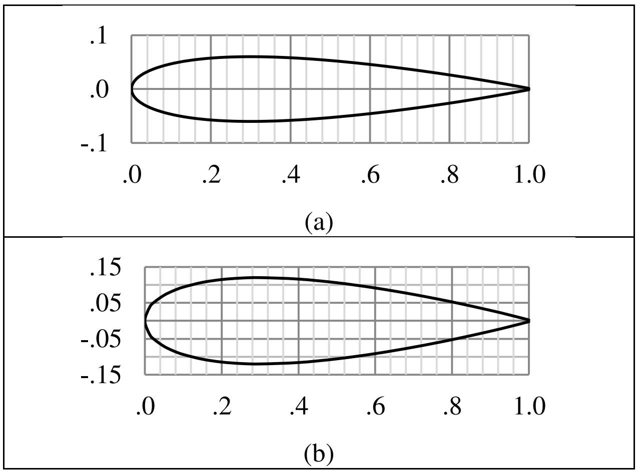

Figure-1. Geometry of symmetrical airfoils (a) NACA 0012 (b) NACA 0024.

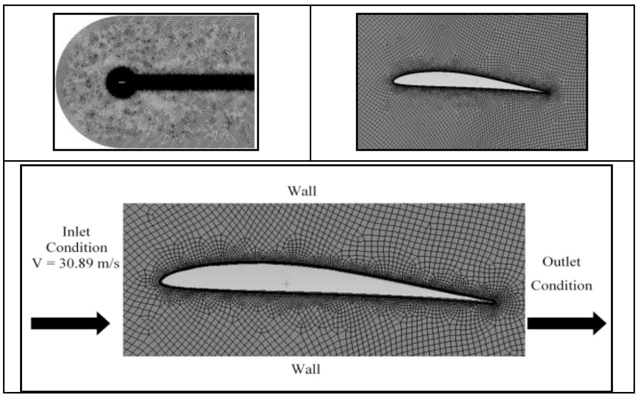

Figure-2. Grid, domain and boundary conditions.

3. VORTEX SHEDDING ANALYSIS

In order to gain information about vortex shedding and reattachment, we focus on the 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.

3.1 NACA 0012

The vorticity-induced velocity curl profile begins to occur at 4° angle of attack (see Figure-3). When $\alpha = 8°$, 10°, 12°, as shown in Figure-3(c) to Figure-3(e), the velocity curl profile is obvious. Note that at $\alpha = 0°$, the

VOL. 14, NO. 22, NOVEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

velocity curl profile shows no vortex shedding occurrence over the airfoil.

3.2 NACA 0024

The vorticity-induced velocity curl profile shown in Figure-4(a) and Figure-4(b) have little vortex shedding occurrence. However, when α = 8°, 10°, 12°, as in Figure-8(c) to Figure-8(e), the vortex shedding is much more significant, yet less obvious than that which occur in the case of NACA 0012 for the same range of α.

4. LIFT AND DRAG PROFILE

In general, the lift profile in the case of NACA 0012 is greater than that of another, except when $\alpha = 0^{\circ}$. Moreover, the airfoil's stall angle of attack α_{stall} is relatively bigger.

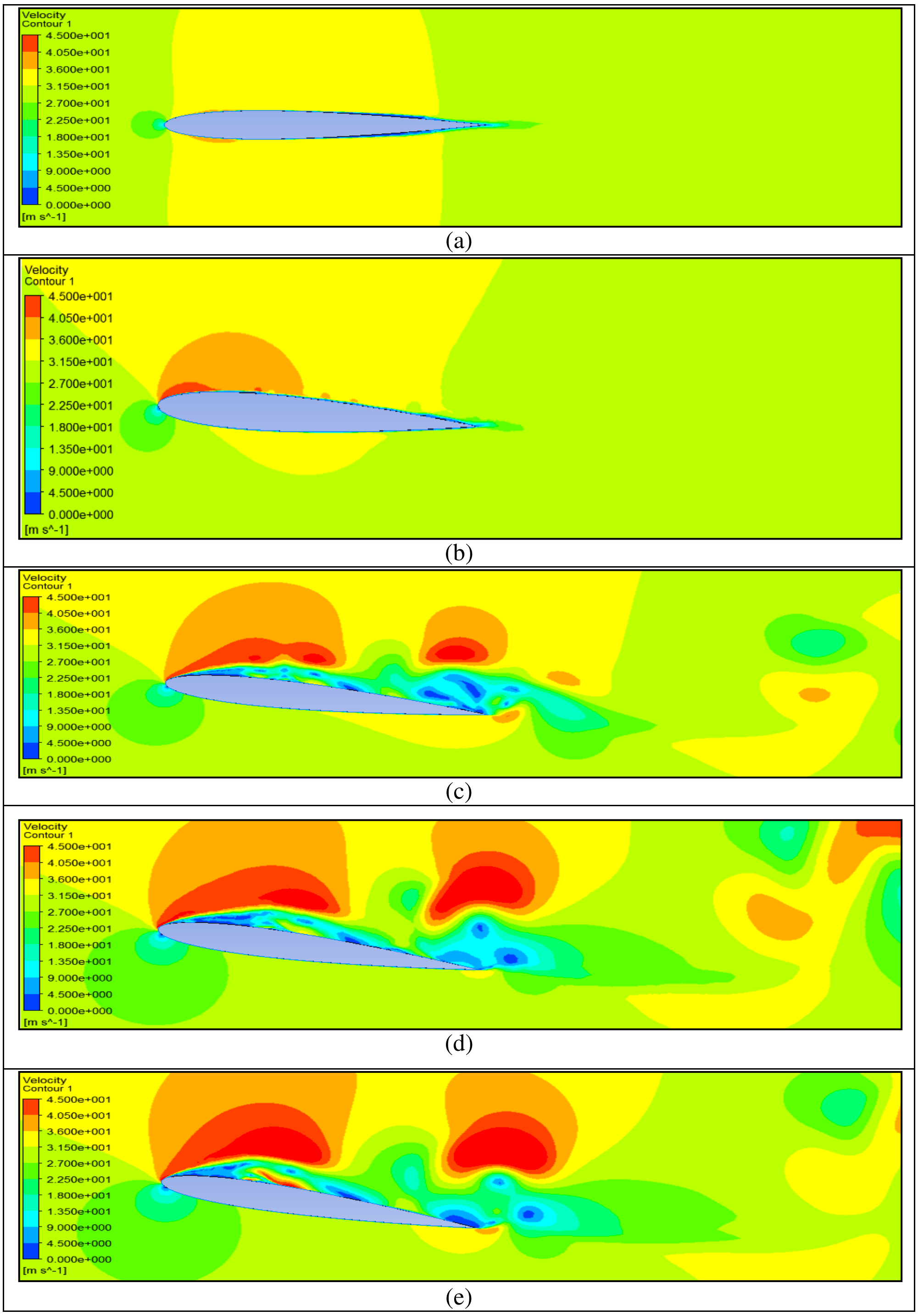

Figure-3. Vorticity map of low Reynolds number flow with Re = 60,000 over NACA 0012 airfoil at t = 1.0 (a) α = 0° (b) α = 4° (c) α = 8° (d) α = 10° (e) α = 12°.

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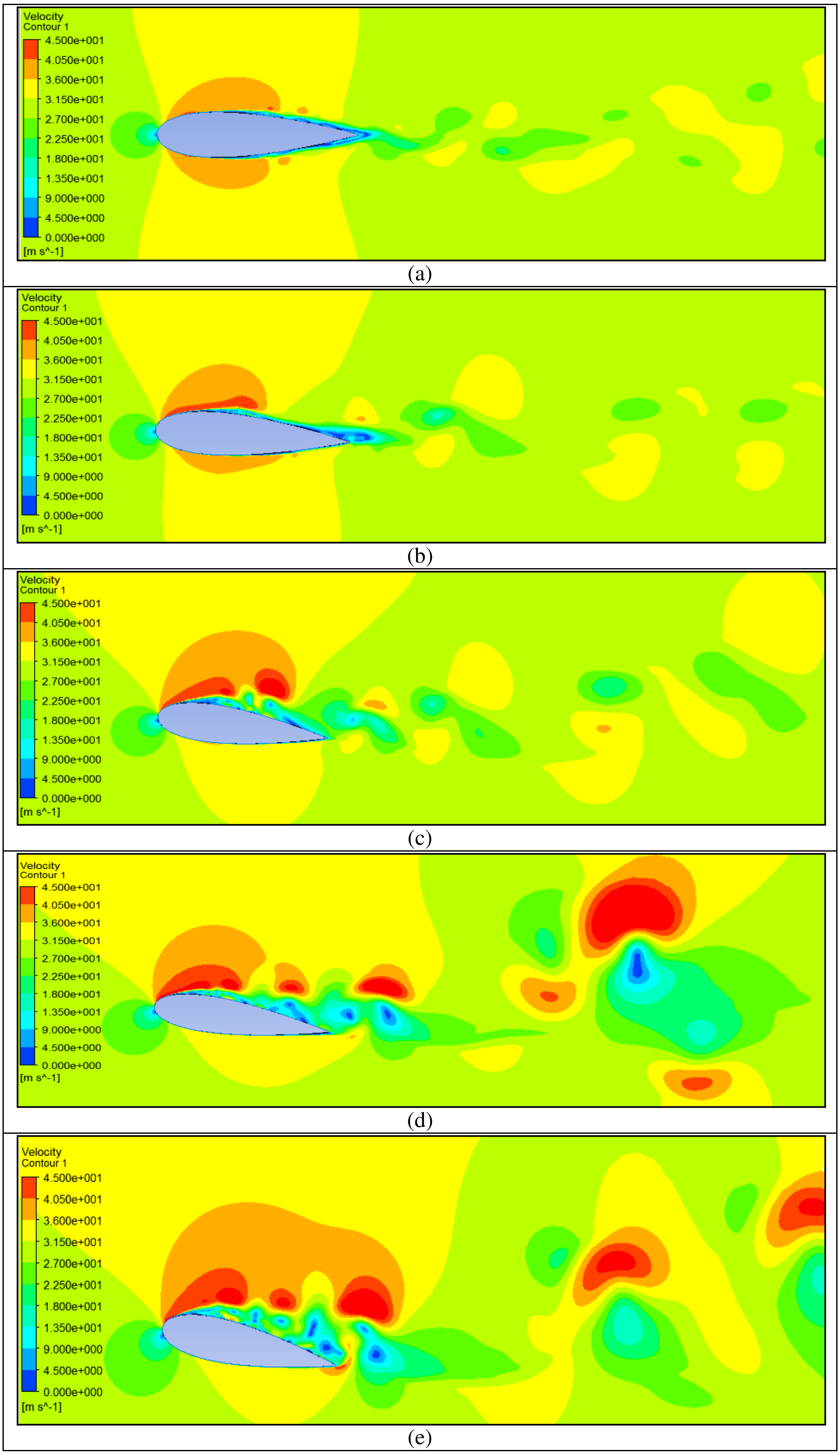

Figure-4. Vorticity map of low Reynolds number flow with Re = 60,000 over NACA 0024 airfoil at t = 1.0 (a) $\alpha = 0°$ (b) $\alpha = 4°$ (c) $\alpha = 8°$ (d) $\alpha = 10°$ (e) $\alpha = 12°$.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

However, the trends of drag profile shows quite the opposite; generally NACA 0012 experiences lower drag in comparison to NACA 0024. The exception is when $\alpha = 4^{\circ}$.

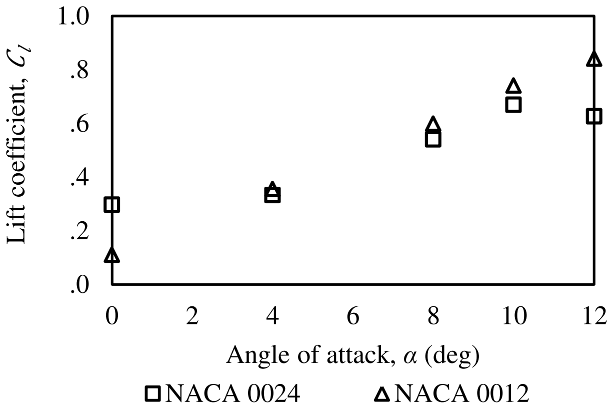

Figure-5. Lift coefficient vs angle of attack results at Re 6 x 10^5.

5. DEVELOPMENT OF SEPARATION BUBBLE

In order to identify the separation bubble formation over airfoil, we denote Δ as elliptic fixed point while ▼ as hyperbolic fixed point. In the case of NACA 0012 airfoil (see Figure-7), there are few significant changes in the development of separation bubbles along the surface of airfoil. As Figure-7(a) transitions to Figure-7(b), H1 and E1 move closer to the rear of vortex centered on point E2 which is ready to be shed. As Figure-7(b) transitions to Figure-7(c), a reverse saddle-node bifurcation occurs as points H1 and E1 collide, destroying each other.

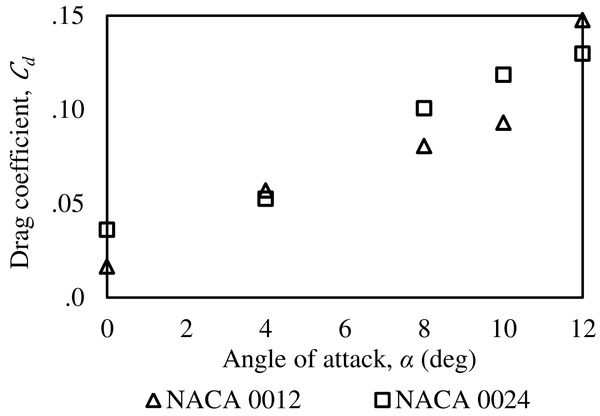

Figure-6. Drag coefficient *vs* angle of attack at Re 6 x 10^5.

The movement of H2 created a shift in point E2 as it moves further towards trailing edge. A subsequent separation may happen with the collision of H2 and H3 creating in new hyperbolic point further downstream.

The development of separation bubble in the case of NACA 0024 airfoil is shown in Figure-8. As Figure-8(a) transitions to Figure-8(b), H1 and E1 move downstream and vortex centered on point E2 is ready to be shed. As Figure-8(b) transitions to Figure-8(c), the vortex centered on point E3 separates itself from the separation bubble. At the same time, a newly developed elliptical point E4 can be seen as the flow progresses through the airfoil, which confirms a coherent structure as the vortex moves downstream.

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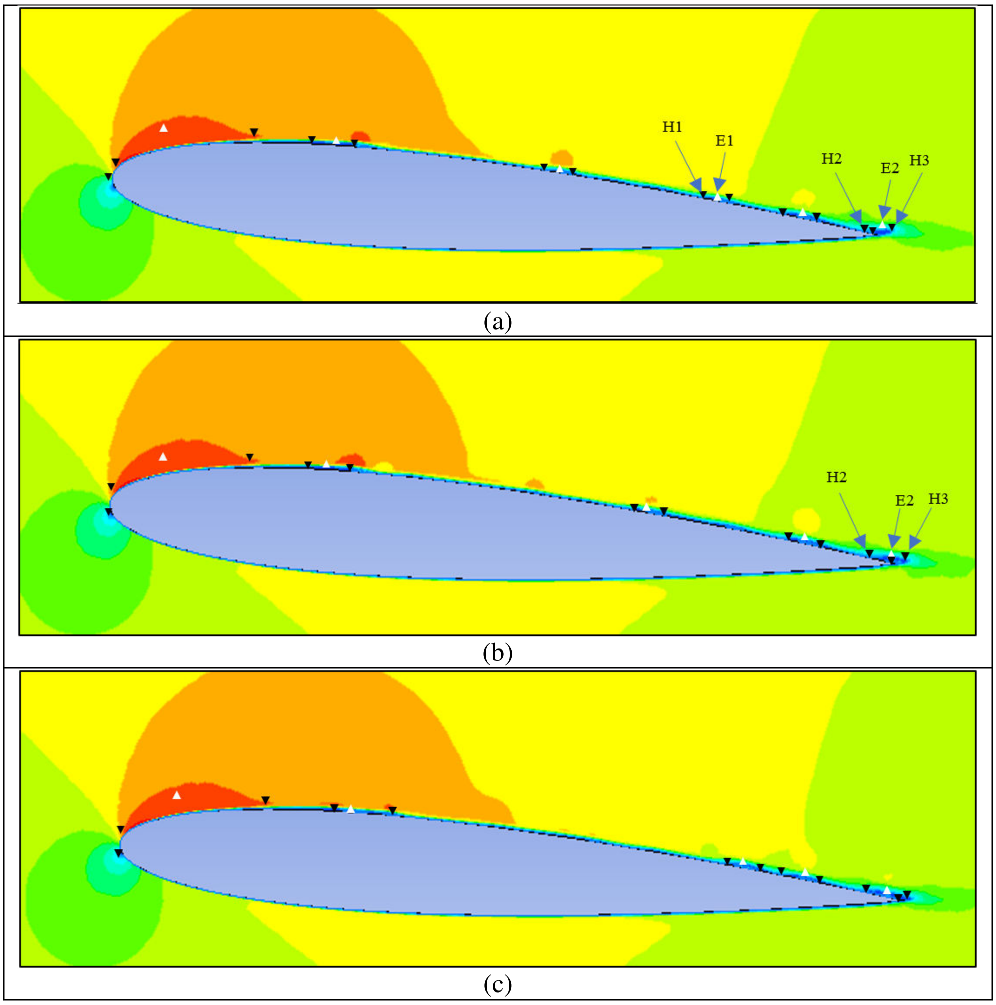

Figure-7. Development of separation bubbles over NACA 0012 airfoil where α=4°, *Re* = 60,000 at three representative times. (a) $t_1 = 0.5$ (b) $t_2 = 0.8$ (c) $t_3 = 1.0$

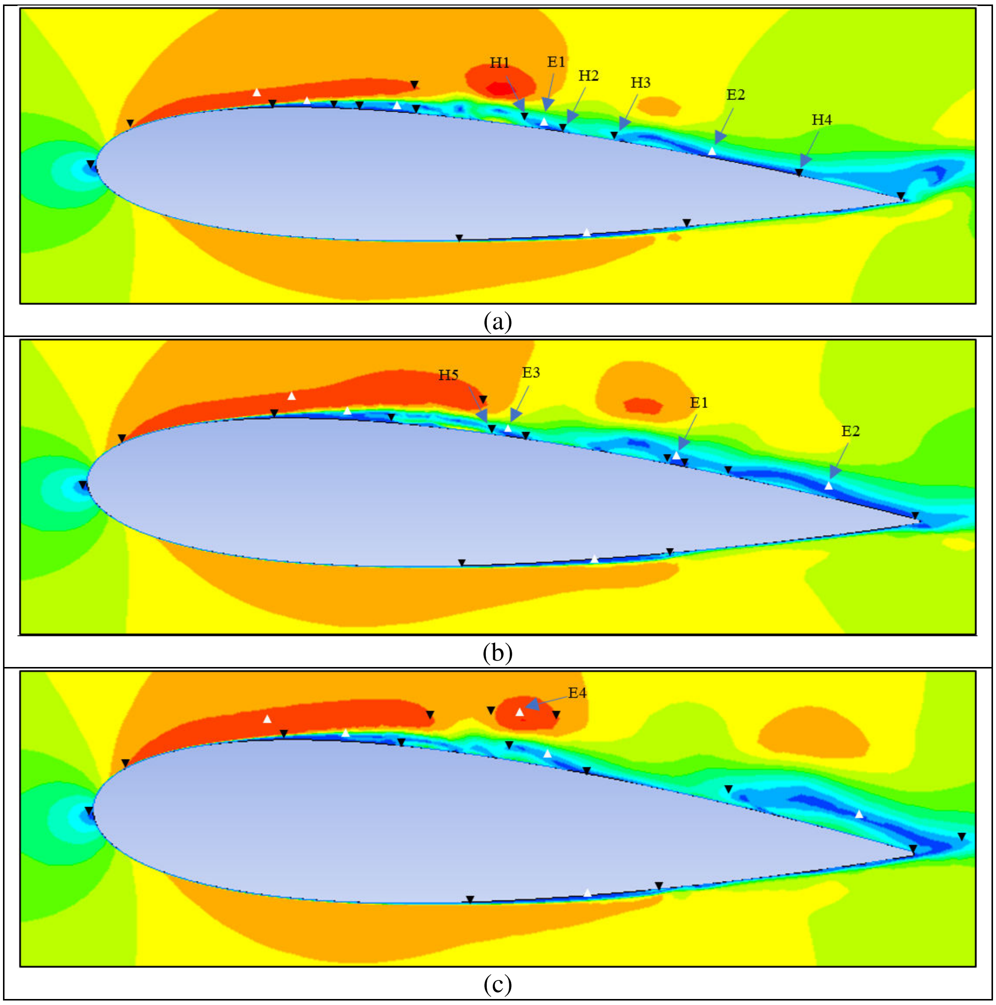

Figure-8. Development of separation bubbles over NACA 0024 airfoil where α=4°, *Re* = 60,000 at three representative times. (a) t_1 = 0.5 (b) t_2 = 0.8 (c) t_3 = 1.0

6. CONCLUSIONS

The simulations succeed in highlighting formation and behaviour 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.

Vortex formations at zero angle of attack are minimum for both airfoils. However, as angle of attack increases, such formations are significant in particular at stall angle of attack (i.e. at α = 10° to α = 12°). This makes the study of fixed points development across airfoils possible.

In addition, the occurrence of vortex shedding seems to have negligible changes over the lift and drag performance of airfoil.

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].

ACKNOWLEDGEMENT

The author would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) and Ministry of Education of Malaysia (MoE) for the research facilities.

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