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ARTICLE

AERODYNAMIC STUDIES OF FLOW CONTROL METHOD USING UTM AEROLAB NACA-0012 AIRFOIL

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Abstract: Many studies have shown that boundary layer tripping is able to delay separation and remove separation bubbles at low Reynolds numbers. However, the effects of boundary layer trip at moderate Reynolds numbers have not yet been well documented. In conjunction to this, the primary objective of this study is to investigate the effect of different transition strip (TS) locations on flow topology on the upper NACA-0012 airfoil and also its corresponding aerodynamic performances at Reynolds number of 1 million. The smooth tape surface is attached at three different locations: 0.0%, 3.8% and 8.8% x/c of the NACA-0012 airfoil. Pressure across the airfoil was measured through electronic pressure scanner. From the results, different strip locations had been shown to affect the flow control above airfoil, which was either to delay or promote separation. Delaying the flow separation can improve lift performance of the wing.

Keywords: flow control; transition strip; flow separation; NACA-0012

1. Introduction

The presence of boundary layer will have some effects on any objects passing through fluid. These viscous fluid effects contribute towards skin friction drag where the drag effects are more pronounced for higher turbulent flows [1]. Moreover, due to adverse pressure gradient across the object's surface and the nature of laminar instability, an abrupt flow separation might occur that significantly increases the pressure drag and results in stall conditions. In this case, the boundary layer might be fully detached from the surface or reattached back on the surface forming laminar separation bubble. To date, various methods have been implemented to control the boundary layer [2]. When manipulating boundary layer, the applied control method can be categorized as either active or passive. In general, the passive flow control has the main benefits of not requiring any external energy. For instance, mechanical turbulators have been applied since the early 20th century to prevent flow separation and laminar separation bubble [3]. This mechanical turbulator could be in the form of vortex generator, transition strip and riblets. It trips the boundary layer, which causes an early transition from laminar to turbulent flow and therefore preventing laminar flow instability across airfoil surfaces [4].

At the moment, the transition strip has found numerous applications in manipulating the boundary layer [5]-[7]. Transitioning boundary layer at the leading edge helps to reduce the risk of laminar bubbles bursting into flow separation [8]. In addition, the emerging utilization of unmanned aerial vehicle (UAV) and wind turbines that operate up to Reynolds number of 2 x 10^6 has led researchers to investigate the effects of strip at low Reynolds number [9]-[10]. At low Reynolds number, the focus has been to prevent any occurrences of laminar separation bubbles and flow separation. Many of such studies have already been conducted but they mostly cover only Reynolds number ranges between 50,000 to 500,000. In the meantime, NACA-0012 airfoil has been well-established in academic researches for the boundary layer studies. However, it can be noted that the effects of the transition strip on separation bubble and flow separation have been less documented on NACA-0012, particularly at Reynolds number above 500,000. It is believed that the proper settings of strips location, heights and surface properties can lead to a wide range of possibilities in optimizing the prevention of separation and the improvement of aerodynamic performances. In conjunction to this, the objective of this research is to study the effect of transition strip on flow characteristics of NACA-0012 and its performances at moderate Reynolds number.

2. Methodology

In this study, NACA-0012 airfoil model with a chord length of 500 mm and a span of 1498 mm is used as shown in Figure 1. It has a maximum thickness 12% that is located at 30% of the chord length. A total of 32 pressure taps are used to measure the pressure distribution across this NACA-0012 model, in which 16 taps are dedicated to each upper surface and lower surface. This airfoil model is then tested using the wind tunnel facility at Universiti Teknologi Malaysia Aerolab. Test section of the wind tunnel has dimensions of 5.8 m length, 2.0 m wide and 1.5 m height. It should be noted that, since the height of the test section is approximately equals to the span of the airfoil model of 1.48 m, the air flow through the airfoil can be considered as two-dimensional (2D).

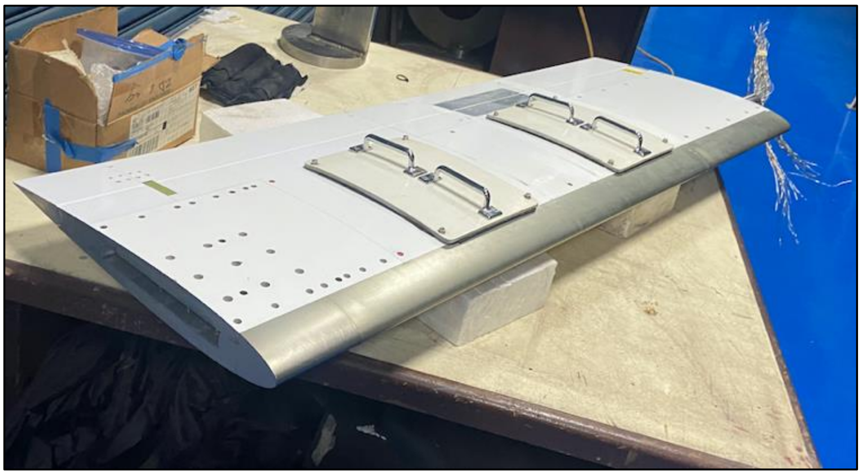

Figure 1: NACA-0012 model used for this flow control study

As depicted in Figure 2, an electronic pressure scanner of FlowKinetics LLC-FKPS series with 30 independent pressure scanners are used in this study. Pressure taps from the airfoil model are connected to the pressure scanner through a long small tube. A single pressure tap from pre-wind tunnel section is set up to measure the freestream static pressure. 29 out of the 32 taps on airfoil's surface are used to obtain the pressure across the airfoil. One pressure tap located on the top surface and two taps at the lower surface located at the trailing edge have been chosen to be sacrificed since major adverse pressure gradient occurs at leading edge.

The room temperature at the wind tunnel facility during the experiment is measured at 29°C using a barometer. Given this air temperature, both the air density, ϱ and kinematic viscosity, μ are calculated as 1.168 kg/m^3 and 1.855 kg/m-s, respectively. The freestream velocity is set to be 30 m/s, which results in a Reynolds number of 945,000. In case of angle of attack, α, the selected values are within the range from -4° to 18° with 2° increment. Transition strip utilized is a smooth surface tape type with 1.5 mm (height) and 25 mm (width). The considered locations of the transition strip for parametric study are 0.0%, 3.8% and 8.8% x/c as shown in Figure 3.

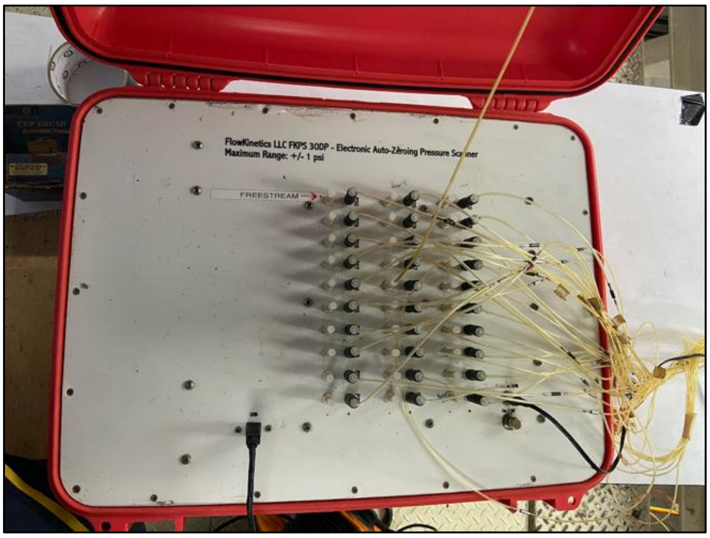

Figure 2: Instrumentation used to measure pressure across the airfoil

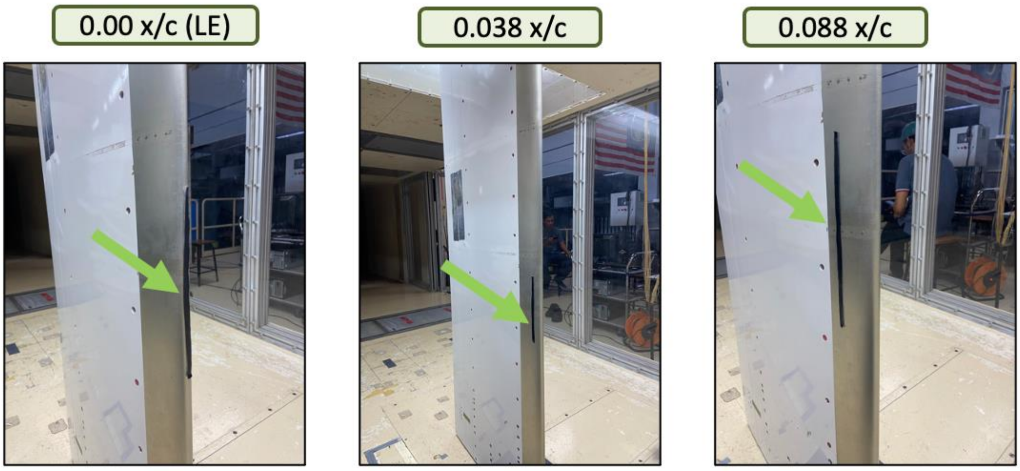

Figure 3: Considered strip locations for the parametric study

The wind tunnel experiment has been first conducted with a clean airfoil model. Subsequently, the experimental procedures are repeated for several different strip locations. The reading from the pressure scanner for each of the iterations, *a* is recorded for 10 seconds through the LabView application and they are then averaged for analysis. The pressure measurement, *P* is then converted to dimensionless pressure coefficient, C_P. The comparison between the clean and attached strip conditions is then made through the constructed graphs of pressure distribution and lift coefficient performance.

3. Results and Discussion

Figure 4 shows the pressure distribution for clean airfoil condition at specified range of angles of attack. Minimum pressure points are reached when $\alpha = 14°$ at C_P of -3.75. Separation bubbles condition is observed at $\alpha = -4°$. On the other hand, flow separation occurs at 20% x/c when $\alpha = 14°$ and full separation occurs when $\alpha = 16°$. The separation phenomenon on this airfoil has a short range of angles of attack with small ranges of separation point values.

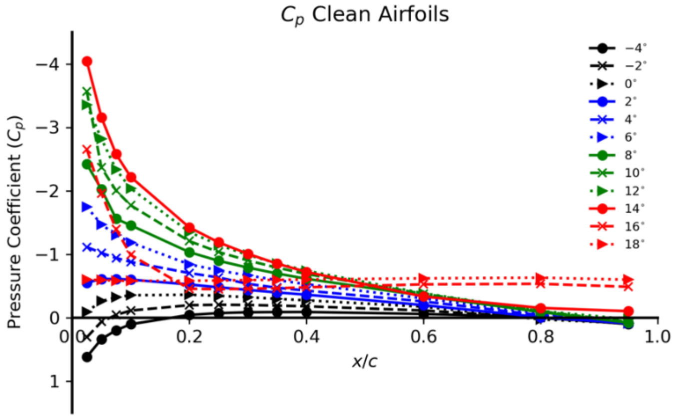

Figure 4: Pressure distribution of upper surface for clean airfoil condition

Meanwhile, Figure 5 to Figure 8 show the pressure distribution of clean versus trip conditions. The vertical dashed blue and green color represent the strip location at 3.8% x/c and 8.8% x/c, respectively. It can be seen that the pressure distribution shape behaves differently near the strip area when compared to the clean condition. The pressure distribution pattern indicates that the pressure increases before the strip and then decreases after the strip. The pressure increment before the strip area is due to reduction in the flow velocity caused by the obstruction of the strip and the pressure will reach to stagnation point locally. When the flow is about to pass through the strip, its velocity will increase and subsequently, the pressure decreases.

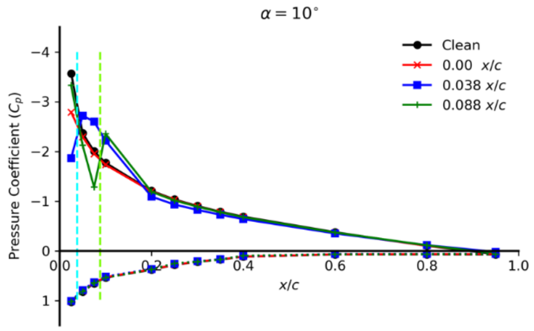

Figure 5: Pressure distribution on clean versus trip at angle of attack of 8°

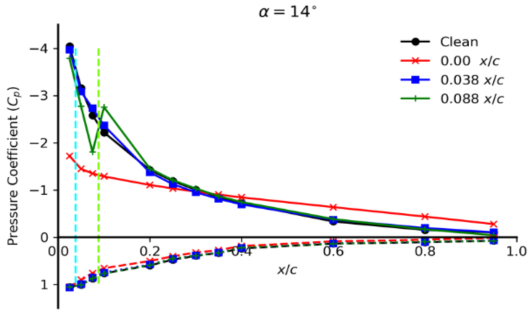

Figure 6: Pressure distribution on clean versus trip at angle of attack of 14°

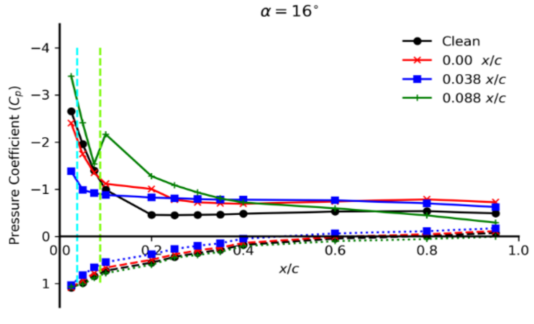

Figure 7: Pressure distribution on clean versus trip at angle of attack of 16°

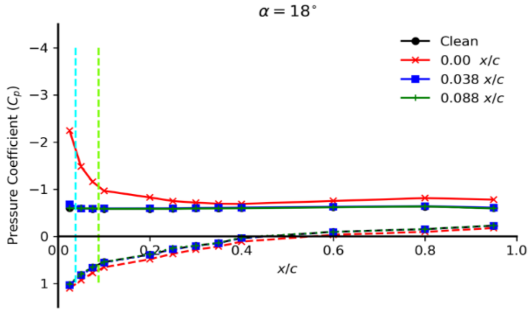

Figure 8: Pressure distribution on clean versus trip at angle of attack of 18°

The most significant effects of transition strip on pressure distributions can be observed when α = 14° to α = 18°. For transition trip at 0.0% x/c, the minimum pressure point is lower when compared to clean condition, which is at 2.5% x/c as depicted in Figure 6. However, the minimum points might reach before 2.5% x/c, which is unknown. Referring Figure 7, which at α = 16°, transition trip at leading edge has separation bubble between 10% to 20% x/c, and the flow is entirely separated at 25% x/c. The transition strip at 3.8% x/c causes the flow to separate earlier at 5% x/c while when the transition strip at 8.8% x/c, there is no flow separation. Referring Figure 8, which at α = 18°, the transition strip at leading edge has delayed separation to 10% x/c. On the other hand, transition strip at 3.8% and 8.8% show full separation similar to clean condition, hence no effect on flow control is observed.

From Figure 9, transition strip at 0.0% x/c shows a lift improvement by 3.1% and 45.6% for α = 16° and α = 18°, respectively, when compared to clean condition. For transition strip at 3.8% and 8.8% x/c, lift improvement/reduction is found to be -18.3% and 26.5%, respectively, for α = 16°. For α = 18°, there is no lift improvement from these two latter locations. In both conditions, there is a full flow separation that is similar to clean condition, thus no flow control effect is expected. Any transition strip attached after 0.0% x/c will not provide any improvement of lift performance since the transition strips are unable to provide any benefits of flow control if it is located at the separated flow regions. Moreover, the C_L and separation point trend with respect to strip location is similar as shown in Figure 10. This shows a correlation between C_L and flow separation point. As separation point increases, i.e. delayed, the lift coefficient is also increased and vice versa. Referring to Figure 10, the best strip location at α = 16° is found to be 8.8% x/c since it has the highest lift improvement and highest separation delay while the best strip location at α = 18° is 0.0% x/c since it is the only location that provides lift improvement and separation delay.

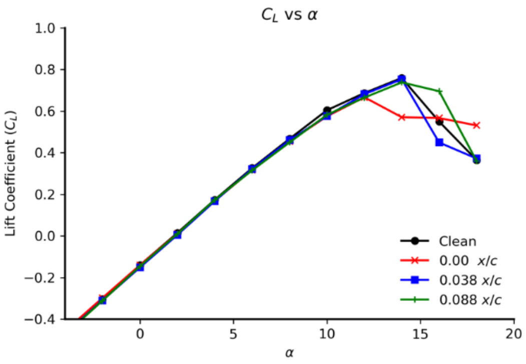

Figure 9: Lift performances clean versus trip conditions

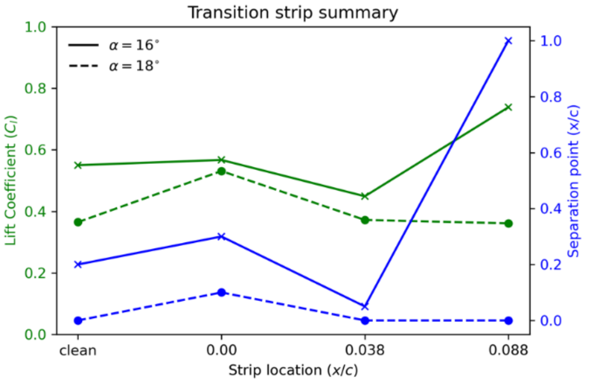

Figure 10: Lift coefficient and separation point on NACA-0012 using transition strip

4. Conclusion

Based on the obtained results in this study, the flow control using the transition strip at low angle of attack, α has been shown to have minimal change to lift performances. However, its relation to drag performance is unknown since this is not covered by this study. By moving the transition strip further behind, no linear pattern of improvement or reduction of the lift performance can be observed. For α = 16°, the transition strip's location possibilities may be varied from 0.0% to 20% x/c where separation occurs at 20% x/c. On the other hand, for α = 18°, the possible location of the transition strip might be limited to 0.0% x/c in order to ensure that applied transition strip is located before the full separation region. In future, further studies might be pursued by implementing drag measurement, additional strip design and considering additional strip locations and Reynolds numbers.

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