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THE EFFECT OF TURBULENCE INTENSITY ON THE AERODYNAMIC PERFORMANCE OF AIRFOILS

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Abstract The experiments have been carried out in low speed, open circuit wind tunnel at the School of Mechanical Engineering, USM to study the effect of turbulence intensity on the airfoil's aerodynamic performance. Two types of airfoil i.e. NACA 0015 and Eagle 150 wing airfoils, are tested at three different Reynolds number. Three different density of wire-mesh are placed before the wind tunnel test section in order to generate turbulence in the range of 2.4% to 5.4%. The mean velocity and the turbulence intensity of the free stream flow are measured using a two-component Laser Doppler Anemometer (LDA). The results show that the increase in turbulence intensity delayed the stall angle but increased the lift and drag coefficients. The results obtained from the NACA 0015 and Eagle airfoil show almost similar trend. The results also show the stall is delayed with the increase of Reynolds number.

Keywords: Turbulence Intensity, Lift coefficient, Drag coefficient, Laser Doppler Anemometer

INTRODUCTION

Most of the aircraft and turbo-machine work in turbulent environment, the level of the turbulence will affect the flow's boundary layer separation. The aerodynamics characteristic of an airfoil is mainly depended on the flow characteristic (separation and reverse flow). As a result, the level of turbulent also affects the lift and drag coefficients of the airfoil. This information could help the designers and engineers to improve the performance of the aircraft or turbo machine.

Many investigators have studied the influence of turbulence to the separation bubbles in turbines blade aerodynamics and aerofoil performance. Hiller and Cherry (1981) have studied the effects of the stream turbulence on two-dimensional, separated and re-attached flows. They found that the mean flow-field responds strongly to the turbulence intensity but with little effect on integral scale and fluctuating pressures depend strongly upon both intensity and scale. However, the mechanism of turbulence interaction with the shear layer is unclear.

Butler et al. (2001) have studied the effect of turbulence intensity and length scale on low-pressure turbine blade aerodynamics. They found that for low Reynolds numbers (4.5×10^4-8×10^4), the boundary layer on the suction surface of the turbine blade always separated at lower turbulence intensity (0.4%-0.8%), increased the turbulence to a higher level (10%) could prevent the separation and the boundary layer transition to turbulent.

Mueller and Pohlen (1983) have studied the influence of turbulence intensity on the Lissaman 7769 airfoil. They have increased the nominal turbulent intensity from 0.08% to 0.30%, and tested at the Reynolds numbers below 3.0×10^5. They concluded that the increase in turbulent intensity could eliminate the hysteresis region, which occurs at the lift, and drag coefficients results. The increase in free stream turbulence and acoustic excitation also caused the laminar shear layer transformed into the transition region much earlier, thus allowing the flow to reattach.

Hoffmann (1991) has studied on the NACA 0015 airfoil at Reynolds number of $2.5\text{x}10^5$. The results show that the increasing in turbulent intensity from 0.25% to 9% has resulted 30% increased in maximum lift coefficient. At a higher turbulent intensity (9%), the maximum lift coefficient reached the saturation. The results also show that the increase in turbulent intensity increased the drag coefficient, however, the rate of change is negligible.

Huang and Lee (1999) had different results, they used NACA 0012 in their investigation and the Reynolds number ranged from $5\text{x}10^4$ to $1.4\text{x}10^5$. Huang and Lee only investigated turbulent intensity in the limited range of 0.2% to 0.65%. They found that the variation of lift and drag are closely related to the behavior of surface flow. The surface flow and L/D at low free stream

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turbulence are different from a higher free stream turbulence (>0.45%). The lift coefficient increased with the increase in turbulence intensity up to 0.45%. However, for the turbulence intensity higher than 0.45%, the lift coefficient decreased with the turbulence intensity. They concluded that the drag coefficient increases and the ratio of lift and drag coefficient decreases with the increase in turbulence intensity. At the lower turbulence intensity (less than 0.45%), the increasing of turbulence intensity has delayed the stall angle, however, at higher than 0.45% its influence is negligible.

EXPERIMENTAL SETUP AND PROCEDURE

The experiments are carried out in the low speed, open-circuit wind tunnel at the School of Mechanical Engineering, Universiti Sains Malaysia. The wind tunnel has a 300 x 300 x 600 mm Plexiglas's test section with three components electronic balance for the measurement of lift, drag and turning moment. The maximum velocity in the wind tunnel is 38m/s. The flow's mean velocity and the fluctuation values are measured by a DANTEC two component Laser Doppler Anemometer (LDA), and using a Spectra-Physics Model 177-G0232 with an air-cooled 300mW Argon ion laser as the light source. The two-component system used each the blue and the green laser light for both components. Signal analysis is obtained by a 58N40 Flow Velocity Analyzer enhanced processor and present in the FVA software. To measure the desired point more effectively, the laser probe is mounted on a traversing mechanism that can be controlled by the FVA software on the computer.

A smoke generator using the Shell ondina oil 15 is used as the seeding in this experiment. The smoke ejector is placed in front of the wind tunnel inlet to allow the smoke flow into the test section (Fig. 1). The purpose of this seeding is to allow the laser beam detect the flow velocity. The airfoils are made from fiberglass and both ends joined with plates, resulting in a rectangular box-shaped (bi-wing) assembly. One of the sides of the model is attached to a rod and connected to the wind tunnel's electronic balancing unit.

In order to generate different turbulence intensities in the test section, the mesh screen with different mesh density and wire diameter are put after the intake just before the test section. The mesh density, wire diameter and the turbulence intensity generated in the experiment at different Reynolds number are listed in Table 1.

In these experiments, the lift and drag forces of NACA 0015 and the Eagle's airfoils are investigated at three different Reynolds numbers i.e. Re=6.4×10^4, 1.27×10^5 and 1.91×10^5 corresponding to three free stream velocity of 10m/s, 20m/s and 30m/s respectively. Four different turbulence intensities are generated in the experiments and tested at various angles of attack from 0 to 15^o.

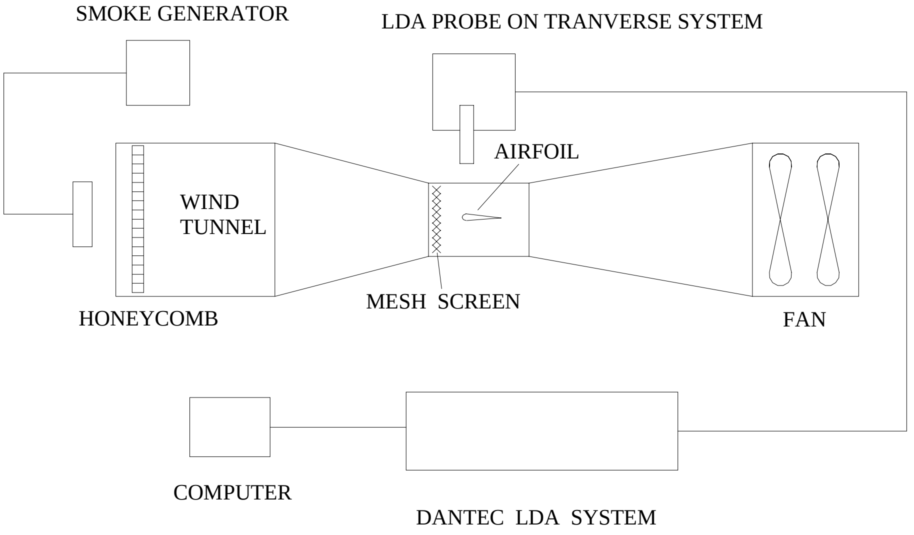

Fig. 1: Experimental Setup

RESULTS AND DISCUSSION

NACA 0015 Airfoil

Fig. 2 shows the variation of lift coefficient with respect to angle of attacks of NACA 0015 airfoil at a Reynolds number of 6.4×10^4. At the lowest turbulence intensity of 2.45%, the lift coefficient is increased (increment rate ≈

1.67π/rad) with the increase of the angle of attack up to the stall angle (9^o). After the stall angle, the lift coefficient dropped rapidly. Fig. 2 also shows that the increasing in the turbulent intensity causes the stall angle occurs at the higher angle of attack, and also increases the maximum lift coefficient. This is probably due to the increase in turbulent kinetic energy produced at the boundary layer with the higher energy on the airfoil which delayed the flow separation. When the stall angle occurs at a higher angle of attack, the lift coefficient reaches a higher value of C_{lmax}. The effect of the turbulence intensity on the drag coefficient for NACA 0015 airfoil is shown in Fig. 3. The result show that at Re= $6.4x10^4$, the increase in turbulence intensity caused small increase in the drag coefficient. The result also shows that the drag coefficient increases slowly with the increase in the angle of attack (increment rate ≈ 0.12π/rad) until it reaches the stall angle, and at the stall point, the drag coefficient increased suddenly with a higher slope (≈1.27π/rad).

In Fig. 4 and 5 show the lift and drag coefficients against angle attack of NACA 0015 at different turbulent intensity for Re=$1.27x10^5$. The results show similar trends as obtained for Re=$6.4x10^4$, the lift and drag coefficients increase with the increase of the turbulence intensity.

Furthermore, Fig. 4 and 5 also show the stall angle at Re=$1.27x10^5$ is higher than the stall angle at Re=$6.4x10^4$ (in Fig. 2 and 3), it illustrates that the increasing of Reynolds number delayed the stall angle. The Fig. 6 and 7 show variation of lift and drag coefficients versus angle of attack at higher Reynolds number (Re=$1.91x10^5$), the stall angle is delayed by the increase in the Reynolds number and the turbulence intensity. The variation of maximum lift coefficient with the Reynolds number is shown in Fig. 8. The maximum lift coefficient is increased with the turbulence intensity; however, the rate of increment is not linear with the increment of turbulent intensity. The result shows that the increase in turbulent intensity increased the maximum lift coefficient, however, when the Re increases, the C_{lmax} does not increase as expected. The C_{lmax} decreases when the Re increased from $6.4x10^4$ to $1.27x10^5$, however, after Re=$1.27x10^5$, the C_{lmax} increases.

Table 1: Turbulence intensities at different mesh and Reynolds number

Mesh screen number	Mesh density (mesh/cm)	Wire diameter (mm)	Turbulence intensity at Re=$6.4x10^4$ (%)	Turbulence intensity at Re=$1.27x10^5$ (%)	Turbulence intensity at Re=$1.91x10^5$ (%)
No mesh	-	-	2.45	2.39	1.81
M1	1.081	0.9	3.03	3.14	2.80
M2	3.077	0.7	3.36	3.41	3.07
M3	0.769	4	5.39	5.27	-

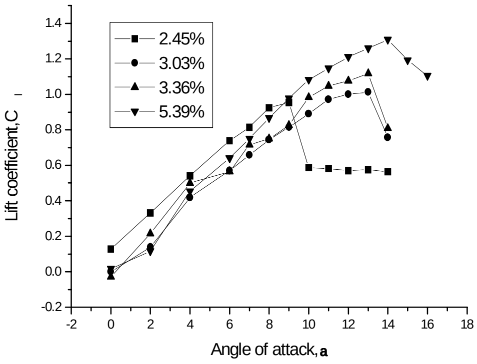

Fig 2: Lift coefficient versus angle of attack for NACA 0015 at Re = $6.4x10^4$.

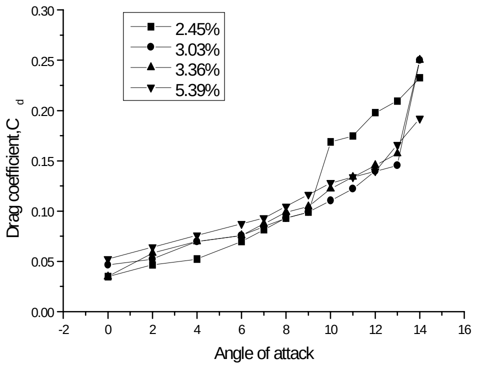

Fig 3: Drag coefficient versus angle of attack for NACA 0015 at Re=$6.4x10^4$

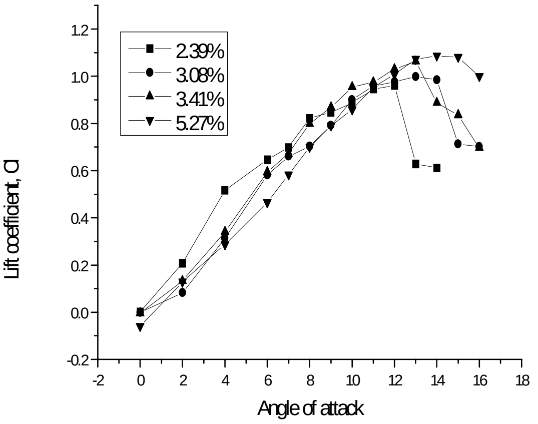

Fig. 4: Lift coefficient versus angle of attack Re= 1.27x10^5 (NACA 0015)

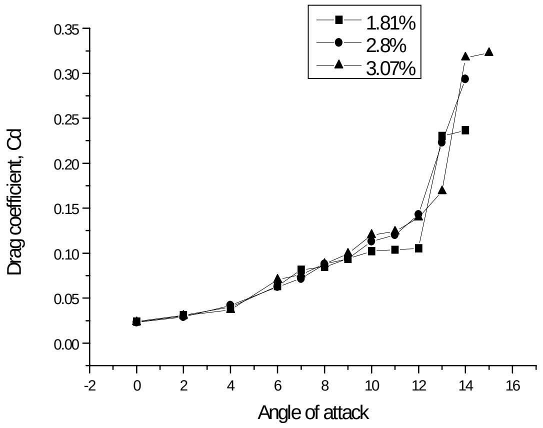

Fig. 7: Drag coefficient versus angle of attack at Re=1.91x10^5 (NACA 0015)

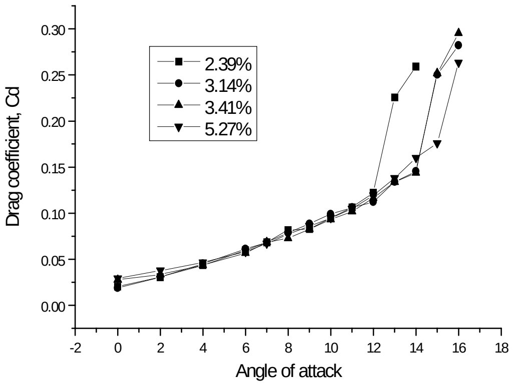

Fig. 5: Drag coefficient versus angle of attack at Re=1.27x10^5 (NACA 0015)

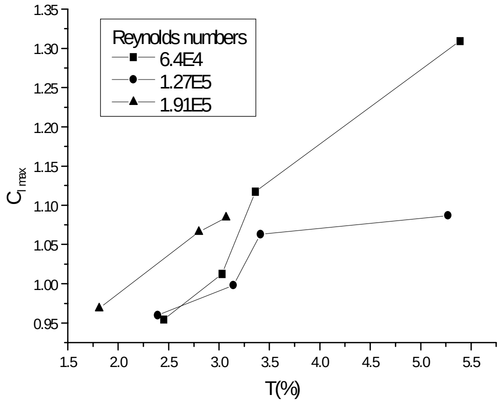

Fig. 8: Variation of maximum lift coefficient with Reynold's number

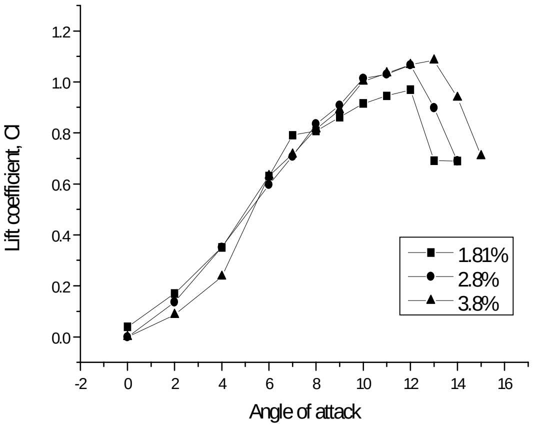

Fig. 6: Lift coefficient versus angle of attack at Re= 1.91x10^5 (NACA 0015)

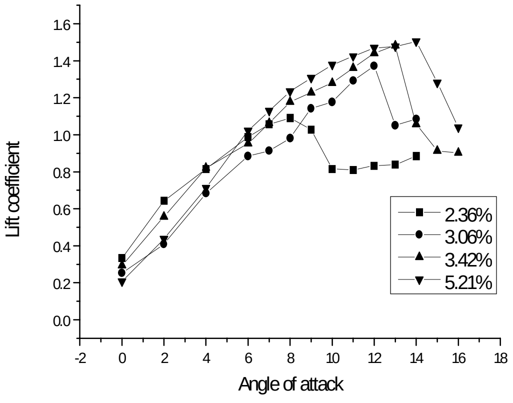

Fig. 9: Lift coefficient versus angle of attack of Eagle airfoil for Re=6.4x10^4

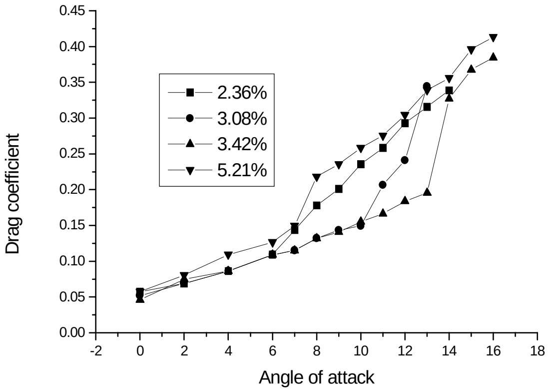

Fig. 10: Drag coefficient versus angle of attack of Eagle airfoil at Re=6.4x10^4

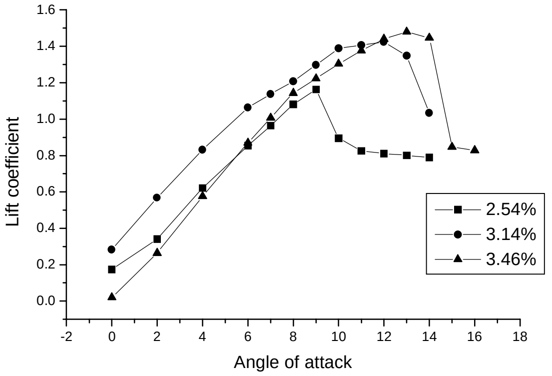

Fig. 11: Lift coefficient versus angle of attack of eagle airfoil at Re=1.27x10^5

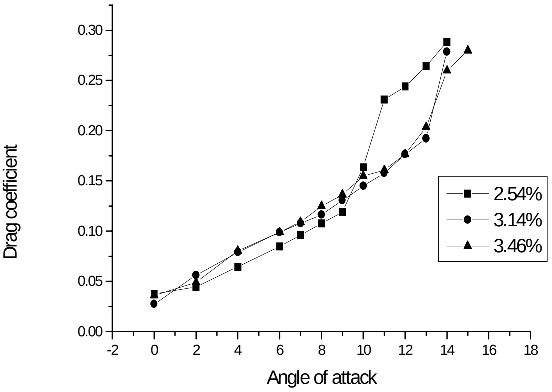

Fig. 12: Drag coefficient versus angle of attack of eagle airfoil at Re=1.27x10^5

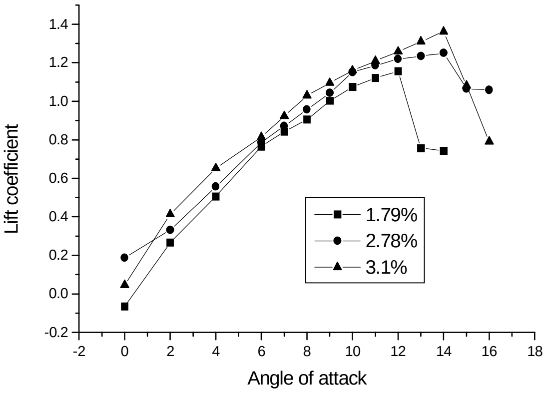

Fig. 13: Lift coefficient versus angle of attack of eagle airfoil at Re=1.91x10^5

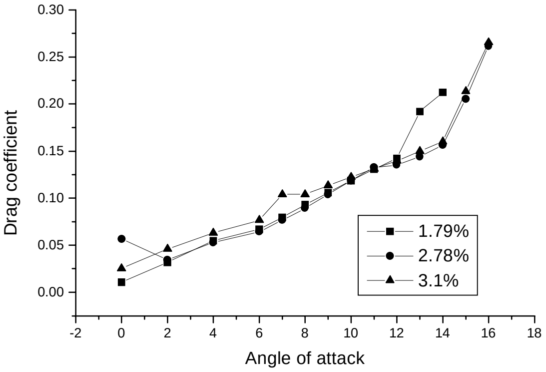

Fig. 14: Drag coefficient versus angle of attack of eagle airfoil at Re=1.91x10^5

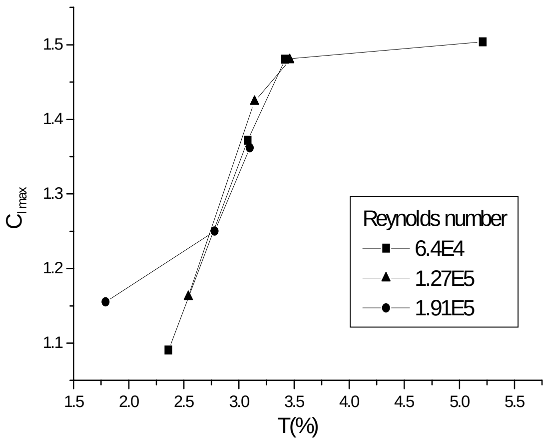

Fig. 15: Variation of maximum lift coefficient with turbulent intensity

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Eagle 150 wing airfoil

The results obtained from the Eagle airfoils are almost similar with the NACA 0015's airfoil. The Fig. 9 shows the relation between the lift coefficient and the turbulence intensity at various angles of attack. Generally, it shows that lift coefficient increases as the turbulent intensity increases.

The lift coefficient increases up to the stall angle and after the stall angle, the lift coefficient begin to decrease, however, the decrement rate is much slower than the slope of the NACA 0015 at the same situation. Fig. 10 shows the relation between the drag coefficient and the turbulent intensity at Re= $6.4\text{x}10^4$. The drag coefficient also increases when the angle of attack increases. The results show the increment rate is small at the beginning, however, after the stall, the increment rate becomes steeper. This is mainly caused by suddenly increase in the pressure drag force due to flow separation.

The Fig. 11 shows the results of the lift coefficient at various angle of attack on Eagle 150 airfoil with three different turbulence intensity, Ti and at Reynolds number, Re=$1.27\text{x}10^5$. The stall angles are 9, 11 and 13° for the turbulence intensities of 2.54, 3.14 and 3.46% respectively. The results show that the increase in turbulence intensity resulted in delaying of the stall angle. Fig. 12 shows the drag coefficient of Eagle airfoil at different turbulence intensity versus the angle of attack. The results show that increase in the angle of attack resulted in a slight increase in the drag coefficient, and the drag coefficient increased suddenly at the stall angle. Fig. 13 and 14 show the results of the lift coefficient at the higher Reynolds number, Re= $1.91\text{x}10^5$. At Re=$1.91\text{x}10^5$, the airfoil showed a similar trends as with the previous investigations. The increased of the turbulent intensity causes delay of the stall angle, and provided higher C_{lmax}. Fig. 14 shows that the increase of the turbulence intensity could increase the drag coefficient, however, the influence of the higher turbulence intensity to the drag coefficient is negligibly small. The slope of the drag coefficient perform almost constant until it reach the stall angle and than increased rapidly after the stall angle.

The variation of maximum lift coefficient, C_{lmax} with the turbulent intensity is shown in Fig. 15. At Re=$6.4\text{x}10^4$, the rate of increasing of C_{lmax} is almost linear (≈0.339) for turbulence intensity of 3.5%. However, the turbulence intensity above 3.5%, the increment rate becomes lower (≈0.011). At higher Reynolds number, Re= $1.27\text{x}10^5$, the increment rate is about 0.345 and at Re=$1.91\text{x}10^5$ increment rate is 0.095. The results also illustrate that in order to increase the maximum lift coefficient, two methods could be used, either increase the turbulent intensity or increase the Reynolds number.

Comparison

In the investigations, two types of airfoil behave differently at different Reynolds number and influence of turbulence intensity has profound. The experiments show the results of lift and drag coefficients for both airfoils have similar trends at different turbulent intensity. In general for particular values of Reynolds number and turbulence intensity the Eagle airfoil has higher C_{lmax} compared to NACA 0015. The maximum lift curve of Eagle 150 airfoil is more stable compared to NACA 0015's.

CONCLUSION

The effect of turbulence intensity on the aerodynamics performance of the NACA 0015 and Eagle 150 airfoils is profound. The increase in air free stream turbulence intensity causes delay of the stall angle and the maximum lift coefficient. However, it causes the increase in drag coefficient.

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