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Computational Fluid Dynamic Simulation on NACA 0026 Airfoil with V-Groove Riblets

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***Abstract*— The aims of this research is to look into the percentage drag reduction on a NACA 0026 airfoil with V-Groove riblets installed around at some locations around its surface. NACA 0026 is a symmetrical airfoil mostly used as turbine blade and aircraft wing. Research on drag reduction by using riblets on the surface was introduced by NASA Langley Research Centre in 1970s. There are many types of riblet designed in this research area such as V groove, segmented blade and continuous saw tooth. This research used NACA 0026 with external geometry 500 mm spans, 615 mm chord and 156 mm thickness. V-groove riblets with 1 mm pitch and 1 mm high and 30 mm width are attached at peak points of the airfoil profile. The CFD simulation used ANSYS Fluent to analyze the velocity, pressure gradient, turbulent kinetic energy and vortex development. The result shows the percentage in drag reduction compared to clean surface for the zero angle of attack is 11.8% and 30^0 angle of attack is 1.64%. By this condition the airfoil will have better motion performance in their applications.**

***Keywords*— airfoil; riblets; turbulent; drag.**

I. INTRODUCTION

NACA airfoils are airfoil shapes for aircraft wings developed by National Advisory Committee for Aeronautics (NACA). The shape of airfoil is prescribed by the digit following the word NACA. NACA 0026 has a symmetry curvature on upper and lower surface mostly used for aircraft wings, helicopter blades and turbine blades. Based on their application shown, the motion of airfoil is related with energy, which has a lot of relationship with the aerodynamics and the surface types. Because of this, research on turbulence control for skin friction reductions to provide the benefits of aerodynamic efficiency are extensively performed in the last several decades. One of the technologies in this research area is employing rib lets on the object's surface. Riblets technology introduced by NASA Langley Technology in 1970s used in aircraft wings. Riblets technology is used to control skin friction in boundary layers [1].

The boundary layer develops on the surface when a solid objects travels through fluid. This can be distinguished by three layers i.e. the 'viscous sub layer' (VSL) and the 'buffer layer' (BL) near to the wall. The second layer is the 'logarithmic layer' (LL), where researchers identified the prominent large scale structures and third layer is the 'outer layer' (OL). The VSL is dominated by the small scales interactions which scale with the viscosity. Mostly the researchers apply riblets to reduce the skin friction in this layer where the thickness of this layer is $y^+ < 5$ [1], [6], [9]. For this, the design of riblets shall be in micro-scale. Peak-to-peak (PTP) dimensions are < 100 µm. For instance, some design is inspired from shark skin texture and bird feather [4], [12]. The riblets play important role to reduce the skin friction in this area in two ways which are by impeding the cross-stream translation of the stream wise vortices and by elevating the high-velocity vortices above the surface, reducing the shear stress and momentum transfer [5].

Fins with several angle configurations are applied onto a surface as vortex generators to generate discrete stream wise vortices [7]. This can be explained as the following: flow separation occurs when boundary layer travels far enough against an adverse pressure gradient. The fluid flow is detached from the airfoil surface and form eddies and vortices. Pressure differential created between the front and rear surface of the object causes the drag [2]. For this reason, much effort and research has gone into the design of the surface which is to delay flow separation. In this case, vortex generators are used to delay the flow separation.

Although both techniques show positive results in skin friction reduction, the manufacturing and maintenance aspects of these riblets need to be considered. The costs to produce the micro scale riblets are high. Besides, in the maintenance point of view, the micro scale particle such as dusts could easily get trapped on riblets surface. As a result, the dusts disturb riblets performance. In this paper, the riblets is used on the airfoil surface is micro scale riblets. The V-groove with PTP spaces and depth are 1 mm. The riblets are attached at both upper and lower surface of airfoil. The simulation will focus on velocity, pressure distribution around the airfoil and vortex development at rear of airfoil. The drag reduction can be estimated by simulation.

II. SIMULATION SET-UP

A. Airfoil Profile

The airfoil profile is designed base on NACA Report No. 460 ‘Characteristics of 78 Related Airfoil Section from Tests in Variable-Density Wind Tunnel’ 1935.

The formula for the shape of NACA 0026 airfoil, with 26 percent of thickness to chord, is

$$y_t = 5tc\begin{bmatrix} 0.2969\sqrt{\dfrac{x}{c}} + (-0.1260)\left(\dfrac{x}{c}\right) + \\ (-0.3516)\left(\dfrac{x}{c}\right)^2 + 0.2843\left(\dfrac{x}{c}\right)^3 + \\ (-0.1015)\left(\dfrac{x}{c}\right)^4 \end{bmatrix} \quad (1)$$

Where;

c is chord length
x is position along the chord along from 0 to c
y_t is a half thickness a given value of x (at center line)
t is maximum thickness as a fraction of the chord

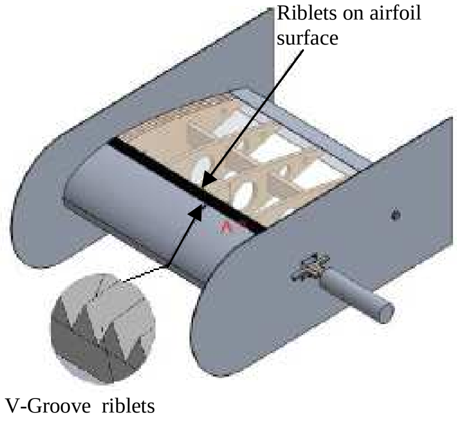


Fig. 1 Location of riblets on airfoil surface [10]

B. Riblets Configuration

The riblets are located at the peak point of airfoil profile or maximum thickness of airfoil on the top and bottom as shown in Fig. 1. The dimensions of riblets are 1 mm PTP and 1 mm depth. Selection of this location is based on the research consideration for riblets effect at favourable pressure gradient (FPG), zero pressure gradient (ZPG) and adverse pressure gradient (APG) [3], [11].

C. Numerical Model

The boundary conditions have been defined as shown in Fig. 2. The domain length x, y and z are 3 m, 0.5 m and 1.2 m respectively. The inlet velocity is 20 m/s and outlet pressure is 0 Pa. The computational domain consists of tetrahedral structures built on 8856 node and 45053 elements. The steady-state conditions have been carried out using ANSYS Fluent CFD. We have employed the K-ε turbulent model for this simulation.

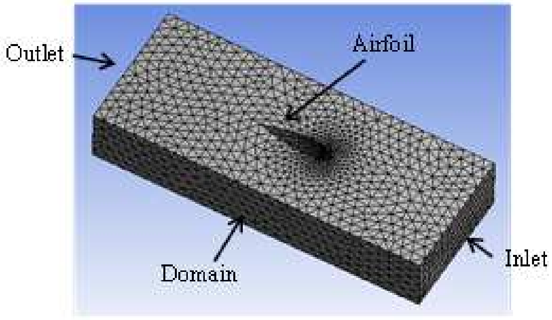


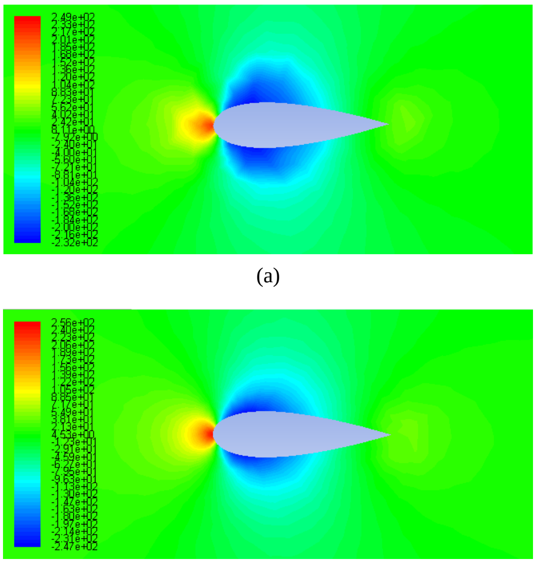
Fig. 2 Mesh around airfoil

III. RESULTS AND DISCUSSIONS

In this paper, the 2D visualization of pressure, velocity, turbulent kinetic energy contour around airfoil and vortex streamlines is analyzed in order to identify the effect of riblets on fluid flow over airfoil surface.

A. Pressure Contour

The airfoil profile is designed base on NACA Report No. 460 ‘Characteristics of 78 Related Airfoil Section from Tests in Variable-Density Wind Tunnel’ 1935.

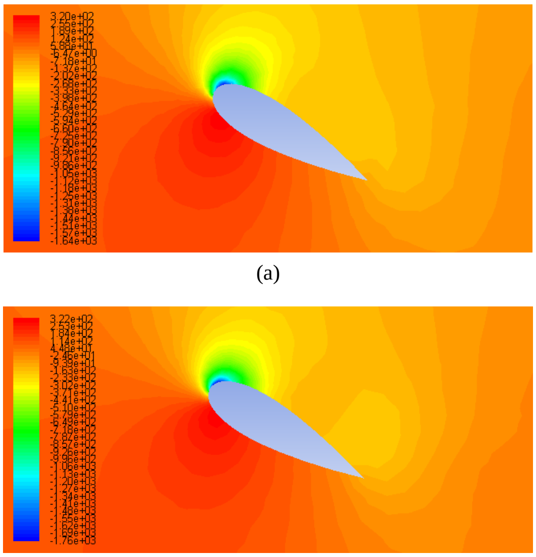


(a)

(b)

Fig. 3 Pressure contour (a) clean airfoil (b) airfoil with riblets

In Fig. 3 and Fig. 4, the pressure transformation happens on two points at the leading edge and the ZPG point. The formation of pressure drop zone appeared at ZPG point but contour characteristics show not much different between riblets and without riblets surface. As a result, in this situation the riblets do not affect pressure drop on the surface as mentioned by Brian Dean & Bharat Bhushan [5].


(a)

(b)

Fig. 4 Pressure contour on airfoil 30^0 angle of attack (a) clean airfoil (b) airfoil with riblets

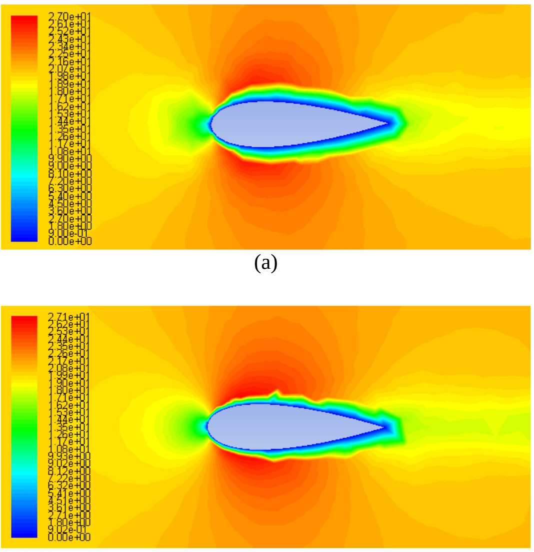
B. *Velocity Contour*

The development starts from the leading edge of the airfoil as a stagnation point until trailing edge. It can be seen in Fig. 5 that the boundary layer develops around airfoil surface. Boundary layer thicknesses in both clean and riblet surface grow towards the trailing edge in Figs. 5 (a) and (b), however, it can be seen that the riblets cause the boundary layer to thin over the remaining length of the airfoil. Once the layer thins, the remaining flow properties also change, for example the low-velocity regions in Fig 5 (b) extends slightly longer than in Fig 5 (a). It can also be seen that the wake regions also thin. But in this position the separation point cannot be seen clearly because of the riblets location is at ZPG point.

The flows get separated at the top side of the airfoil which is also the APG sides of the flow in both clean and riblets surface in Fig. 6 (a) and (b). However these two figures are distinguished by the delayed separation point in the riblet surface. Separation occurs at approximately 1 of 5 of the entire length of the top air foil surface for the clean surface. However the separation is delayed to approximately 1 of 3 of this length. It can also be observed that the wake region also decreases. However, the riblets do not significantly influence velocity profile on the surface at bottom surface which is the FPG section of the airfoil. This is also identified by Leonardo et. al. [1] in the riblets application strategies. It can be observed from this simulation that the effective location of the riblets is at APG area.

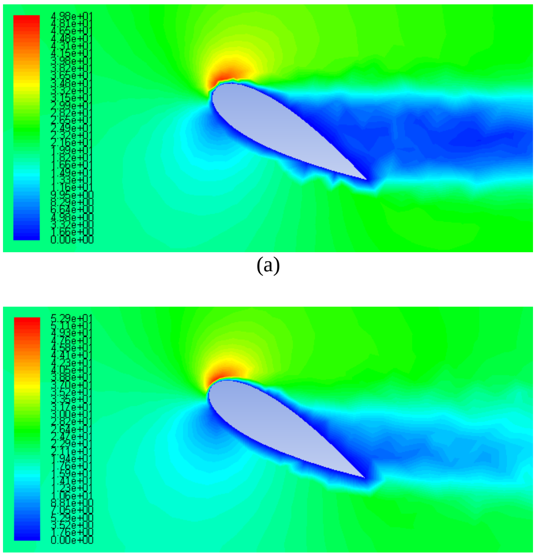
C. *Turbulent Kinetic Energy and Vortex Development*

Turbulent kinetic energy (TKE) in incompressible fluid flow is obtained from the Navier-Stoke equation. In K-ε turbulent model, the kinetic energy depends on fluid density, averaging velocity and eddies dissipation rates. When a flow becomes turbulence, transport mechanisms like the diffusion increases beyond the molecular diffusion (which is encountered in laminar flows). TKE is the energy content of eddies in turbulent flows. The larger the size, the higher is the energy content of eddies. TKE is extracted from the mean flow to larger eddies, from larger eddies, to smaller ones and finally it is going to be dissipated to very small eddies where viscous effects defeat the kinetic energy. High TKE regions occur when high amount of turbulent energy is extracted from the mean flow. The formation of eddies in turbulent flow can form a vortex/vortices. The vortex is a region which fluid flows mostly rotating at axis line. It creates dynamic pressure and the lowest occurs near to its rotating axis. It also means that the vortices could cause pressure drop.


(a)

(b)

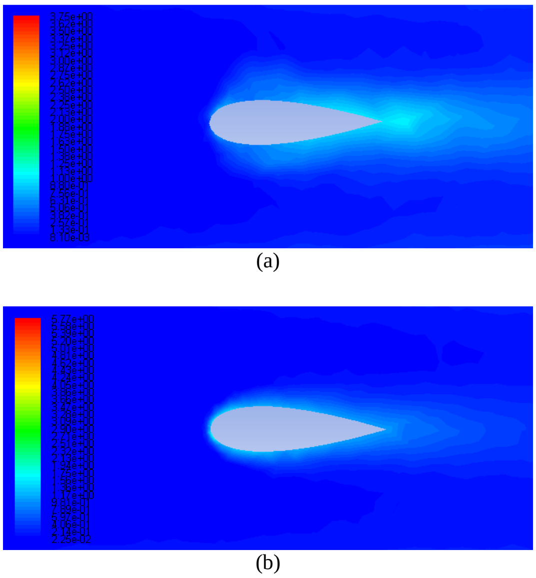
Fig. 5 Velocity contour (a) clean airfoil (b) airfoil with riblets


(a)

(b)

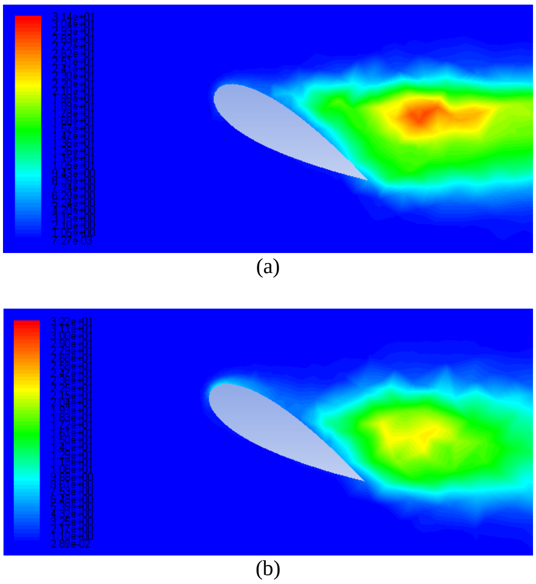
Fig. 6 Velocity contour on airfoil 30^0 angle of attack (a) clean airfoil (b) airfoil with riblets

The turbulence kinetic energy region around surface at zero angle of attack as shown in Fig. 7 is not high if compared to 30^0 angle of attack as shown in Fig. 8, but riblets can reduce the size of kinetic energy region around the surface for both condition as shown in Fig. 7 (b) and Fig. 8 (b).


(a)

(b)

Fig. 7 Turbulent kinetic energy (a) clean airfoil (b) airfoil with riblets

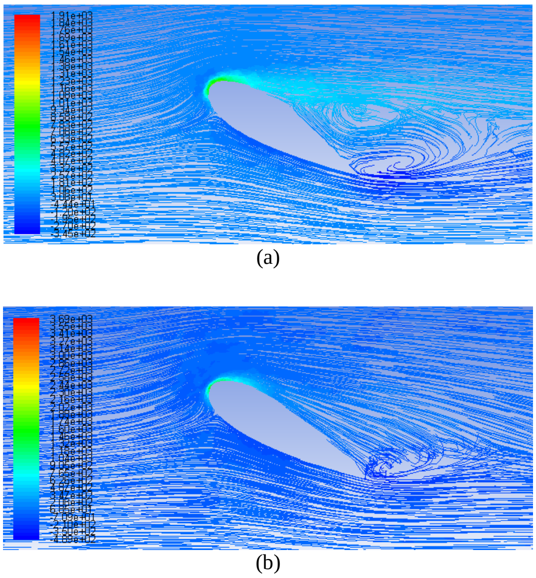

(a)

(b)

Fig. 8 Turbulent kinetic energy on airfoil 30^0 angle of attack (a) clean airfoil (b) airfoil with riblets

The vortex size can be reduced by using the riblets on the airfoil surface as shown in Fig. 9 (b) if compared to Fig. 9 (a). The flows tend to break the vortex. This condition is related to the kinetic energy region reduction and large eddies formation. Fig. 9 (b) shows the dissipation of eddies when the kinetic energy region is reduce.

The results in Table 1 indicate the percentage of the drag reduction for the surface with riblets compare to clean surface at zero degree angle of attack higher then 30^0 angle of attack. However the difference drag is high at 30^0 angle of attack is 0.8 N compared to zero degree angle of attack is 0.65 N. This situation may be is affected by lift force. However lift force is not the focus in this research. The authors now actively prepare an experimental set up for similar geometry airfoil and riblets to be performed on a wind tunnel at UKM [14]. The study to be performed are similar to the ones at the University of Melbourne [15],[16].


(a)

(b)

Fig. 9 Vortex development on airfoil 30^0 angle of attack (a) clean airfoil (b) airfoil with riblets

TABLE I
PERCENTAGE OF DRAG REDUCTION

Angle of Attack	**Constant Drag (N)**		**% Drag Reduction**	
	Clean Surface Airfoil *(a)*	**Airfoil With Riblets *(b)***	**Difference *c = b - a***	**Percentage *(c/a)100%***
0^0	5.52	4.87	0.65	11.8
30^0	48.7	47.9	0.8	1.64

IV. CONCLUSIONS

Simulations have been carried out to investigate the effect the riblets and vortex development on a NACA 0026 airfoil. The results show the riblets play the role in drag reduction in airfoil especially in APG region. It can control the flow separation from the surface and reduce the high kinetic energy region. Vortex development also can be controlled by the riblets. Riblets reduce the pressure drop. For this reason, riblets reduce the form drag. As a result, the percentage in drag reduction compared to a clean surface for the zero angle of attack is 11.8% and 30^0 angle of attack is 1.64%

NOMENCLATURE

c	chord length	m
x	position along the chord	m
y_t	half thickness at given value of x	m
t	maximum thickness	m

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