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Lift Enhancement of NACA 4415 Airfoil using Biomimetic Shark Skin Vortex Generator

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Abstract**:** ***An experimental study was conducted to investigate the aerodynamic performance of the NACA 4415 airfoil with and without passive vortex generators. The measurement has been carried out for three considered cases: smooth airfoil for baseline case, airfoil with triangular vortex generator and also airfoil with shark skin shape vortex generator. Both the triangular and shark skin vortex generators were located at 50% of chord from leading edge of the airfoil with a 20° counter-rotating incident angle. The experiments were conducted with Reynold's number of 100,000. Overall, the results indicate that the lift and drag coefficients, and lift-to-drag ratio, for the airfoil with sharkskin vortex generator are comparatively higher than the other airfoils at some angles of attack. The findings can be applied in optimizing shark skin shape vortex generator for the airfoil performance enhancement.***

Keywords**:** ***lift coefficient, drag coefficient, NACA 4415, shark skin vortex generator, triangular vortex generator***

I. INTRODUCTION

Aerodynamic efficiency of an airfoil is one of the primary concerns for the researchers. One of the objectives is to ensure that there is no flow separation over an airfoil at high angles of attack. Manipulation of the flow behavior within the boundary layer is one of the primary techniques to delay flow separation and increase lift force. Other effects of flow manipulation are reduced drag force and improved airfoil performance. Vortex generator, which is typically a small object attached onto the surface of an airfoil, is one of the methods to manipulate the flow pattern within the boundary layer. It is easy to install with no moving part, hence does not require frequent maintenance. The triangular or rectangular vortex generators are commonly used in the aviation industry. The size and location of vortex generators on the airfoil are crucial, which lead to significant efforts being put by researchers to understand their effects on the airfoil's aerodynamic performance.

After countless efforts to increase lift and reduce drag of an airfoil in the past few decades, researches have a tendency to observe nature and try to imitate how they are engineered. To achieve better efficiency, some flow control devices through an adaptation of surface morphology of nature to achieve drag reduction and lift enhancement have been developed. These bio-inspired shapes are applied to the leading-edge, trailing edge and also airfoil surface, and have successfully enhanced the lift force and reduced the drag force [1]. For instance, the structure of the short fin mako shark skin has been found to reduce 8% of skin friction drag, increase the drag reduction, prevent losses of lift at high angles of attack, trip the boundary layer and generate short reattaching separation bubbles that enhances lift [2]. In the meantime, the morphology of sailfish skin only reduces skin and drag friction by 1% [3]. The unique micro-geometry of bristled shark skin has notable potential in controlling the boundary layer to decrease the overall drag [4]. Riblets from mako shark skin have a proven potential in reducing drag due to lifting vortices formed in the turbulent flow, decreasing overall shear stresses [5]. Furthermore, the alignment-segmented and also the staggered-segmented shark skin riblet configurations have been shown to reduce the drag by approximately 5% and 3%, respectively, with longer riblet showing a better performance [6].

In this paper, the lift and drag coefficients of NACA 4415 airfoil are compared with the identical airfoil with triangular or shark skin vortex generator. The evaluation is done through experiments at Reynolds number of 100,000. The range of the angle of attack is considered to be between 0° and 20°.

II. METHODOLOGY

For the experiments, NACA 4415 airfoil is fabricated with a slot to accommodate smooth surface and surface with vortex generators at 50% of the chord as shown in Fig. 1. The airfoil has 130 mm chord length and 300 mm spanwise length, which will perfectly fit to the width of wind tunnel test section. Fig. 2 shows the schematic design of triangular and shark skin vortex generators.

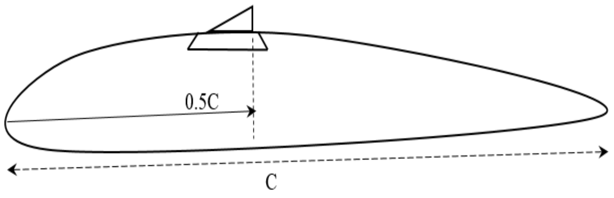

Fig. 1.Sketch of NACA 4415 airfoil with convertible slot at 50% chord length

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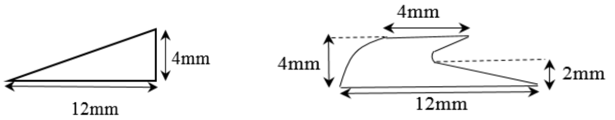

(a) (b)

Fig. 2.Dimensions of vortex generators: (a) triangular, (b) shark skin

The height of vortex generators is 4 mm with length of 12 mm. The spacing, *D* between the devices is 4 mm whereas the spacing between two pairs of vortex generator is set to 28 mm. As depicted in Fig. 3, the angle of incident, β is set to 20° with counter-rotating configuration.

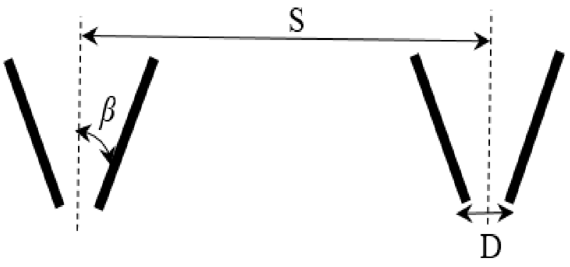

Fig. 3.Angle of attack, β for counter-rotating vortex generator configuration

The experiments were conducted in open circuit subsonic wind tunnel as shown in Fig. 4. Dimension of the test section is 300 mm x 300 mm x 600 mm. One side of the test section has a transparent cover that enables observation of the model and visualization of flow around the model. For all tests, the velocity of air is fixed at 11.2 m/s (corresponding to Reynolds number of 100,000), which is far lower than the capability of the wind tunnel that can be operated up until 50 m/s. The wind tunnel balance provides lift and drag force measurement with uncertainty of ±0.46 N.

Test for smooth airfoils and for the airfoils with triangular or shark skin vortex generators are conducted at the angles of attack between 0° and 20°. The increment used for the angle of attack is 2°. At every angle of attack, three readings have been taken to get the average lift and drag forces. The lift and drag coefficients are found by manipulating the lift and drag force equations.

Fig. 4.Wind tunnel used in this study – the test section is located between the two blue sections on the left and right

III. RESULTS AND DISCUSSION

Results from the experiments are compared with available data in literatures. The closest data with similar test conditions are available in [7], where the lift and drag coefficients of the NACA 4415 were obtained from wind tunnels tests with the Reynolds number of 120,000. Another comparison is with lift and drag coefficients from the Airfoil Tools software, which are generated using mathematical equation with the Reynolds number of 100,000 and standard level turbulence [8]. For the presented study in this paper, the lift and drag coefficients are evaluated at Reynolds number of 100,000.

Fig. 5 shows the lift coefficient validation between the data obtained from experiment and the recorded results in [7] and [8]. As can be observed, all the cases follow a similar trend up to angle of attack of 12°, with obvious different trend between angles of attack of 12° and 20°. Reference [8] has produced a higher lift coefficient compared to other cases, most probably due to its method in generating lift coefficient. Nevertheless, differences of the results from [8] and [7] are approximately 25% compared to the ones obtained from experimental work in this paper.

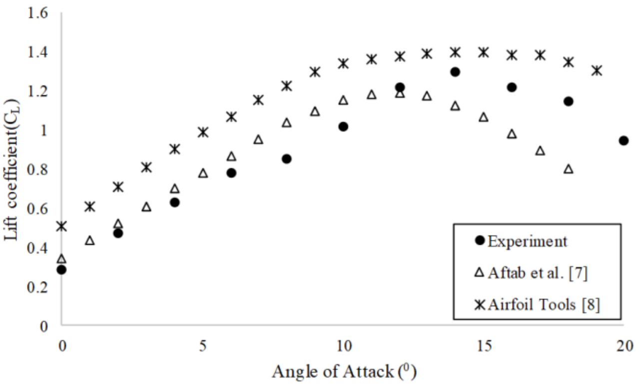

Fig. 5.Comparison of lift coefficient for smooth airfoil

For comparison of drag coefficient as depicted in Fig. 6, the experiment generally has higher drag coefficient up to 10° in comparison to the ones obtained in [7] and [8]. However, the better agreement of results between the conducted experiment and the values obtained in [8] are apparent for angles of attack larger than 16°.

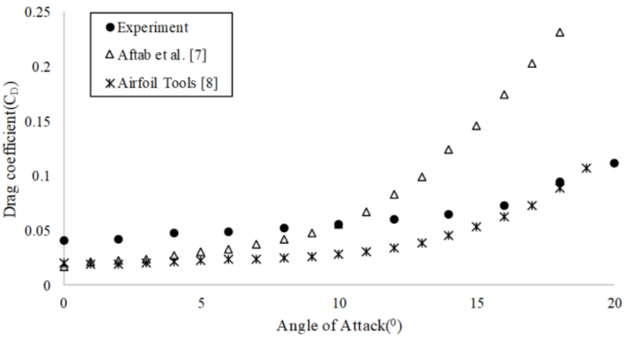

Fig. 6.Comparison of drag coefficient for smooth airfoil

The lift coefficients for the airfoil without vortex generator, airfoil with a triangular vortex generator and also airfoil with a shark skin vortex generator over the angles of attack shown in Fig. 7. In all cases, the lift coefficient increases steadily up to 14°. The airfoil with shark skin vortex generator produced a higher lift coefficient compared to the smooth airfoil and the airfoil with the triangular vortex generator at lower angles of attack and at 14° where the highest lift coefficient is recorded. The difference in lift coefficient between the other airfoils and the airfoil with shark skin vortex generator can reach almost 10%.

In the meantime, there seems to be no significant difference in drag coefficient between the airfoils with vortex generator when the angle of attack is lower than 10° as illustrated in Fig. 8. However, a significant increase in drag coefficient for the airfoil with shark skin vortex generator is observed when the angle of attack becomes higher than 10°. This increase in the drag coefficient for airfoil with a shark skin vortex generator needs further investigation before any useful conclusion can be made.

Last but not least, as indicated in Fig. 9, the airfoil with the shark skin shape vortex generator has the highest lift-to-drag ratio at low angles of attack. This may be useful in the cruising phase of flight, which may contribute to less fuel consumption to the aircraft operation. Nonetheless, for angles of attack that are higher than 16°, the lift-to-drag ratio for airfoil with shark skin shape vortex generator is found to be lower than that of the other airfoils. Arguably, however, aircraft will often spend negligible percentage of the total flight time at these angles of attack anyway.

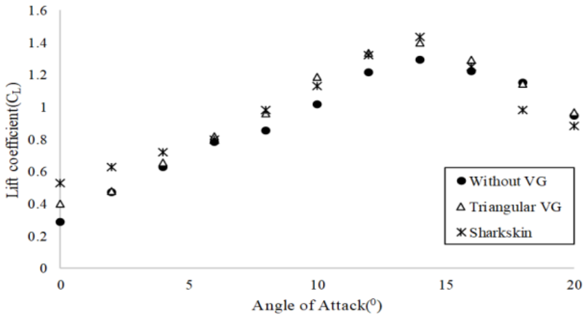

Fig. 7.Lift coefficient at various angles of attack for smooth NACA 4415 airfoil, and airfoils with triangular and shark skin shape vortex generators

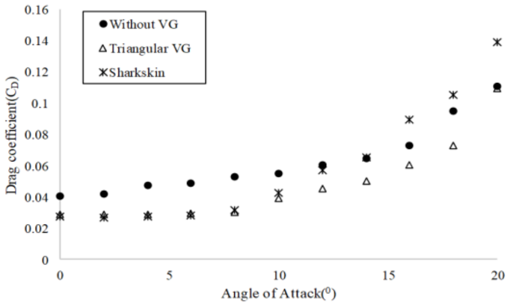

Fig. 8.Drag coefficient at various angles of attack for smooth NACA 4415 airfoil, and airfoils with triangular and shark skin shape vortex generators

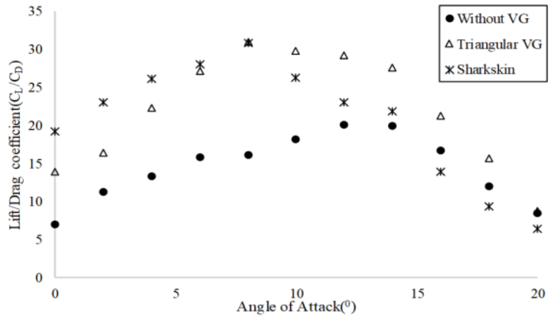

Fig. 9.Lift-to-drag ratio at various angles of attack for smooth NACA 4415 airfoil, and airfoils with triangular and shark skin shape vortex generators

IV. CONCLUSION

Performance of a novel shark skin shape vortex generator for NACA 4415 airfoil has been presented in this paper. It has been shown from the obtained results that airfoil with a shark skin shape vortex generator has relatively better aerodynamic performance in comparison to the other considered airfoils at some ranges of angles of attack. The airfoil with the shark skin shape vortex generator has the highest lift coefficient but it is also shown to have the highest drag coefficient at high angles of attack. By comparison of the lift-to-drag ratio between the considered airfoils, the shark skin shape vortex generator has a distinct better performance at lower angles of attack. These findings are useful for the future work on the optimization of shark skin shape vortex generator for the airfoil performance enhancement.

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