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EFFECT OF TRIANGULAR AND PLASMA ACTUATOR VORTEX GENERATOR ON AIRFOIL SURFACE

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Abstract

The present study investigates the effectiveness of the vortex generator with plasma actuator on NACA 23012 airfoil models. The airfoil was constructed in CATIA V5R19 software. The subsonic wind tunnel was set at the velocity of 5m/s equivalent to low Reynolds number 50 000. The plasma actuator was located at 1/3 leading-edge, 1/2 leading-edge and 1/3 trailing edge from the main wing. The 39 deg deflected flap was used to test the effectiveness of flow control devices with the presence of a triangular vortex generator and plasma actuator. The deflected flap with vortex generator attached at 20% chord gives an increment of C_L by 2%, decrease C_D by 1% and increase C_L/C_D by 5%. From the result of the analysis, the vortex generator with a plasma actuator at the location of 1/3 from trailing-edge reduced C_D approximately by 2% and gave a better performance for C_L/C_D by almost 5 %. Overall, the vortex generator with a plasma actuator improved the aerodynamic performance by almost 5 % at a low Reynolds number.

Keyword: Triangular vortex generator, plasma actuator, lift coefficient, drag coefficient

1. INTRODUCTION

A passive vortex generator (VG) is a small device attached to a lifting surface, such as an aircraft wing or rotor blade or a wind turbine. This vortex generator creates a vortex when the airfoil or the body is in motion relative to the air, by removing a part of the slow-moving boundary layer on the airfoil surface, delays local flow separation aerodynamic stalling, and therefore improve the effectiveness of the wings and control surfaces, such as flaps, elevators, ailerons and rudders. In general, a vortex generator is positioned at the angle with respect to the local freestream flow. With appropriate dimensioning and positioning, stream wise vortices can be created to control the flow[1]. However, if the airflow is separated from the wing, aircraft performance can suffer loss in the form of increased drag, loss of lift and therefore higher fuel consumption. To overcome this, most aircraft will attach vortex generators at the leading edge[2]. The sub-boundary layer VG performed improvement in reducing flow separation compared to larger VG without the effects of increased drag. It also increases lift by 10% and drag reduction by 50% when the VG is attached to the leading edge and trailing edge flapped airfoil. As for today, the use of the Dielectric Barrier Discharge (DBD) plasma actuator has been studied. This method can delay the boundary layer transition, reduce skin friction drag, decrease aircraft fuel consumption. The DBD can be easily implemented on the surface, lightweight and easy to control[3][4]. The plasma actuator consists of two electrodes and is separated by an insulating dielectric layer. The electrode usually consists of copper foil tape while the dielectric layer used any substances with insulating properties[5]. The materials commonly used are Kapton polymer tape, Teflon tape , quartz glass and micro ceramic[6]. A purplish glow and spread out across the surface of the dielectric when it is activated. Moreover, to improve the effectiveness of controlling boundary layer separation, the hybrid micro-vortex generator has been investigated by [7] of NACA 4415 in subsonic conditions. The hybrid is the combination between a passive vortex generator (triangular vane) and an active vortex generator (blowing jet). The result shows that CL and CL/CD increased but however the CD also increased. The use of a vortex generator will produce drag when the aircraft in cruising motion and at low speed. The installation of VG itself will change the design of the airfoil shape at the aircraft wing, making it not smooth for a perfect aerodynamically usage.

To overcome this problem, a plasma actuator was attached at 3 different locations after the installation of the vortex generator which can reduce the drag force when the aircraft is flying in a straight motion or at low speed was investigated in this paper. The airspeed was set at 5m/s corresponding to Reynolds number 50 000.

2. METHODOLOGY

2.1. Catia V5R19Design

CATIA V5R19 software has been used to design the vortex generator and the airfoil wing of NACA 23012. The triangular shape vortex generator has a height of 5mm, 10mm length and 2mm thickness as shown in Figure 1. The vortex generator is attached parallel to the airflow and located at 20% chord length of the airfoil. There are 6 pieces of triangular vortex generator attached to the airfoil separated by 30mm from each. The top view of NACA 23012 was shown in Figure 2. The airfoil had 165mm chord length, 200mm spanwise length. The main airfoil has a 110mm chord length and 55mm flap chord length.

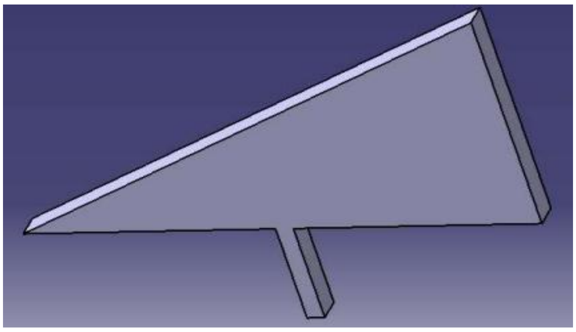


Figure 1: Vortex generator

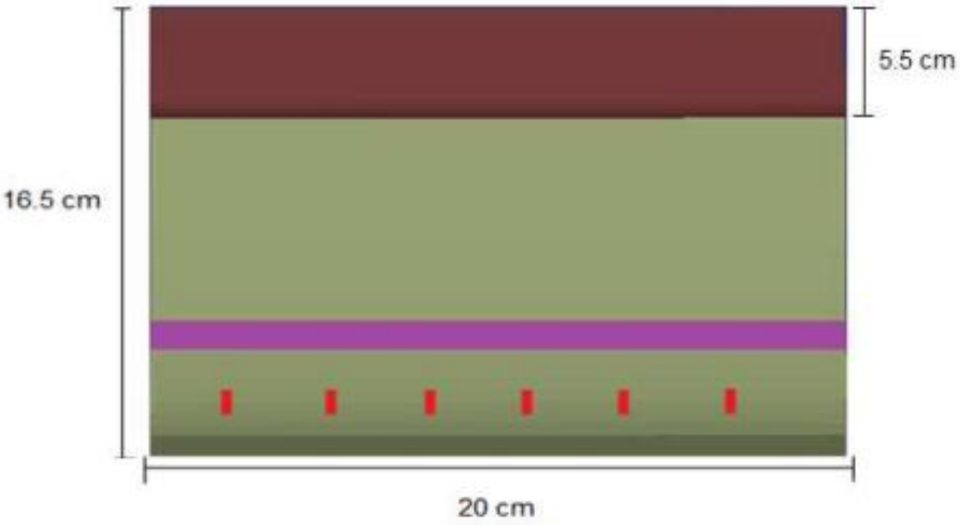
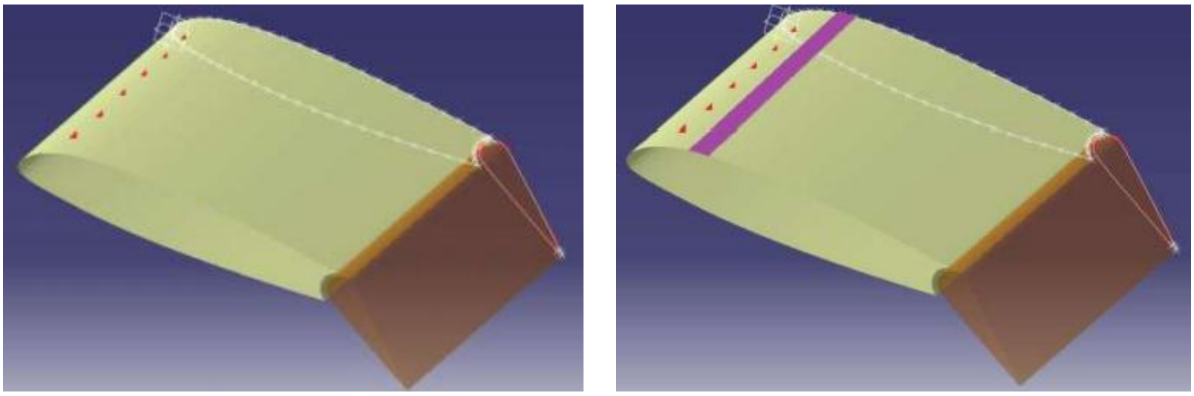
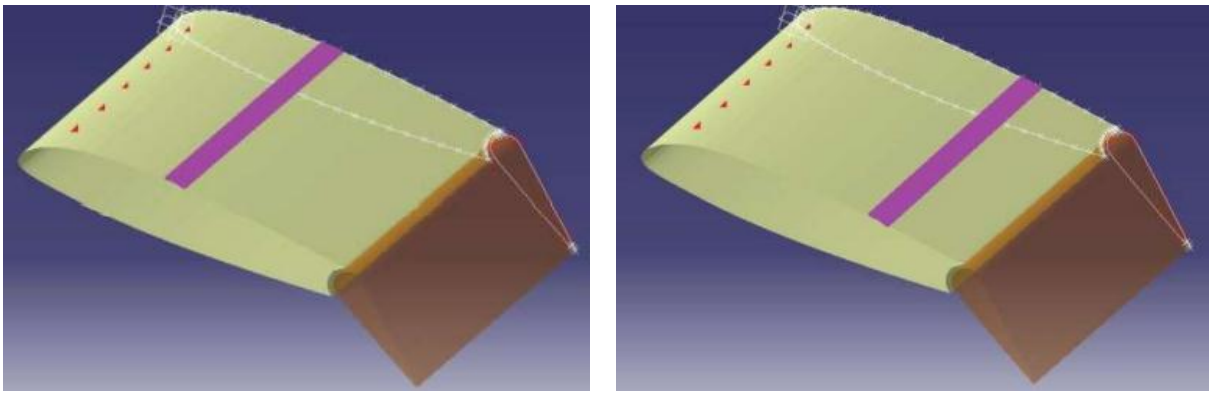


Figure 2: Top view of model airfoil NACA 23012 with retracted flap

The three locations of plasma actuator on the wing have been designed using CATIA and Paint software as shown in Figure 3. The triangular was indicating in red colour while the plasma actuator was indicated by the thick purple line. The triangular vortex generator without plasma actuator and with plasma actuator located at 1/3 chord length from leading-edge, 1/2 chord length from the leading edge and 1/3 chord length from trailing edge.



(a) (b)



(c) (d)

Figure 3: Location of vortex generator is at 20% from leading-edge airfoil (a) without plasma actuator, (b) plasma actuator 1/3 leading-edge; (c) plasma actuator 1/2 leading edge, (d) plasma actuator at 1/3 trailing edge from the main airfoil.

2.2. Plasma actuator Setup

The airfoil was fabricated using high-density balsa wood to achieve a stronger model so it can withstand the airspeed in the wind tunnel. The vortex generator was carved from steel, shaping into a small triangular shape and attached in front of the airfoil. The plasma actuator was made using 2 electrodes separated by 1 dielectric barrier. The copper was used as an electrode and Teflon tape as a dielectric barrier as shown in Figure 4. Figure 5 shows the final attachment of a 3 phase AC (alternating current) system step up by 15 kV Boost Step-Up power module was used to power up the plasma actuator. The schematic diagram of the plasma actuator circuit is shown in Figure 6. The exposed electrode indicated as positive while the insulating electrode indicated as negative using copper tape. The dielectric barrier suing Teflon tape is attached in the middle of the copper tape with a small gap.

(a) (b)

Figure 4: (a) Copper tape as electrode barrier and (b) Teflon tape as a dielectric barrier.

Figure 5: Final attachment of plasma actuator on the airfoil

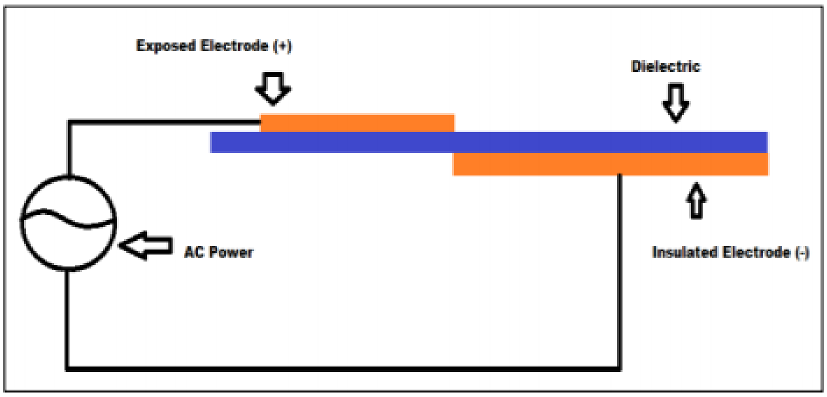


Figure 6: Schematic diagram of the plasma actuator

2.3. Subsonic Wind Tunnel Experimental Setup

The subsonic wind tunnel used in this experiment is shown in Figure 7. This wind tunnel is an open-circuit wind tunnel with 300mmx300mmx600mm transparent test section for visualization and measurement purposes (refer Figure 8). The Perspex was used as a test section due to as high quality of vibration and ductile. The model is attached to the axis balance system. The axis balance is connected to the sensor beam to provide the value of lift and drag forces. The lift and drag forces in unit Newton and need to change into dimensionless value such as lift coefficient (CL) and drag coefficient (CD).

Figure 7: Subsonic wind tunnel

(a) (b)

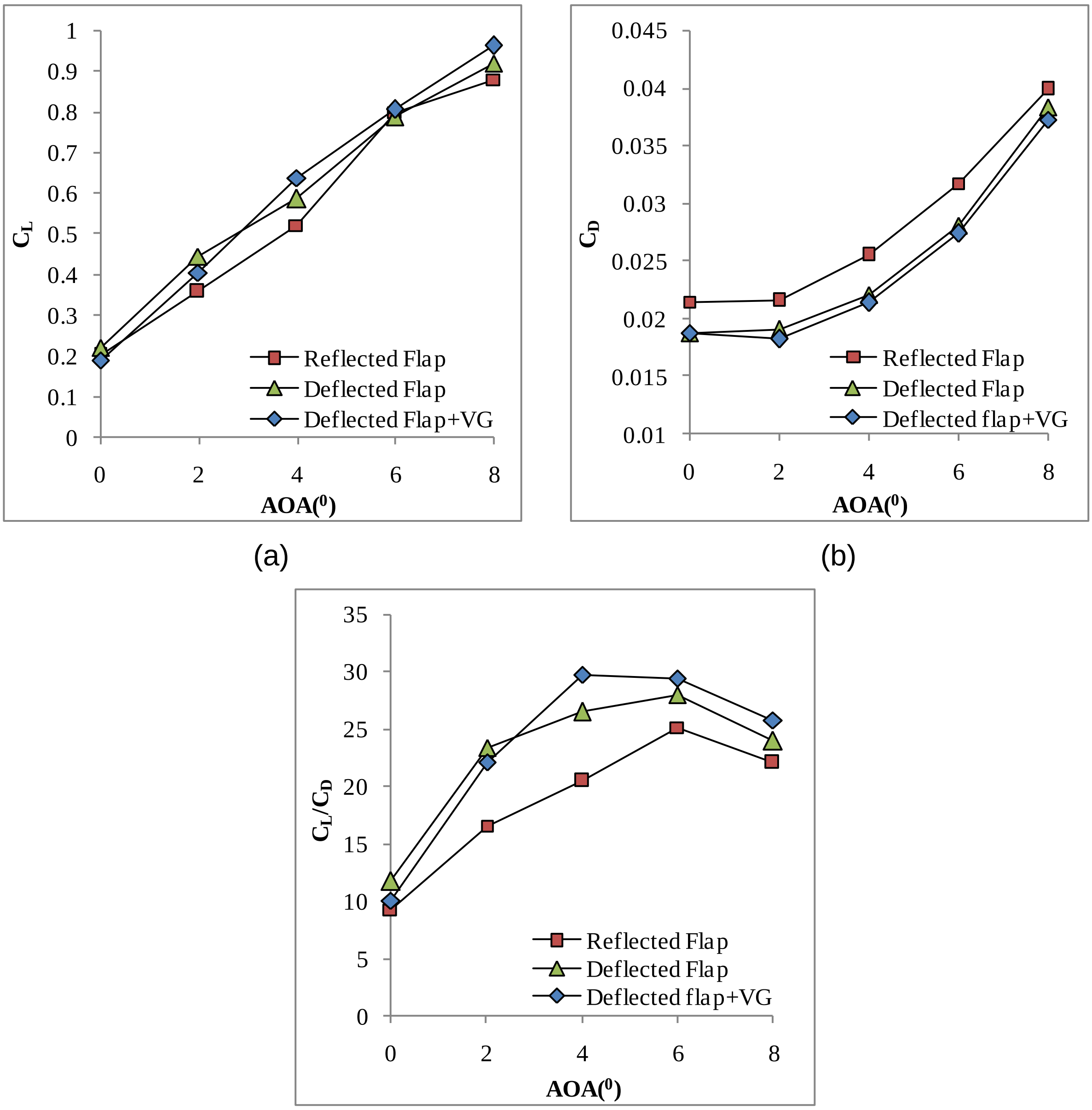
Figure 8: (a) Wind tunnel transparent test section, (b) Airfoil model attached to the axis balance system in the wind tunnel

3. RESULT AND DISCUSSION

There are two experiment testing had been conducted through this experiment. The data for the first experiment was collected for an airfoil with and without a vortex generator but without a plasma actuator. In this section, the plasma actuator was switched OFF with velocity 5m/s corresponded to Reynolds number 50 000. The angle of attack was set at 0 deg, 2 deg, 4 deg, 6 deg and 8 deg. The second experiment was conducted for the airfoil that was attached to a triangular vortex generator with 3 different locations of the plasma actuator. The plasma actuator was ON during wind tunnel testing. The velocity and angle of attack were set as same as the first experiment. The flap was extended or deflected to 30 deg for both of the experiments.

3.1. Retracted and Deflected Flap with Vortex Generator

The reflected flap was a flap without a deflection angle compared to the deflected flap 39 deg with and without vortex generator as shown in Figure 9. The lift coefficient (CL) for the retracted flap, deflected flap with and without vortex generator almost followed the same trends as the angle of attack increase. The deflected flap show better performance in CL by 1.5% compared to the retracted flap. However, the deflected flap with vortex generator increase higher and almost 2% compared to the deflected flap. Meanwhile, the drag coefficient (CD), the retracted flap provides higher CD compared to deflected flap with vortex generator (refer Figure 9(b)). In figure 9(c), the lift-to-drag (CL/CD) ratio shows the deflected flap with vortex generator provides higher CL/CD compared to deflected flap without vortex generator by almost 5% and 9% from the retracted flap. It shows that the deflected flap with vortex generator increase CL (2%), decrease CD (1%) and increased CL/CD (5%) compared to deflected without vortex generator.



(a)

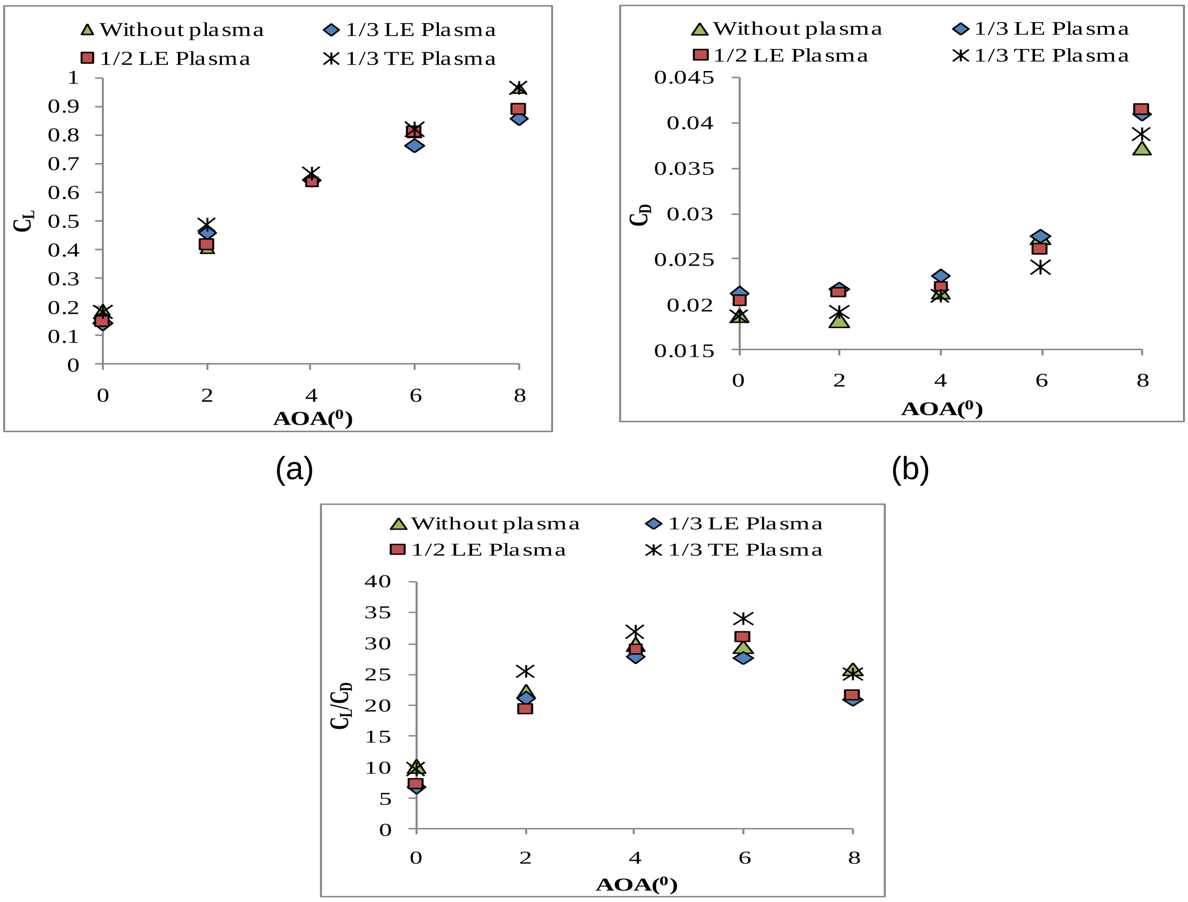
(b)

(c)

Figure 9: Reflected flap and deflected flap without and with vortex generator (a) CL vs AOA, (b) CD vs AOA, (c) CL/CD vs AOA

3.2. Comparison between Vortex Generator and different location of the plasma actuator

Figure 10 shows the data of CL, CD, CL/CD over the angle of attack for vortex generator attachment for deflected flap without plasma(plasma actuator OFF), plasma actuator at the location of 1/3 from leading-edge, 1/2 from the leading edge and 1/3 from trailing edge of the main airfoil. The result shows that the CL for deflected flap without plasma and three different locations of plasma actuator are almost the same (refer Figure 10(a)). This shows that CL does not have any major change even if the plasma actuator was ON. However, based on Figure 10(b), the CD has almost 2% changes depending on the attachment of the plasma actuator. Moreover, the plasma actuator at 1/3 trailing edge produces the lowest CD compared to 1/3 leading-edge plasma actuator. For the lift/drag ratio, based on Figure 10(c), the result shows that the plasma actuator at 1/3 trailing edge achieved approximately 5% higher value compared to other cases. It shows that the plasma actuator attached with a vortex generator and with a plasma actuator located at 1/3 trailing edge significantly used for take-off and landing conditions.



(a) (b)

(c)

Figure 10: Deflected flap attachment of vortex generator with different location of plasma actuator (a) CL vs AOA, (b) CD vs AOA, (c) CL/CD vs AOA

4. CONCLUSION

The performance of the deflected flap with a vortex generator and attachment of three different locations of plasma actuator has been investigated in this study. The deflected flap with triangular vortex generator increase CL by 2%, decrease CD by 1% and increase CL/CD by almost 5% compared to the deflected flap without vortex generator. Moreover, the deflected flap with a vortex generator gives better performance in CL and CL/CD compared to the deflected flap without a vortex generator. For the vortex generator with different locations of plasma actuator, the 1/3 location from the trailing edge provides higher CL/CD by almost 5% compared to the plasma actuator at 1/3, 1/2 location from the leading edge and without plasma actuator ON. It also shows that the attachment of the vortex generator together with the plasma actuator improves the aerodynamic performance by approximately 5% for overall experimental studies. For the improvement, further studies will be based on the orientation of the triangular vortex generator with the plasma actuator location.

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