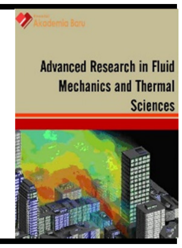
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Wind Tunnel Experiments on a Generic Sharp-Edge Delta Wing UAV Model

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ARTICLE INFO

Article history:
Received 2 November 2017
Received in revised form 1 December 2017
Accepted 24 December 2017
Available online 26 December 2017

ABSTRACT

Delta wing is a triangular shape platform from a plan view. Delta wing can be applied to aircraft development as well as UAV. However, the flow around delta wing is very complicated and unresolved to date. On the upper surface of the wing, vortex is developed which need more studies to understand this flow physics. This paper discusses an experiment study of active flow control applied on the sharp-edged generic delta wing UAV. This paper focuses on the effect of rotating propeller on the vortex properties above a generic 550 swept angle model. The model has an overall length of 0.99 meter and the experiments were performed in Universiti Teknologi Malaysia Low Speed wind tunnel sized of 1.5 x 2.0 meter2. In this experiment, the experiments were conducted at a speed of 18 m/s. In order to differentiate the effect of propeller size on the vortex system, the experiment was carried out in three stages, i.e., experimental without propeller called as clean wing configuration and followed by the experiment with propeller diameter of 13”. The final experiment was the experiment with propeller diameter of 14”. During the experiments, two measurement techniques were employed; steady forces and surface pressure measurements. The experimental data highlights an impact of propeller size on the coefficients of lift, drag, and moment and vortex system of the delta-shaped UAV. The results obtained indicate that the lift is increased particularly at high angle of attack. The results also show that vortex breakdown is delayed further aft of the wing when propeller rotating at about 5000 RPM.

Keywords:
Delta Wing UAV, Propeller, Vortex, Wind Tunnel Experiment, Surface Pressure

1. Introduction

Delta wing is commonly used for high speed application as its advantage can sustain lift force at higher angle of attack [1]. Nonetheless, delta wing configuration also can be applied in micro air vehicle (MAV) and unmanned aerial vehicle (UAV) because its weight effectiveness and the structure of a delta wing that is rigid [2]. Delta wing produced more lift at higher angle of attack because of the vortex formed near the leading edge [3, 4]. Strong vortices generate at higher angle of attack produce high speed flow above the wing, resulting in low pressure region above the wing [5, 6]. Thus, the wings lift increase significantly. The formation of leading edge vortex is affected by

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several factors such angle of attack, leading edge geometry, wing thickness, sweep angle, freestream condition and delta wing configurations [2, 6]. From the previous study by Zheng and Ahmed [7], the coefficient of lift is increased when the wing swept angle increases. This is related to the stronger vortex generated. Freestream condition such airspeed also affecting the flow structure above the delta wing. Flow control techniques i.e. active and passive were applied on the delta wing to improve the aerodynamic performance at low speed [8]. One of the techniques is downstream suction at the trailing edge of the delta wing. This technique improves the aerodynamic performance of delta wing as found by previous research [2, 9]. However, for smaller scale of delta wing like MAV and UAV, propeller is installed in the rear position to obtain the optimum aerodynamic efficiency. Figure 1 shows an example of delta wing UAV with rear propeller configuration. The propeller actuation modifies the axial pressure gradient above the wing, hence creating greater lift force.

Thus, this study is performed to investigate the effects of active flow control techniques on the aerodynamic properties above the wing.

Fig. 1. The Bateliur - a surveillance and patrol aircraft that utilize the delta wing with rear propeller configuration

2. Wind Tunnel Experiment

In this project, a generic sharp-edged delta wing UAV model fabricated from UTM Research Grant has been tested in UTM low speed wind tunnel facility. The model is designed to have 55° sweepback angle and its mean aerodynamic chord (M.A.C) is 0.4937 m. The detail dimensions of the model are shown in Table 1. The model was fabricated from aluminum material. The model has been design based on the existing delta-winged UAV [10-12]. For the future research, the model was fabricated with several control surfaces such as rudder and elevator which can be controlled manually.

Table 1
UTM delta-winged model

Specification	Size
Overall length	0.99 m
Overall width	1.062 m
Mean aerodynamic chord (MAC)	0.4937 m
Wing area, S	0.38 m^2
Wing + fuselage area	0.4424 m^2
Aspect ratio, AR	2.7027

The experiments were performed in 1.5m × 2.0m × 6m UTM-LST wind tunnel. Two measurement techniques were employed on the model, i.e. steady balance and surface pressure measurement. Force and moment were captured using 6-axis balance measurement system located underneath the test section as shown in Figure 2. For pressure measurement, a digitized pressure scanner of Scannivalve has been used. The location of pressure taps on the wing were shown in Figure 3.

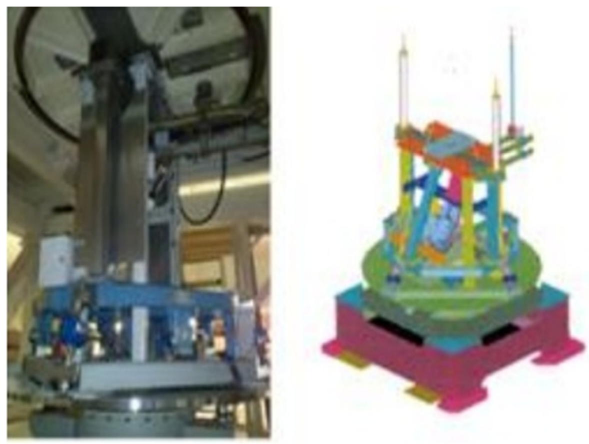


Fig. 2. UTM- LST Balance measurement system

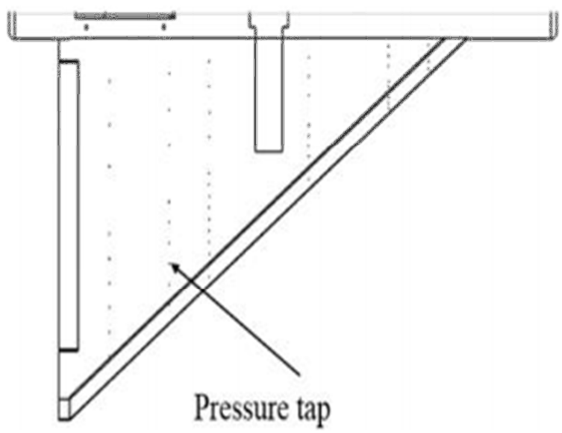


Fig. 3. Location of pressure taps

The experiments were conducted at constant air speed of 18 m/s. In order to investigate the effects of propeller size on the vortex system above sharp-edged delta wing, the experiments were performed at two different propellers sized of 13” and 14” diameter. During the experiment the rotation of the propeller was maintained at approximately 5000 RPM respectively. A servometer has been used to control this RPM as shown in Figure 4. The propeller was powered by EMAX brushless out-runner motor of maximum voltage 11.1 V that was connected to the DC power supply unit (shown in Figure 4 and 5).

During the experiment, the model was attached to 6 axes external balance through two strut support located at about 1/3 and 2/3 of wing length of the wing as shown in Figure 6 below. The model angle of attack can be created by adjusting the rear strut vertically. For this experiment, steady forces data and surface pressure measurements were captured at angles of attack from varies from α = 0° to 18°. To differentiate the effects of propeller on the vortex properties, the experiments were also performed at two conditions, namely clean wing configuration and followed by the experiments with the propellers.

Fig. 4. Tachometer to measure the propeller speed

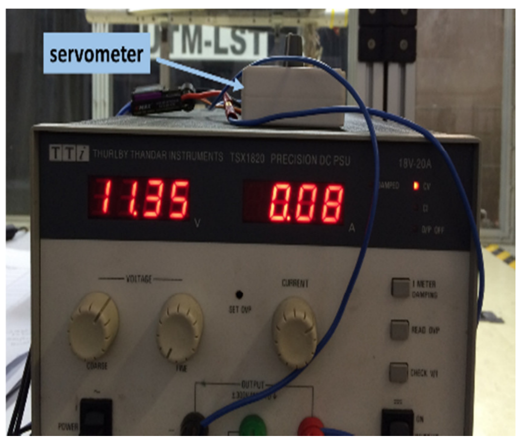


Fig. 5. DC power supply unit and servometer

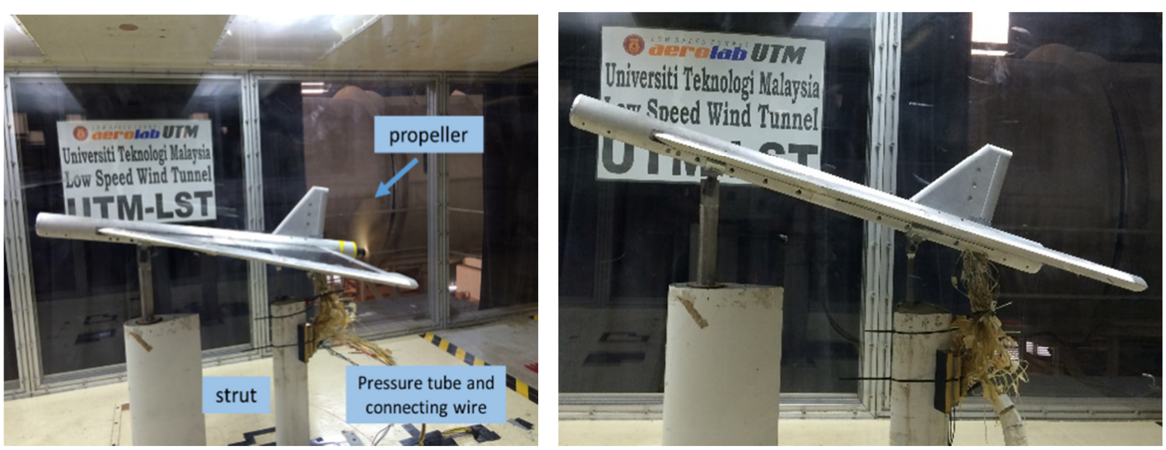


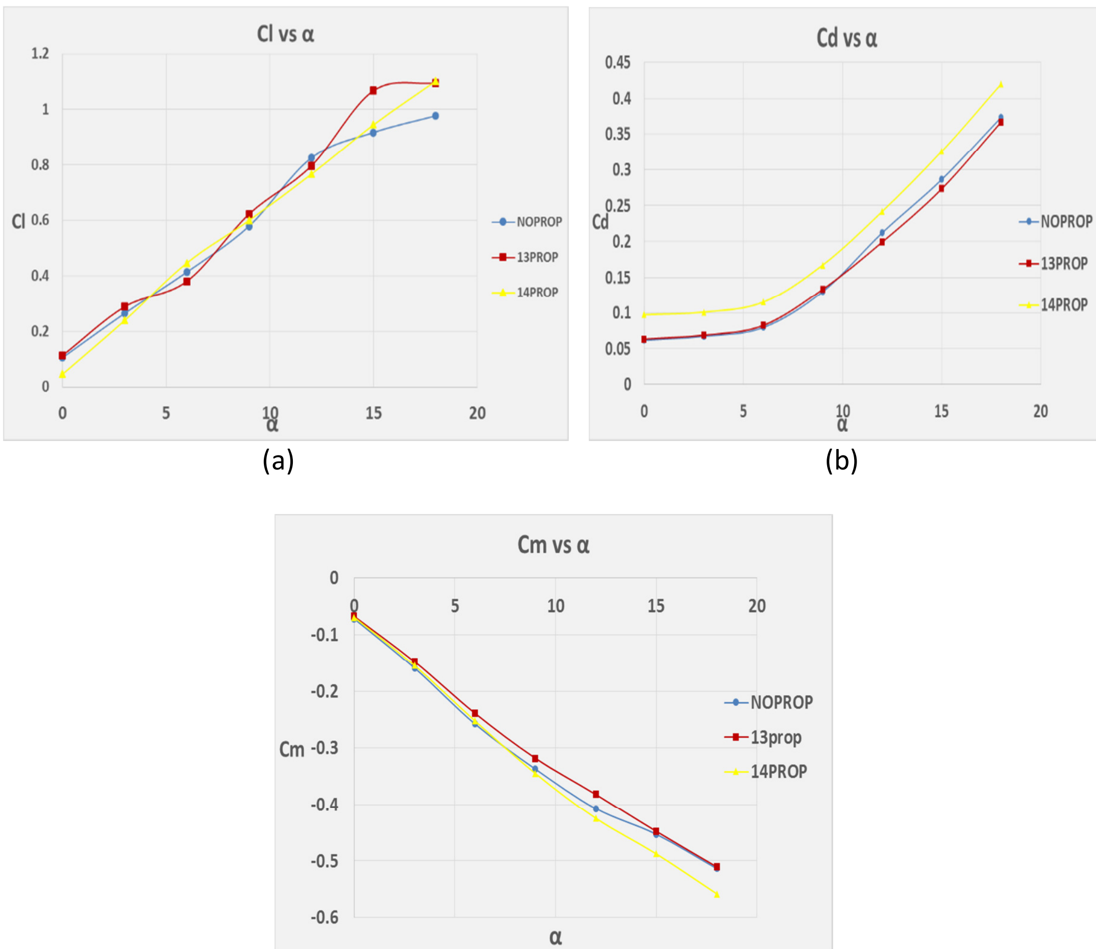
Fig. 6. Installation of UTM-LST sharp-edged delta wing UAV model

3. Results and Discussion

This section discusses the results obtained from steady balance and surface measurement study.

3.1 Steady Balance Measurements

The coefficients of lift, drag and pitching moment are presented in Figure 7. From the figure (fig. 7(a)), the lift force keeps increasing as the angle of attack is increased. The result obtained indicates that the stall condition not occur even though the angle of attack had reached α = 18°. The formation of the vortex above the wing resulting in non-linear lift, thus delayed the stall. The results obtained here consistent with [1, 4, 13, 14, 16].



(c)

Fig. 7. Force coefficients versus angle of attack

Generally, the lift coefficient is increased when the propeller is installed on the wing. This situation happened because the suction force generated by the propeller has pressurized the flow above the wing. The propeller itself may delay the turbulent separation on the wing leading to stable vortex formation [11, 15]. Propeller operation on the UAV model produced greater lift compared to the non-propelled configuration as the angle of attack increases (in this experiment, α=18° is the maximum). The results obtained here showed that the C_l – α graph is not zero when α = 0°, this may be related to the existing of several control surfaces. Further studies need to be carried out to validate this phenomenon.

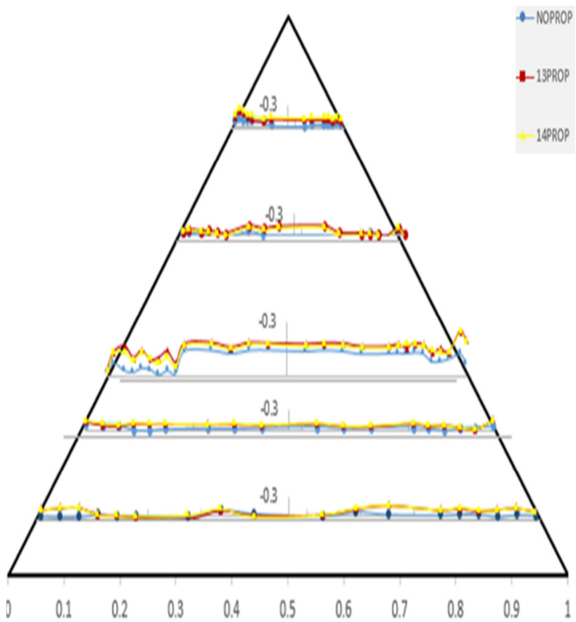
Figure 7 (b) shows the drag coefficient obtained from this experiment. It should be noted that the drag is higher for wing configuration with propeller compared to clean wing configuration. This situation may be linked with the unsteadiness of the flow occurs behind the propeller that may generate more drag. The accelerated flow on UAV surface has increased the friction drag [15].

Figure 7 (c) shows pitching moment coefficient for this sharp-edged delta wing, C_m versus α. It can be seen that as α is increased, the nose down pitching moment also increases. This situation happens because of the propeller rotation has generated larger moment deviation especially for the bigger size propeller [2, 9].

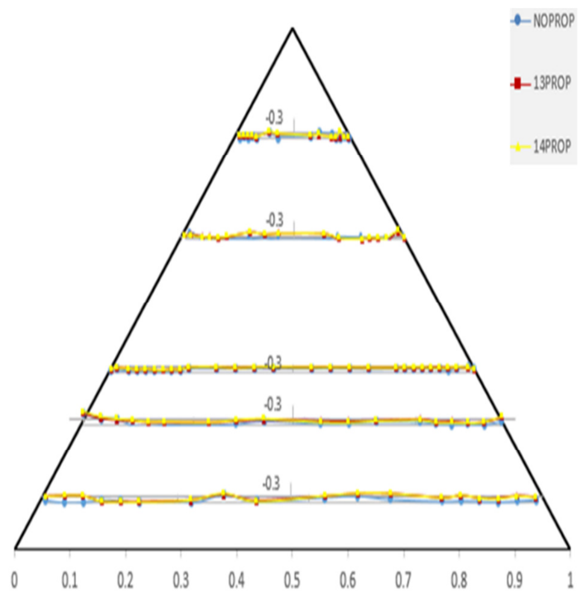
3.2 Surface Pressure Measurements

This section discusses the results obtained from experimental surface pressure measurement studies. The raw data obtained had been normalised in terms of local pressure, C_P. C_P is plotted in chordwise position of the wing width at each local chord length respectively on the upper wing surface. To differentiate the propeller's effect on vortex performance, data from the clean wing configuration were compared with those from two propeller configurations.

The results at lower angle of attack from α = 0^0 to 3^0 are shown in Fig. 8. They can be observed that the air flow is still attached to the surface of the wing for all three conditions.



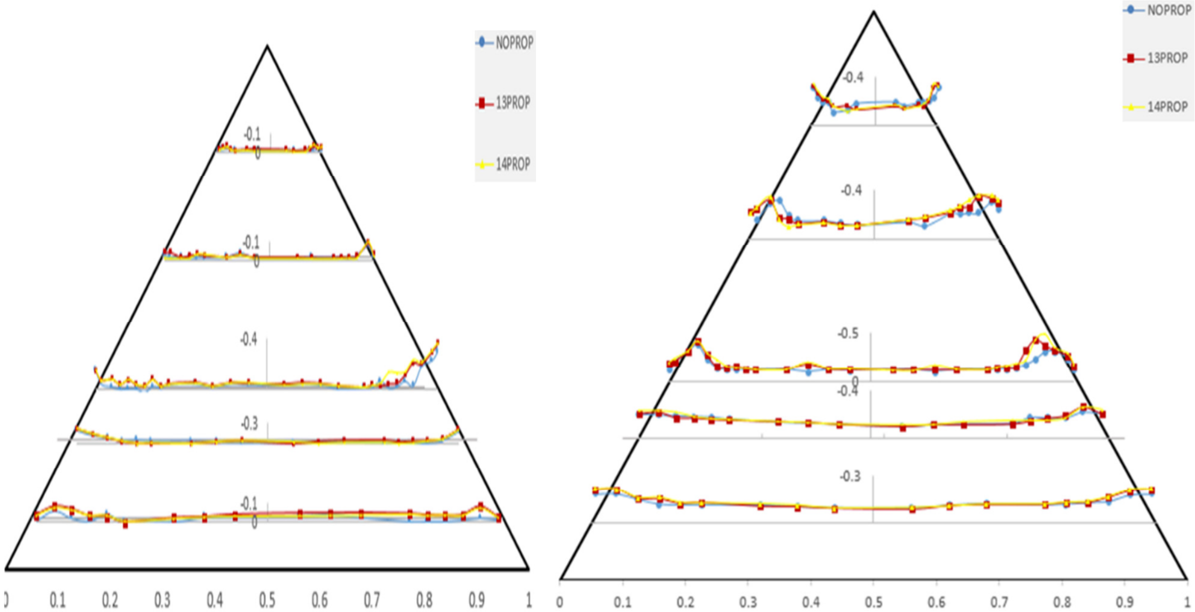
(a)



(b)

Fig. 8. Pressure distribution at lower angle of attack (a) α = 0° and (b) α = 3°

At medium angles of attack between α = 6^0 to 9^0, the suction peak is observed in the region of leading edge as shown Fig. 9 below. The attached flow started to detach from the trailing edge towards the apex region. However, at this condition, the effects of propeller are not obviously observed except in the region near to the trailing edge.



(a) (b)

Fig. 9. Pressure distribution at (a) α = 6° and (b) α = 9°

At higher angle of attack from α = 12^0 to 18^0 as shown in Fig. 10, a bigger vortex is developed in the leading-edge region with the effects of propeller is obvious. The airflow totally separated from the wing surface. The peak suction also increases significantly. It should be noted here that the propeller actuation has absorb the incoming airflow, thus lowering the size of the primary vortex. The results obtained also showed that the vortex breakdown is delayed to further aft of the wing model. The results obtained here consistent with [9].

4. Conclusions

A detail experimental study on the effect of propeller rotation on the vortex properties above a generic sharp-edged delta wing UAV model has been performed in this project. The result shows the installation of the propeller in the rear position of the model can improve the aerodynamic performance of UAV such as lift and drag properties of the model. The rear propeller configuration produced greater lift compare to the clean wing configuration. However, the installation of the propeller has increased the drag and pitching moment coefficient. Another important note from this study is the installation of the propeller also can delay the vortex breakdown further aft of the wing at higher angle of attack.

Acknowledgements
This research was funded by a grant from Ministry of Higher Education of Malaysia and Universiti Teknologi Malaysia (FRGS Grant R.J130000.7824.4F718). The data presented, the statement made, and views expressed are solely the responsibility of the authors.

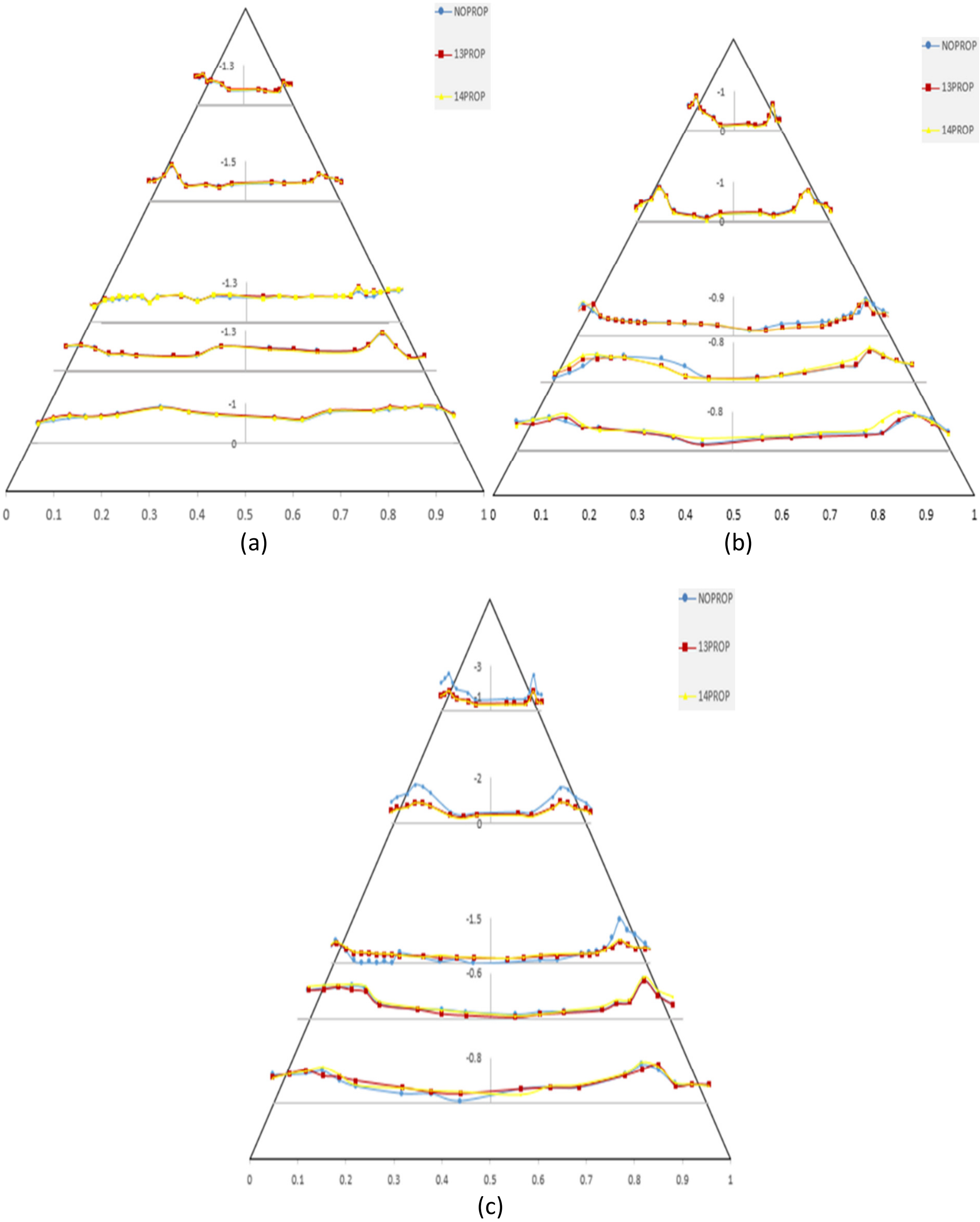


Fig. 10. Pressure coefficient at (a) α=12°, (b) α=15° and (c) α=18°

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