Transactions of the TSME (2019) Vol. 7, No. 2, 102-111
Journal of Research and Applications in Mechanical Engineering

ISSN 2229-2152 Print: ISSN 2697-424x Online
DOI: 10.14456/jrame.2019.10

Research Article

EXPERIMENTAL INVESTIGATION OF PROPELLER-WING AERODYNAMIC INTERACTION OF VTOL UAV

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Received 22 April 2019
Revised 26 May 2019
Accepted 27 May 2019

ABSTRACT:
This paper will present an experimental investigation of propeller-wing aerodynamic interaction for vertical take-off and landing unmanned aerial vehicle. Due to one type of VTOL UAV is called Dual System or QuadPlane which is similar fixed-wing UAV with quadcopter and has separated operation of propeller during hover and forward flight. Main objective was to show the effect of the aerodynamic interaction compared between clean wing and wing with propellers in forward flight and found the position which provided the best aerodynamic performance. The test model was a haft-span rectangular platform wing with an NACA 4412 airfoil and aspect ratio of 8 which installed two motor-propellers at leading and trailing edge and shut off. The position of propellers had several configurations such as the changing position in X-axis which shift motor-propellers along fuselage, the changing position in Y-axis which shift motor-propellers along spanwise and the changing position in Z-axis which shift motor-propellers in Perpendicular spanwise. All tests were conducted in the range of freestream 6 to 18 m/s and varied the incidence angle -6 to 12 degrees in the subsonic wind tunnel at Kasetsart University Sriracha Campus. The result of the experiment found that the wing with propellers configuration XYZ111, which was installed the nearest motor-propellers in all direction, provided the best aerodynamic performance in forward flight. However, the result especially shows the total aerodynamic force. It should create the additional instrument for measuring the propeller at front and rear wing and be additional test flow visualization.

Keywords: *Aerodynamic, Propeller-Wing Interaction, UAV, VTOL*

1. INTRODUCTION

The Vertical Take-Off and Landing Unmanned Aerial Vehicle (VTOL UAV) is combination of advantages between fixed wing UAV and multirotor which cause to enhance the performance and decrease disadvantage of UAV in the operation for mission. This has been shown by [1, 2]. In [3] the VTOL UAVs were classified by position of fuselage in forward and hovering flight such as Tail-Sitter, Tilt Rotor, Tilt Wing, etc. This research was interested on one type of VTOL UAV is called Dual System or QuadPlane. Normally, that is similar fixed-wing UAV with quadcopter which has separately operation of propellers due to forward and hovering flight as shown in Fig. 1. In forward flight, all motors of propellers for hovering flight are closed and oppose flow cause the aerodynamic performance is poor.

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Fig. 1. The example of Dual System.

It has been shown in [4-9] for the study about wing-propeller aerodynamic interaction in forward flight but there studied especially interaction of wing which was installed perpendicular propellers. Such as the tractor-wing and pusher-wing configuration provided the aerodynamic characteristics improvement. That showed the effect of interaction between wing and propeller significantly. Especially, the prop-wash effect mainly increased the aerodynamics performance of the wing. The tractor and pusher wing could take advantage from both the upstream and downstream of the propeller. However, it could not describe the aerodynamic characteristics for QuadPlane because the wing was installed parallel propellers.

In this research will study the effect of aerodynamic interaction of half-span wing which was mounted with two parallel propellers at leading and trailing edge respectively in wind tunnel. The result will show the effect of the aerodynamic interaction compared between clean wing and wing with propellers in forward flight. Moreover, the wing with propellers aerodynamic characteristics of each position and their force parameters were compared in this study which led to the position which provided the best aerodynamic performance.

2. MODEL TEST

The model information is shown in Table 1. Due to the cost and the budget of CNC machining wing model by aluminum as traditional method, the wing model was built by foam and hand laid-up with fiberglass in this research. The polystyrene foam was cut by hotwire CNC. Then for enhancing wing stiffness and surface quality, fiberglass hand laid-up was applied. In wing with motor-propellers experiment, the length for each position is shown in Table 2.

3. EXPERIMENTAL SETUP

The test was conducted in the subsonic wind tunnel at Kasetsart University Sriracha Campus. The wind tunnel is a closed loop and generates a freestream velocity in the range 6-18 m/s. The experiments were carried out in the square cross-section which has dimensions of 1x1x3 m3 (width x height x length) as shown in Fig. 2. The fan speed was controlled by monitor control panel. The model was set in the middle of the wind tunnel test section and was connected to the test bench which contained the two-components aerodynamic force balance. The force balance was designed to measure the lift and drag force which was mounted on the manual rotation system for adjustment the incidence angle as shown in Fig. 3. Two load cells were installed on the balance and were connected to the NI9237 for sample recording at 10 HZ. All load cells were calibrated by standard weights. The atmosphere pressure, dynamic pressure and temperature are recorded by NI 9401. In the wing and propellers experiments section, the model consisted of propellers and two motors which connect the wing by aluminum shaft. Experimental wing with propellers setup is shown in Fig. 4 (a) - (j) and is explained specification of each configuration for experimental in Table 2. All model configurations were tested in the range of freestream velocity 6 to 18 m/s and varied the incidence angle -6 to 12 degrees. The motors of propellers were closed.

Table 1: Model information.

Information	Value
Airfoil	NACA4412
Wing chord	0.15 m
Half-Wingspan	0.6 m
Platform shape	Rectangular
Aspect Ratio	8
Motor	SunnySky V2216 900Kv
Electronic Speed Controller	T-motor 30A
Propeller	APC propeller 6x4” (CW and CCW)

Table 2: Specifications of the installation of propellers position.

Config		Distance (m)	Specification
X	1	0.24	Distance is length where the rear propeller located far from 20% of wing chord (where the front propeller located far from 20% of wing chord at same distance) and each configuration increases 30% of wing chord.
	2	0.285	
	3	0.33	
Y	1	0.1	Distance is length between root wing to center of propeller and each configuration increases 100% of chord.
	2	0.25	
	3	0.4	
Z	1	0	Propeller’s plane is on the leading edge’s plane and other configurations are increase 30% of chord above/below the leading edge’s plane.
	2	-0.045	
	3	+0.045	

Fig. 2. Subsonic wind tunnel at Kasetsart University Sriracha Campus with the test facilities.

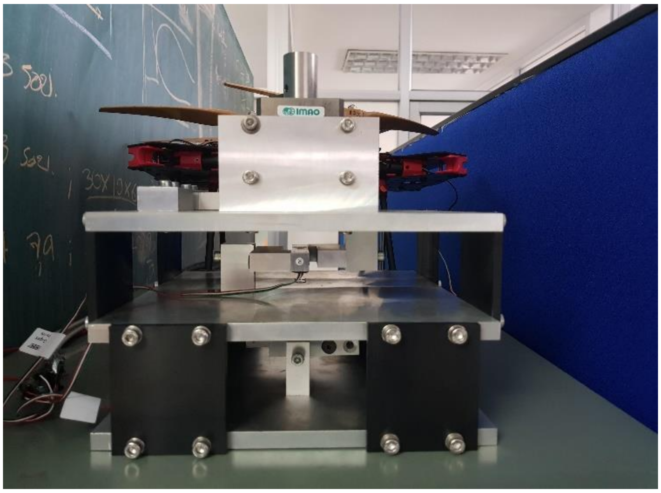

Fig. 3. The two-components aerodynamic force balance.

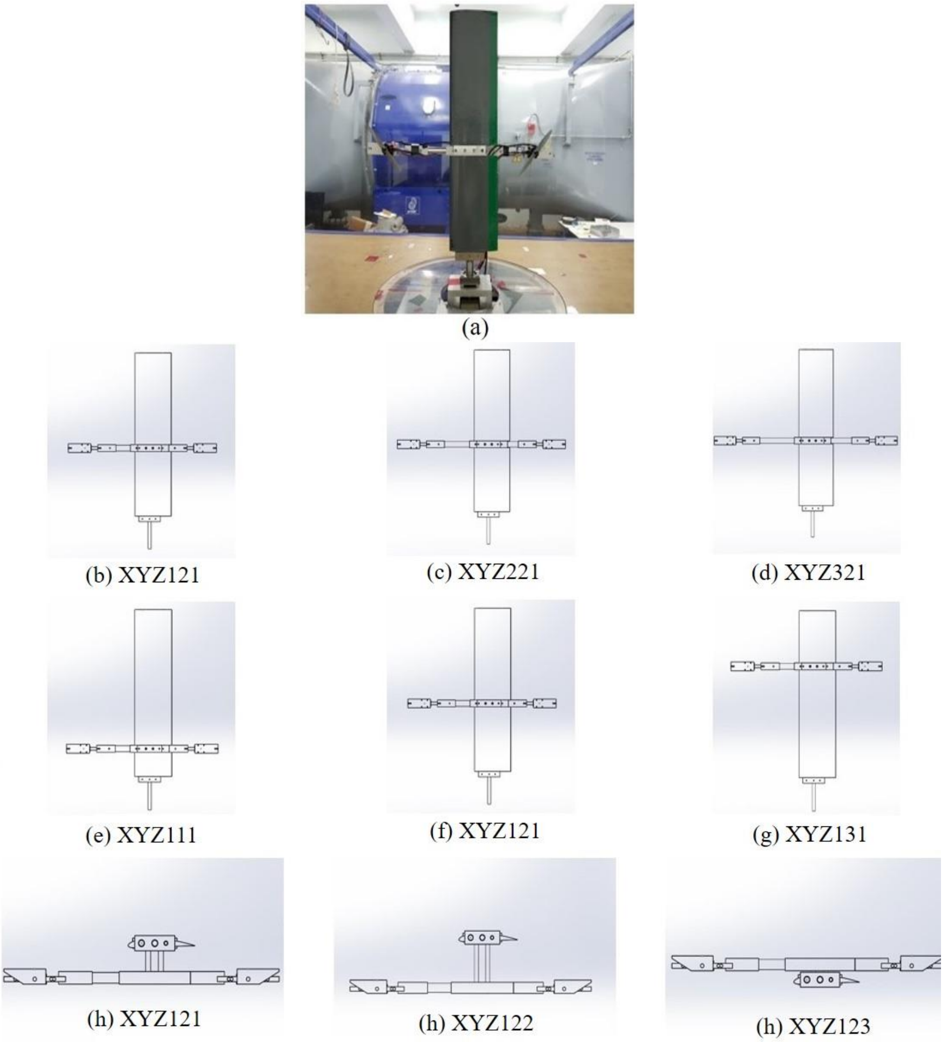

Fig. 4. Experimental setup of (a) real model XYZ121 and (b) - (j) all of experiments.

4. RESULTS AND DISCUSSION

In this research the lift and drag coefficient can be calculated by:

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 S} \tag{1}$$

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 S} \tag{2}$$

4.1 Comparison between clean wing and wing with propellers

In this section, clean wing easily compares with wing with propellers when shows especially XYZ111 configuration.

4.1.1 Lift coefficient

The clean wing in the air freestream 6 m/s provided lift curve slope less than in the air freestream 12 and 18 m/s and early stall at 9 degrees due to air freestream 6 m/s provided the low Reynolds number. The wing with propellers provided lift curve slope less than the lift coefficient of clean wing and early stall at 3 degrees in the air freestream 6 m/s because the wake of additional structure, for motors and propellers, disturbed the wing which cause decreasing lift force as shown in Fig. 5.

4.1.2 Drag coefficient

The characteristic of drag coefficient graph of clean wing and wing with propellers were parabola. The clean wing in the air freestream 6 m/s provided drag coefficient more than in the air freestream 12 and 18 m/s due to air freestream 6 m/s provided the low Reynolds number. The drag coefficient of wing with propellers in the air freestream 6 m/s oscillated due to the load cell had low precision for measuring low drag force. The wing with propellers provided drag coefficient more than clean wing because the additional structure, motors and propellers increased drag force as shown in Fig. 6.

4.2 Comparison of wing with dual propeller in each direction

According to the result presented in section 4.1. Aerodynamic coefficient obtained from the test at velocity of 6m/s, it clearly shows the error and low precision of force measurement for very low speed and easily to compare, therefore in this section the result will present especially at freestream velocity 12 m/s.

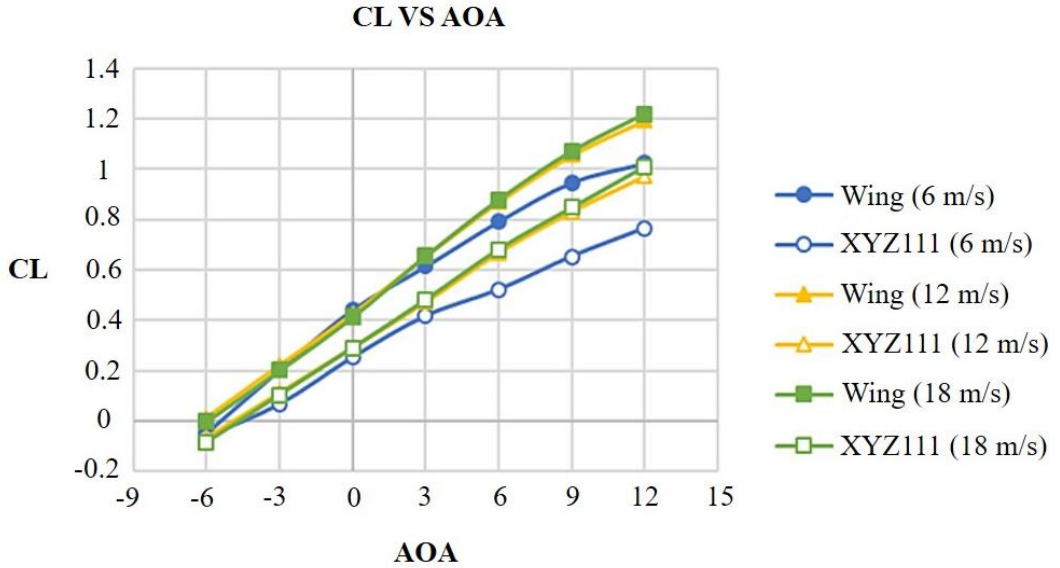

Fig. 5. The lift coefficient of clean wing and wing with propellers XYZ111 configuration vs AOA

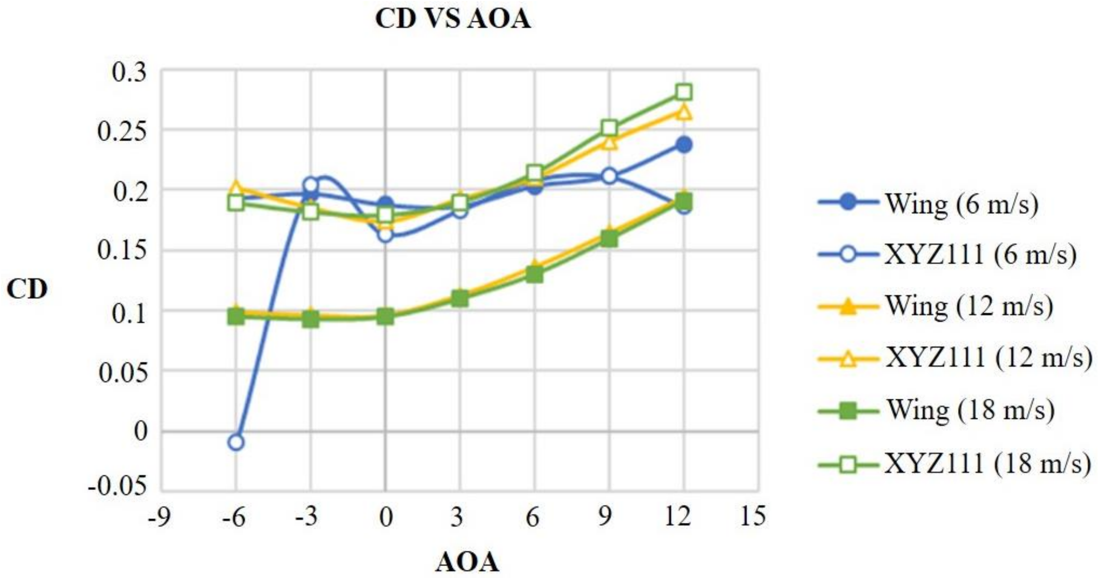

Fig. 6. The drag coefficient of clean wing and wing with propellers XYZ111 configuration vs AOA

4.2.1 Lift coefficient

4.2.1.1 X-axis direction (along fuselage)

All configurations tended to same lift coefficient that showed the changing propeller's position along fuselage insignificantly as shown in Fig. 7.

4.2.1.2 Y-axis direction (along spanwise)

Wing with propellers, which was installed nearest root wing, provided the most lift curve slope because it caused to create the least wingtip vortex and induce drag as shown in Fig. 8.

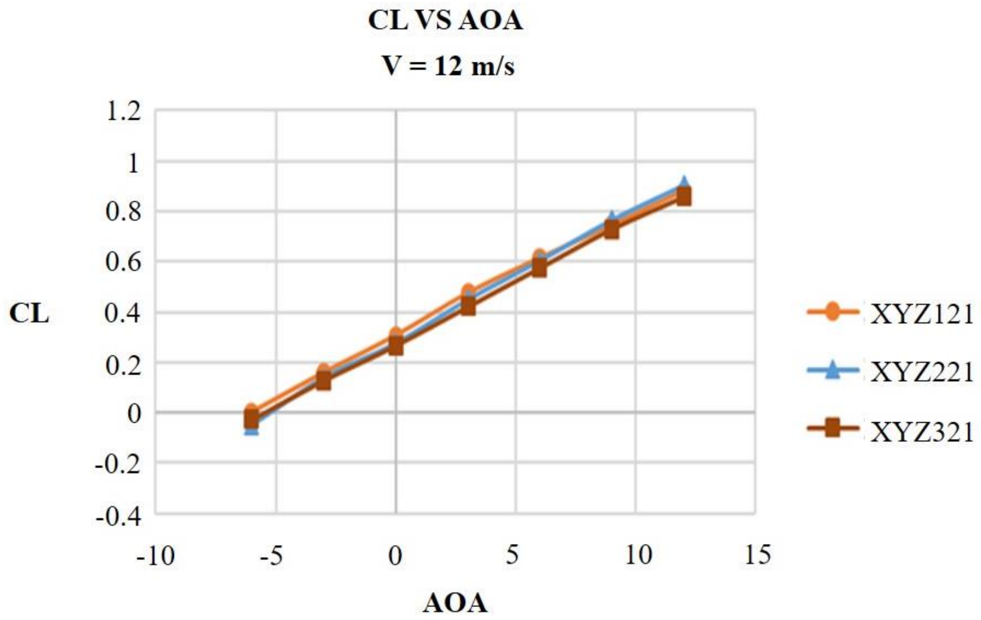

Fig. 7. The lift coefficient of variation X-axis vs AOA

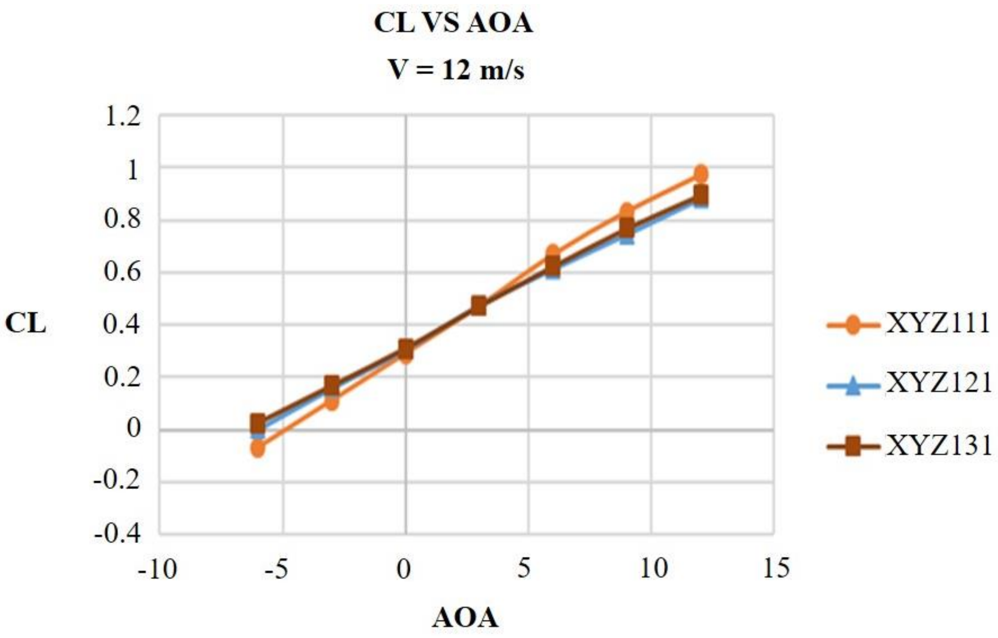

Fig. 8. The lift coefficient of variation Y-axis vs AOA

4.2.1.3 Z-axis direction (along Perpendicular spanwise)

Wing with propellers, which the propeller's plane was installed same level wing's plane, provided the most lift coefficient. When wing was installed propeller's plane above wing's plane, the lift coefficient provided the least lift coefficient because it created the wake which disturbed the wing as shown in Fig. 9.

4.2.2 Drag coefficient

All configurations of wing with propellers tended to same drag coefficient that showed the changing propeller's position insignificantly as shown in Fig. 10, 11 and 12.

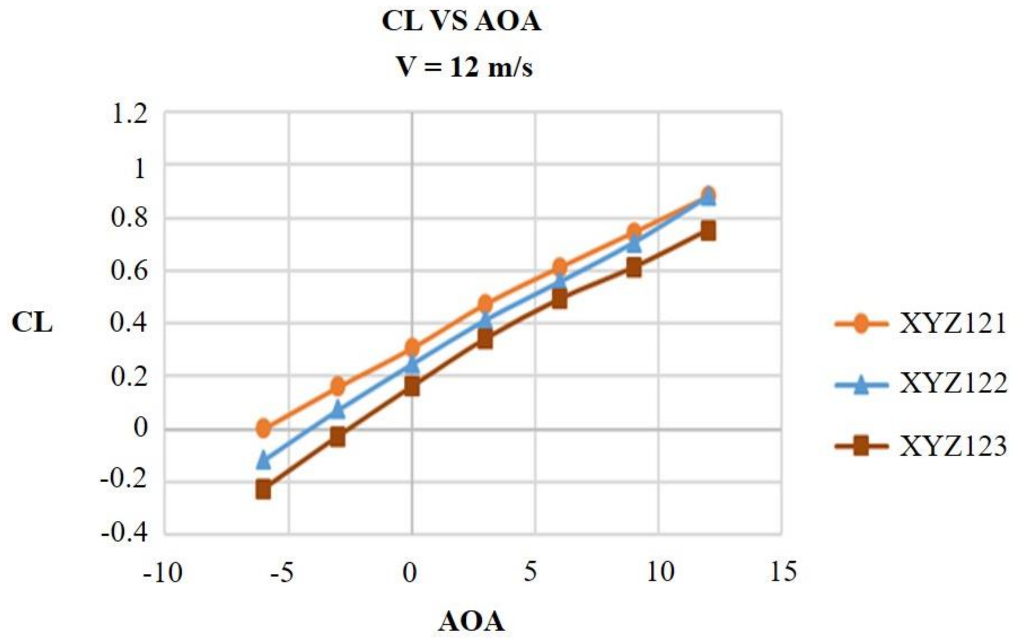

Fig. 9. The lift coefficient of variation Z-axis vs AOA

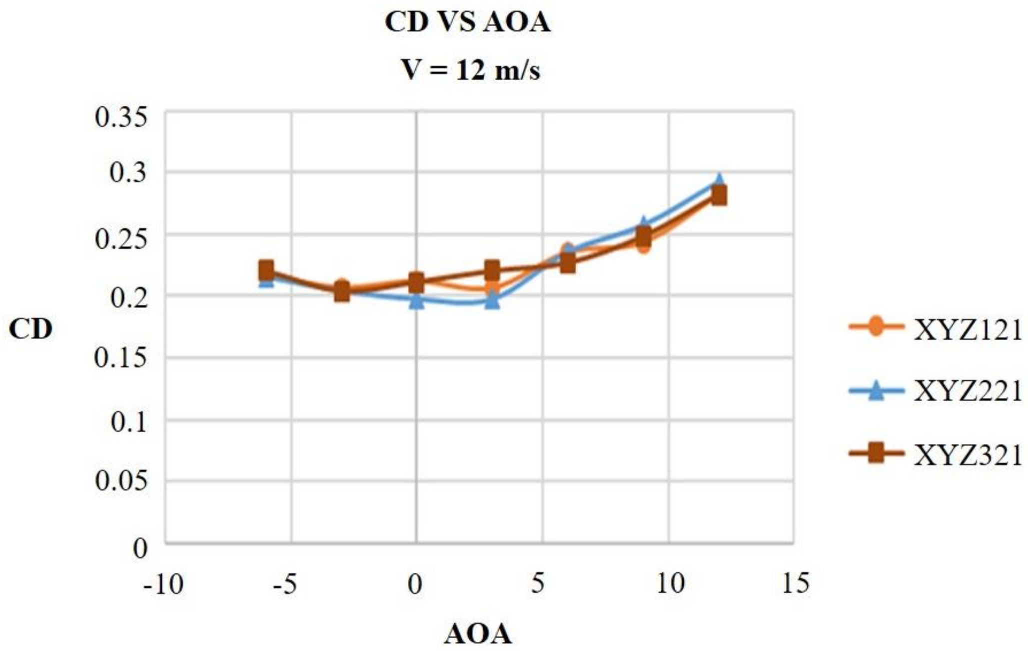

Fig. 10. The drag coefficient of variation X-axis vs AOA

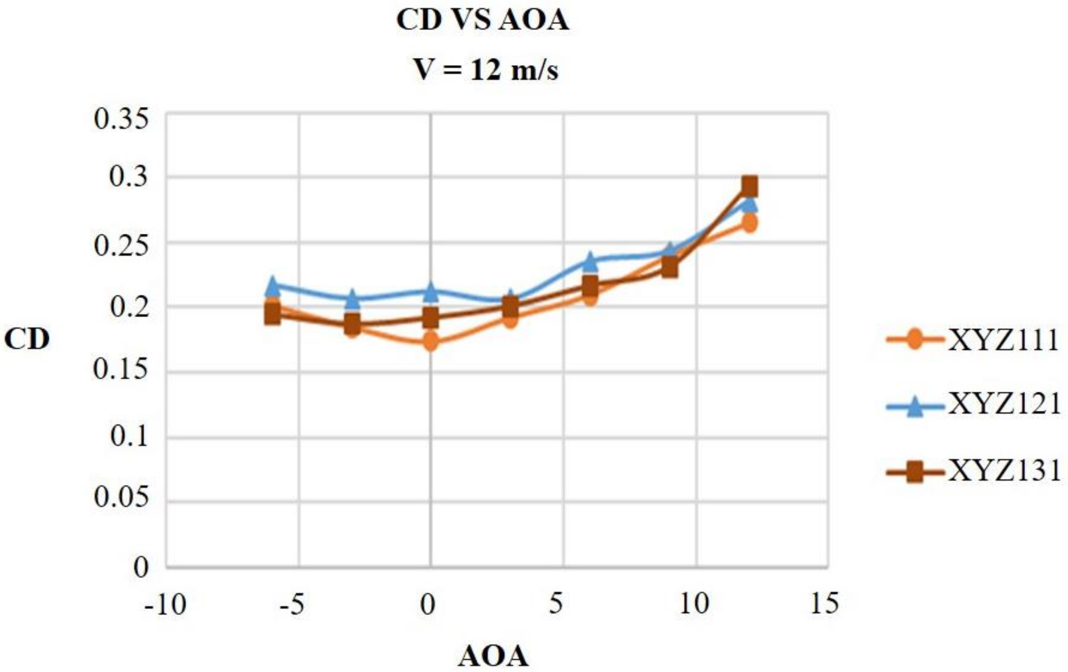

Fig. 11. The drag coefficient of variation Y-axis vs AOA

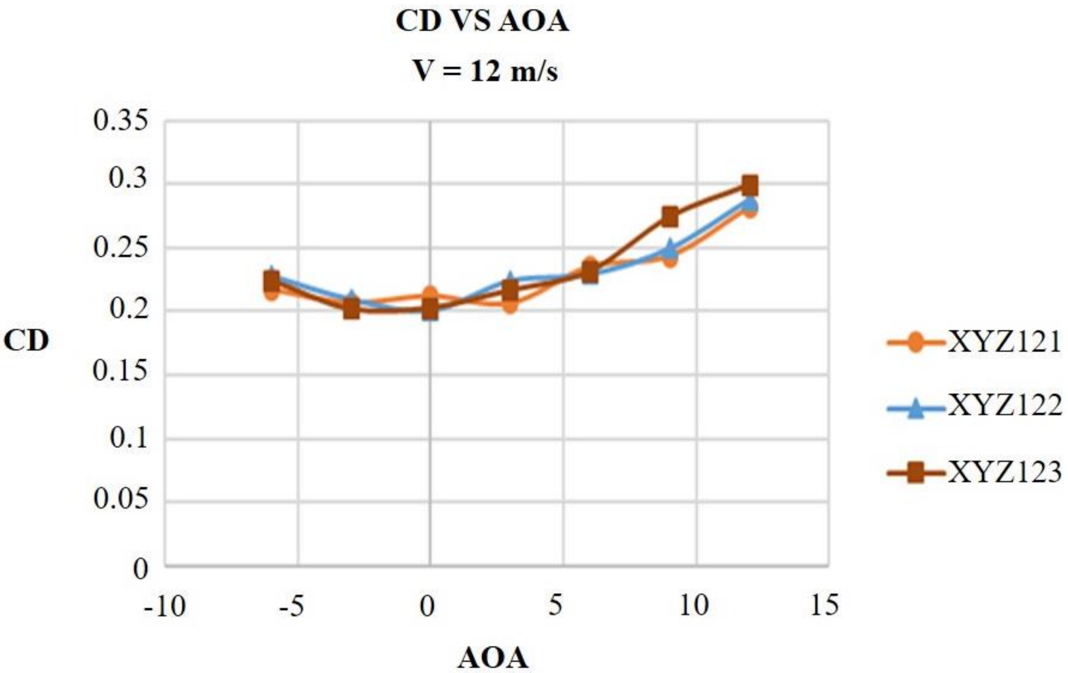

Fig. 12. The drag coefficient of variation Z-axis vs AOA

4.3. The position of propeller for the best aerodynamic performance

The method, for to find propeller's position which provide the best aerodynamic performance, is the lift to drag coefficient ratio consideration. As shown Fig. 13, the wing was installed the nearest motor-propellers in all direction (XYZ111 configuration) provided the best aerodynamic performance because this position provided the most lift to drag coefficient ratio.

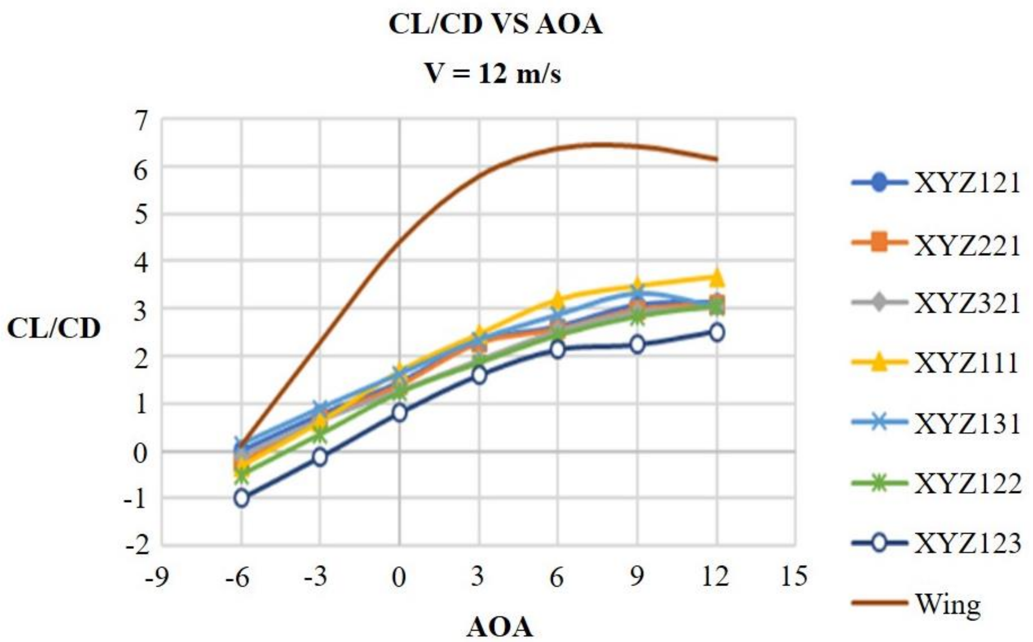

Fig. 13. The lift to drag coefficient ratio of clean wing and wing with propellers vs AOA

5. CONCLUSIONS

This research provided a comparison between the wing and wing with propellers of QuadPlane by using experimental data. All test was conducted in range of air freestream 6 - 18 m/s and incidence angle -6 to 12 degree. Two propellers were shut off. The result show that wing with propellers provided less aerodynamic performance than clean wing and XYZ 111 configuration, which was installed the nearest motor-propellers in all direction, provides the best aerodynamic performance for QuadPlane in forward flight. However, the result may be error due to the force measurement for drag force has low precision. The future work should create the high precision of force measurement and additional force measurement for measuring the propeller at front and rear wing and add the test of flow visualization.

ACKNOWLEDGEMENT

The authors would like to thank for the support this research by the personnel of Department of Aerospace Engineering of Kasetsart University.

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