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Aerodynamic of UiTM's Blended-Wing-Body Unmanned Aerial Vehicle Baseline-II Equipped with One Central Vertical Rudder

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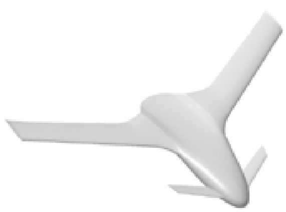
Graphical abstract



Abstract

In this paper, a study of aerodynamic characteristics of UiTM's Blended-Wing-Body Unmanned Aerial Vehicle (BWB-UAV) Baseline-II in terms of side force, drag force and yawing moment coefficients are presented through Computational Fluid Dynamics (CFD) simulation. A vertical rudder is added to the aircraft at the rear centre part of the fuselage as yawing control surface. The study consists of varying the side slip angles for various rudder deflection angles and to plot the results for each aerodynamic parameter. The comparison with other yawing control surface for the same aircraft obtained previously are also presented. For validation purpose, the lift and drag coefficients are compared with the results obtained from wind tunnel experiments.

Keywords: Blended-Wing-Body (BWB), Unmanned Aerial Vehicle (UAV), Computational Fluid Dynamics (CFD), aerodynamics, side force coefficient, drag force coefficient, yawing moment coefficient

1.0 INTRODUCTION

Blended-Wing-Body Unmanned Aerial Vehicle (BWB-UAV) Baseline-II (Fig. 1) has been introduced in 2009 at Universiti Teknologi MARA (UiTM) Malaysia [1]. It is an improvement of UiTM BWB-UAV Baseline-I that has been studied since 2005 [2]. Several aerodynamic studies have been conducted on this BWB-UAV Baseline-II. It started with experimental tests in a low speed wind tunnel to obtain lift, drag and pitching moment of the aircraft. The tests have been executed at various wind speeds at zero canard deflection angle [3] and with variation of canard deflection angles [4][5]. Computational Fluid Dynamics (CFD) analysis on the lift, the drag and the pitching moment has been done together with the study of static stability of the aircraft [6][7].

The study on yawing behavior of the BWB-UAV Baseline-II has been started by Mohamad et al. [8][9]. He introduced two pairs of split drag flaps at both wing ends as yaw control surface. CFD analysis was performed by varying side slip angles and split drag flaps deflection angles. It is observed that the values of yawing moment coefficient are relatively small, in the order of 10^{-3}. It is also found that, at the design point of the centre of gravity, the aircraft is statically unstable directionally. The position of the centre of gravity needs to be pushed forward by 50% from the design point in order to achieve directional stability of the aircraft. However, advancing the centre of gravity may lead to the ineffectiveness of the canard as pitching control surface.

The directional instability behavior of the aircraft is mainly due to the absence of vertical stabilizer. Based on this hypothesis, a vertical surface is added to increase the directional stability and also to increase the yawing moment of the BWB (Fig. 2).

The objective of this paper is to present the aerodynamic characteristics of BWB-UAV Baseline-II in terms of Side Force coefficient (C_Y), Drag Force coefficient (C_D), and Yawing Moment coefficient (C_N). The analysis is done through CFD. For this study, the canard is removed to simplify as it has negligible effect to the yawing motion of the aircraft. The validation is performed by comparing the CFD results in lift coefficient (C_L) and drag coefficient (C_D) with those obtained from wind tunnel experiments [4]. This validation is applied to the BWB without canard and without rudder at wind tunnel model size (scaled down at 1/6).

Figure 1 UiTM's BWB-UAV Baseline-II

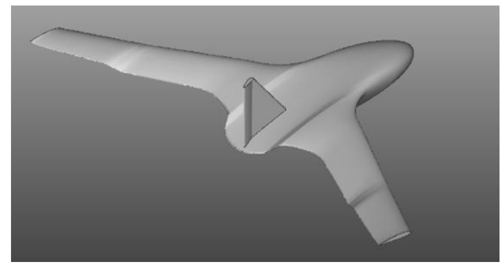


Figure 2 BWB-UAV Baseline-II with a central vertical rudder without canard

2.0 SIGN CONVENTION

Fig. 3 shows the convention used in this paper for different aerodynamic forces and moments. It also shows the positive directions of the wind side slip angle and the rudder deflection angle.

3.0 CFD SETUP

The CFD simulation is done using NUMECA FineOpen v.3.1-1. The meshing produces around 8×10^5 cells. The simulation is performed under steady configuration; using air as perfect gas at room temperature (300K) and at 1 atm. Spallart-Allmaras is used as turbulence model for this simulation. The wind speed is set at 35 m/s.

For the study of yawing, it consists of varying side slip angles (β) at zero angle of attack for different deflection angle of the rudder (δ). Nine values of β are used from -12° to +12° and four values of δ from 0° to +30° are studied. The curves of C_Y, C_D and C_N are extracted from the simulation and plotted against β for different values of δ.

For validation purpose, the simulation is done for angles of attack (α) varying from -12° to +34°. After simulation of each angle of attack, the values of C_L and C_D are extracted and plotted against α.

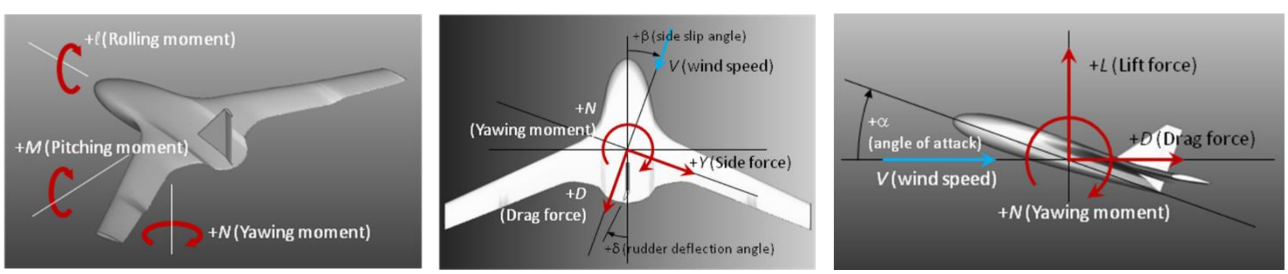
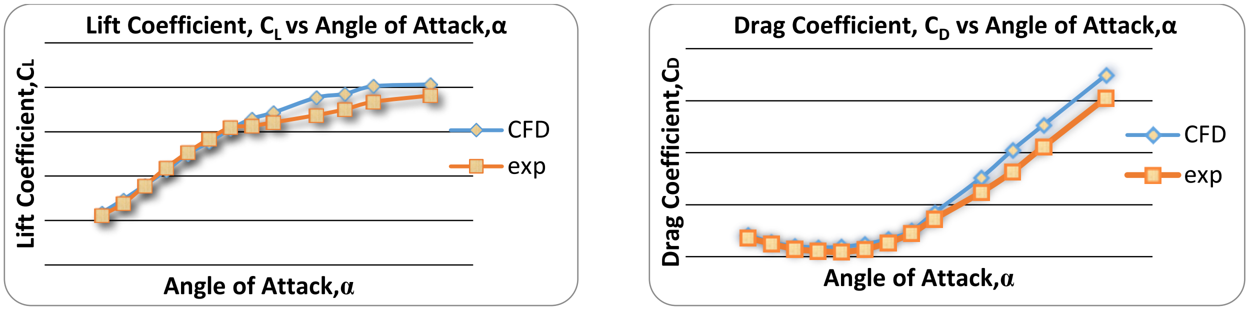


Figure 3 Sign convention for aerodynamic forces and moments

4.0 RESULT ANALYSIS

4.1 Validation

Fig. 4(a) and Fig. 4(b) show the curves of lift and drag coefficient, respectively. They are compared with the values obtained from wind tunnel experiments. It is observed that, for low angles of attack (between -10° and +8°), both curves of lift and drag coefficient show good agreement between the simulation and the experiments. Beyond these angles of attack, the curves still have the same trend, but the difference increases. This shows that the simulation model is good enough for low angle of attack where there is no separation of flow from the aircraft surface. At higher angles of attack, separation may occur at different surfaces of the aircraft. For this case, different turbulence model/setting may be used.



(a) (b)

Figure 4 Curves of lift coefficient (a) and drag coefficient (b)

4.2 Drag Coefficient

Fig. 5 shows the curves of side force coefficient (C_Y) against side slip angles (β) for different rudder deflection angles (δ). All curves have negative slopes which mean, when β increases from negative values to positive values, the side force decreases from positive values to negative values. For zero rudder deflection angles, the curve is symmetrical to the origin: positive side force for negative β and negative side force for positive β. The aircraft is pushed towards the direction of the wind. For positive rudder deflection angles, the aircraft is more sensitive to move to the right (positive side force); only after β reaches a certain value, the side force becomes negative. Higher rudder deflection angle, higher value of β for the side force to change its value from positive to negative. By comparing with the results obtained by Mohamad et al. [8], the use of vertical rudder produces much higher side force than the split drag flaps about 10 times in magnitude.

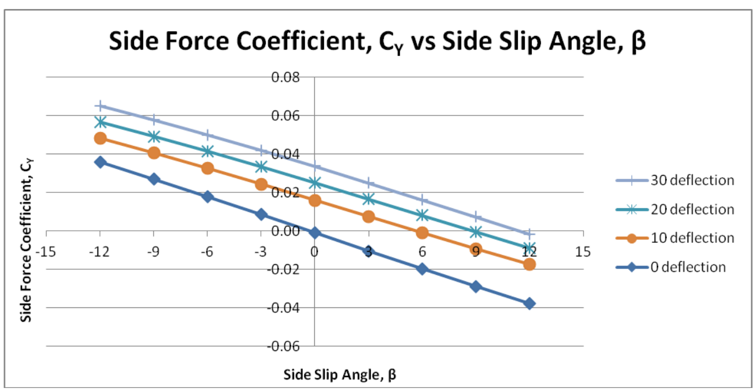


Figure 5 Side force coefficient (CY) against side slip angle (β)

4.3 Drag Force Coefficient

Fig. 6 shows the curves of drag force coefficient (CD) against side slip angles (β) for different rudder deflection angles (δ). For δ = 0, the curve is symmetrical to the vertical axis, which means the amount of drag is the same for the same value of β positive or negative. This is normal as when the rudder is not deflected, the aircraft is symmetrical to the longitudinal axis. For negative β, increasing δ positively means increasing the frontal area to the wind. This increases the drag force as shown by the curve. Even at zero side slip angle, deflection of the rudder (positive or negative) increases the frontal area to the wind, hence CD increases. When β is high, positive rudder deflection angles reduce the frontal area to the wind, which reduces the drag force. From the curves, it is observed that for β > 6°, higher rudder deflection angles give less drag.

The comparison of the strength of the drag force produced between the vertical rudder and the split drag flaps from reference [8] is shown in Fig. 7. It is observed that overall the vertical rudder produces higher drag force than the spilt drag flaps. The slopes of both curves are comparable, which means that the increment of drag is almost similar.

4.4 Yawing Moment Coefficient.

Fig. 8 shows the curves of yawing moment coefficient (C_N) against side slip angles (β) for different rudder deflection angles (δ). The moment is measured at the aerodynamics centre of BWB, which is located at 60.3% of the centre chord from the nose [9]. For $\delta = 0$, the yawing moment is negative for negative β and positive for positive β. This means the aircraft has tendency to rectify its position to face the wind, which shows its static stability behavior from disturbance in yaw direction. Having rudder deflected, the curve is translated downward (or to the right) from the curve at zero rudder deflection angle. The slope of the curve remains positive that maintains the stability towards yawing motion. Higher rudder deflection, higher β required to change the direction of yawing moment from negative to positive direction.

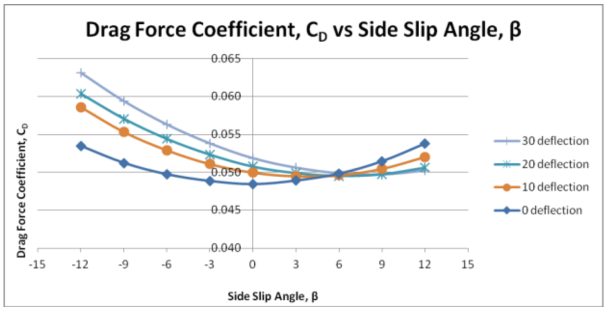


Figure 6 Drag force coefficient (C_D) against side slip angle (β)

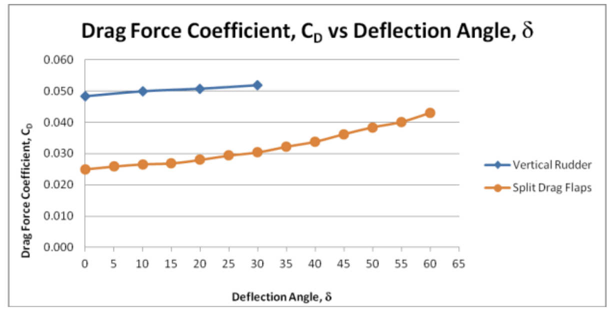


Figure 7 Drag force coefficient (C_D) against deflection angle (δ) at $\beta = 0°$

The comparison of the yawing curve at zero slide slip angle with the one from the split drag flaps from reference [8] is given in Fig. 9. It is observed that the behavior is different between these two yawing control surfaces. Using vertical rudder, increasing the rudder deflection angle increases the yawing moment in the negative direction. In the case of split drag flaps, increasing the deflection angle on the right wing increases the yawing moment in the positive direction. Observing the magnitude of the slope, the vertical rudder gives steeper slope compared to the split drag flaps. This means that the response in yawing due to the deflection of the vertical rudder is faster compared to the split drag flaps.

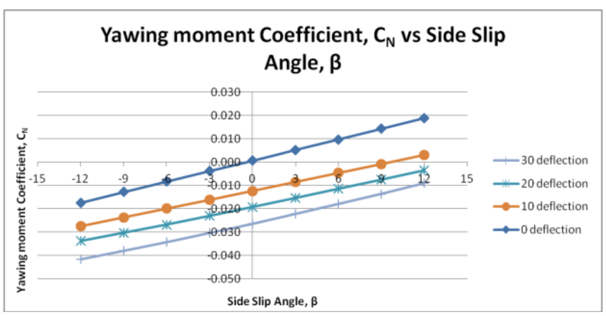


Figure 8 Yawing moment coefficient (C_N) against side slip angle (β)

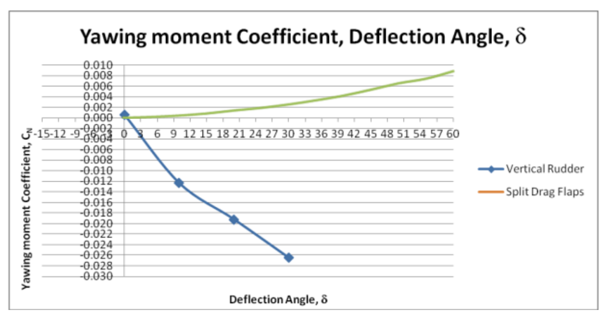


Figure 9 Yawing moment coefficient (C_N) against deflection angle (δ) at $\beta = 0°$

4.0 CONCLUSION

The aerodynamic characteristics of BWB-UAV Baseline-II are presented in this paper. Side force coefficient (C_Y), drag force coefficient (C_D), and yawing moment coefficient (C_N) are plotted against side slip angles for different rudder deflection angles. Comparison with the results obtained from split drag flaps for different values of deflection angles are given at zero slide slip angle. Overall, the values produced by the vertical rudder are more significant than those from split drag flaps. The use of vertical rudder, on the other hand, augments the static stability towards yawing motion.

Validation of the CFD simulation is done by comparing with wind tunnel results for lift and drag coefficients. Both give good accordance for low angles of attack.

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