

Aerodynamic Analysis of Blended Wing Body - Unmanned Aerial Vehicle (BWB-UAV) Equipped with Horizontal Stabilizers

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Abstract. This paper presents an aerodynamic characteristic study in longitudinal direction of UiTM Blended Wing Body-Unmanned Aerial Vehicle Prototype (BWB-UAV Prototype) equipped with horizontal stabilizers. Flight tests have been conducted and as the result, BWB experienced overturning condition at certain angle of attack. Horizontal stabilizer was added at different location and size to overcome the issue during the flight test. Therefore, Computational Fluid Dynamics (CFD) analysis is performed at different configuration of horizontal stabilizer using Spalart - Allmaras as a turbulence model. CFD simulation of the aircraft is conducted at Mach number 0.06 or $v = 20$ m/s at various angle of attack, α . The data of lift coefficient (C_L), drag coefficient (C_D), and pitching moment coefficient (C_M) is obtained from the simulations. The data is represented in curves against angle of attack to measure the performance of BWB prototype with horizontal stabilizer. From the simulation, configuration with far distance and large horizontal stabilizer gives steeper negative pitching moment slope indicating better static stability of the aircraft.

1 Introduction

Blended Wing Body (BWB) aircraft is tailless design that combined wing and fuselage [1, 2]. Compared to conventional aircraft, BWB is usually better in terms of aerodynamic performance, lower fuel burn and lower noise emission [3]. Reduction of maximum takeoff weight (MTOW) by 15% and reduction of fuel burn per seat by 28% lower the operating cost of BWB [4]. BWB increases range and payload capacity with 27% reduction in fuel burn per seat [5]. According to M. Nasir et al., BWB concept can save up to 30% of fuel consumption by improving the lift-to-drag ratio [6]. However, there are some issues in BWB related to aerodynamic, structures and control [2].

Aerodynamic characteristics of an aircraft can be obtained through simulations and experiments. Panagiotou et al. applied Reynolds-Averaged Navier-Stokes (RANS) equations solver with the Spalart-Allmaras turbulence model to obtain the aerodynamic characteristics on three different configurations of BWB design: 1. V tail, 2. canards with a set of winglet and rudder, and 3. winglets with elevons. The analysis was conducted at airspeed of 39 m/s. From the simulation, configuration 2 gave highest lift coefficient (C_{LMax}) at an angle of attack of -12° and configuration 3 produced higher aerodynamic efficiency and lower zero-Lift Drag coefficient [2]. CFD simulation also has been done on

BWB by Dehpanah and Nejat using Spalart Allmaras turbulence model with $Re = 200,000$ at various angles of attack from -16° to 25° . The curve of lift-to-drag ratio against lift coefficient shows its maximum value of 8.5 at 0.175 lift coefficient. High lift coefficient and low drag coefficient is needed to reduce fuel consumption and to increase the range [7]. Wind tunnel experiments have been conducted by Shim and Park on BWB-UCAV model at free stream velocity of 50 m/s. Internal balance was used to measure different forces and moment coefficients. Maximum lift coefficient obtained is 0.868 at 20° angle of attack and the zero lift angle is produced at about 0.75° angle of attack [8].

Since September 2005, UiTM has started a research on BWB-UAV [9]. There were several studies that had been carried out on BWB using CFD, wind tunnel, and finite element method [10]. Recently, wind tunnel experiment has been done in Baseline-V at Mach number 0.05. When the angle of attack ranges from -5° to -2° , zero coefficient of lift is recorded and highest L/D ratio is 32 [11]. Wisnoe et al. performed CFD analysis on Baseline-II equipped with one central vertical rudder. The meshing produced 8×10^5 cells and the air speed was set at 35 m/s. The vertical rudder produced higher side force than slip drag flaps ten times in magnitude when compared with other study [12].

In August 2014, Universiti Teknologi Mara (UiTM) Malaysia has been granted a research project under

Prototype Research Grant Scheme (PRGS) from Malaysian Ministry of Higher Education (MOHE) to fabricate a prototype of Blended Wing Body–Unmanned Aerial Vehicle (BWB-UAV) for aerial surveillance [13]. Fig. 1 is the BWB Prototype at different views. Wind tunnel experiments have been done on ¼ scaled half model of BWB aircraft at various angles of attack. The results show the maximum lift coefficient of around 0.65 at 28° angle of attack, the minimum drag coefficient is below 0.03 at zero angle of attack and the maximum lift-to-drag ratio is 20 at 3° angle of attack [13]. CFD simulation also was conducted on various angles of attack and various angles of elevator deflections of the canard. At angle of attack 30° and canard deflection 0°, lift coefficient maximum is 1.0505 [14].



Fig. 1. UiTM BWB-UAV Prototype.

During the flight test of BWB Prototype, it was observed that the prototype has some issues in the longitudinal direction. After certain angles of attack, the BWB experienced overturning after a few seconds airborne. The addition of horizontal stabilizer was done to overcome these issues. Fig. 2 shows the BWB Prototype fitted with tail boom and horizontal stabilizer. This paper aims to analyse the aerodynamic characteristics of BWB-UAV equipped with horizontal stabilizer at different locations and sizes. Lift, drag, and pitching moment coefficients will be presented.

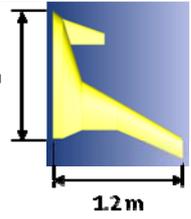
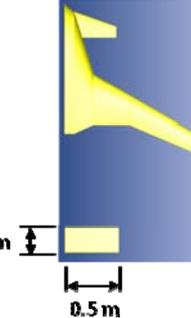
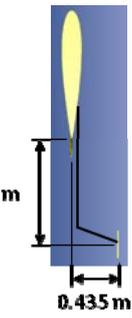
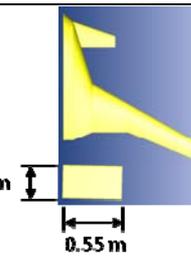
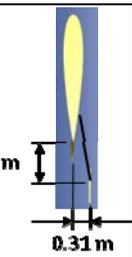
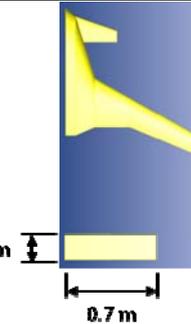
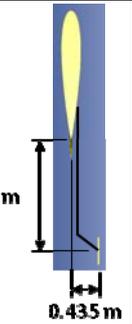


Fig. 2. UiTM BWB-UAV Prototype with horizontal stabilizer.

2 CFD setup

Table 1 shows the three configurations of horizontal stabilizer on BWB on which the simulation was performed.

Table 1. Table of three configuration of horizontal stabilizer.

Config.	Top view (Half body)	Side view
Original config. without wingtip		
A		
B		
C		

The CFD simulation was done in NUMECA FineOpen v3.1-1 software. The number of cells for configuration A, B and C are 770,000, 690,000 and 1,480,000 respectively. In processing stage, simulation was run at velocity 20 m/s with corresponding Reynolds number around 5.31×10^5 . The simulation was performed under steady state configuration using air as perfect gas at room temperature (300 K) and at 1 atm. Spalart-Allmaras was used as a turbulence model for this simulation. The simulation was performed at angle of attack of -10° up to 34° . The tail boom and wingtip were removed to simplify the simulation. Table 2 shows the parameter used in the simulation.

The results obtained were plotted to obtain the curves of C_L , C_D and C_M at various angles of attack

Table 2. Simulation parameters.

Parameter	Value
Reference velocity	20 m/s
Reynold number	5.31×10^5
Type of fluid	Air (perfect gas)
Turbulence model	Spalart-Allmaras
Reference length	0.49569 m
Reference area	0.59609 m^2
Angles of attack	-10° to 34°

3 Validation

Comparison of CFD results with the results from wind tunnel tests is executed for validation. For this purpose the BWB Prototype original configuration (with wing tips and canard) was used both in the CFD and wind tunnel tests with 1/4 of the real size model. The model's reference length is 0.291 m and its reference area is 0.035054 m^2 . The airspeed was set at 20 m/s. The results are presented in Fig. 3 and Fig. 4.

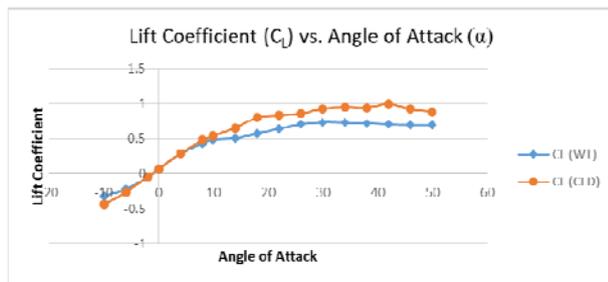


Fig. 3. Lift Coefficient (C_L) vs angle of attack (α) of BWB Prototype model.

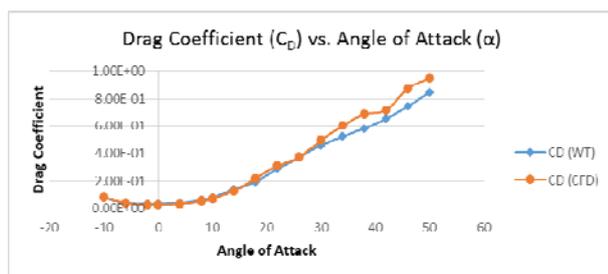


Fig. 4. Drag Coefficient (C_D) vs angle of attack (α) of BWB Prototype model.

From these figures, it is observed that both curves from CFD and wind tunnel have similar trends with only slight deviation at higher angles of attack (above 10° for C_L and above 30° for C_D). The C_L curve from wind tunnel shows a slight deflection at $\alpha = 12^\circ$ (Fig. 3) which corresponds to the occurrence of stall at the outer wing (visualized using thread tufts visualization) [13]. The graph representing CFD result does not detect any partial stall at that angle of attack. This might be due to the setting of parameters for the CFD simulation including the selection of turbulence model.

4 Results and discussion

4.1 Lift coefficient analysis

Fig. 5 below shows a graph of lift coefficient versus angle of attack. All configurations were observed to have the same trend where C_L increases as the angle of attack increases. When C_L is at maximum, the curves start to decrease. After $\alpha = 10^\circ$, the configuration C shows higher values compared to other configurations. The original configuration shows a deflection around this angle, which is due to partial stall on the outer wing [13]. Configuration A also shows deflection around this angle. The effect of partial stall on the outer wing to the lift coefficient is insignificant in configurations B and C. This may be due to the fact that horizontal stabilizers used in B and C are larger. Configuration C shows highest C_L at $\alpha = 34^\circ$ with C_L value of 1.551.

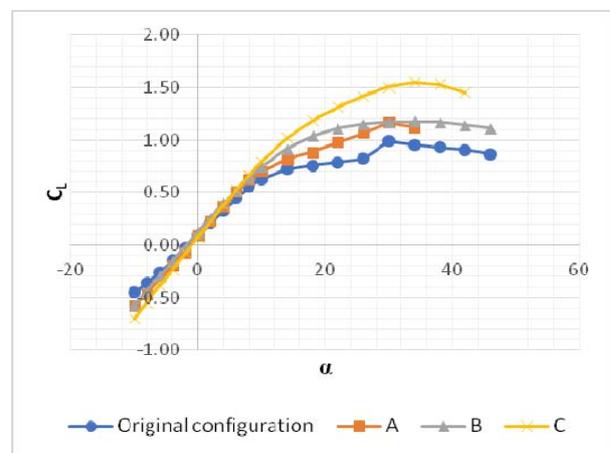


Fig. 5. Lift coefficient (C_L) vs angle of attack (α).

4.2. Drag coefficient analysis

Fig. 6 shows the curves of drag coefficient against angle of attack for various configurations. The curves have the same trends for all configuration with small differences among the curves from $\alpha = -10^\circ$ to $\alpha = 6^\circ$. At low angles of attack, the airflow is still attached to the body and wing. The value of C_D at zero angle of attack is about 0.03. Above 4° , C_D increases as angle of attack increases. Configuration C has the highest drag value of $C_D = 1.22$ when $\alpha = 40^\circ$. This is because it has the largest contact area compared to other conditions. Original configuration has the least drag coefficient following by Configuration B and Configuration A. A deflection occurs at $\alpha = 26^\circ$ for original configuration and $\alpha = 34^\circ$ for Configuration A.

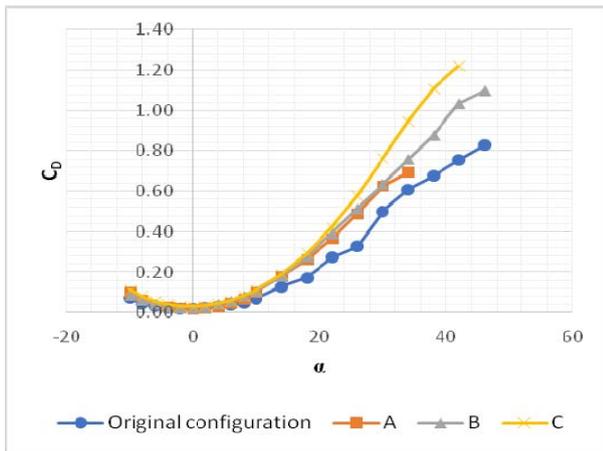


Fig. 6. Drag coefficient (C_D) vs. angle of attack (α).

4.3. Pitching moment coefficient analysis

Graph of pitching moment coefficient versus angle of attack is shown in the Fig. 7. The measurement of the pitching moment is taken at 600 mm from the nose of BWB Prototype, which is approximately at the midpoint of the length of BWB. It is seen that moment coefficient decreases for all conditions as the angle of attack increases. At $\alpha = 0^\circ$ all curves show negative pitching moment which means the aircraft has tendency to nose down at zero-degree angle of attack. A positive slope is detected (on original configuration) at $\alpha = 30^\circ$ which corresponds to the maximum of lift coefficient. When positive slope is detected, there is a tendency for the aircraft to nose up. Deflection of positive slope also occurs on Configuration A but it is not obvious at $\alpha = 34^\circ$ also correspond to maximum lift coefficient. Between $\alpha = 14^\circ$ and $\alpha = 18^\circ$ of configuration A and Configuration B, there are almost zero slope which means that the moment is almost independent of α . The CFD result shows Configuration C has highest negative pitching moment with a steep slope compared to others condition.

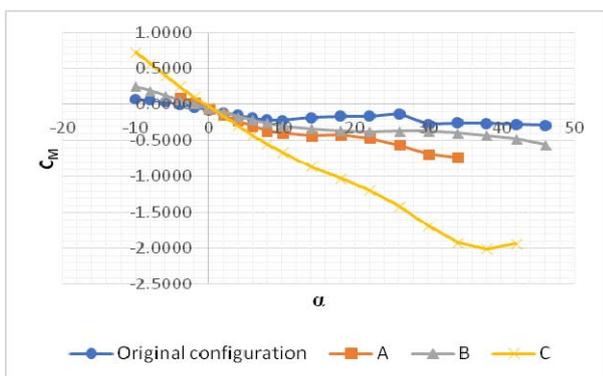


Fig. 7. Pitching moment coefficient (C_M) vs. angle of attack (α).

4.4. Drag polar analysis

The drag polar (C_L versus C_D) curves was plotted in Fig. 8 for all conditions. The value of C_D at zero lift (C_{D0}) is

obtained approximately equal to 0.03. This is the minimum drag coefficient at zero lift. The curves' patterns are all the same where Configuration C shows higher C_L at higher C_D .

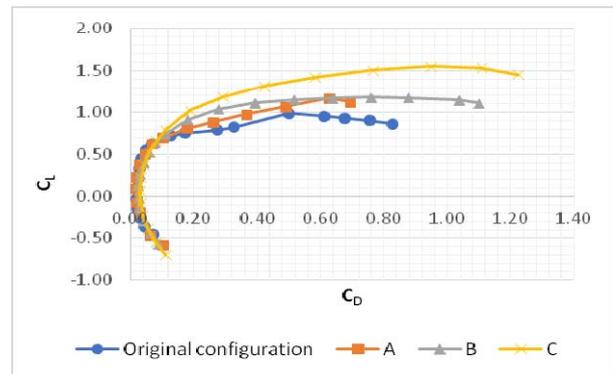


Fig. 8. Lift Coefficient (C_L) vs. Drag Coefficient (C_D).

4.5. Lift-to-drag ratio analysis

The curves of L/D versus angle of attack was plotted in Fig. 9. Here, the curves almost coincide for α below 2° . For all conditions, L/D increases after $\alpha = -6^\circ$ until it reaches its maximum peak and then gradually decreases. The original configuration and Configuration A both have high peak lift-to-drag ratio around 13 at $\alpha = 6^\circ$ and $\alpha = 4^\circ$ respectively. This angle of attack indicates the optimum flight configuration for the aircraft. Configuration C has the lowest peak in the curve.

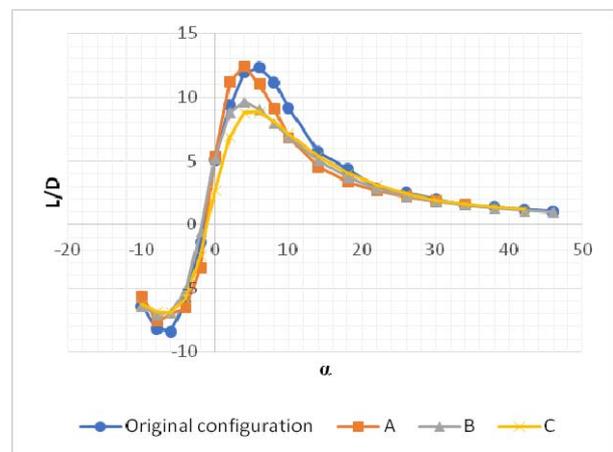


Fig. 9. Lift-to-drag ratio (L/D) vs. angle of attack (α).

5 Conclusion

In this paper, the aerodynamic characteristics of UiTM BWB-UAV Prototype have been presented in terms of lift, drag and pitching moment coefficients.

The use of horizontal stabilizer reduces the effect of partial stall on the outer wing above 10° of angle of attack. The original configuration and Configuration A produce highest lift-to-drag ratio of 12 at $\alpha = 6^\circ$ and $\alpha = 4^\circ$ respectively. Configuration C has the steepest negative pitching moment slope compared to all configurations. It gives a strong moment to nose down

when the angle of attack increases in the positive side. It increases the static stability during flight.

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