Experimental Results Analysis of UiTM BWB Baseline-I and Baseline-II UAV Running at 0.1 Mach number

WIRACHMAN WISNOE, FIRDAUS MOHAMAD, RIZAL EFFENDY MOHD NASIR, NOR F REDUAN, ZURRIATI ALI, WAHYU KUNTJORO
Faculty of Mechanical Engineering
Universiti Teknologi MARA (UiTM)
40450 Shah Alam
MALAYSIA
wira_wisnoe@yahoo.com http://www.uitm.edu.my

Abstract: - This paper presents analysis of two models of UiTM Blended Wing Body (BWB) UAV that had been tested in UiTM Low Speed Wind Tunnel. The first model is named BWB Baseline-I and the second one is Baseline-II. Baseline-II has a simpler planform, broader-chord wing and slimmer body compared to the first one while maintaining wingspan. The experiments were executed at around 0.1 Mach number or about 35 m/s using 1/6 scaled down model. The angle for centre elevator and canards are setting at zero for both models. The lift coefficient, drag coefficient, pitching moment coefficient, L/D ratio and drag polar curves are plotted to show the performance of aircraft at various angle of attack. The results obtained from the experiments show that Baseline-II has better lift coefficient and can achieve higher aerodynamic efficiency (L/D ratio) as compared to Baseline-I. However, the drag produced by Baseline-II is higher than Baseline-I.

Key-Words: - Aerodynamics, Blended Wing Body, Unmanned Aerial Vehicle, Wind Tunnel.

1 Introduction

Blended Wing Body (BWB) is a concept where fuselage is merged with wing and tail to become a single entity [1]. BWB is a hybrid of flying-wing aircraft and the conventional aircraft where the body is designed to have a shape of an airfoil and carefully streamlined with the wing to have a desired planform [2].

The major advantage of this BWB concept is the way how it generates lift. Conventional aircraft obtains lift from its wings. However, BWB aircraft obtains lift from wings together with the fuselage. Besides that, the streamlined shape between fuselage and wing intersection reduces interference drag [3]. The slow evolution of fuselage to wing thickness which is carefully designed may suggest that more volume can be stored inside the BWB aircraft, hence, increasing payload and fuel capacity [4]. The BWB concept thus combines the advantages of a flying wing with the loading capabilities of a conventional airliner by creating a wide body in the center of the wing to allow space for passengers and cargo.

Universiti Teknologi MARA (UiTM) through Flight Technology & Testing Centre (FTTC) also takes part in research and development of Blended Wing Body (BWB) concept. The preliminary study of BWB Baseline-I is discussed in [5] together with its Computational Fluid Dynamics (CFD) analysis at 0.3 Mach number. It is a four-meter span mini UAV class of aircraft with MTOW of 200 kg that shall loiter at its design air speed of Mach 0.1. The planform of BWB Baseline-I UAV can be seen in Figure 1. The preliminary structural analysis of the BWB Baseline-I had been conducted using finite element model as explained in [6]. The aerodynamic study of the Baseline-I has also been done using wind tunnel at 0.1 Mach number for the basic configuration without elevator deflection [7][8]. The study of the effect of centre elevator deflection was carried out for different elevator angles and explained in [9]. It has been done using Computational Fluid Dynamics (CFD) at Mach 0.3 for various elevator deflections (+5, +10, -5, -10). Experimental testing in UiTM Low Speed Wind Tunnel at 0.1 Mach number completed the study of the effect of elevator on the aerodynamics performance of Baseline-I.

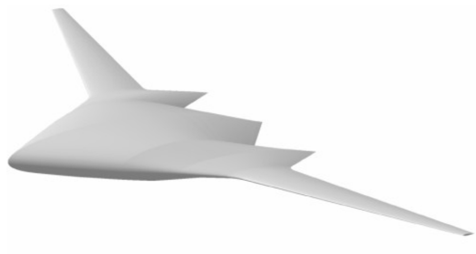

Fig.1: BWB Baseline-I

Since 2009, the group started a new design of BWB named Baseline-II. This new aircraft is equipped with a pair of canards in front of its main wings (Figure 2). Baseline-II is actually a completely-revised, redesigned version of Baseline-I BWB. It has a simpler planform, broader-chord wing and slimmer body than its predecessor while maintaining wing span. The intention is to improve flight performance at low cruising speed by increasing lift-to-drag ratio through planform and shape redesign and inverse twist method on airfoils throughout its span [10].

Fig. 2: BWB Baseline-II UAV

This paper focuses on the aerodynamic study for both models Baseline-I and Baseline-II of UiTM BWB UAV. The study had been carried out using wind tunnel in order to obtain the aerodynamics characteristic such as lift coefficient, drag coefficient, pitching moment coefficient and L/D ratio.

2 Model and Wind Tunnel Setup

The experiments had been carried out in UiTM low speed wind tunnel (Fig.3). It is a suction type tunnel. This wind tunnel has a test section area of 0.5 m x 0.5 m x 1.25 m and equipped with 6-Component External Balance. For this study, only 3 components are used with half model of aircraft as the working model.

Fig. 3: UiTM Low Speed Wind Tunnel

Both models are scaled down to 1/6 of the real size. Figure 4 and 5 shows the dimension and manufactured model for Baseline-I and Baseline-II respectively. The experimental parameters for both models are shown in table 1.

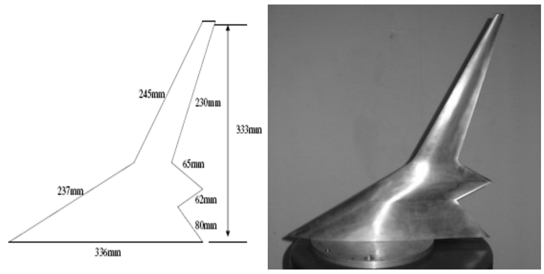

Figure 4: Dimension and manufactured model of BWB Baseline-I UAV

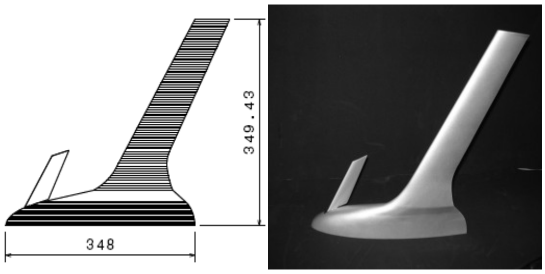

Figure 5: Dimension and manufactured model of BWB Baseline-II UAV

Table 1: Experimental Parameters

Model	L_{ref}	S_{ref}
Baseline-I	0.336 m	0.04652 m^2
Baseline-II	0.348 m	0.03995 m^2

The experiments were conducted at airspeed of 35 m/s or about 0.1 Mach number at Reynolds number of 8.0×10^5. The pitching angle (angle of attack) was varied from -10º to +52º. The elevator and canard deflection is setting at zero degree for Baseline-I and Baseline-II respectively.

3 Results and Discussion

In this section, results from the wind tunnel tests for both models are presented. The data obtained are plotted to form the lift coefficient versus angle of attack curve, drag coefficient versus angle of attack curve, pitching moment coefficient versus angle of attack curve, drag polar and lift-to-drag versus angle of attack curve.

3.1 Lift Coefficient

The lift coefficients (C_L) versus angle of attack (α) for both models are shown in fig.6. From the curve, it is observed that both models show the same trend. The value of C_L increases as angle of attack increases until it reaches its maximum value at around α = 35º for Baseline-I and α = 42 º for Baseline-II. The maximum value of C_L produced by Baseline-I is 0.68. The maximum value for Baseline-II is 1.1 which is 61.8%

greater than Baseline-I. Small deviations appear at both curves at α around 8º to 10º. The small deviation for Baseline-I curve is due to the flow separation, which occurs on the wing part as shown in Figure 7. Figure 7 shows visualization using mini tuft. It can be seen that the flow is still attached to the overall surface at α = 7º. However, at α = 8º, the flow has almost completely separated from the wing, except around the wing tip. It means that, beyond this angle of attack, only the body produces the lift for the whole aircraft. For Baseline-II, the small deviation of the curve may also come from the flow separation on the wing part and/or maybe due to the existing of canard in front of the wings. Further investigation is required to clarify the phenomenon that causes the reduction of lift around this pitching angle. Table 2 summarizes some quantitative values obtained.

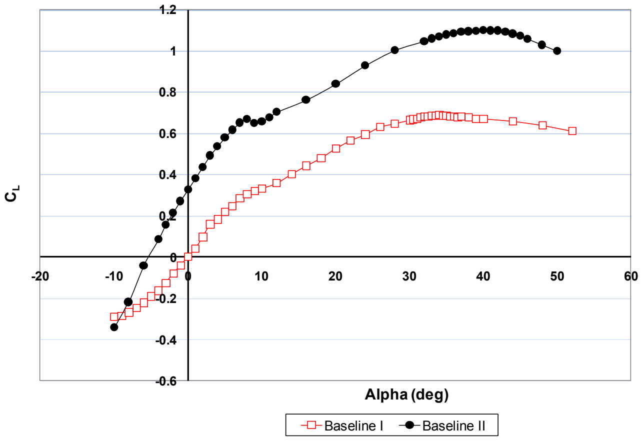

Figure 6: C_L versus α

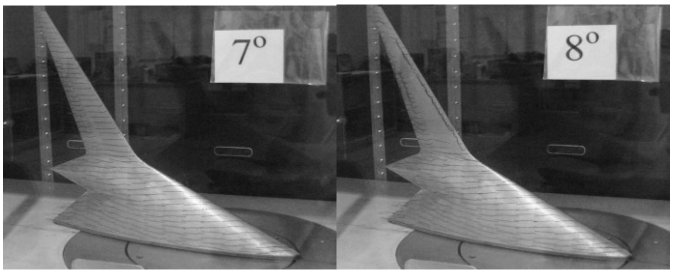

Figure 7: Visualization at α = 7º and α = 8º

Table 2: Summary of data from C_L curves

Model	Baseline-I	Baseline-II
C_{Lo}	0	0.328
$\alpha_{CL=0}$	0	-4
C_{Lmax}	0.68	1.1
$C_{L\ \alpha=8}$	0.302	0.669
$C_{L\ \alpha=9}$	0.318	0.651

3.2 Drag Coefficient

Figure 8 shows the variation of drag coefficient C_D versus angle of attack (α). The Baseline-I curve shows a constant value of C_D (around 0.03) at low angles of attack (between -10º to 8º). Deviation is observed at 8º where the wing of Baseline-I experiences stall. Beyond 8º the value of C_D then grows at higher rate as α increase. On the other hand, the Baseline-II curve also shows a constant value of C_D (around 0.03) at low angles of attack (between -10º to 8º). At 8º the curve shows a steep rise, and afterwards, C_D increases as α increases with a higher rate compared to Baseline-I. Table 3 shows some quantitative data obtained from the C_D graph.

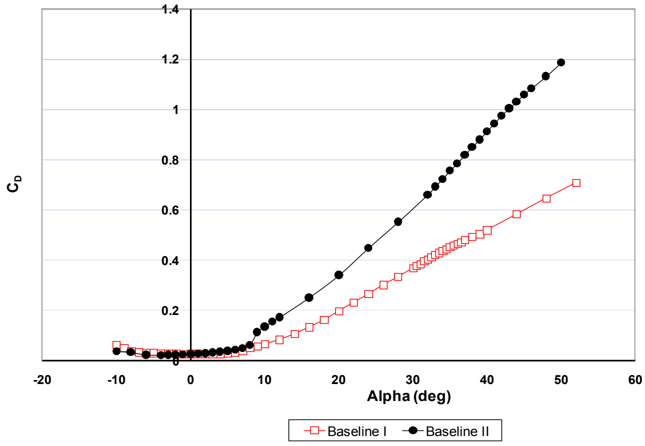

Figure 8: C_D versus α

Table 2: Summary of data from C_D curves

Model	Baseline-I	Baseline-II
C_{Do}	0.0268	0.0262
$C_{L\ \alpha=8}$	0.0495	0.0628
$C_{L\ \alpha=9}$	0.0567	0.1142

3.3 Lift Coefficient versus Drag Coefficient

The drag polar (C_L versus C_D) curve can be seen in Figure 9 for both models. From the curves, it is shown that Baseline-II has better flight performance compared to Baseline-I. The maximum value of C_L at minimum C_D for Baseline-I and Baseline-II is 0.28 and 0.67 respectively. The curve shows the value for C_D at zero lift is approximately 0.03 for both aircraft. This is the minimum drag coefficient of the BWB at zero lift (C_{Do}). It is also observed that, at high angles of attack, Baseline-II may have larger drag but at the same time it can generate higher lift.

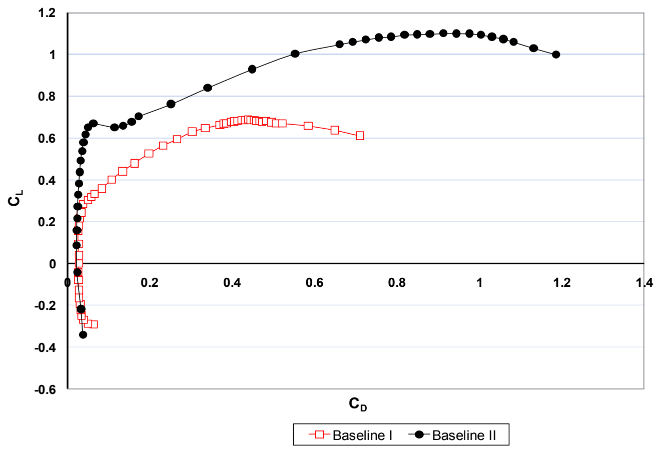

Figure 9: C_L versus C_D

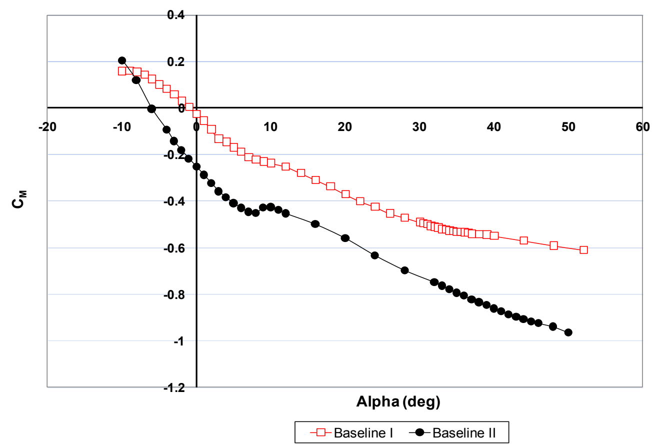

Figure 11: CM versus α

3.4 Lift-to-Drag Ratio

Lift-to-drag ratio (L/D) versus angle of attack curves are presented in Figure 10. The Baseline-I curve shows a maximum value of L/D about 8 at α = 7°, while Baseline-II curve reaches its maximum value of about 15 at α = 5°. These angles of attack indicate the optimum flight configuration for both aircrafts.

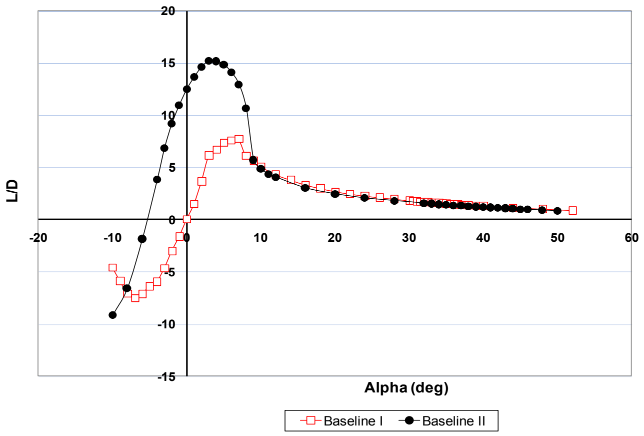

Figure 10: L/D versus α

3.5 Pitching Moment Coefficient

The curve of pitching moment coefficient (C_M) versus angle of attack (α) is presented in Figure 11. The measurement of pitching moment is taken at base leading edge of the models. Baseline-I has positive moment at negative angle of attack. It means that, it has a tendency to nose up during the pitching down. At positive angle of attack, pitching moments for both aircraft turn to become negative. Here also, it is noticed a small deflection of both curves around 8° which corresponds to flow separation around the wing. For Baseline-II, at α = 0°, the curve shows a negative pitching moment that gives a tendency to nose down at zero degree angle of attack.

4 Conclusion

All data obtained from the wind tunnel experiments have been studied and analyzed to obtain aerodynamics performance characteristics of BWB Baseline-I and Baseline-II. The wind tunnel results show substantial improvement of performance for the new design Baseline-II. In terms of stall angle, Baseline-II can achieve higher stalls angle (42°) compared to its previous design (34°). The maximum Lift-to-Drag ratio obtained is approximately 15 at α around 5° for Baseline-II whereas for Baseline-I the value is approximately 8 at α around 7°. This will represent the optimum flight configuration.

As stated earlier, further investigation should be conducted to observe the phenomenon of Baseline-II that cause the lost of lift around 8°. Further study should also be carried out to minimize the disturbance effect of the canard by designing different shape of canard or reposition the canard vertically. The effect of canard deflection angles to overall performance of BWB also needs to be performed. Study on the yaw and roll direction of the BWB is also to be conducted.

References:

[1] N Qin, A Vavalle, A Le Moigne, M Laban, K Hackett, P Weinerfelt. *Aerodynamics Studies for Blended Wing Body Aircraft*. 9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and optimization, 4 – 6 September (2002), Atlanta, Georgia.

[2] S Siouris, N Qin. *Study of the Effects of Wing Sweep on the Aerodynamic Performance of a Blended Wing Body*. (2006) Aerodynamics and Thermofluids Group, Department of Mechanical Engineering, University of Sheffield, UK.

[3] N. Qin, A. Vavalle, A. Le Moigne, M. Laban,

K. Hackett, P.Weinnerfelt. *Aerodynamic considerations of blended wing body aircraft*. Progress in Aerospace Science (2004) pp. 321-343.

[4] H. Engels. W. Becker, A. Morris *Implementation of A Multi Level Methodology within E-Design of a Blended Wing Body*. Aerospace Science and Technology (2004) pp. 145-153.

[5] A. M. Mamat, R. E. Mohd Nasir, Z. Ngah, W. Kuntjoro, W. Wisnoe, R. Ramly. *Aerodynamics of Blended Wing Body Unmanned Aerial Vehicle using Computational Fluid Dynamics*. Journal of Mechanical Engineering, Volume 5 No. 2, October (2008) pp. 15-25.

[6] W. Kuntjoro, R. E. Mohd Nasir, W. Wisnoe, A. M. I. Mamat, M. R. Abdullah. *Computer Aided Design and Engineering of Blended Wing Body UAV*. Proceedings RAeS/CEA Aircraft Structural Design Conference, 14-16 October (2008) Liverpool, UK,

[7] W. Wisnoe, R. E. Mohd Nasir, W. Kuntjoro, A. M. I. Mamat. *Wind Tunnel Experiments and CFD Analysis of Blended Wing Body (BWB) Unmanned Aerial Vehicle (UAV) at Mach 0.1 and Mach 0.3*. Proceedings of the Thirteenth International Conference On Aerospace Sciences & Aviation Technology (ASAT 2009), 26-28 May (2009) Cairo, Egypt.

[8] W. Wisnoe, W. Kuntjoro, R. E. Mohd Nasir, A. M. I. Mamat, R. Ramly. *Wind Tunnel Experiments of Blended Wing Body (BWB) Unmanned Aerial Vehicle (UAV) at Loitering Phase*. International Conference on Mechanical Engineering and Manufacturing. 21-23 May (2008) Johor Bahru.

[9] R. E. Mohd Nasir, W. Kuntjoro, W. Wisnoe, A. M. I. Mamat. *The Effect of Centre Elevator Deflection Aerodynamics of UiTM Baseline-I Blended Wing Body (BWB) Unmanned Aerial Vehicle) at Mach 0.3 using Computational Fluid Dynamics*. Journal of Mechanical Engineering, Volume 6 No. 2, December (2009) pp. 73-96.

[10] Rizal E. M. Nasir, Wahyu Kuntjoro, Wirachman Wisnoe, Zurriati Ali, Nor F. Reduan, Firdaus Mohamad, Shahrizal Suboh. *Preliminary Design of Baseline-II Blended Wing Body (BWB) Unmanned Aerial Vehicle (UAV): Achieving Higher Aerodynamic Efficiency Through Planform Redesign and Low Fidelity Inverse Twist Method.* Proceedings of EnCon2010, 3rd Engineering Conference on Advancement in Mechanical and Manufacturing for Sustainable Environment, 14-16 April (2010), Kuching, Sarawak, Malaysia,