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# An analysis on 45° sweep tail angle for blended wing body aircraft to the aerodynamics coefficients by wind tunnel experiment

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**Abstract**. This paper presents the analysis of a model from UiTM Blended Wing Body (BWB) UAV, Baseline V that has been tested at UPNM high speed wind tunnel. Baseline V has a unique design due to different NACA sections used for its fuselage, body, wing root, midwing, wingtip, tail root, tail tip and the tail is swept 45° backward. The purpose of this experiment is to study the aerodynamic characteristics when the tail sweeps 45° backward. The experiments are conducted several times using 71.5% scaled down model at about 49.58 m/s airspeed or 25 Hz. The tail angle deflection is fixed and set at zero angle. All the data obtained is analyzed and presented in terms of coefficient of lift, coefficient of drag and also lift-to-drag ratio, and is plotted against various angles of attack. The angles of attack used for this experiments are between -10° to +30°. The blockage correction such as solid blockage, wake blockage and streamline curvature blockage are calculated in order to obtain true performance of the aircraft. From the observation, Baseline V shows that the aircraft tends to stall at around +15°. The maximum L/D ratio achieved for Baseline V is 20.8, however it decreases slightly to 20.7 after blockage corrections.

## 1. Introduction

The aviation industry nowadays is facing a serious problem with fuel efficiencies, noise and emission related to the aircraft operation [1]. The idea of blended wing body (BWB) aircraft is fundamentally based on flying wing designs, which are likely to become the configuration of future aircraft designs [2, 3]. BWB has smaller ratio of wetted surface area to volume and has less interference drag due to its smoother overall figure, which gives a good lift-to-drag ratio [4]. However, the flying quality of BWB is poor in some cases due to its tailless design, although BWB has better aerodynamic efficiency with higher lift-to-drag ratio [5, 6]. The horizontal and vertical tails offer stability for an aircraft. Elevator and rudder act as control surfaces and are located at the tail. Some information is needed to determine the configuration of tail surfaces, which include position of the centre of gravity (C.G.) of the aircraft, change in C.G. location throughout the flight and intended level of stability. In order to determine the C.G. of the aircraft, the weight of vertical and horizontal tails must be determined depending on their size [7].

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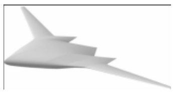
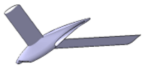
Flight Technology and Test Centre (FTTC) in UiTM Shah Alam has started the research on BWB since 2005, focusing on the aspect of design and fundamental aerodynamics [8]. There are five designs that have already been made and studied, which are referred to as Baseline I, Baseline II, Baseline III, Baseline IV and Baseline V. Table 1 below shows the aerodynamic efficiency of each design, which is measured by its maximum lift-to-drag ratio ($L/D_{max}$).

Table 1: Aerodynamic efficiency of each BWB design

| Year | Design | ($L/D_{max}$) |
|---|---|---|
| 2005 |  Baseline I | 14 |
| 2009 |  Baseline II | 24 |
| 2012 |  Baseline III | 13 |
| 2013 |  Baseline IV | 15 |
| 2014 |  Baseline V | 32 |

The first BWB Baseline-I is designed under UiTM research teams. It has a span of four meter and is equipped with large central elevator for longitudinal control and stability. Baseline-I aircraft has a poor aerodynamics performance with L/D less than 10 [9]. The second BWB aircraft, known as the Baseline-II, is designed based on lessons learned from Baseline-I. Planform shape and twisted angle airfoil along spanwise location as recommended by Bolsunovsky, and also the Inverse-Twist Method are applied in the Baseline-II aircraft design [10]. Baseline-II has a high aerodynamic efficiency with L/D of 24. Next, Baseline-III is designed to further study on aerodynamics efficiency of BWB aircraft. Baseline-III concept is inspired from the shape of flying birds. However, the results show that it has major flaws in its aerodynamics efficiency with its L/D value is only around 12 [11]. Baseline-IV is also a bird-inspired BWB aircraft designed by referring to the existing configuration of Baseline-III aircraft. For this design, the L/D is increased but the value is still not as efficient as to be expected for a BWB aircraft. Baseline V is then designed as shown in Figure 1 and it has underwent a wind tunnel experiment at UTM Skudai with its tail design blended at the side of its body. At elevator deflection angle equals to 0˚, the L/D reaches its maximum of 32. The L/D is at its minimum, which is 16, when the deflection angle is at +20˚.

This project is focusing on Baseline V design that is equipped with 45˚ sweep angle of the tail. The experiment has been conducted at Pusat Maritim Universiti Pertahanan Nasional Malaysia. The 45˚ of sweep tail design is chosen because hypothetically, the tail will provide more stability compared to at 0˚ angle. The area of the 45˚ tail is identical to that of the 0˚ tail. The purpose of the experiment is to determine the aerodynamic characteristics for this Baseline V design such as L/D, lift coefficient and drag coefficient.

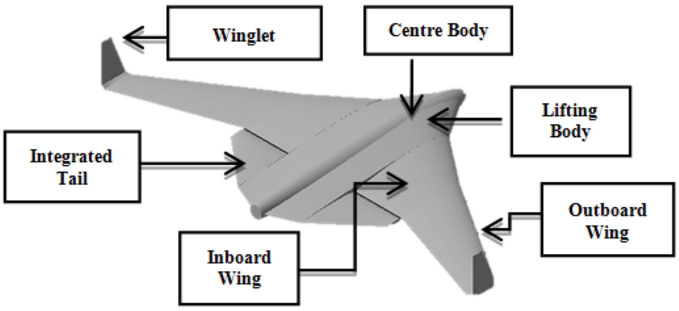



Figure 1: Baseline V configuration

## 2. Model Fabrication and Wind Tunnel Setup

The actual model wingspan for Baseline V is 1.4m. For this wind tunnel testing, the model has been scaled down to 71.5% from its actual size and only half part of the model is used. The structure of the model is 3-D printed and layered with fibreglass as shown in Figure 2 and Figure 3. The dimension of the model can be seen in Figure 4. The experiments are conducted at Universiti Pertahanan Nasional Malaysia (UPNM) high speed wind tunnel (Figure 5 and Figure 6). It is a suction type wind tunnel with test section area of 0.3m x 0.3m x 1.25m and it is equipped with 6-Component External Balance. The experiments in this study only uses three components, which are lift, drag and moment, and they are carried out at airspeed of 49.58 m/s or 25 Hz with Reynolds number of 7.0×105. The test is conducted at velocity 49.58 m/s to get the same Reynolds number with the actual size of the aircraft, which will be conducted at velocity 15 m/s. In order to achieve accurate results, the Reynolds number for both models must be the same by increasing the velocity for the scaled-down model. The pitching angle (angle of attack) is varied from -10º to +30º. The tail deflection is set at 0º.

Figure 2: 3-D printed model

Figure 3: Layered with thin fibreglass

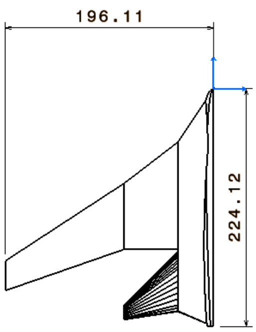



Figure 4: Model dimension

Figure 5: UPNM high speed wind tunnel

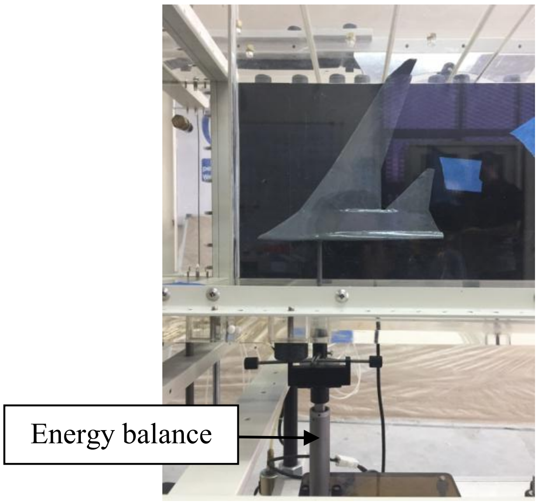



Figure 6: Wind tunnel model mounted at the energy balance

## 3. Results and Discussions

The data acquired are plotted to form the lift coefficient against angle of attack curve, drag coefficient against angle of attack curve, and L/D against angle of attack curve. The blockage correction is also has been made to obtained the true performance of the aircraft. As the model undergoes a wind tunnel experiment, the experimental data must be corrected using the following correction formulas [12]:

For solid blockage,

$$\Delta V = \varepsilon_{sb} V_U \quad (1)$$

$$\varepsilon_{sb} = \frac{K_1 V_b}{S^{3/2}} \quad (2)$$

where $V_U$ is the uncorrected airspeed, $K_1$ for vertical model is 0.52 and $S$ is the working section area.

For wake blockage,

$$\Delta V = \varepsilon_{wb} V_U \quad (3)$$

$$\varepsilon_{sb} = \frac{c}{2h} c_{d_u} \quad (4)$$

where $c_{d_u}$ is uncorrected coefficient of drag, *c* is the model's length and *h* is the height of the working section.

For streamline curvature correction,

$$\propto = \propto_u + \frac{57.3\sigma}{2\pi}(C_{lu} + 4C_{m\,1/2u}) \quad (5)$$

$$C_l = C_{lu}(1 - \sigma - 2\varepsilon) \quad (6)$$

$$C_{m\,1/2} = C_{m\frac{1}{2u}}(1 - 2\varepsilon) + \frac{\sigma C_l}{4} \quad (7)$$

$$\sigma = \frac{\pi^2}{48}\left(\frac{c}{h}\right)^2 \quad (8)$$

Total corrected airspeed, $V = V_u(1 + \varepsilon)$ (9)

Total corrected drag, $C_{d0} = C_{d0u}(1 - 3\varepsilon_{sb} - 2\varepsilon_{wb})$ (10)

Figure 7 shows the plot of coefficient of lift, $C_L$ against angle of attack. From the curve, it can be observed that as the angle of attack increases, the coefficient of lift is also increased. The maximum $C_L$ obtained from the experiment is 1.114 at angle of attack 29.5˚. On the other hand, the lowest $C_L$ is at angle of attack -9.5˚, which is only -0.472. From the blockage correction curve, the coefficient of lift reaches its maximum at around +28˚ angle of attack, which is 0.974. The minimum corrected $C_L$ is higher compared to the uncorrected $C_L$, which is -0.457. The $C_L$ values for uncorrected and corrected almost same until it reaches +13˚ angle of attack where the corrected $C_L$ starts to decrease for the next angle of attack.

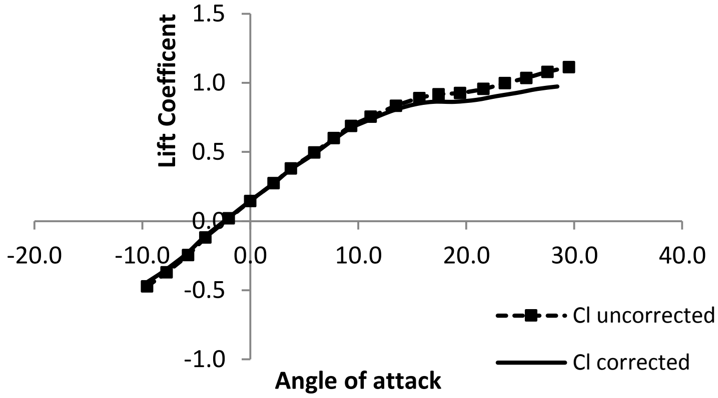



Figure 7: Lift coefficient versus angle of attack

Meanwhile, plot of coefficient of drag against angle of attack for both uncorrected and corrected for blockage data can be seen in Figure 8. The corrected coefficient of drag, $C_D$ shows lower values compared to the uncorrected $C_D$ data at angle around +22˚. For the corrected $C_D$, the minimum value is 0.019 and for uncorrected data, the minimum $C_D$ obtained is also 0.019. The maximum $C_D$ after been corrected is 0.449 while for uncorrected data is 0.51. At angles of attack -10˚ to +21˚, $C_D$ is almost the same.

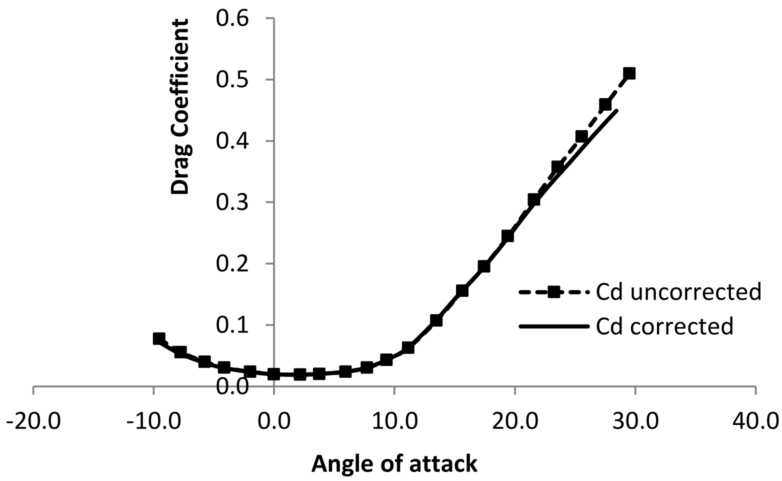



Figure 8: Lift coefficient versus angle of attack

The curve of L/D against angle of attack is shown in Figure 9. The corrected L/D shows almost the same values to the uncorrected L/D. For the corrected data, the maximum L/D achieved is 20.7 at the angle of attack +5.9˚ while for the uncorrected values, the L/D obtained is 20.8 at the same angle of attack. These angles of attack indicate the optimum flight configuration for Baseline V with 45˚ sweep tail angle.

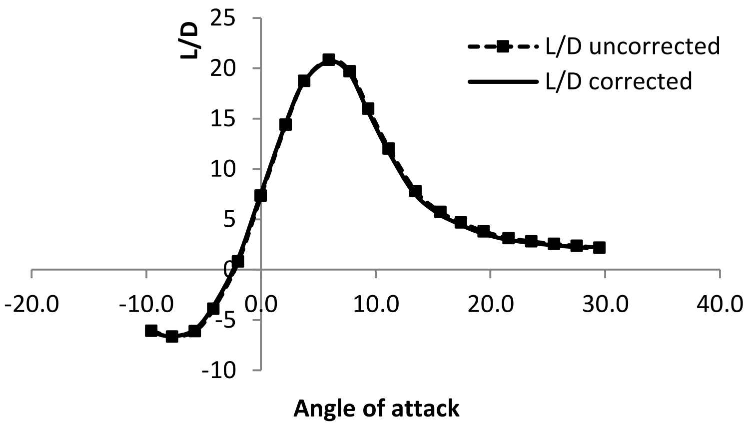



Figure 9: L/D versus angle of attack

## 4. Conclusion

All data obtained from the conducted wind tunnel experiment at UPNM has been studied to establish the aerodynamics characteristics for Baseline V with 45˚ sweep tail angle. The blockage correction has been made in order to estimate the actual data performance. The results show that Baseline V with 45˚ sweep tail angle will stall at +15˚. The maximum L/D for Baseline V is 20.7 at +5.9˚ angle of attack, which is the optimum flight configuration. From the analyses that have been made, it is shown that the 45˚ sweep tail reduces the L/D of the Baseline V. Some improvements must be made such as moving the C.G. of the model and deflecting the tail of the model. For future study, different angles of swept tail can be tested in order to achieve the best performance of the Baseline V.

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