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Research paper

Comparison on the Aerodynamic Coefficients Obtained from Three Different Size of Wind Tunnel Model on Baseline V Set at 45 Degree Sweep Tail Angle

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Abstract

This paper analyzes the aerodynamic coefficients of a blended wing body, Baseline V which is equipped with 45˚ sweep tail angle. Baseline V is one of the Universiti Teknologi MARA (UiTM) Shah Alam Flight Test Technology Centre's blended wing body designs that have unique configuration as it uses different NACA airfoil for its fuselage, body, wing root, midwing, wingtip, tail root, and tail tip. The intention of the comparison for three different size of wind tunnel model is to determine the similarity of the aerodynamics coefficients and the behaviour of the model itself. The wind tunnel experiments were conducted at three different wind tunnel locations: Universiti Teknologi Malaysia Skudai, UiTM Shah Alam and Universiti Pertahan Nasional Malaysia Kuala Lumpur, using 1:1 scale full model, 1:2 scale half model, and 2:7 scale half model, respectively. The data obtained are studied and plotted in term of lift coefficients, lift-to-drag ratio, and drag coefficients. The pitching angle for all experiments were varied between -10˚ to +17˚. The blockage corrections have been applied to the data to obtain the actual performance of the aircraft. From the observations, the results show some similarity between those experiments, except for the lift-to-drag ratio of UPNM's data which are slightly higher compared to others.

Keywords: *Aerodynamics; Blended Wing Body; Wind Tunnel Experiments.*

1. Introduction

For the past years, the study on blended wing body aircraft has been done by many researchers. The Blended Wing Body (BWB) is a tailless design that integrates the wing and the fuselage and was initially conceived to-wards the end of the 20th century to serve as a novel platform for high-speed subsonic commercial airliners [1, 2]. The idea of blended wing body (BWB) aircraft [3, 4] fundamentally is based on flying wing designs which likely to be the next aircraft configuration for the future aircraft design.
There is many research on blended wing body focussing on aerodynamics, structures and control regarding to make blended wing body as commercial aircraft[1, 5-11]. The BWB is not likely to be commercialize before the late 2030s although it has unique features and potential[12], because its revolutionary shape is also responsible for a number of issues that have to do with passenger safety and comfort. Boeing has mentioned that the blended wing body also can be used as cargo aircraft. [13, 14].
However, the concept of tailless aircraft seems to have some problems with its flying quality. In order to overcome the issues, adding tail to blended wing body may provide stability of the aircraft. Some criteria should be considered in order to add the tails which are (a) the position of the centre of gravity (C.G.) of the aircraft, the change in C.G. location throughout the flight and projected level of stability. [15]
In 2005, Flight Technology and Test Centre (FTTC) in UiTM Shah Alam started the research on the BWB focusing on the design and fundamental aerodynamics [16]. There are five designs that have been made and studied which were name as Baseline I, Baseline II, Baseline III, Baseline IV and Baseline V. The first BWB Baseline-I is designed under UiTM research teams has four meter span and it is equipped with large central elevator for longitudinal control and stability. Baseline-I aircraft has poor aerodynamics performance with lift-to-drag ratio less than 10[17]. The second BWB aircraft, known as Baseline-II, is designed based on lessons learned from Baseline-I. Planform shape and twisted angle airfoil along spanwise location recommended by Bolsunovsky and Inverse-Twist Method were applied in Baseline-II aircraft design[18]. Baseline-II has achieved high aerodynamic efficiency with lift-to-drag ratio of 24.
Baseline-III is then designed to further study aerodynamics efficiency of BWB aircraft. Baseline-III concept is inspired from the shape of flying birds. However, the results show that the Baseline-III has major flaws in its aerodynamics efficiency. Lift-to-drag ratio value is only around 12[19]. Baseline-IV is also a bird-inspired BWB aircraft designed by referring to the existing configuration of Baseline-III aircraft. *L/D* ratio is increased compared to Baseline-III, but the value was not as efficient as expected for a BWB aircraft. Baseline V was undergo wind tunnel experiment at UTM Skudai with the design of the tail was blended at the side of

the body. As the elevator deflection angle is 0˚, the lift to drag ratio reach its maximum at 32. The lift to drag ratio reached it minimum which was 16 when the deflection angle at +20˚.

This research used Baseline V which equipped with 45˚ tail that have three different size of wind tunnel model. The experiments were conducted at three different wind tunnels which were Pusat Maritim Universiti Pertahanan Nasional Malaysia, Universiti Teknologi MARA Shah Alam, and Universiti Teknologi Malaysia Skudai. The focuses of the experiments were to obtain the aerodynamics characteristics as the tails were swept backward 45˚.

2. Theoretical Framework

This experiment only focussed on the 45˚ sweep tail angle configuration for Baseline V as shown in figure 1. This configuration of tail was applied to all size of the wind tunnel models.

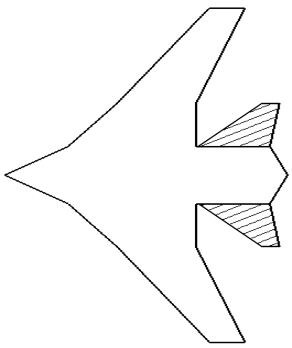


Fig1: Baseline V with 45˚ tail

The four forces of flight consists of lift, weight, thrust, and drag, represented by L, W, T, and D, respectively, are illustrated in Figure 2. The freestream velocity, V∞, is always in the direction of local flight path, and therefore presuming that the drag and lift is perpendicularly with each other [22]. The equation of motion for an airplane is a statement from Newton's Second Law of Motion of which: [23].

$$F = ma \tag{1}$$

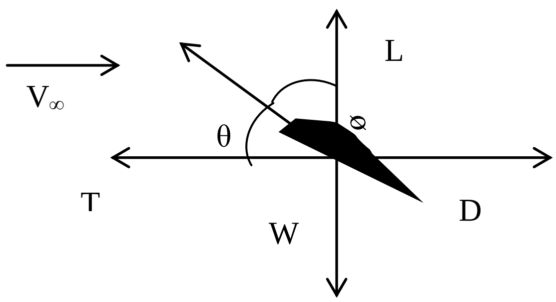


Fig2: Forces on the plane from free-stream velocity

The equation signifies the vector equations, F stands for Force and a, is for acceleration, both are in vector quantities. The equation of motion for parallel force to the flight path is determine directly through the vertical forces including changes of pitch of the airplane [23]. The equation of motion of Thrust, T is equal to Drag, D, same goes to weight, W is equal to Lift, L. These phenomenon can only exist when the plane endure a free-flight with steady condition [14].

$$T = D = \frac{1}{2}\rho V_\infty{}^2 S C_D \tag{2}$$

$$W = L = \frac{1}{2}\rho V_\infty{}^2 S C_L \tag{3}$$

The value of density, ρ always change with respect of altitude of the plane itself. The value of free-stream velocity V_∞ also correlates with the speed of the airplane. Lift coefficient, C_L and drag coefficient, C_D derives with the value of aerodynamic characteristic of the plane with relation to its design and pressure difference. The value of wingspan area, S is not least important value to determine an airplane's aerodynamic coefficient [22, 24, 25].

$$M = \frac{1}{2}\rho V_\infty{}^2 S b C_M \tag{4}$$

The area of horizontal tail was based on the ratios (Sht / S) for same airplanes. Here, these areas are refined based on the tail volume ratios (Cht) of the similar airplanes. These ratios are defined as:

$$C_{ht} = I_{ht} S_{ht} / \overline{C}_w S_w \tag{5}$$

Where, Cw and Sw are mean aerodynamic chord and area of the wing, Sht is the areas of horizontal tail; Iht is distance between c.g. of airplane and aerodynamic centre of the horizontal tail. To obtain the area of the horizontal tail, the equation is given as [15];

$$S_{ht} = C_{ht} \frac{S_w}{I_{ht}} \overline{C}_w \tag{6}$$

For sweep cases, the sweep angle of the horizontal tail is equal to that of the wing or slighter higher;

$$\Lambda_{ht} \approx \Lambda_{wing} + 5^\circ \tag{7}$$

3. Model Fabrications and Wind Tunnel Setup

There are three wind model used for this research which were 1:1scale full model, 1:2 scale half model and 1:7 scale half model. Each of the models was built with different material. For the 1:1 scale full model was been tested at UTM Skudai, 1:2 scale half model was tested at UiTM Shah Alam and 1:7 scale half model was tested at UPNM.

UTM wind tunnel model was fabricated from pine woods, some lightweight plywood, carbon fiber rods, balsa skin and plastic coverings. UiTM wind tunnel model was built from plywood and balsa skin and then coated with spray paint. While, for UPNM model, the structure of the model is 3-d printed and layered with fibreglass.[20]

The experiments were conducted at Low speed wind tunnel. At UTM Skudai, the test section is 4.9 ft x 6.6 ft x 19.0 ft (1.5 m x 2 m x 5.8 m) and it is a closed circuit type. Meanwhile, at UiTM Shah Alam and UPNM, the wind tunnels are open circuit type. The test section at UiTM is 0.5m x 0.5m x 1.2m and for UPNM the test section is 0.3 m x 0.3 m x 1.25 m. All of the wind tunnels are equipped with six-component external balance. The speeds used for each of the experiment conducted were different as at UTM was 15m/s, at UiTM were 30m/s, and at UPNM were 49.58m/s. The pitching angle,□□ was varied from -10˚ to +17˚. The experiments were conducted several times in order to get the accurate results.

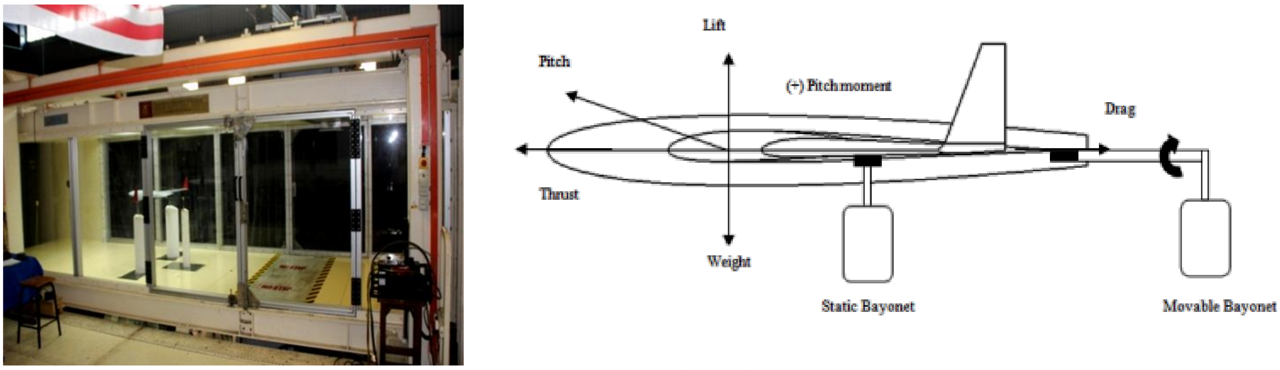


Fig. 3: AEROLAB Wind Tunnel – UTM

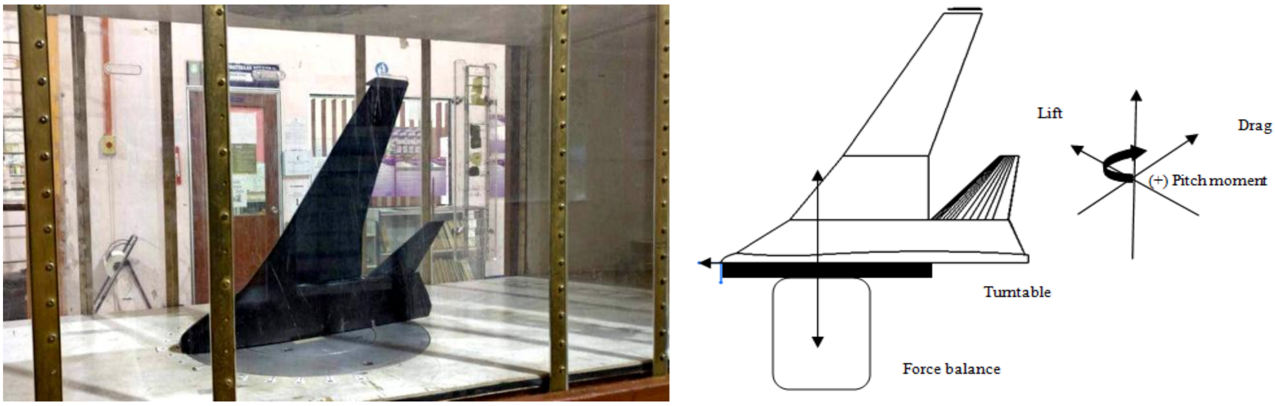


Fig. 4: LST-1 Wind Tunnel - UiTM

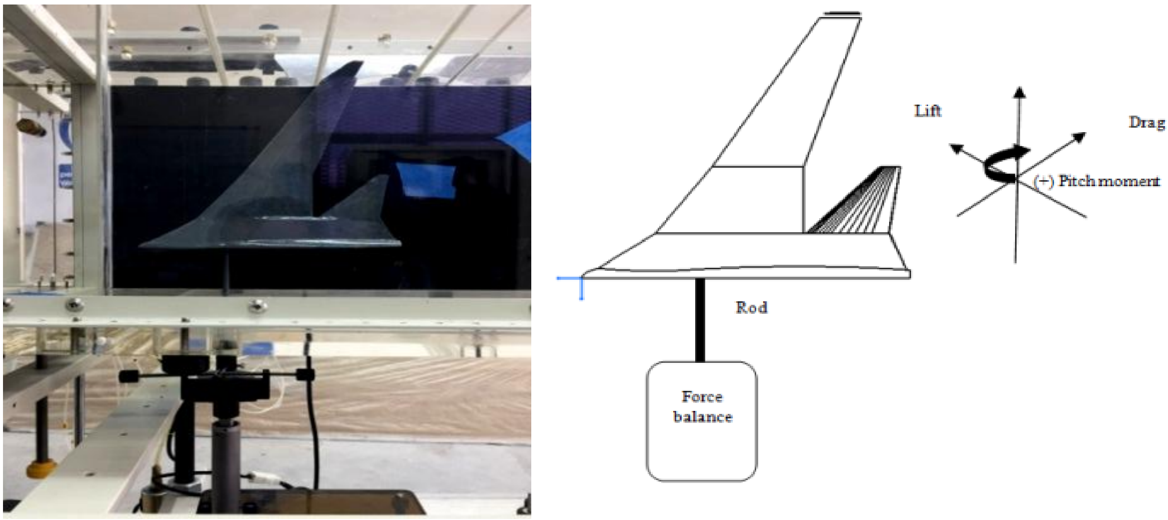
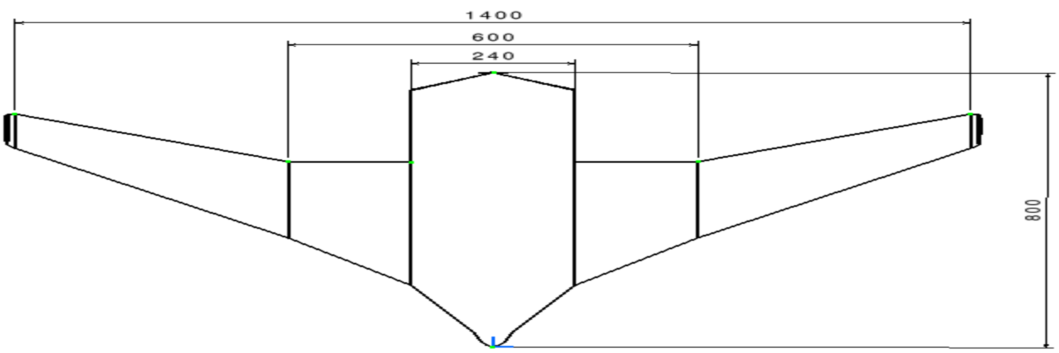


Fig. 5: Wind Tunnel - UPNM



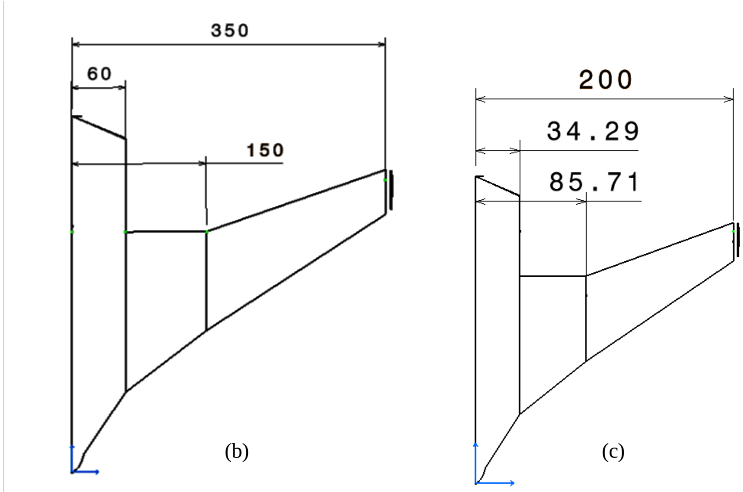


Fig. 6 : (a) Full scale, (b) 1:2 scale half model, (c) 2:7 scale half model

4. Blockage Correction

As the model undergo wind tunnel experiment rather than testing using CFD, the experimental data must be corrected by using the formula below [21]:

Solid blockage,

$$\Delta V = \varepsilon_{sb} V_U \tag{8}$$

$$\varepsilon_{sb} = \frac{K_1 V_b}{S^{3/2}} \tag{9}$$

Where V_U is the uncorrected airspeed, K_1 for vertical model is 0.52, for horizontal model is 0.74 and S is the working section area.

Wake blockage,

$$\Delta V = \varepsilon_{wb} V_U \tag{10}$$

$$\varepsilon_{sb} = \frac{c}{2h} c_{d_u} \tag{11}$$

Where c_{d_u} is the uncorrected coefficient of drag, c is the model's length and h is the height of working section.
Streamline curvature correction,

$$\propto = \propto_u + \frac{57.3\sigma}{2\pi}(C_{lu} + 4C_{m\,1/2u}) \tag{12}$$

$$C_l = C_{lu}(1 - \sigma - 2\varepsilon) \tag{13}$$

$$C_{m\,1/2} = C_{m\frac{1}{2u}}(1 - 2\varepsilon) + \frac{\sigma C_l}{4} \tag{14}$$

$$\sigma = \frac{\pi^2}{48}\left(\frac{c}{h}\right)^2 \tag{15}$$

Total corrected airspeed,

$$V = V_u(1 + \varepsilon) \tag{16}$$

Total corrected drag,

$$C_{d0} = C_{d0u}(1 - 3\varepsilon_{sb} - 2\varepsilon_{wb}) \tag{17}$$

5. Results and Discussions

The results for each of the experiments have been analyzed and plotted in term of lift coefficient against angle of attack, drag coefficients against lift coefficients and lift-to-drag ratio against angle of attack. Some discussions have been made regarding the trend of the results for each of the experiments. All the data acquired have been corrected by using blockage correction such as solid blockage, wake blockage, and streamline curvature. All the data presented is after correction data.

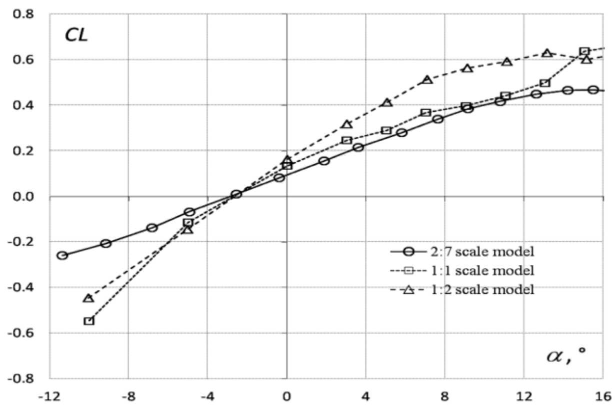


Fig. 7: Lift Coefficients versus angle of attack

Figure 7 shows the coefficient of lift against angle of attack for each of the experiments. From the graph plotted, it can be seen that the trend are the same for all the experiments. The trend is linear for all of the experiments. As the angle of attack increases, the values of lift coefficient also increase. The results from 1:2 scale model has higher coefficient of lift start from angle of attack 0°.

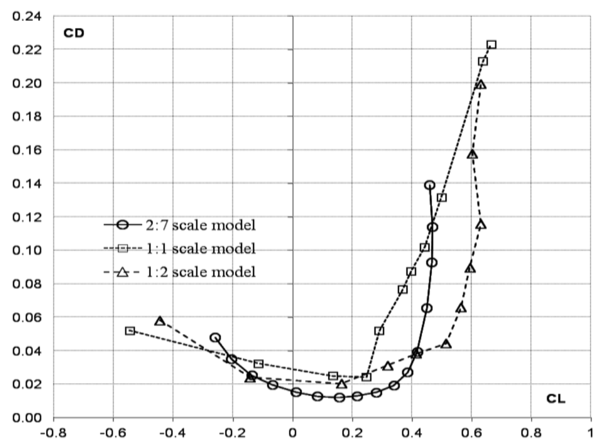


Fig 8: Drag coefficient versus Lift Coefficient

The drag coefficient against lift coefficient graph is plotted in the figure 9. From the observations, the trend line for all of the experiments is similar as all of them showing parabolic trend. The drag results for 2:7 scale model shows the lowest values compared to the data of 1:1 scale model and 1:2 scale model. The minimum drag obtained was 0.0121 at C_L 0.15 from the 2:7 scale model data. The 1:1 scale model has the highest drag coefficients recorded. This differences happened due to the some external factors such as material used on fabrication of the model and surface finishing of the model itself.

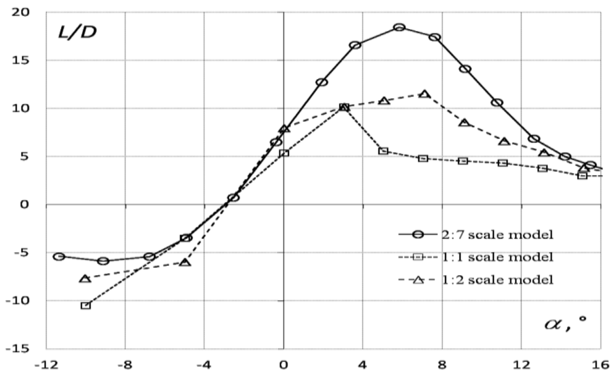


Fig 9: Lift-to-Drag ratio versus Angle of attack

The curve of L/D ratio against angle of attack is shown in figure 4. From the curve, the L/D ratio of 2:7 scale model gives the highest value compared to the others. This happened to be different due to the lowest drag coefficients obtained from the experiments. The L/D max for 2:7 scale model is 18 at angle of attack +5.81˚. The L/D max for 1:1 scale model is 10.16 at angle of attack +3˚ meanwhile for 1:2 scale model, the L/D max is 11.53 at angle of attack +7˚. All of the experiments show bell curve trend.

6. Conclusion

All results obtained from three wind tunnel experiments from UTM, UiTM and UPNM have been analysed to determine the aerodynamic characteristics of Baseline V with 45˚ sweep tail angle. The results show similar trends for the lift coefficients, drag coefficients and lit-to-drag ratio. From the observation, the 2:7 scale model gives the best results of the aerodynamics coefficients. It can be concluded that, the fabrication of wind tunnel must be made smoother or built with the more suitable material which will give more accurate data. The blended wing body Baseline V is possible to fly with the correct centre of gravity location and the right sweep tail. Further study on the tail sweep angle design will be done in order to get the most suitable tail configurations for blended wing body aircraft.

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References

[1] R. H. Liebeck, "Design of the Blended Wing Body Subsonic Transport,," Journal of Aircraft, vol. 41, pp. 10-25, 2004.

[2] J. D. Anderson, Aircraft performance and design: McGraw-Hill Science/Engineering/Math, 1999.

[3] M. A. Page, M. A. Potsdam, R. H. Liebeck., "Blended wing body analysis and design[J]," AIAA Paper, p. 2317: 1997, 1997.

[4] R. H. Liebeck, "Design of the blended wing body subsonic transport[J]." Journal of Aircraft, pp. 41(1): 10-25., 2004.

[5] J. van Dommelen and R. Vos, "Conceptual design and analysis of blended-wing-body aircraft," Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, vol. 228, pp. 2452-2474, 2014/11/01 2014.

[6] M. Voskuijl, G. La Rocca, and F. Dircken, "Controllability of blended wing body aircraft," in 26th International Congress of the Aeronautical Sciences, 2008, pp. 14-19.

[7] S. Siouris and N. Qin, "Study of the effects of wing sweep on the aerodynamic performance of a blended wing body aircraft," Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, vol. 221, pp. 47-55, 2007/01/01 2007.

[8] N. Qin, Vavalle, A., Le Moigne, A., Laban, M., Hackett, K., and Weinnerfelt, P, "Aerodynamic Considerations of Blended Wing Body Aircraft," Progress in Aerospace Science,, pp. 321-343, 2004.

[9] P. Li, B. Zhang, Y. Chen, C. Yuan, and Y. Lin, "Aerodynamic Design Methodology for Blended Wing Body Transport," Chinese Journal of Aeronautics, vol. 25, pp. 508-516, 2012.

[10] Z. Lyu and J. R. R. A. Martins, "Aerodynamic Design Optimization Studies of a Blended-Wing-Body Aircraft," Journal of Aircraft, vol. 51, pp. 1604-1617, 2014/09/01 2014.

[11] H. Engels, W. Becker, and A. Morris, "Implementation of a multilevel optimisation methodology within the e-design of a blended wing body," Aerospace Science and Technology, vol. 8, pp. 145-153, 2004/03/01/ 2004.

[12] R. Wittmann, "Passenger acceptance of BWB configurations," in Proceedings of the 24th ICAS Congress, Yokohama, Japan, 2004.

[13] R. C. Odle, D. Roman, and B. K. Rawdon, "Blended wing body cargo airplane," ed: Google Patents, 2011.

[14] Boeing. (2017). Blended Wing Body Goes with the Flow in New Visualization Test, .

[15] Prof. E. G. Tulapurkara, "Airplane design(Aerodynamic) ", ed: Dept. of Aerospace Engg., Indian Institute of Technology, Madras, 2013.

[16] W. Kuntjoro, Rizal E.M. Nasir, W. Wisnoe, "Aerodynamic, stability and flying quality evaluation on a small blended wing-body aircraft with canard foreplanes," Procedia Technology 15, pp. 783-791, 2014.

[17] W. Wisnoe, R. Effendy, M. Nasir, W. Kuntjoro, A. Mohd, and A. Bin Mamat, Wind Tunnel Experiments and CFD Analysis of Blended Wing Body (BWB) Unmanned Aerial Vehicle (UAV) at Mach 0.1 and Mach 0.3, 0002.

[18] W. Kuntjoro, Rizal E M Nasir, Wirachman Wisnoe, Zurriati Ali, "Longitudinal Flight Dynamics of Baseline-II BWB UAV," Advanced Materials Research, vol. 433-440, pp. 6636-6640, 2012.

[19] Rizal E. M. Nasir. Wirachman Wisnoe, Ramzyzan Ramly, Wahyu Kuntjoroa, Firdaus Muhammad, "Aerodynamic of UiTM's Blended-Wing-Body Unmanned Aerial Vehicle Baseline-II Equipped with One Central Vertical Rudder," Jurnal Teknologi, vol. 12, pp. 133-139, 2015.

[20] M. Z. A. A. Latif, M. A. Ahmad, R. E. M. Nasir, W. Wisnoe, and M. R. Saad, "An analysis on 45° sweep tail angle for blended wing body aircraft to the aerodynamics coefficients by wind tunnel experiment," IOP Conference Series: Materials Science and Engineering, vol. 270, p. 012001, 2017.

[21] Ross and A. Altman, "Wind tunnel blockage corrections: Review and application to Savonius vertical-axis wind turbines," Journal of Wind Engineering and Industrial Aerodynamics, vol. 99, pp. 523-538, 2011/05/01/ 2011.

[22] Etkin, B. and L.D. Reid, Dynamics of flight: stability and control. Vol. 3. 1996: Wiley New York.

[23] Anderson, J.D., Aircraft performance and design. 1999: McGraw-Hill Science/Engineering/Math.

[24] Hoerner, S.F. and H.V. Borst, Fluid-dynamic lift: practical information on aerodynamic and hydrodynamic lift. 1985: LA Hoerner.

[25] Brumbaugh, R.W., Aircraft model for the AIAA controls design challenge. Journal of guidance, control, and dynamics, 1994. 17(4): p. 747-752.