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Static Structural Analysis of Blended Wing Body II-E2 Unmanned Aerial Vehicle

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ABSTRACT

To Blended Wing Body (BWB) is a type of aircraft which its fuselage and wing section are being blended together which results in a single lifting surface. In this paper, airframe design of an in-house BWB model named BWB Baseline II-E2 UAV from Flight Technology and Test Centre (FTTC), Universiti Teknologi MARA is analyzed. The aim of this study is to determine the static structural characteristic for fulfilling the airframe strength requirement. Maximum allowable stress of materials and maximum displacement of the airframe are considered. Aluminum alloys 2024-T4 is used as the airframe material. Static strength analysis with Von Mises stress and structural displacement analysis were performed by using Finite Element Method (FEM). The stresses and displacements results shows that the BWB airframe strength and stiffness are fulfilling the requirement.
KEYWORDS: Blended Wing Body, Finite Element Method, Static Strength Analysis.

INTRODUCTION

The Blended Wing Body (BWB) aircraft is designed in such a way that the wing and fuselage were blended to form a large flying wing area [1]. This large wing area is advantageous in reducing the interference drag and the overall wetted surface area due to clean aerodynamic configuration [2, 3].

Research related to unmanned BWB aircraft has been carried out extensively. One of them is, the design and fabrication of BWB DEMON UAV demonstrator [4-8]. This project was aimed to develop a novel and low cost flapless type of UAV. The projects started with an earlier models, named ECLIPSE, which acting as the baseline model for DEMON UAV. Another study related to BWB of unmanned combat aerial vehicle (UCAV) named CERBERUS UAV [9]. Two concepts of UCAV layout were proposed; lambda and delta wing. It was found, lambda wing was advantageous in terms of fuel requirement, aerodynamic efficiency and low radar cross section. A study related to characteristic of flying wing similar to BWB aircraft also has been done [1]. This BWB named as SEKWA BWB UAV has the capability of moving the avionics tray transverse inside the spar carry-through airframe via screw-jack mechanism.

For this study, an in-house designed BWB model named as BWB Baseline II-E2 (shown Figure 1) is analyzed to determine the static structural characteristic for fulfilling the airframe strength requirements. The geometrical design of BWB aircraft is unique when compared to other studies due to UiTM's BWB aircraft has the canards on its body.

Figure 1: BWB baseline II-E2 [10]

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Table 1: Basic dimension of BWB baseline of BWB baseline II-E2 UAV model [11]

Parameter	Wing Span	Overall Length of Aircraft	Body Length
Dimensions (m)	4.016	2.367	2.000

The BWB is divided into five modules; wing body (fuselage), starboard (right) wing, port (left) wing, left and right side canards. Figure 2 shows the BWB modular layout.

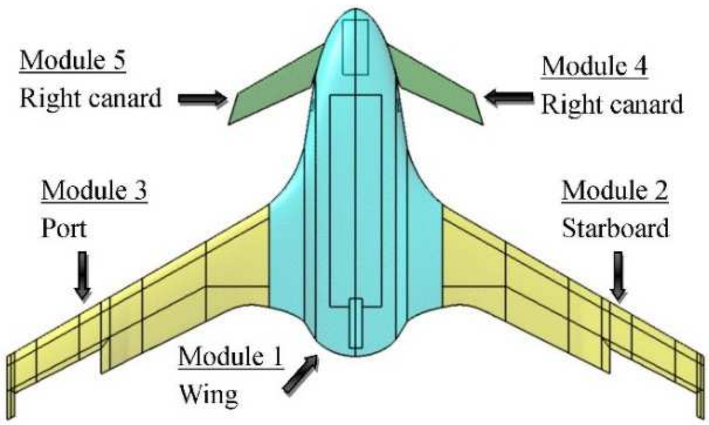

Figure 2: BWB modular layout

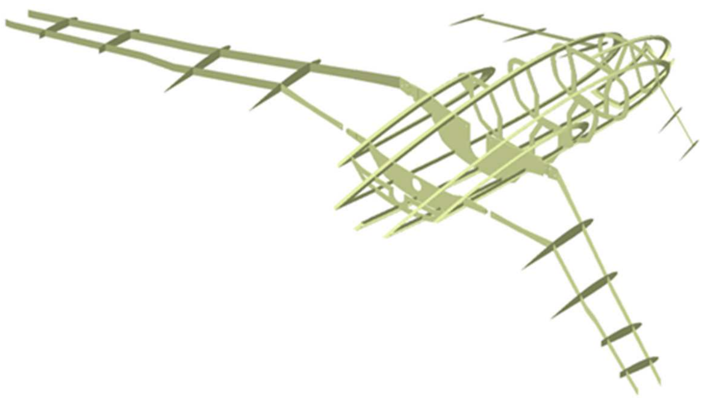

Figure 3:BWB airframe concept

DETERMINATION OF LOADING

Loading determination is based from the differences of pressure coefficient, C_p between lower and upper surface of BWB airplane. Computational Fluid Dynamics (CFD) was used to generate the pressure contour. In normal condition, lower surface will produce higher C_p compared to upper surface. Accordingly, the method of obtaining the loads through differences in $C_p$was done by superimposing BWB lower (see Figure 4) and upper (see Figure 5) pressure contour with the BWB airframe layout. This pressure contour was taken at Mach number of 0.1, normal cruise at 35 ms^{-1} at the angle of attack, α of 1^0. Later, these BWB lower and upper pressure contour is divided into smaller section for ease of identification and calculations of lift forces. For that reason, a total of 37 areas were set up (see Figure 6).

However, before lift forces can be distributed along the airplane, these loads need to be multiplied with Load Factor, LF. LF is the ratio of overall lift of an airplane to its overall weight. According to FAR (Federal Aviation Regulations) Part 23 (classification of light weight type of airplane with normal operational maneuver), the LF at which an airplane (at maximum take-off weights) must be built is between +3.8 g to -1.5 g. As for this study, the LF was set to be at +3.8 g. Later, this LF is multiplied with the overall load from lifting force and airplane weight to obtain the total design force. Table 3shows the total force of BWB airplane.

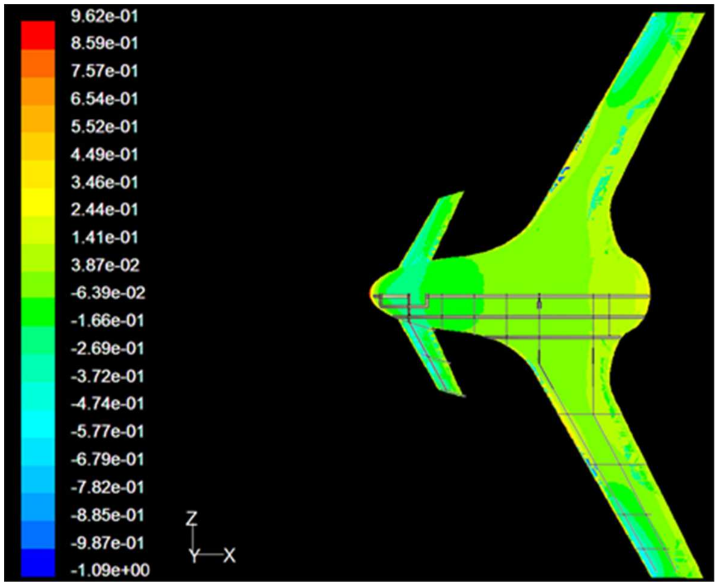

Figure 4: Contours of pressure coefficient on lower surface of BWB at Mach number 0.1, α = 1^{O}

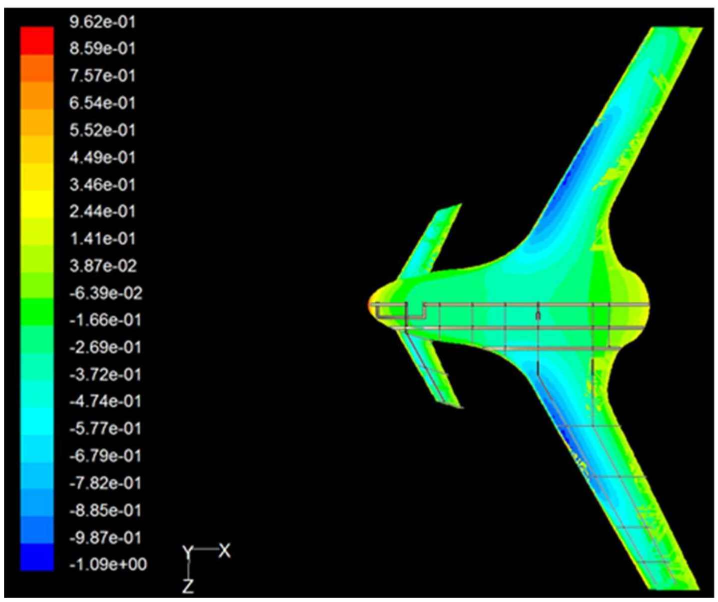

Figure 5: Contours of pressure coefficient on upper surface of BWB at Mach number 0.1, α = 1^{O}

Table 2: Total force acting on the BWB aircraft with respect to +3.8g LF

Load Factor, LF(g)	Mass BWB, M_{BWB} (kg)	Gravity Acceleration, G (ms^{-2})	Total Weight Force, $W_{Total,3.8g}$ (N)
3.8	110	9.81	4100.58

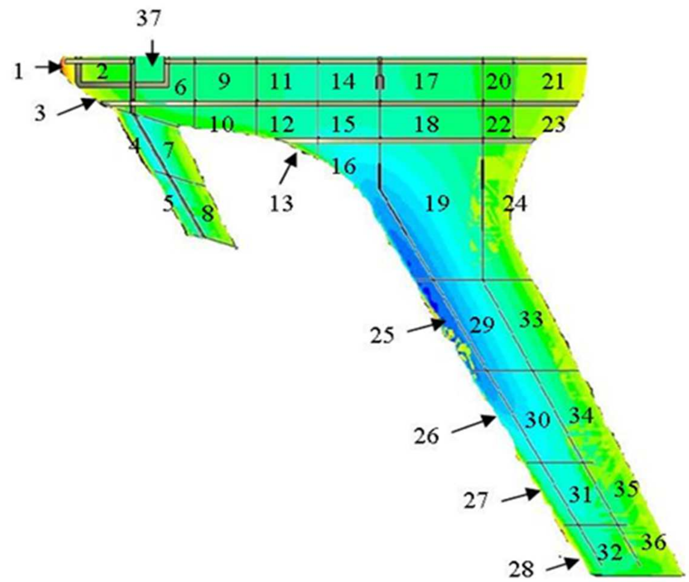

Figure 6: Numbering of divided area of BWB airplane surface

From Table 2, the total force produced during flight is 4100 N. However, only half of the total weight force is considered; 2050 N. This is due to BWB symmetrical layout.

FINITE ELEMENT MODELING

The static structural analysis was performed using FEM. FEM is defined as a tool for analysing a prediction of engineering systems response [12]. In this study, shell and beam elements were used. Shell elements were used to represent the skins, spars and ribs structures. While, beam elements were used to represent the frames, stringers and longerons structures. Figure 7 shows the finite element (FE) model after meshing process is done. Table 3 shows the overall numbers of nodes and elements used in this FE model. Selection of meshing size was set to be nearly the same as the size of the geometrical shape area. This is due to reducing the computer resources usage. The material is based on aluminium 2024-T4 alloys.

Figure 8 shows the FE model of the BWB (combined skin and structure). Figure 9 shows the plot contour of load on lower surface for the FE model.

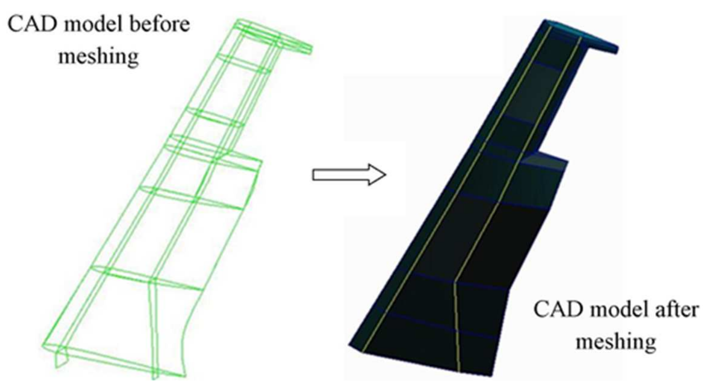

Figure 7: FE model after meshing process

Table 3: Number of nodes and elements generated for each module

Module	1	2	3	Total
Node	229	79	13	321
CBAR	36	3	0	39
CBEAM	81	35	0	116
CQUAD4	194	83	10	287
CTRIA3	21	13	6	40
Total				803

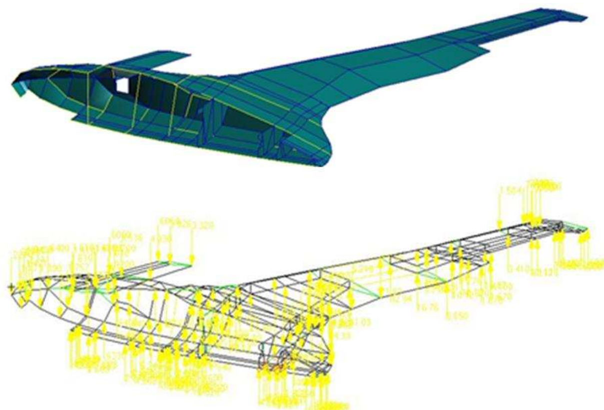

Figure 8: FE model of the BWB combined skin and structure (smooth shaded and wireframes)

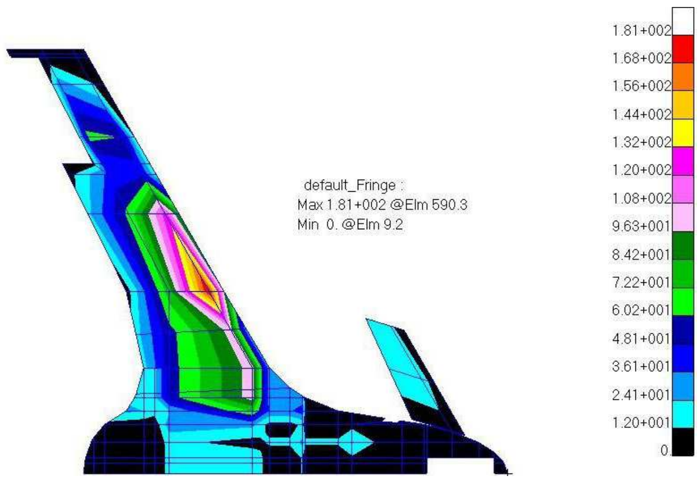

Figure 9: Plot contours of loads on lower surface of the FEA model (load unit is in Newton)

RESULTS AND DISCUSSION

Linear static case displacement and deformation results are shown in Figure 10. Stress contour of Von Mises stress results of skin, the internal structure of wing module, canard module and wing body module were shown in Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15 respectively.

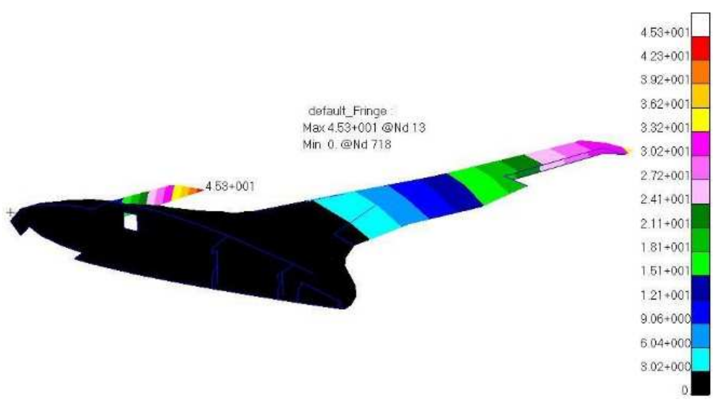

Figure 10: Deformation: Displacement result for FEA

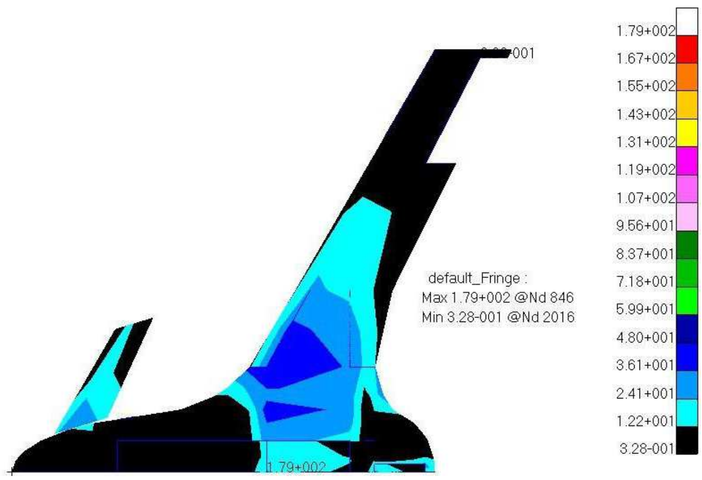

Figure 11: Stress contour: Von Misesstress on the upper surface of FEA

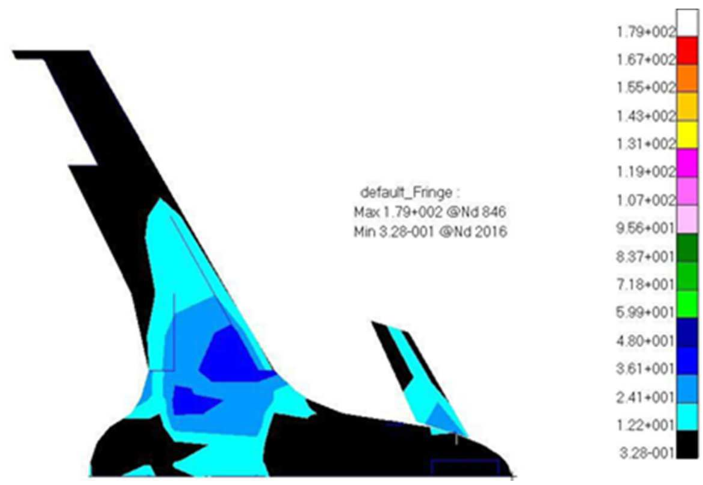

Figure 12: Stress contour: Von Misesstress on the lower surface of FEA

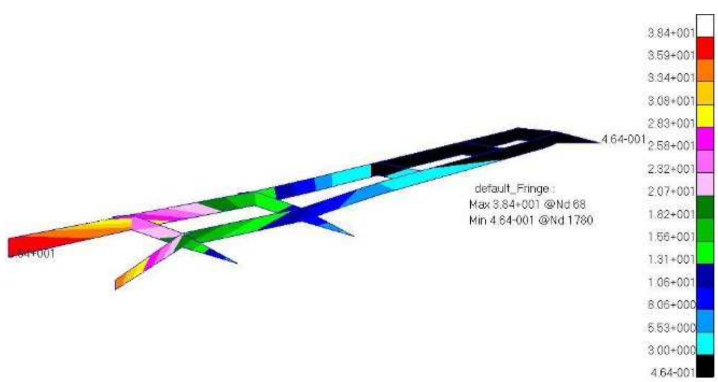

Figure 13: Stress contour: Von Misesstress on the ribs and spar of module 2 of FEA

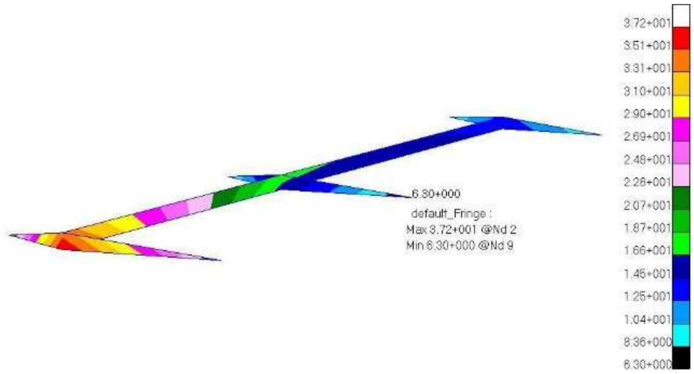

Figure 14: Stress contour: Von Misesstress on the ribs and spar of module 4 of FEA

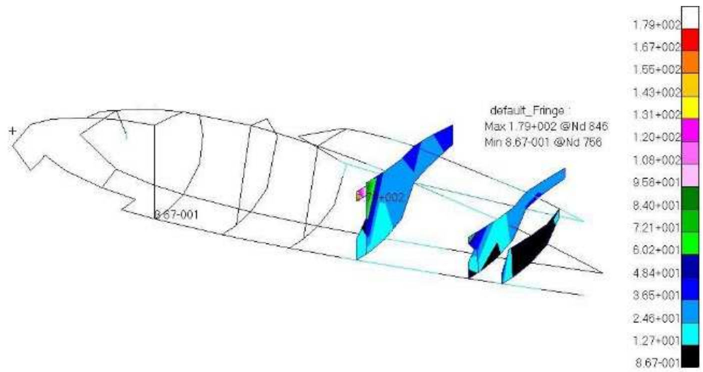

Figure 15: Stress contour: Von Misesstress on the stringers and frame of module 1 of FEA

It was found that, the maximum Von Mises stress is 179 MPa. This maximum stress was located at the carry through structure inside the wing body section (Module 1). Thus, this maximum stress value was less than the aluminium 2024-T4 tensile yield strength. Accordingly, this analysis shows that the airframe design was capable to withstand the maximum stress that occurs in the BWB airplane. It needs to be mentioned here that the stress is due to symmetrical cruise condition at +3.8 g normal acceleration. While, the maximum deflection of canard tip and wing tip are 45.3 mm and 33.8 mm. From these results, it was found that both displacements were within in the range of safe condition which was less than 10 cm. Table 5 shows the values obtained from the FEA results.

Table 5: Values obtained from the FEA

Description	Load Factor +3.8g
Maximum Stress-Von Mises	179 MPa (Module 1)
Canard Tip-Maximum Deflection	-45.3 mm (Deflection Downwards)
Wing Tip-Maximum Deflection	33.8 mm (Deflection Upwards)
Remarks	Acceptable

CONCLUSION AND RECOMMENDATIONS

In this paper, the structural layout of BWB airframe is evaluated at 0.1 of Mach numbers with +3.8 g of load factor. The aluminium alloys 2024-T4 is used as the sole material of the aircraft. FEA is used to find the resultant stresses and displacement in the airframe. It was found that, the values of stress are acceptable due to maximum value of Von Mises stress is lower than the tensile yield strength. Therefore, the objective to obtain the BWB static structural characteristic for airframe requirements has been achieved.

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