Aerodynamics Analysis on the Effect of Canard Aspect Ratio on Blended Wing Body Aircraft using CFD Simulation

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Abstract. Blended Wing Body Aircraft (BWB) is an unconventional aircraft that combined the conventional and flying wing aircraft's design. The unique design of the BWB offers a high fuel efficiency, low noise, and large payload volume for the size of aircraft. However, the BWB is unstable due to the absence of the its vertical stabilizer. A possible solution to improve this problem is using a horizontal control surface, the canard. For this purpose, the numerical simulation using NUMECA Computational Fluid Dynamic (CFD) software were conducted to obtain the aerodynamics forces subjected on this aircraft. The lift coefficient (C_L), drag coefficient (C_D) and moment coefficient (C_M) are analysed at Mach number 0.1. The study is specifically to discuss the effect of canard setting angle ™ of BWB from ™ = -10° to 10° in that particular of aspect ratio (AR 2, 4, 6 and 8) towards aerodynamics parameters, C_L, C_D, and C_M.

1. Introduction

The idea of BWB comes from the flying wing (FW) concepts. FW is an aircraft with the absence of fuselage, tail and only a wing. Due to its design, it has low drag, limited payload and is unstable. FW enables an entire payload or its portion to be accommodated in the wing. From the hybrid FW studied by [1] the maximum lift-to drag achieved by the airplane was approximately 24.5 at Mach = 0.85. It confirmed preliminary assumption on the possibility of achieving higher technical and economical characteristics of FW configuration airplane as compared with conventional airplanes. However, FW was a not a blended wing body designs because the fuselage contributed no lift and had little cargo and passenger room. The interest in tailless aircraft has emerged since then. The requirement to have a large transport with economical design and low efficiency has driven the engineer to come out with a new aircraft concept. The blended wing body, was an aircraft that blends the fuselage, wing and engines into a lifting surface, has been introduced by [2]. It features wide curved fuselage and a thick delta wing. The BWB (X-48A), the prototype has been constructed by Boeing Company and Air Force team for wind tunnel testing. Then, the Boeing and Cranfield Aerospace, a United Kingdom firm has introduced two X-49Bs BWB. The X-49Bs has a 6.4 m wingspan, weighs 181 kg and flies at up to 240 km/h at 3 km. Three engines mounted above the wing and use a carbon-fiber airframe and carbon-composite skin. The movable surface on the trailing edge of wing are responsible for all aircraft control [3]. In initial design of 800-passenger BWB (Boeing BWB-450), the reduction of 15% of takeoff weight and 27% fuel burn per seat mile shows the BWB has a better performance over the conventional aircraft.

Among all the advantages of the BWB, there is still shortcoming. The BWB's pitch control has a short lever arm to the center of gravity compared to a conventional aircraft. This affects flight path control during rotation and landing since flare pitch changes are accompanied by unwanted initial plunging. [4] studied the advantages using a belly-flaps to enhance the lift and pitching moment coefficient during landing, go-around and take off. A belly flaps is located near the mid-section on the lower surface of wing. The wind tunnel model result using a generic BWB-450 model has been used for the study. Due to the study, the lift and moment coefficient increases with the employment of the belly flaps. The increase of lift improves the landing field length, takeoff field length and pitch lagging in go-around.

Determining the performance of BWB with canard using numerical methods has proven to be extremely difficult due to the viscous flow region that needs to be modeled. The flow over a BWB has greatly been complicated by the rounded trailing edge and the introduction of the canard. Many numerical studies were conducted which examined the possibility of using Navier-Stokes equations to predict the characteristics of aircraft, BWB or an aircraft with canard. [5] has been developed an unsteady three-dimensional Navier-Stokes analysis procedure has applied to Circulation Control Wing (CCW) configurations. The solver can be used in both a 2-D and a 3-D mode and can thus model airfoils as well as finite wings. [6] used a steady state, CFD code FLUENT to calculate a BWB model using the standard one equation turbulence model, Spalart-Allmaras. [7] investigates the design of conventional and unconventional wings with winglet. One of the methods that have been used in the design process is by using a CFD to analyze the flow mechanisms and optimize winglet design.

The Universiti Teknologi MARA (UiTM) BWB's research and development has started since 2005. The first design known as BWB-Baseline I. It has sharp edges, broad body, small wing area and elevator as a pitching moment control. Due to ineffective control of elevator, the BWB was then modified, while maintaining the wing span, body length and reference planform area. The BWB-Baseline-II was a completely-revised and redesigned version of BWB-Baseline- I [8]. Its feature has a simpler planform, broader-chord wing and slimmer body than previous. The small control canard is incorporated on Baseline-II since the center body elevator located at the aft of the body of BWB-Baseline I is ineffective as the pitching moment produced, causing change of trim impossible [9]. After that, the studies of BWB with canard were aggressively done through experimental and computer simulation [10]. This research, therefore, is considered a continuation of earlier efforts. However, the BWB being used for this study has a rectangular shape of canard and the aspect ratios having constant area were varied.

2. Methodology

2.1 Geometry Set-up and Grid Generation

The half body of BWB's geometry, is constructed in CATIA V5 software and has been scaled down to 1:6 from its original size, as shown in Figure 1. The scaling procedure is performed from the central body to the wing tip at the interval 349.43mm (~350mm), and nose (leading edge) to tail (trailing edge) about 348mm respectively. The advantages of scaling down the model is, it can save the time when calculating in the CFD simulation.

The boundary condition has been constructed with the dimension of 1 meters from nose to internal wall and 3 meters from external wall. The top and the bottom wall are 1 meter far from the BWB body, as shown in Figure 2. The unstructured grid generator, HEXPRESSTM software is used to generate the flowfield and surface grid of the BWB model. The HEXPRESS™ is unstructured hexahedral mesh generator software designed to automatically generate meshes in complex 2D and 3D geometries. A major obstacle to the treatment of arbitrarily complex configurations is the difficulty and cost of mesh generation. This can be mitigated by the use of unstructured meshes. The advantage of unstructured mesh is it provides flexibility to handle complex geometries. In this grid generator, a three dimensional (3D) unstructured hexahedral meshes are utilized for computing a flow around the aircraft configuration. The finer mesh was created near the aircraft model, to ensure the accuracy of the result can be achieved. Figure 3 shows the baseline surface grids generated for the wing-body without the canard configuration. The meshing size is coarser as it is away from model. The figure also shows a typical mesh employed around the BWB for the computation. The number of cells of the computed flow field for the BWB was 500000.

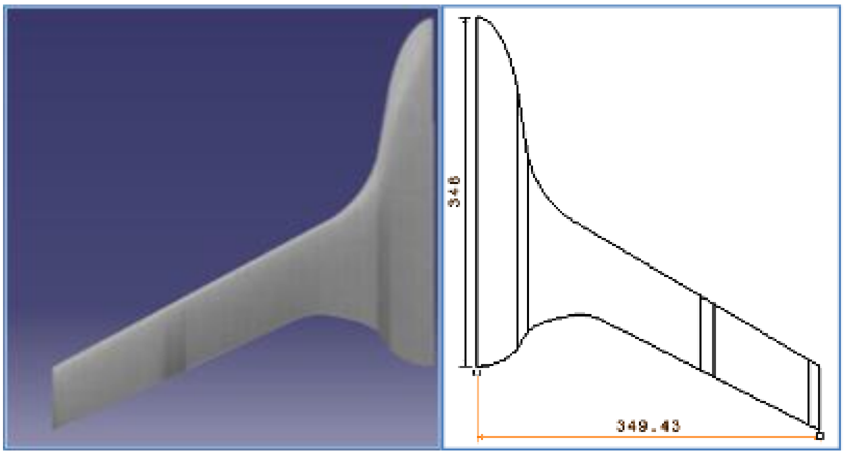


Figure 1. The scaled model of BWB aircraft

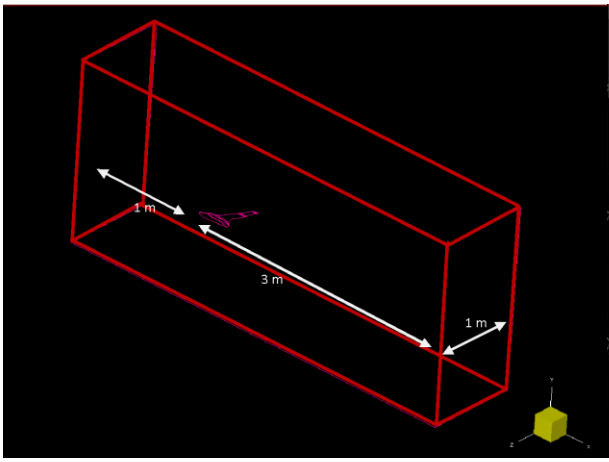


Figure 2. The boundary condition set-up

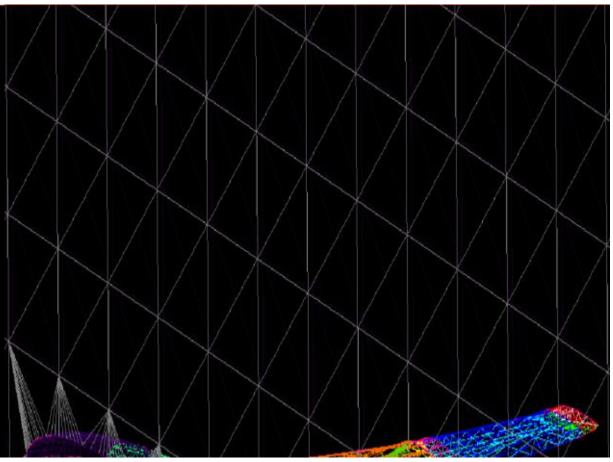


Figure 3. The meshing around the body

2.2 Computation

The CFD result was obtained using FINE™/Hexa flow solver. Table 1 shows the BWB-Baseline aircraft main characteristics and Table 2 is the pre-processing properties for the simulation setup. For the present study, the segregated solver is selected to solve the equation. The implicit formulation takes less computer time [9]. The effects of turbulence are accounted for by the Spalart-Allmaras model. To solve the governing equation, comprising the model, boundary conditions are needed at each part of the domain boundary [10]. No slip boundary condition is imposed at the solid boundary.

Table 1. Model Geometry Characteristics (based on scaled model)

References area	$0.03995m^2$
Mean Aerodynamics Chord	$0.114m^2$
Body Length	*0.348m*
Half Wing Span	*0.348*
Canard Area	$0.005m^2$

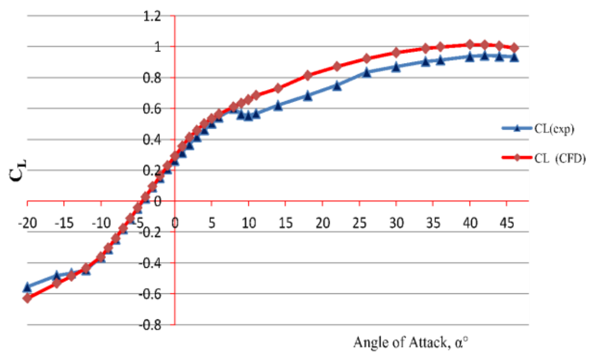
Table 2: Pre-processing properties

Fluid	air

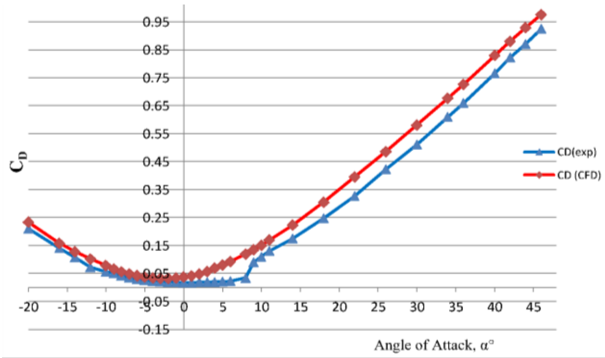
Reference Pressure	101325 Pa
Reference Temperature	297 K
Reference Velocity	35 m/s
Turbulence Model	Spalart Allmaras

2.3 Post-Processing – Parameter Validation

Figure 4 (a) and (b) show the comparison between lift and drag coefficient with respect to angles of attack with the experimental result obtained by [11]. It is observed that the lift and drag coefficient have the same trend with the experimental. The lift is increases as the angles of attack, but the CFD is not being able to predict the stall that occurs around 8-degree angles of attack. The differences between the CFD and experimental result is small at angles of attack ranged between -10 to 10 degree. After that, the CFD result predict higher lift coefficient compare to the experimental result. The same trend is also observed in drag coefficient graph. Since the study is only fixed at one angle of attack (10 degree), the result obtained from the CFD is assumed to be validated.



(a)

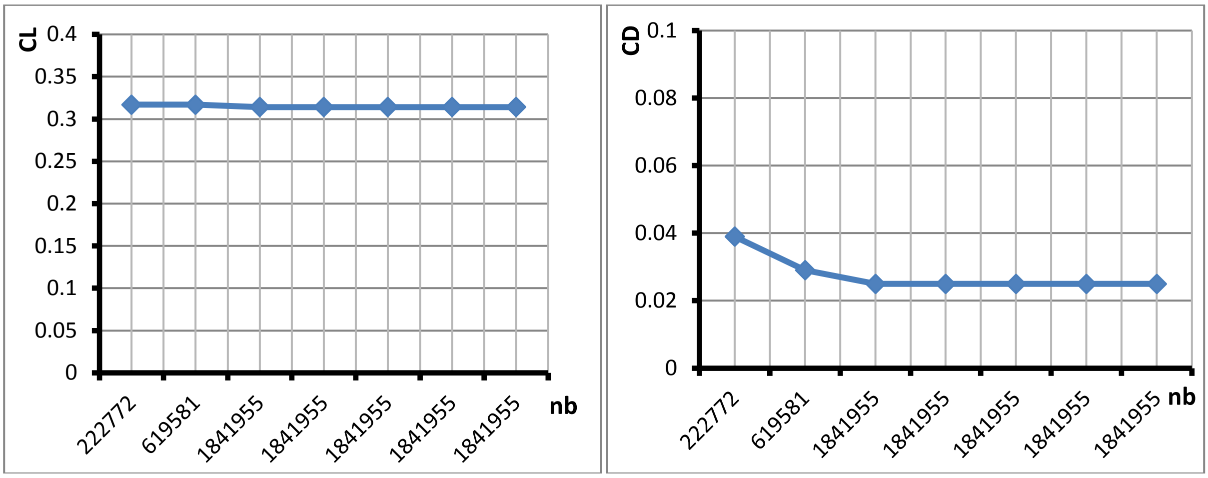


(b)

Figure 4. (a) Lift Coefficient vs Angles of Attack. (b). Drag Coefficient vs Angles of Attack

2.4 Grid Independent Study

The Grid Independence Study (GIS) is performed to observe the effect of number of cells towards the computation results. The GIS is achieved when the computation results has no effect by the change of parameters given (number of cells) . In this study, the size of the meshing has been change from coarse to finer on BWB aircraft model at 〈= 0°. Six different sizes of unstructured grids were used for flow solver FINE™/Hexa computation. The number of cells, nb represents the increasing in grid size from the coarsest to the finest. The convergence of lifts and drag coefficient with regard to number of cells is illustrated in Figure 5(a) and (b). From the result, it can be seen that the computed lift and drag force converges with increasing of grid density. It was clearly indicated at 1841955 numbers of cells; the calculation is converged.



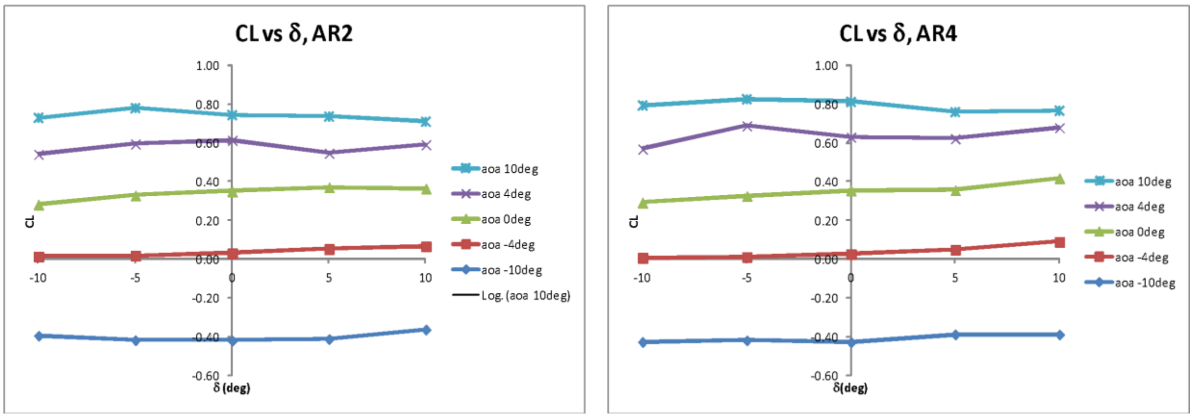
(a) (b)

Figure 5. (a) lift coefficient vs angles of attack, (b) drag coefficient vs angles of attack

3. Result and Discussion

3.1 Lift Coefficient

The lift coefficient versus canard deflection angle for each canard has been presented in Figure 6. The lift coefficient trend for the BWB aircraft with all four canard ratios almost the same particularly at a low angle of attack, 〈 = -4° to 0°. It can be observed that at angle of attack 〈= 0°, the lift coefficient of BWB with canard AR 2, 4, 6 and 8 is continuously increases as the canard deflection is increasing. The maximum lift coefficient ($C_{L,max}$) for the BWB with canard (except AR2) was 0.4 when canard was deflected to ™ = 10°. The canard with aspect ratio 2 starts to stall starting at ™ = 5°. As the 〈 increased, the lift coefficient increases. The lift performance of BWB with canard AR 2, 6 and 8 starts to decrease at ™ = 5° when the BWB aircraft is notch up to 〈= 4° and 10°. This result eliminates the ability of the canard at AR 6 and 8 to increase the lift of the aircraft. The BWB with canard AR4 however, shows the increasing of lift when the deflection is increases for each increasing angles of attacks. Therefore, this configuration has a good potential mechanism in increasing a lift force.



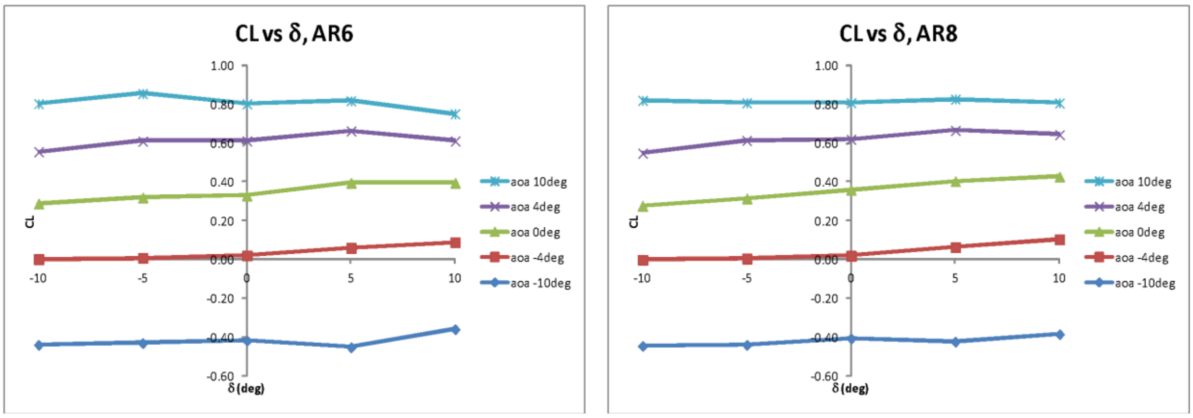


Figure 6. Lift Coefficient vs Canard setting angles

3.2 Drag Coefficient

The drag coefficient, C_D versus canard setting angles, ™ plots is presented in Figs. 7. Overall graphs show the same trend, where the drag is increases as the angles of attacks were increasing, as well as canard deflection angle. At angle of attack 〈 = 0°, the BWB with canard has an average drag (C_D = 0.04) when it ™ = 10°. However, at the same canard deflection angle, the drag was greatly increase to 0.08 (for BWB with canard AR2, 6 and 8) when the aircraft is increase to 〈 = 4°. The BWB with canard AR 4 has a lower drag that is 0.06. At angle of attack 〈 = 8°, the drag was drastically increase. This is due to the fact that, the flow on the upper surface of the canards was deteriorated.

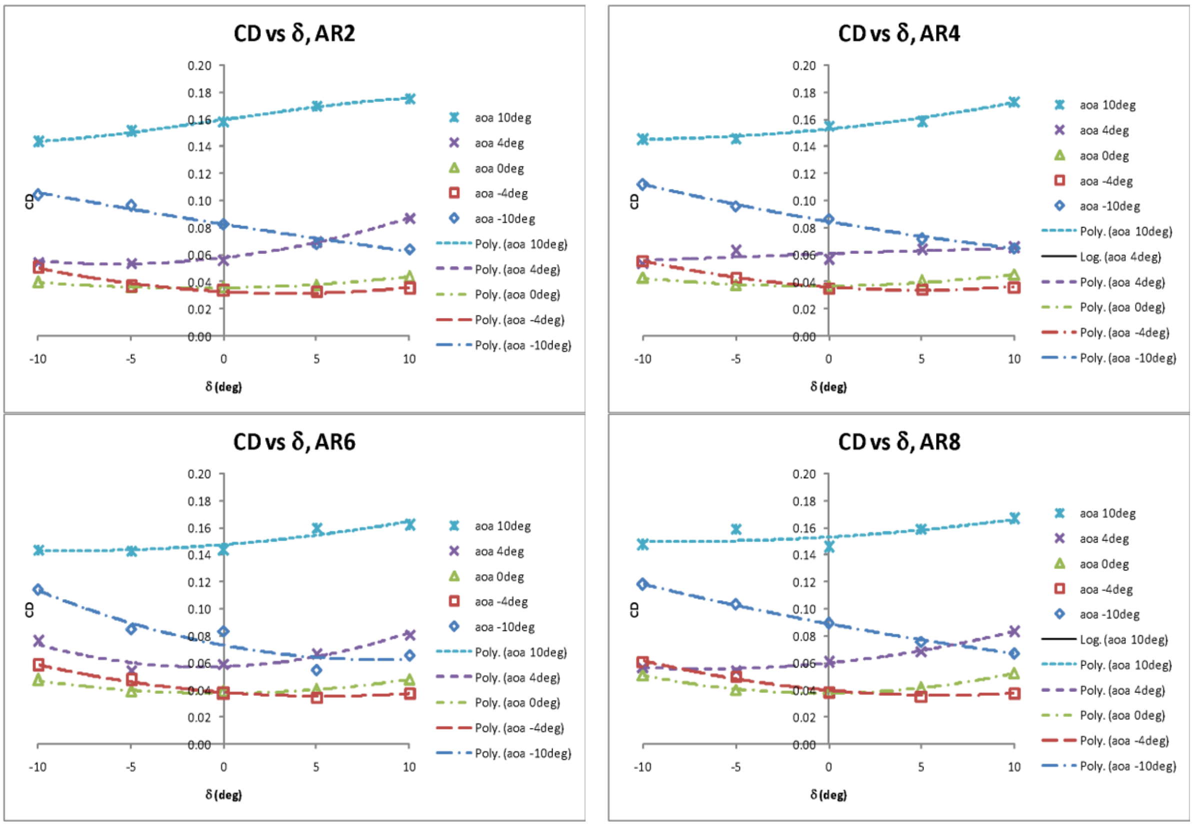


Figure 7. Drag Coefficient vs Canard setting angles

3.3 Flow Visualization

The physical flow around the BWB aircraft, particularly on the canard can be clearly seen through the flow visualization, as shown in Figure 8. From observation, it can be seen that the flow on the upper surface of canard has an increasing velocity as the canard setting angles are increased. The flow from canard is passing over the upper surface of wing and lower pressure area which indicates the high velocity, is seen near the leading edge of centre wing, as shown Fig. 8 (b). The flow is smooth and streamline around the BWB when canard is deflected to -0°, as seen in Fig. 8 (c). At d = c°, the lower pressure area starts to develop near the leading edge of canard, as shown in Fig. 8 (d). The flow at the upper surface of wing is streamline and it can be observed that the lower pressure area near the leading edge of main wing is getting bigger. The lower pressure area is getting bigger and spread to the whole wing and canard, except at the trailing edge, as the canard is increase to 3°. However, the flow is streamline and the flow at the tip of canard start to curl up to produce small vortex.

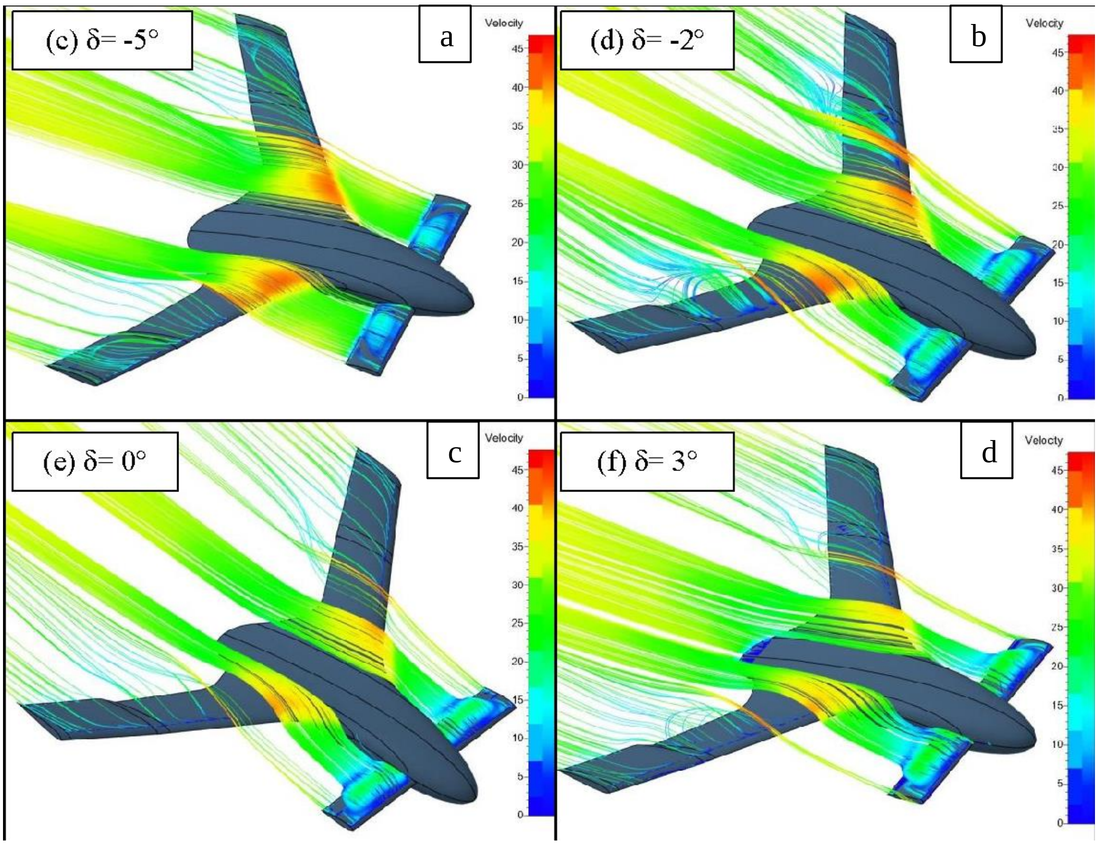


Figure 8. Flow Visualization

4. Conclusion

Aerodynamic analysis of UiTM's BWB-UAV aircraft with different canard aspect ratio was completed through CFD. The lift, drag and pitching moment coefficients were obtained and discussed. Grid independence study was performed showing almost independent results for the range of number of cells used. Parameter validation indicates the CFD results agreed with the wind tunnel test results. The lift, drag and moment coefficient has shown a similar trend among different canard aspect ratio. The results may be summarized as follows:

- The BWB with canard increases the lift coefficient particularly at higher angles of attack.
- The increasing of canard setting angle caused an increment of the lift curve depending on the aspect ratio of the canard itself.

- Canard caused a higher drag on the BWB configuration.
- The BWB without canard has a maximum lift-to-drag ratio. The existing of canard decreases the maximum L/D of the BWB. The BWB with canard AR 2 and 4 has maximum L/D compared to others when canard setting angle is not deflected. However, the L/D continuously reduces as the canard setting angle is increased depending to the canard aspect ratio

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