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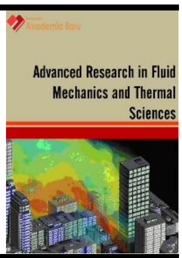

Experimental and Numerical Study on the Aerodynamics and Stability Characteristics of a Canard Aircraft

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ABSTRACT

Modern day fighter aircrafts are mostly canard configured because of its advantages over conventional configuration. The primary objective of this work is to investigate the low speed aerodynamic and stability characteristics of a canard configured aircraft. Using CFD -ANSYS Fluent package, numerical flow simulations were carried out for a typical canard configuration such as Burt Rutan's VariEze, a composite homebuilt canard aircraft. To validate the numerical results, wind tunnel testing of a scaled model was carried out. Finally the effect of horizontal location of canard on the aerodynamics and stability characteristics was studied.

1. Introduction

The first successful human-controlled powered flight by Wright Brother's was a canard-configured aircraft. Despite tail-aft designs dominated the market, the canard arrangements are still used in modern aircrafts ranging from home built aircrafts to fighter aircrafts due to their advantages. As canards provide positive lift resulting in a higher C_{Lmax} and the aircraft can be smaller with less drag and moreover it has an inherent stall-proof characteristic that can be achieved by the proper design of enabling the canard to stall earlier than the main wing.

Numerous work on aerodynamics and stabiliity characteristics of such canard configuration are reported in the literature. Handling qualities of canard aircraft was discussed in detail by Anderson [1]. Rokhsaz and Selberg [2] used vortex lattice method to study on the comparison of induced drag for canard aircraft, three-surface aircraft and conventional aircraft. Eugene [3] conducted a numerical study on the canard-wing flowfield interactions and studied the effect of canard on aerodynamic performance of canard-wing-body under steady and unsteady aerodynamics. Strohmeyer *et al.*, [4] extended a design code for design and optimization of canard for a conventional wide-body transport aircraft.

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Coiro and Nicolosi [5] designed a three surfaces aircraft model and later Coiro *et al,* [6] studied the influence of the canard surface on the aircraft's aerodynamic characteristics and flight behaviour. Guoqing *et al*., [7] studied the vortex interference mechanism at low Reynolds number between the canard and main wing of the canard-forward sweep wing (Canard-FSW) configuration. The variations of aerodynamic characteristics of Canard-FSW configurations with different positions of the canard were investigated. Rizzi *et al*., [8] used CEASIOM software to design a canard configured TransCruiser, while Zeng *et al*., [9] conducted aeroservoelastic modeling and analysis of a canard-configured air-breathing hypersonic vehicles.

Nasir *et al*., [10] has studied the effect of canard on the stability of a blended wing-body aircraft with canard foreplanes. Kim *et al*., [11] conducted a study on the estimation of stability parameters for general aviation canard aircraft. Davari *et al*., [12] has studied on the flow field structure over split canard using low-speed wind-tunnel. Recently Ghoreyshi *et al*., [13] conducted CFD simulation for flow over a canard configured TransCruiser and validated against the wind tunnel results. In the present work, the aerodynamic and stability characteristics of a canard configured aircraft is investigated both experimentally and numerically. The effect of canard on the aerodynamics and stability characteristics of a typical high-performance homebuilt canard aircraft is studied in detail.

2. Methodology

Static stability is defined as the tendency for a body to return towards its equilibrium position after a disturbance. Longitudinal stability is considered the most essential static stability mode, due to it being in the forward motion, parallel to the flight of the aircraft. Be it in wind tunnel testing, aircraft design, or flight research, longitudinal stability is more often paid attention compared to directional or lateral stability. Thus, in this work, only longitudinal static stability is considered.

A common method in this age of technology is to use computational fluid dynamics (CFD) simulation software validated with wind tunnel experiments. CFD simulations are expected to be the paramount tool in the design of modern day aircrafts. CFD predictions are now the most significant for pre-fabrication of aircraft, because flight tests are high in cost and in risk. Distinctly, it is sufficient to depend on CFD to seek the source of an unfavourable characteristic encountered during flight. Nonetheless it is a major key to validate and evaluate CFD simulations through experimental data due to CFD being subjected to uncertainties such as those which arise from the choice of its geometrical and numerical models. In the present work, CFD simulations were carried out using ANSYS R17.0 accompanied by wind tunnel experiments in a TE-45 subsonic wind tunnel at Interantional Islamic University Malaysia.

2.1 Experimental Work

The experimental work consists of a wind tunnel test which is done primarily to validate the results obtained from CFD simulations. The wind tunnel chosen for this experiment is the TE-45 wind tunnel as the study is limited to static longitudinal stability, thus only a three component balance is needed, which is available with the TE-45 wind tunnel.

The model aircraft imitates the specifications of Burt Rutan's VariEze aircraft (Figure 1) , a high-performance homebuilt canard aircraft. The model also neglects the vertical tail due to the fact that study on the longitudinal stability of the aircraft is independent of the directional stability. Also the vertical tail does not impact the investigated aerodynamic characteristics of the aircraft, which are lift and drag, although it does produce a small component of drag which can be neglected in this study.

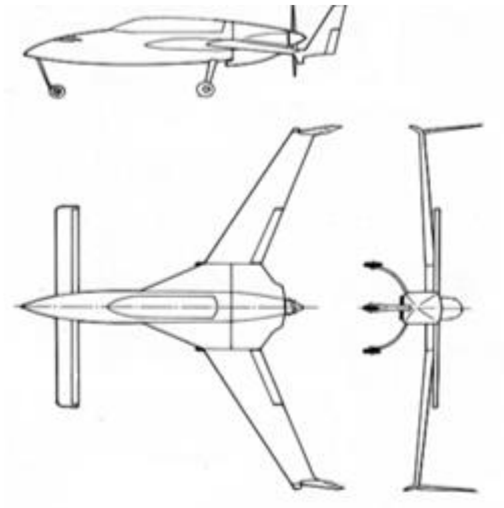

Fig. 1. Three view drawing of Burt Rutan's VariEze aircraft [17]

The airfoil used for both the wing and the canard would be the NACA 23012. However, the canard would be attached with an incidence angle of +5° with respect to the horizontal axis to provide positive lift, which will also provide positive moment. Due to this angle, the canard would be able to stall first, thus complies with the longitudinal static stability of a canard aircraft.

The model is made half along the plane of symmetry, scaled with the ratio 1:12.5 (Figure 2). This is to enable the model to fit and varied its angle of attack inside the wind tunnel (Figure 3) work space. The model is created through computer aided drawing (CAD), and then it is produced by 3D printing with ABS (Acrylonitrile-Butadiene Styrene) material.

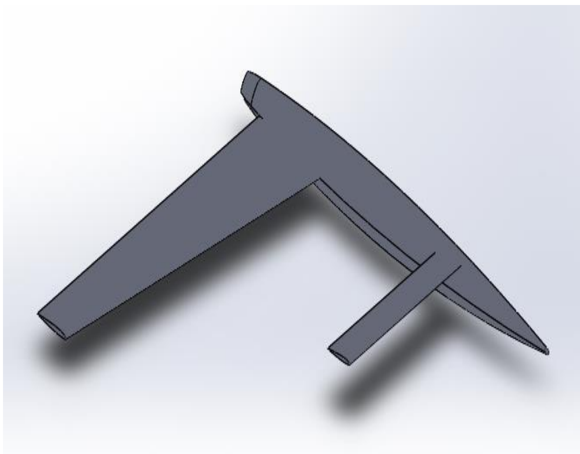

Fig. 2. Scaled (1:12.5) Half-cut CAD model of Burt Rutan's VariEze (without vertical tail)

The details of the fabricated model with a scale factor of 1:12.5 is as follows

Fuselage
- Length: 348.6 mm

Canard
- Half-span: 135.4 mm
- Chord: 25.76 mm
- Incidence angle: +5°
- Vertical position: High-fuselage

Wing
- Half-span: 270.8 mm
- Root chord: 78.48 mm
- Tip chord: 19.64 mm
- Incidence angle: 0°
- Vertical position: Mid-fuselage
- Taper ratio: 0.5

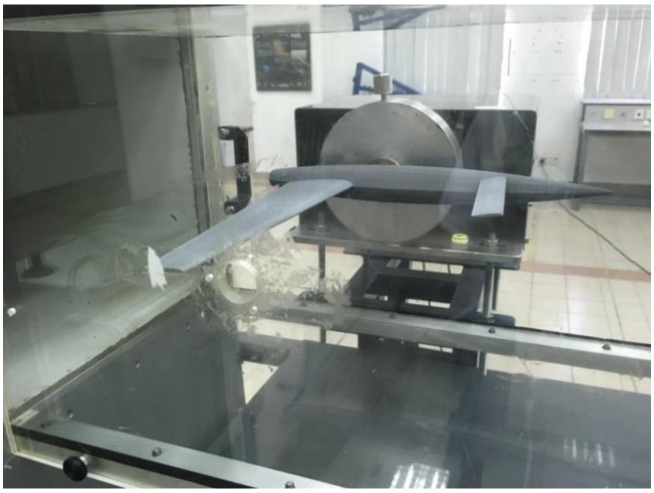

Fig. 3. 3D model mounted at 0° pitch, to a three component balance inside a wind tunnel

The scaled model's angle of attack will be varied from -25° to 25° with a 5° step. Values of the coefficient of lift, drag, and pitching moment measured from the three component balance are recorded.

2.2 CFD Simulation

For the simulation work, the same CAD canard aircraft model (Figure 2) developed was used. The model made is then imported to ANSYS Fluent for CFD analysis (Figure 4 and 5). The choice of using this software is due to its accuracy in its analysis and results. Following are the input parameters for CFD analysis

- Fluid: Air (Ideal gas)
- SST k-ω viscous model
- Ideal wall
- Density based
- Energy equation
- Temperature: 288.16 K
- Density: 1.225 kg/m^3 (sea level)
- Pressure: 101.325 kPa (sea level)
- Mach number: 0.2~0.4
- Turbulence intensity ratio: 10

The first simulation done imitates the wind tunnel experiment, with velocity 10 m/s. The angle of attack is then varied from -10° to 25° with a 5° step. Lift, drag and pitching moment are recorded. These results would be validated against the results obtained from the wind tunnel experiment.

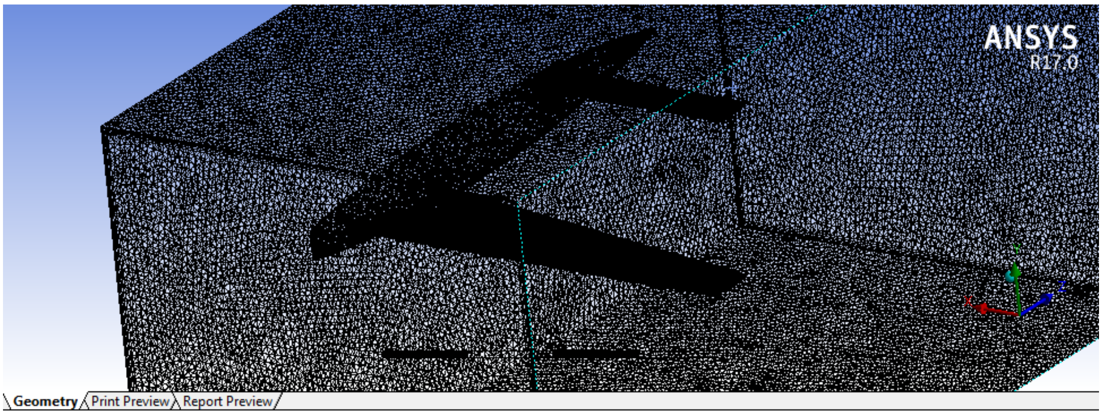

Fig. 4. Final mesh in ANSYS (isometric view)

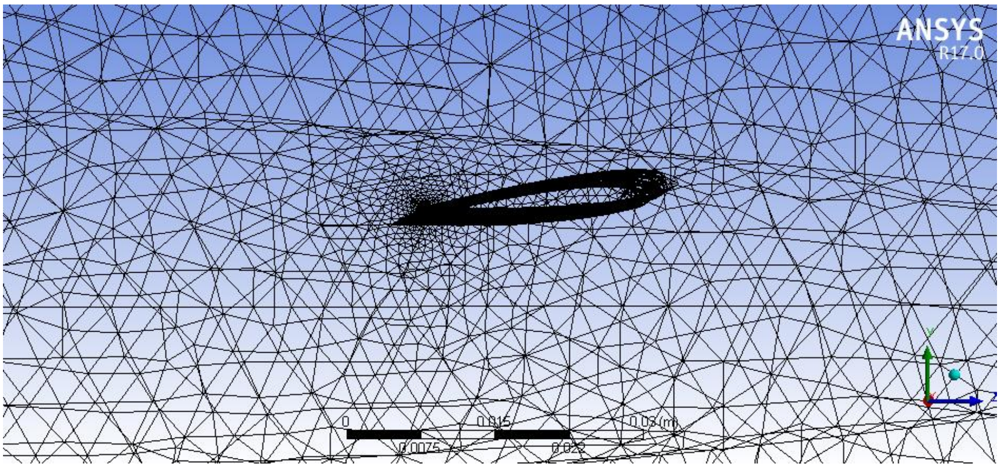

Fig. 5. A zoom-in of the final mesh of the canard. Inflation layers are observed to simulate more accurate results

Once validation done, to observe the influence of the canard on the aircraft, the first two simulations were done on an aircraft model with and without its canard. The speed of the flow is varied between ranges of Mach number 0.2 to 0.4, and the angle of attack is again varied from -10° to 25° with a 5° step. Results regarding aerodynamics and stability characteristics are again recorded. The reason for specifically choosing the range of Mach numbers between 0.2 and 0.4 is to observe the compressibility effects around Mach number 0.3, thus, results are expected to vary slightly.

Finally, the free-stream velocity is kept at a constant speed while varying the horizontal position of the canard, in other words, the distance between the canard and the wing is changed. This is done to investigate the effect of canard horizontal position on the aerodynamics and stability of the aircraft. Results from this study would also be able to trace the optimal position for a canard on an aircraft. The angle of attack is again varied between ranges -10° to 25°.

3. Results

3.1 Wind Tunnel Experiment and Simulation for Validation

Firstly to validate the CFD simulation, both the wind tunnel experiment and simulation was carried out for a velocity of 10 m/s and the angle of attack is then varied from -10° to 25° with a 5° step as discussed earlier. The distance from aircraft c.g. to leading edge of canard in this case is taken to be 130 mm.

It is observed from Figure 6 and 7, that the results from numerical flow simulation agree very well to the wind tunnel experiment results for all angle of attack except with a small error. The trend of C_m vs angle of attack (Figure 6) is exactly similar to that predicted by Anderson [1]. The graph obtained from measurements of the wind tunnel experiment may not be smooth enough due to the lack of sensitivity of the three component balance.

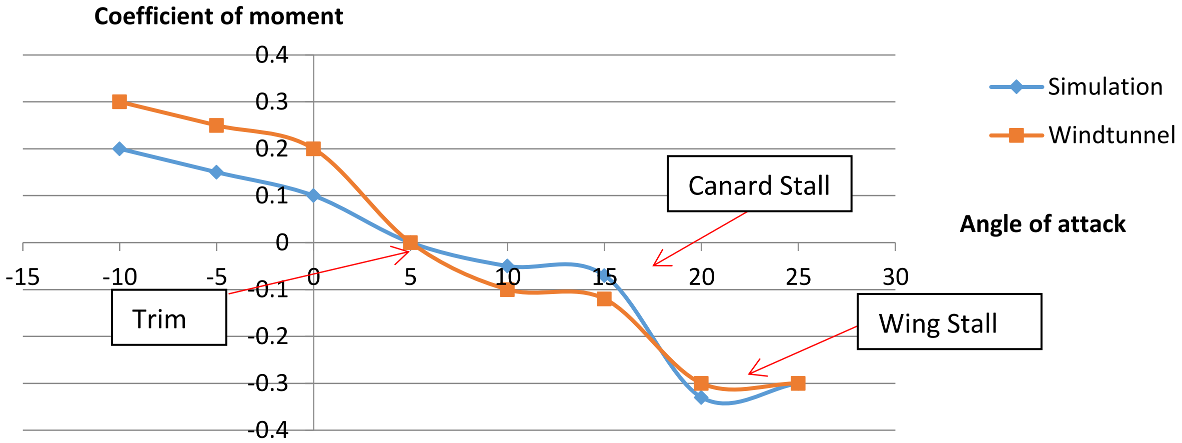

Fig. 6. Coefficient of moment, C_m against Angle of attack (°) from the simulation and wind tunnel experiment

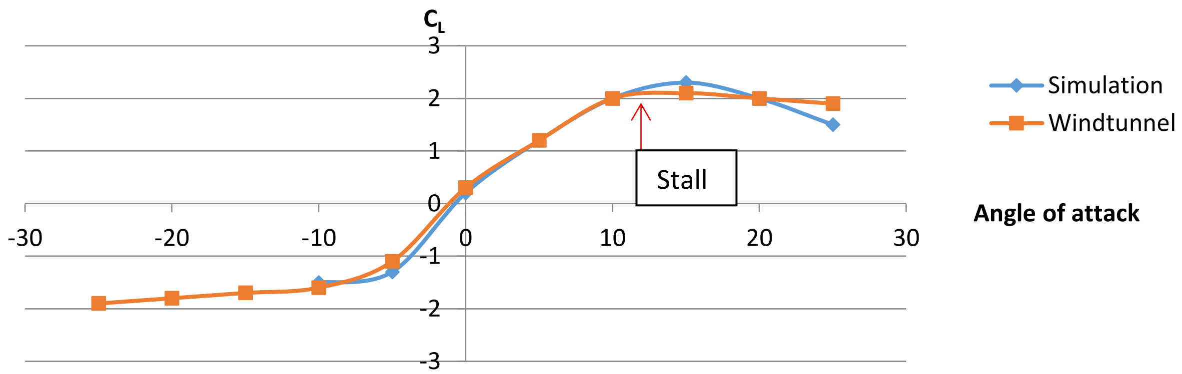

Fig. 7. Coefficient of lift, C_L against angle of attack (°) from the simulation and wind tunnel experiment

From Figures 7, it can be seen that the maximum value of coefficient of lift is 2.1 for the wind tunnel experiment and 2.3 for the simulation. This value is high compared to the airfoil maximum coefficient of lift because it is the sum of both canard and wing contribution to lift.

3.2 Effect of Canard Availability

With the CFD simulation validation done, in this section the availability of the canard is varied and its effect on the aerodynamic and stability characteristics is studied. It is clearly seen from Figure 8 and Figure 9 that the canard is providing extra lift to the aircraft, and at the same time decreasing the stability range of the aircraft whilst increasing the manueverability of the aircraft. Without the presence of the canard, the aircraft trims at 0° angle of attack. While the aircraft is reasonably still statically stable, it can be concluded from the graph that it has less control or maneuvarability.

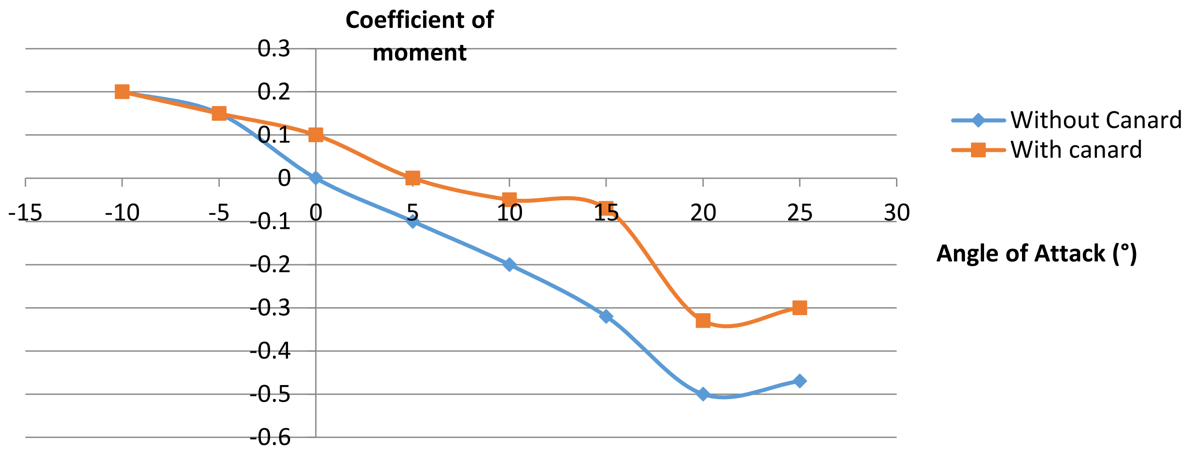

Fig. 8. Varying canard availability; coefficient of moment, C_m against angle of attack (°) from simulation

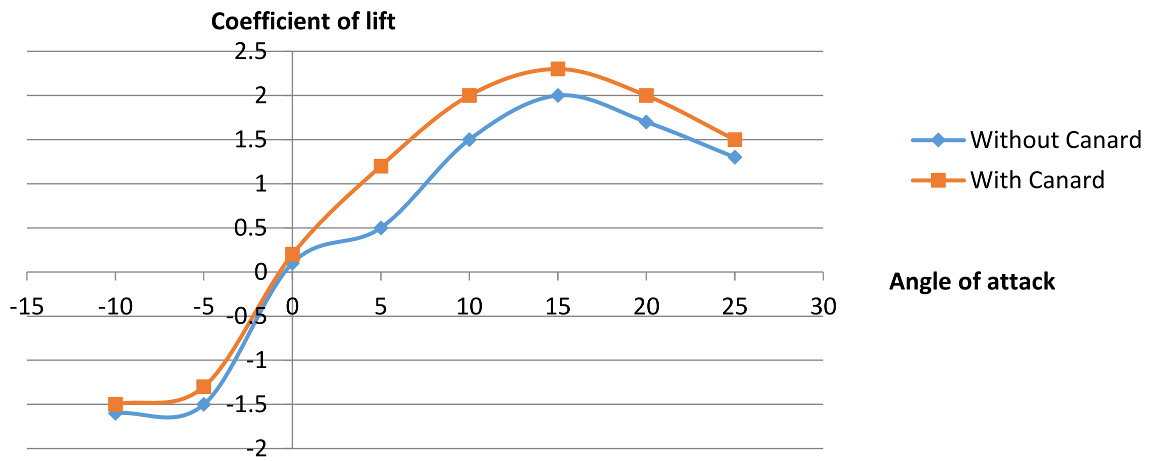

Fig. 9. Varying canard availability; Coefficient of lift C_L measured against angle of attack (°) from simulation

3.3 Effect of Speed

Next, the effect of speed on the stability and aerodynamic characteristics is studied by increasing the speed of the aircraft from Mach no < 0.2 to Mach no of 0.4. It can be seen from Figure 10 that with the increase of Mach no, compressibility effects comes into action and makes the aircraft stalls slightly earlier.

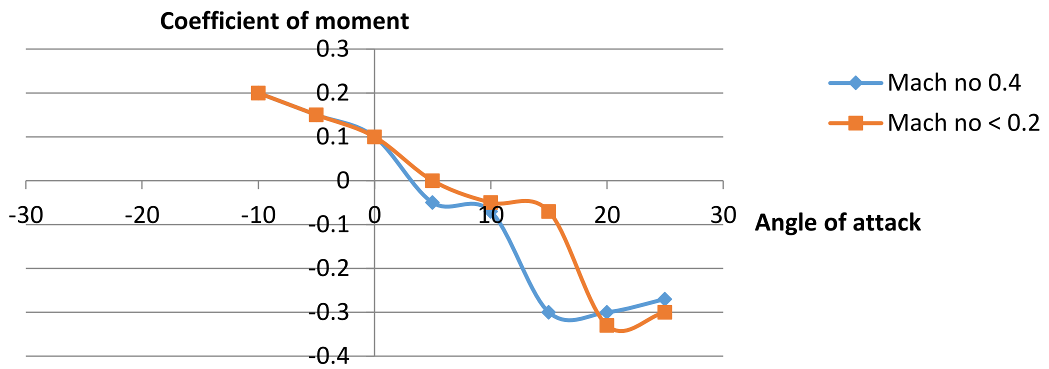

Fig. 10. Varying the speed; Coefficient of moment, C_m against Angle of attack (°) from the simulation

3.4 Effect of Location of Canard

The horizontal location of canard with respect the c.g. of the aircraft will change the moment arm and hence the aircraft stability. In this section, the distance between the leading edge of the canard and the center of gravity (cg) of the aircraft which was taken to be 130 mm in other case studies is varied i.e. it is moved horizontally both forward (140 mm) and backward (120 mm) position on the fuselage. The effect of this movement is demonstrated in Figure 11 and Figure 12.

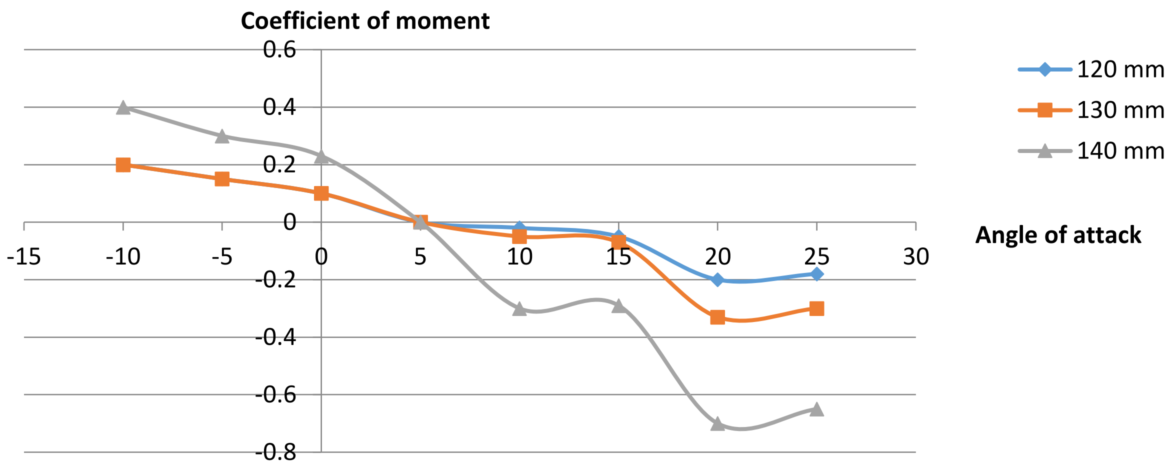

Fig. 11. Different location of canard ; Coefficient of moment, C_m against Angle of attack (°) from the simulation

From Figure 11, it is seen that as we increase the distance between the canard's leading edge to the aircraft's cg, by 10 mm, the graph of C_m against angle of attack becomes much more steeper compared to the initial graph of C_m against angle of attack. This is due to increase in the length, in turn increases the moment arm about the cg. This increases the range of stability of the aircraft, but, however it decreases the controllability of the aircraft, thus harder for quick maneuvers. But as seen from Figure 12, it increases the lift at a smaller angle although makes the aircraft stall earlier.

As we decrease 10 mm from the initial distance (130 mm) between the canard's leading edge to the aircraft's cg, it can be observed from Figure 11 that the steepness of the graph of Cm against angle of attack reduces. This means that the aircraft is easier to maneuver vertically but is slow to react to longitudinal stability. Thus, this decreases the stability of the aircraft. From the Figure 12, it is seen that decreasing this distance delays stall to a higher angle of attack.

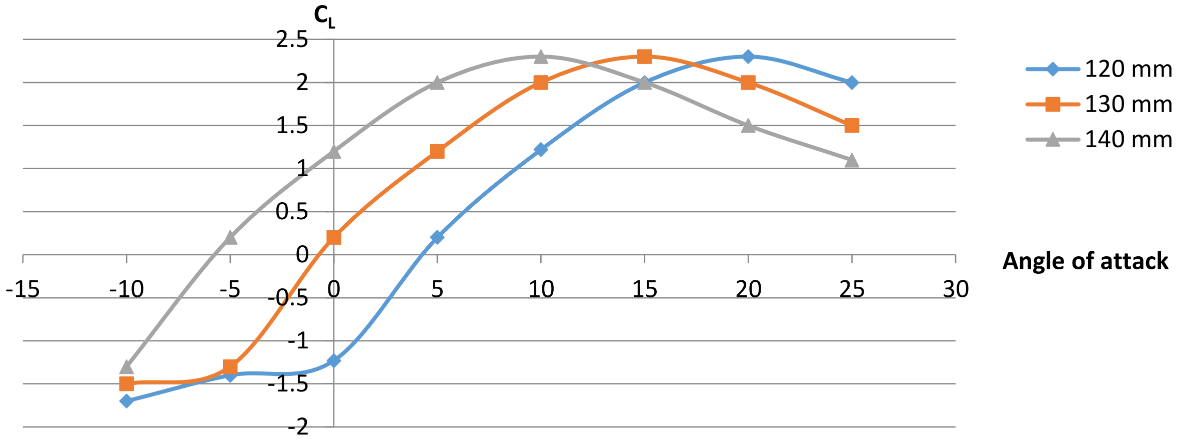

Fig. 12. Different location of canard; Coefficient of lift, C_L measured against angle of attack (°) from the simulation

The stability range and easiness of maneuverability in this discussion determines the anti-stall effect, which is said to be one of the advantages of a canard aircraft. The response of the magnitude of moment when angle of attack is varied is considered as the anti-stall effect. Higher magnitudes give the aircraft a better anti-stall effect. However, it reduces the ease of maneuverability of an aircraft.

4. Conclusion

In the present work, an experimental and numerical study on the stability and aerodynamics characteristics of a canard aircraft configuration has been carried out. The results from CFD-ANSYS Fluent package agree well with wind tunnel based experimental results.

The results prove that the canard configuration provides a positive lift with a higher C_{Lmax} and also, with adequate configurations, an anti-stall effect. However, installing a canard on an aircraft leads to longitudinal stability problem which can be handled easily with latest modern technology.

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