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Abstract- This study investigates the viscous skin friction drag generation due to the three different vertical canard locations on the mid winger un-swept aircraft scaled-down model by using boundary layer measurements in the wind tunnel. The N22 airfoil was selected for the canard and the modified S1223 airfoil was selected for the wing. The laser cutting technique was employed for the fabrication of the wing, and canard airfoils, which gave sufficient dimensional accuracy to the model. The canard, wing, and fuselage were fabricated by balsa wood and strengthened by Aluminum stripes. The assembled model is tested in an open subsonic wind tunnel a fixed chord Reynolds number $3.8*10^6$. The boundary layers were measured at 70% of the chord and at three different wingspan locations i.e. 30%, 60%, and 90% with 0^0 incidence angle. The canards were positioned at three vertical positions one at fuselage reference line (FRL) and the remaining two locations at ± 0.16 c from the FRL. The results were compared with wing-body alone and with three canard locations and found that the high canard configuration outperformed the other two configurations and also wing-body alone configuration as it provides half of the total drag. However, the high canard produces 15% more drag than the wing-body alone at the wing tip (90%).The aerodynamic performance of the high canard configuration was found to be significantly promising for the future use in drones and other small aircrafts.

Keywords: Airfoil, Canard vertical location, Boundary layer, Un-swept wing, Skin friction drag.

1. INTRODUCTION

Canard is the configuration of the aircraft in which a small wing is placed ahead of the main wing. Canard configuration is the oldest configuration used by Wright Brothers in their first flight in year 1903. The substantial advantages of the closed-couple canards were investigated by Behrbohm[1] in 1965 and found that maximum lift coefficient can be obtained with high stall angle. The effects of short coupled canards and effects of varying planform have been studied extensively by US Navy and NASA to find practicable solutions to use in warships and aircrafts [2-4]. The controlling capability of the canard configuration were investigated and compared with the conventional horizontal tail configuration [6,7]. The aerodynamic effects of such configuration at high angles of attack beyond the stall angle were investigated [8, 9]. The investigation to understand the flow physics of the Vortex flow over the short-coupled canard and wing configuration were carried out experimentally[10, 11].

Effects of canard configuration on the wing body of aircraft have been studied by computational methods since many decades. The Euler equations have been used [14] and the Navier Stokes (N-S) computational simulation results for this configuration were performed [12, 13,15]. It was observed that there is a considerable discrepancy between experimental data and computational results for the larger angles of attack. The primary cause may be the canard vortex not properly represented during the numerical approach. The recent computational studies performed to find the stability aspects of the canard in a blended wing body configuration as this type of aircraft lag in lateral stability due to absence of vertical tail [16]. Many numerical studies were performed to examine the applicability of N-S equations to predict the aircraft performance in viscous regime. [17] has developed a 3-D unsteady N-S analysis technique and [18] has used a steady state one equation turbulence model , Spalart-Allmaras.

The University of Teknoloy, MARA has started work to steady the blended wing configuration from 2005 onwards. The unsteadiness of the blended body made the researchers to adopt the canard wing ahead of the main wing in baseline model I, and II to have a better control of the airplane. After that number of numerical and experimental work have been done to find the trim condition [19]. A recent work has predicted the effectiveness of canard by varying its aspect ratio using experimental and computational work [20, 21]. It is found that the all these researchers worked for the lift or stability aspects but no one work to find the viscous drag which contribute to 50% of the total drag. Also the quantity of viscous drag contribution in different span location of the wing due to canard was not investigated by any researchers.

The present work is intended to find the effect of canard vertical locations on the wing body configuration on the viscous drag arising due to boundary layer zone. For this the experimental work is performed in a subsonic wind tunnel by installing canard at three different vertical locations and measuring the boundary layer velocity gradients at 30, 60 and 90% of the wingspan, and at 70 % of the chord to get the insight of the drag produced by the aircraft wing and the maximum drag producing span zone so that future best model configurations can be selected for the drones or any other flight vehicles likely to fly in this Reynolds number.

2. METHODLOGY

2.1. Experimental Setup and the procedure

2.1.1. Mathematical Formulation

Near the solid surface, due to high viscous effects, the velocity gradients (du/dy) become significant. This region near solid boundaries where the frictional effects are dominant are called boundary layers. Generally, for streamlined bodies, the boundary layers are enormously thin. Though the boundary layer is thin, it influences the fluid flow behavior and generation of drag over the body. The aerodynamic performance of a flying object depends on the thickness of the boundary layer and its effect on the main flow. Boundary layers may be defined as the distance, δ normal to the surface, in which the flow velocity rises from zero to some specified value (e.g., 99%) of its local mainstream flow. The velocity of the fluid at the surface of the airfoil is zero. This is called the no-slip boundary layer condition of the flow. The local shear stress (τ) is related to the velocity gradient ($\frac{\partial u}{\partial y}$) normal to the surface as given in equation1.

$$\tau = \mu(du/dy) \tag{1}$$

Where μ= fluid viscosity, τ= local shear stress, du/dy = velocity gradient. The friction drag coefficient (c_f) is related to the wall shear stress (τ_w) and inversely related to the free stream flow velocity (V_∞). The skin friction drag coefficient is related to wall shear stress (τ_w) as given in equation 2. In this work the velocity gradient du/dy is measured by using boundary layer rack over the model main wing by fixing it in side the wind tunnel.

$$C_f = (\tau_w / (0.5^* \rho V^2_\infty)) \tag{2}$$

2.1.2. Model aircraft and dimensions

Scaled down (4:1) aircraft model and its dimensions used for the wind tunnel testing is shown in figure 1. The selected airfoil profiles of the canard is N22 and the airfoil of the wing is modified S1223. These airfoils are taken after doing analyis in XFL5 software. The modification of the S1223 is done to make its trailing edge thicker than the original airfoil, so that it's strength is inceased and also it's fabrication becomes easier than the original airfoil profile. The maximum thickness of modified S1123 is 12.13% of chord and the maximum camber is 8.67% of chord.

The figure 1 shows the mid wing and mid canard position of the fabricated model. The canard airfoil N22 and wing modified airfoil S1223 is shown in figure 2.

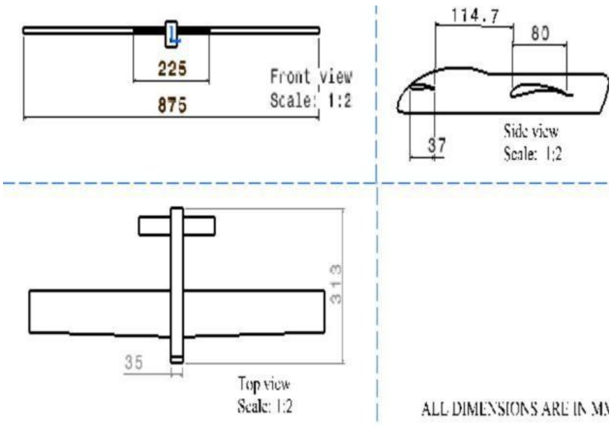

Figure 1. Three view drawing of sweep wing aircraft model

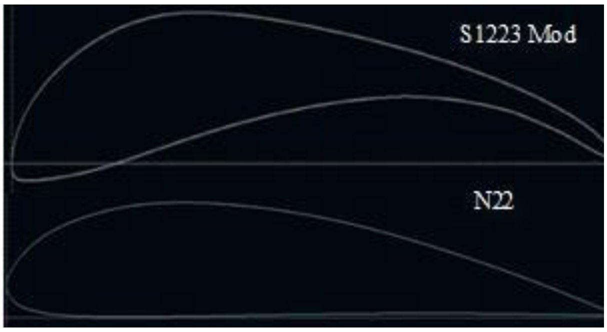

Figure 2. Wing airfoil S1223M and canard airfoil N22

2.1.3. Model fabrication

The configuration of the main wing with a taper ratio of 0.89 was chosen since a tapered configuration adds the advantage of both elliptical and rectangular configurations. One of the important factors for foreplane configurations is to ensure that the canard should stall before the main wing, to ensure control on the aircraft in case of higher angles of attack flight. For this reason the aspect ratio of the wing was given 5 and for the aspect ratio of the canard it was 6. The material used for the fabrication of the model was balsa wood, which is light in weight and having sufficient strength to sustain the airpressure and wing loading inside the wind tunnel during high wind flow and during real flight testing of the aircraft model during flight. The wing, canard, and fuselage were fabrictaed using balasa wood and the longerons were fabricated by aluminum pipes for providing sufficient strength to sustain in wind tunnel and during flight tesring of the model. The airfoils (N22 and S1223 M) were fabricated using laser cutting on a 4 mm balsa wood sheet. These airfoils were mounted by hollow aluminum rod for strength, later a 1mm sheet of balsa is applied over them as shown in figure 3. The fuselage is also made through laser cutting by the same material and the wing, canard are joined with using adhesives, scews and fasteners.

Figure 3. Fabricated aircraft model with canard, wing, and fuselage

2.1.4. Experimental Setup

An open subsonic wind tunnel was used to find the boundary layer velocity gradients of a scaled-down model (4:1). To conduct the experiments on an aircraft model in the wind tunnel the Reynolds number of the full-scale model and the scaled model was made the same. The experiment was conducted by considering the Reynolds number and is given in equation 3.

$$R_e = ((\rho V L) / \mu) \tag{3}$$

Where, ρ is density (Kg/m^3), V is flow velocity (m/s^2), L is length (m), μ is viscosity (Nm/s^2). The calculated Reynolds number (Re) = $3.80*10^6$, taking free stream velocity 35 m/s, chord length 0.0875 m, and kinematic viscosity at 30^0 C is $0.80*10^{-6}$.

The boundary layer rack is used to measure the velocity gradient (du/dy) and boundary layer thickness. The model along with rack is shown in figure 4, fitted inside the wind tunnel. The boundary layer rack vertical distances (y) with probe numbers are given in table 1. The velocity gradient measured at 70% of the chord from the leading edge and at three different span locations i.e. 30% , 60% and 90% of the wing taking root as the reference point for the distance measurements.

The configuration of the model was mid un-swept wing with three vertical canard locations. The centerline of the aircraft passing from the aircraft center of gravity from nose to tail is call fuselage reference line (FRL). The three locations of the canards were at center or on FRL and at 0.16 chord (c) above and below the FRL called ±0.16c. The boundary layer measurement is followed as per Dwivedi and Sudhir Sastry, 2019 [22] and Dwivedi, 2020 [23].

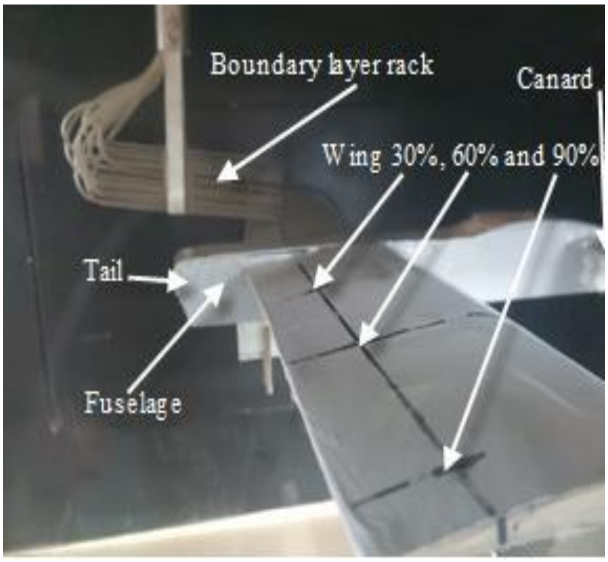

Figure 4. Boundary layer rack with a wing model

Table 1. Distance with probe number

Tube Number	Distance (mm)
1	0
2	1.5
3	2.5
4	4.5
5	5.5
6	7.0
7	8.5
8	10.5
9	12.0
10	14.5

3. RESULT AND DISCUSSION

The skin friction drag coefficient (c_f) is directly related to the wall shear stress (τ) and velocity gradient (du/dy) as given in Equation 1 & 2 respectively. Results are given in the following paragraph. The experiments conducted at Re $3.8x10^6$, for mid wing configuration by changing canard to three vertical locations. First case high canard, mid unswept wing, second case mid canard with mid unswept wing and third case low canard and mid unswept wing. Also a case was taken without canard with mid wing condition. The results and discussions are given in the following paragraphs.

3.1 Comparison of velocity gradients at 30% of the span of mid un-swept wing with three different canard vertical location

The result shows that at 30% of the span the non dimensional velocity gradient of the the high canard shows 15%, witout canard shows 20%, low canard shows 24 % and the mid canard shows the highest 24% of velocity gradients (Fig.5). This shows that the high canard with mid un-swept wing produces the best results as the viscous drag is the least in this configuration, followed by without canard and the worst result is given by mid canard and the mid unswept wing configuration.

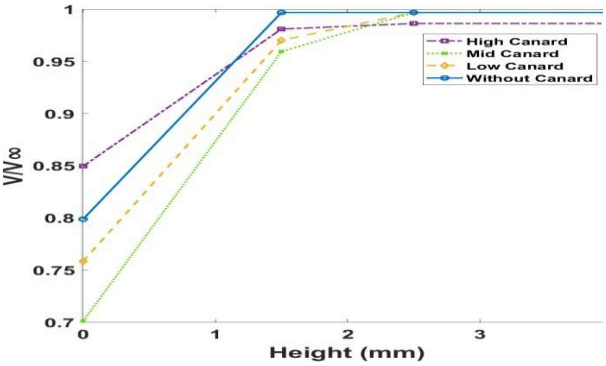

Figure 5. Variation of the velocity with boundary layer height for mid unsweep wing with a high, mid, low, and without canard configuration at 30% of the wing span.

3.2 Comparison of velocity gradients at 60% of the span of mid un-swept wing with three different canard vertical location

The high canard configuration at 60% of the wing span shows the non dimensional velocity gradient is 14%, for low canard configuation the velocity gradient is 15% and for the mid canard and the wing alone without canard configuration the velocity gradient is 18% (Fig.6 as the without canard and mid canard results are overlapping so green line not visisble). This shows that the high canard with mid un-swept wing produces the least velocity gradient in this configuration, followed by low canard and the worst result is given by mid and without canard wing alone configuration. The highest viscous drag at 60% of the span is obtained without canard configuration.

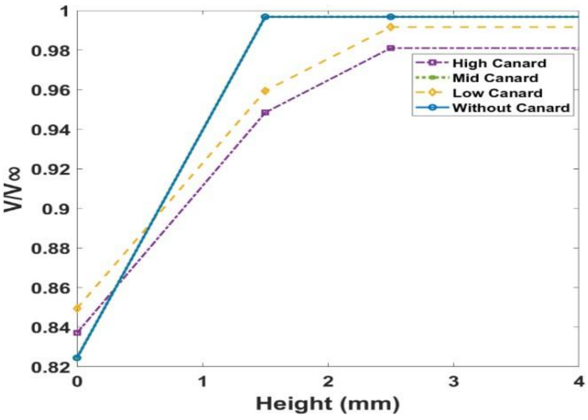

Figure 6. Variation of the velocity with boundary layer height for mid unsweep wing with a high, mid, low, and without canard configurations at 60% of the wing span.

3.3 Comparison of velocity gradients at 90% of the span of mid un-swept wing with three different canard vertical location

The low canard configuration at 90% of the wing span shows the non dimensional velocity gradient is 15%, for without canard configuration the velocity gradient is 16% and for the high canardshows 18% and the the mid canard configuration the velocity gradient is 19% (Fig.7). This shows that the low canard with mid un-swept wing produces the least velocity gradient and hence the lowest skin friction viscous drag, followed by without canard and the worst result is given by mid canard configuration. The highest viscous drag at 90% of the span is obtained in the mid canard configuration.

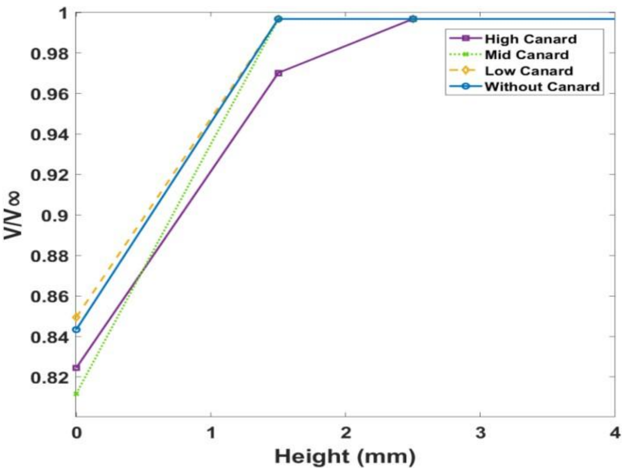

Figure.7: Variation of the velocity with boundary layer height for mid unsweep wing with a high, mid, low, and without canard configurations at 90% of the wing span.

4. CONCLUSIONS

Wind tunnel experimantal analyis of the three canard vertical locations i.e. at center and ±0.16 of the chord length up and down from the ceneter line with mid un-swept wing with wind velocity 35 m/s. The velocity gradients measured at 30% , 60% and 90% of the wing span. Following conclusions are drawn.

1. At 30% and 60% of the wing span the amount of velocity gradient for the high canard configuration is lowest than other canard and wing alone configuration. This shows that the high

canard configuration with mid wing un-swept wing gives the lowest drag and hence best aerodynamic performance (highest L/D).
2. The wing alone configuration i.e. without canard produces highest velocity gradient in 30% of the span produces 100% more drag in comparison with high canard and at 60% of the wing span location the wing alone produces 23% more drag.
3. However, at 90% wing span the low canard and wing alone produces nearly 30% less drag than the high and mid canards position. Its due to wing tip vortices at the wing tips are less in low and wing alone configurations.

The results shows that the more than 80% of the wing span produces significantly less drag in high canard and mid un-swept wing configuration. This shows that if the aircraft model is made with high canard and mid unswept wing will give best results for the tested Reynolds number of $3.8x10^6$ or at the wind velocity of 35 m/s. The tip of the wing in high canard configuration produces 15% higher drag than the wing alone configuration. This need the modification of the wing tip from 80% to 100% span so that this disadvantages can be eliminated by some innovative desigh or winglet installation.

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