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An Experimental Investigation of the Effects of Canard Position on the Aerodynamic Forces of a Fighter Type Configuration Model

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An extensive experimental investigation is conducted to study the effect of canard position relative to the fuselage reference line on the aerodynamic forces of a fighter type configuration model. Aerodynamic forces at different flight conditions are measured in a subsonic wind tunnel. The wing and the canard have triquetrous shapes. Experiments are conducted at Reynolds number of 342209 and at 0 to 40 degree angles of attack. The results show that canard increases the lift and drag forces while it decreases the static stability of the model. The canard at its up position increases the aerodynamic forces and decreases the static stability, i.e. superior maneuver capability. Furthermore, when the forward position of the canard is considered, both lift and drag are increased; moreover, the overall aerodynamic efficiency and also the static stability are improved. The canard at up and forward position with respect to the wing-body is an appropriate choice for the best performance at moderate to high angles of attack from among the various wing-canard-body configurations.

Keywords*: Fighter Model, Wind Tunnel, Delta Wing, Canard Position, Maneuverability.*

Nomenclature

M_∞	free stream Mach number
V_∞	free stream velocity
R_e	Reynolds number
C_r	wing root chord
α	angle of attack
C_L	lift coefficient
C_D	drag coefficient
$C_{M_{c.a}}$	pitching moment coefficient

1 Introduction

Several different ideas and configurations have been suggested for improving the maneuverability of fighters in their flight envelops. The Canard is a significant device that dictates high aerodynamic efficiency especially when the aircraft operates at high angles of attack. The first human-powered flight was skilled with a canard-configured aircraft in 1903 by Wright Brothers [1]. Behrbohm [1] in 1965 found out that a close-coupled canard configuration has considerable advantages. A wide variety of canard designs have been proposed over the years with varying degrees of success. The number of aircraft utilizing canard arrangement has increased significantly since1985, starting from the home-built and carrying on to the military fighters and short-haul commuter designs (e.g., Anderson et al. 1985) [2]. One of the first fighter delta configurations to use the close-coupled canard is Saab Viggen. This aircraft required high Mach number performance for its interceptor role combined with good low-speed capability to allow its use on short runways or roads in Sweden (e.g., Anderson et al. 1985). Many modern aircrafts utilize canards for maneuver control and improved aerodynamic performance. Mikoyan Mig-8, XB-70, SABB 37 Viggen, Rutan's-long EZ, X-29, Euro Fighter Typhoon, Rafale, X-31, XFV_12A, J-10, Saab Gripen, Beech Starship, Su-35, Atlas Cheetah have delta/canard layout[2].

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ing the aerodynamic advantages of a closed-coupled canard configuration while minimizing its disadvantages [3]. Numerous sources have shown a considerable delay in flow separation of the wing upper surface attributed to the canard. The premature tip stall of the canard would result in a forward shift of the canard aerodynamic center and a reduction in the hinge moment with high canard lift coefficient. This would be perceived by the pilot as a reduction in the stick force [3].

The addition of canard of an aircraft increases the maximum lift coefficient and delays the stall angle of attack. This advantage mainly results from the favorable interference between the canard and wing (e.g., Anderson et al. 1985 and Soltani et al. 2009) [2, 21].

An experimental study of a closed-coupled tandem wing configuration at low Reynolds number was conducted by Scharpf et al. (1990). Results for a Reynolds number of 0.2×10^6 showed that downwash from the canard appeared to be the most significant factor in altering the performance of the wing [5].

Computational study using the thin-layer Navier-Stokes equations was used to solve the flow aournd a close-coupled canard wing- body configuration at $M_\infty = 0.9$ and at angles of attack ranging from 0 to 12 degrees(e.g. Eugene, L.,T.,1990)[6].

The effect of canard on delta wing vortices was investigated in a water tunnel at Wichita state university [7]. The Results of this research showed that there was a delay in the vortex breakdown due to the presence of the canard and the dynamic pitch motion. The most favorable delay was obtained when the canard was located closest to the main wing and the model was pitched up at a fast rate or pitched down at a slow rate (e.g. Myose et al. 1997)[7].

Effects of wing and canard sweep on the lift enhancement of the canard configurations are studied by Ma et al. (2004) [19]. These results indicate that the lift enhancement of the canard configurations is substantially affected by the wing sweep [19].

The canard-induced downwash was found to weaken or delay the formation of the wing leading-edge vortex. These results confirmed the potential of canard for delaying the wing vortex breakdown which has been also documented in numerous other experimental studies (e.g. Soltani et al. 2009) [21].

The effect of canard interference on the loading of a delta wing is studied by Er-El (1987). The results showed that suction induced by the wing vortices decreases in the apex region and increases in its downstream. When the canard sweep angle is sufficiently large, the canard vortices induce suction directly on the wing upper surface [4].

Authors in their previous study (Soltani et al. 2009) investigated the flow field of canard and wing in a subsonic wind tunnel at different angles of attack by using seven holes probe [21]. They were able to predict the velocity profile on the delta wing with and without the canard by means of a neural network. Their results show that the canard downwash passes over the main wing surface, and causes a reduction of the pressure over the wing surface. These phenomena delay the model stall angle of attack; hence the performance of the model is increased [21].

Soltani et al. (2010) explore the effect of canard position on the wing surface pressure [22]. Their results show a remarkable increase in the wing suction peak for the canard-on configurations. They found that among different vertical positions of the canard, the mid-canard configuration developed a higher suction on the wing surface, while at high angles of attack, the upper-canard was found to induce the most favorable flow field on the wing. Furthermore, for the different horizontal positions of the canard, higher suctions were achieved on the wing at moderate to high angles of attack as the wing-canard distance was increased, i.e. the forward position of the canard [22].

The aforementioned researches as well as other studies (e.g. Hummel et al. 1989; Mcgeer et al. 1983; Bandyopadhyay 1990; Khan et al. 1991; Hummel et al. 1994; Howard et al. 1994; Sigal 2001; Pandya et al. 2001; Mitchell et al. 2001 and Liu et al. 2006) indicate that many experimental and numerical studies have been conducted on a canard configuration. The experimental studies are generally divided into two categories, i.e. force measurements to find practical configurations, and the flow mechanism studies of the lift enhancement based on the pressure measurement, flow visualization, etc. [8-14, 16-20].

In this study, a series of experiments were performed to study the effects of different canard settings, i.e., up, mid or down, and also rear, mid or forward positions, on the aerodynamic forces of a fighter type configuration model. Aerodynamic forces at different flight conditions and different canard settings were measured in a subsonic wind tunnel. The used wing and canard for this study have triquetrous shapes with flat leading edges.

2 Experimental Set up and Test Procedure

2.1 Model

Fig.1 shows a sketch of the model used for the present investigations. The experiments have been done on a canard-wing-body configuration. The flat 62-deg swept canard is placed in front of the main delta wing. The model has a replaceable conical nose with 15 deg angle, a circular body with a diameter of 76 mm and a length of 663 mm as well as a flat plate cropped delta wing. The wing has a leading edge sweep angle of 62°, a trailing edge sweep angle of 0° and thickness of 15 mm. Moreover, the wing aspect ratio is 2.2, with a half span of 142 mm and its mean aerodynamic chord is 187.87 mm. The selected wing is attached to the middle part of the body with an incidence angle of 0°. The model is installed on a 6-component balance through an appropriate strut. The canard has a triangle shape with a thickness of 7 mm and aspect ratio of 2.81.

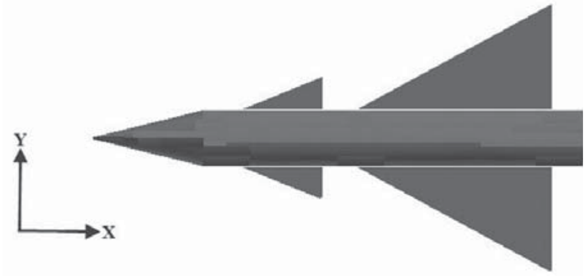

Figure 1. Schematic of the model.

2.2 Wind tunnel

The experiments are carried out in a subsonic wind tunnel in Iran. The tunnel is of closed return type and has an opened circular test section with the diameter of 50 cm. A maximum air speed of 50 m/s in the test section is achievable. The flow quality of the wind tunnel is very high and hence acceptable. The turbulence intensity of the wind tunnel at this speed is almost equal to 0.1%. A schematic of the wind tunnel is illustrated in the Fig.2.

Figure 2. Schematic of the wind tunnel.

2.3 Balance System

The aerodynamic forces and moments are measured with a six-component external balance capable of measuring lift, drag, and side force as well as 3-component moments. Data are recorded via a 16 bit A/D board capable of sample rates up to 100 KHz. The balance has 6 strain gages in 6 different positions so that they sense the forces and moments of the model in voltage form. The voltages are amplified and recorded on a PC. At the next stage, these data are reduced to forces and moments by consideration of calibration coefficients of the balance. The details of calibration procedure of the balance are reported by Aelaei M [15] (1997).

3 Experimental Procedure

The role of canard on the efficiency of a delta wing is investigated by measuring the aerodynamic forces and moments for the following cases:

- Case I: only wing; clean configuration
- Case II: different vertical positions of the canard with respect to the wing, i.e., up, mid or down, as shown in Fig.3.
- Case III: Different horizontal positions of the canard with respect to the wing, i.e., forward, mid and rear, as shown in Fig.3.

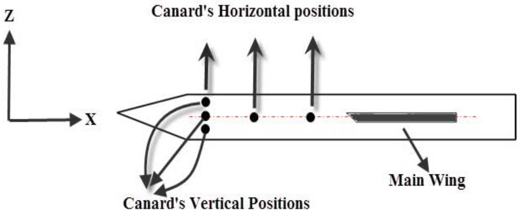

Figure 3. Different vertical and horizontal positions of the canard with respect to the main wing

A free stream velocity of V_∞=30 m/s is used thru the course of these experiments. It corresponds to a Reynolds number of 342209, based on a mean chord aerodynamic (MAC=187.87mm). The angle of attack of the model varies from 0 to 40 degrees with a step of 5 degrees. The canard is arranged at 15 mm above or beneath the wing for case II.

4 Results

As indicated, the main purpose of the present work is to explore the role of the canard in improving the aerodynamic forces and also the maneuverability of aircraft. The results for all cases are presented in the following sections.

4.1 Results for case I

Fig.4 depicts variations of the lift coefficient with angle of attack for the main wing with and without the presence of the canard. Here, the canard is installed at the mid section of the wing-canard configuration. It is obvious that with an angle of attack equal to 5 degrees, the formation of the leading edge vortex on the main wing has caused non-linear variation of CL with α. These vortexes become stronger with the increase in the angle of attack and will occupy the entire upper surface of the wing. Therefore, the lift will be improved. The main wing stalls at an angle of attack of about 34 degrees.

Beyond this angle of attack, the lift is reduced due to the bursting of the vortices covering a large portion of the wing surface.

Fig.4 also shows that, when the canard is installed, the lift of the wing is increased for angles of attack of 12 degrees and higher. This increase is due to the downwash of the canard that passes over the entire surface of the wing and interferes with the wing leading edge vortices and amplified the vortex zone over the wing surface. In this case, the stall angle of attack of the main wing increases to about 36 degrees. This finding is in agreement with the results presented by Hummel et al. (1989) [8]. One possible conclusion is that this advantage is due to the favorable interference between the vortex system of canard and those of the wing.

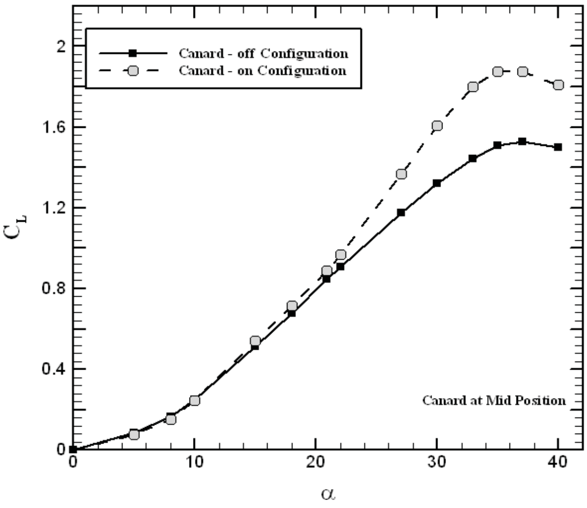

Figure 4. Variation of lift coefficient with angle of attack.

The variations of the drag coefficient with angle of attack for the wing with and without the canard are shown in Fig.5. The results show that the drag coefficient increases for angle of attack of about 20 degrees and above for lower angles of attack, but at a higher angle of attack the canard increases the drag extensively. This growth to some extent is due to the parasite and induced drag.

Results for case I show that the canard has a very effective role in the performance characteristics of a fighter model. This effect is due to the remarkable increase on the wing suction peak for the canard-on configurations. In other words, canard induces a non-uniform distribution of local angles of attack on the wing surface, which leads to a non-conical vortex formation over the wing and delays the vortex breakdown to higher angles of attack. As a result, the wing produces an up wash field on the canard that increases its lift. (E.g. Soltani Et al. 2009; Soltani Et al. 2010 and Hummel ET al.1989) [21-22, 8].

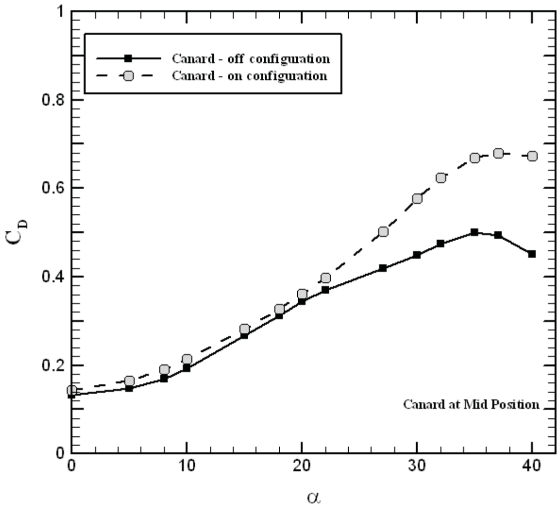

Figure 5. Variation of drag coefficient with angle of attack.

4.2 Results for case II

In Fig.6, variations of the lift coefficient with angle of attack for different canard vertical locations, i.e., up, mid and down are compared with each other. The canards are installed on the main wing at 15 mm above and under the main wing reference line for up and down configurations. respectively. It can be seen that the canard at a high position significantly affects the lift of the model. In this case the maximum lift coefficient, $C_{L\ max}$ as well as the corresponding angle of attack $\alpha_{c_{Lmax}}$ are higher than those for clean and down configuration cases. For a high canard location, the induced downwash of the canard passes over the wing more than the other two locations and it could be concluded that the benefits of the canard are largest for a high canard location (e.g. Soltani et al. 2010)[]. The minimum amount of the lift obtained when the canard was attached at the mid location due to the decreased effect on the formation and position of wing vortices.

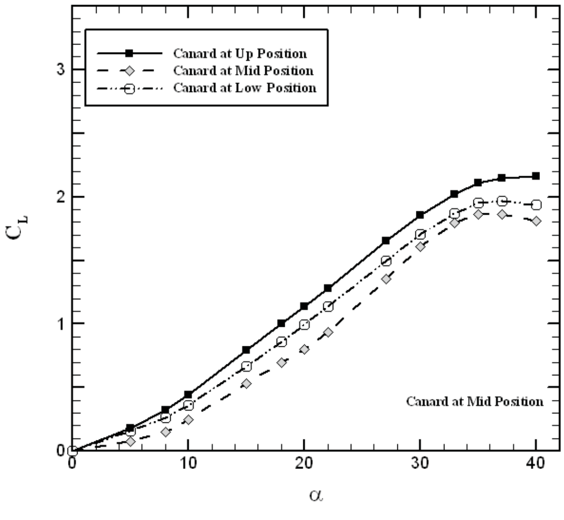

Figure 6. Effect of canard position on the lift coefficient.

Fig.7 reveals variations of the drag coefficient with angle of attack for different vertical positions of the canard. The results show that for every angle of attack, the minimum and maximum of drag is obtained when the canard is positioned at its down and up location, respectively. Abovementioned results show that the canard at high position produces more lift, thus it is clear that the induced drag would be increased for the canard installed in this position. Variations of the aerodynamic efficiency of the wing-body model with and without the canard at different vertical positions with respect to the wing are shown in Fig.8. Aerodynamic efficiency is one of the key parameters that determines the weight and cost of an aircraft. The range of an aircraft is roughly directly proportional to its aerodynamic efficiency without any increase in the fuel usage. Higher endurance can be obtained with higher aerodynamic efficiency. Fig.8 shows that the wing-body with canard at its up position has superior aerodynamic efficiency in comparison with the other positions at angles of attack of less than 28 degrees, while the canard positioned at its down location minimizes the aerodynamic efficiency of the model. This means that the canard at its up position significantly improves the efficiency and performance of the military aircraft. The results of this research corroborate with those by Hummel et al. (1989) which indicate thatwith high canard location more aerodynamic efficiency is achieved.

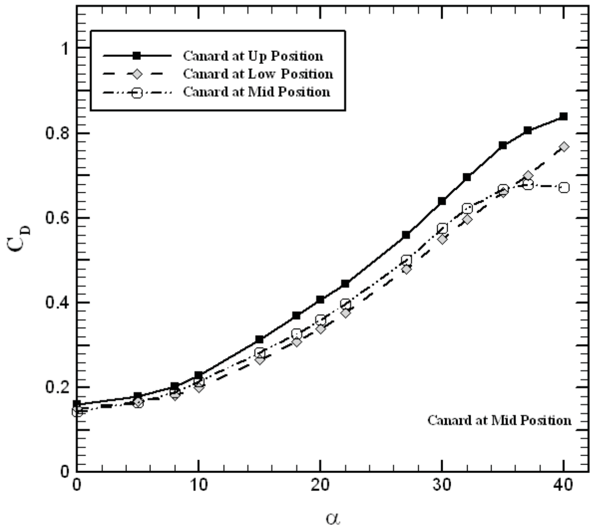

Figure 7. Effect of canard position on the drag coefficient

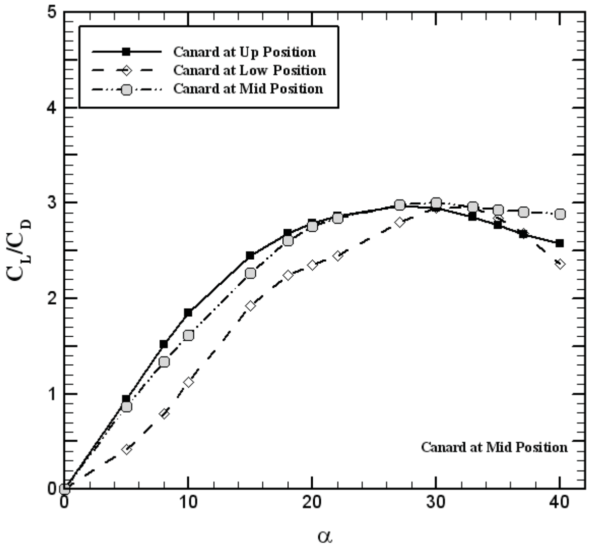

Figure 8. Variation of the aerodynamic efficiency for different vertical positions of the canard.

Both the lift coefficient and the drag coefficients are functions of the angle of attack, thus the drag coefficients can be interpreted as parameters that depend on the lift coefficients. The drag coefficient related to the lift coefficient, i.e. the drag polar for different vertical positions of the canard are shown in Fig.9. In this figure, the parasite drag is subtracted from the total drag and only the induced drag is being considered. The drag polar is very important for the performance analyses and can often be very difficult to obtain from an aircraft manufacturer (e.g. Hale 1984). Fig.9 shows that the canards located at high and down positions with respect to the wing–body have a nearly similar trend in the drag polar while the drag polar of the canard at its mid position is lower than the other locations of the canard.

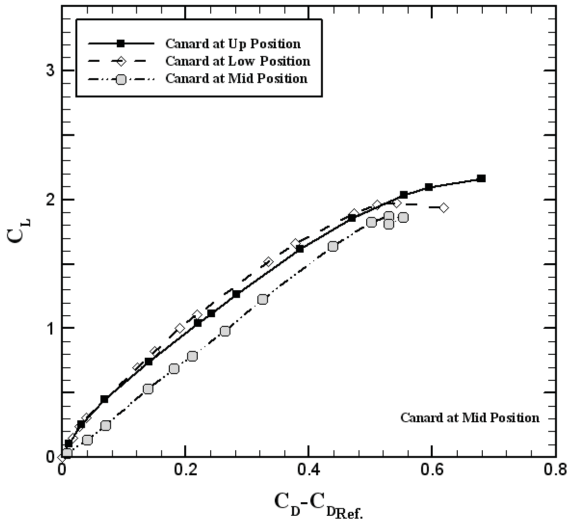

Figure 9. Drag polar for different vertical positions of the canard

In Fig.10, variations of the pitching moment coefficient with angle of attack for the clean configuration; case I at different vertical positions of the canard are presented. Fig.10 shows that the model without the canard above the angle of attack of equal to 22 is stable and its stability is decreased for higher angles of attack. The stability of the model with angle of attack for case II is similar to the clean configuration, although the stability has diminished with canards. It is evident that, these configurations for angle of attack at locations of equal to 18 degrees are stable and for higher angles of attack, the stability is decreased, Fig.10. One can conclude that the minimum stability and higher maneuverability, is obtained for the canard at its up position with respect to the wing.

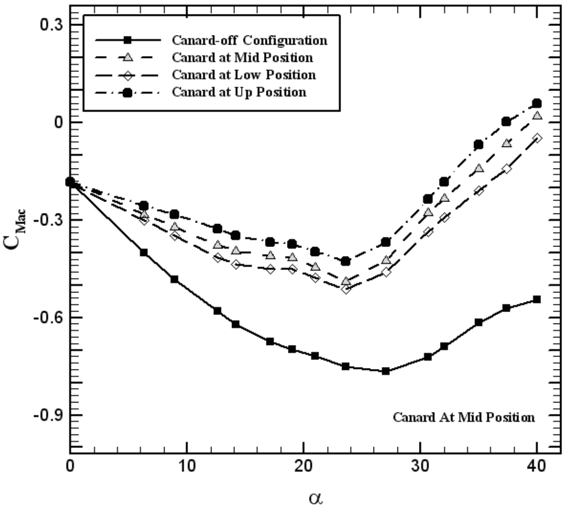

Figure 10. Variation of pitching moment for different vertical positions of the canard.

The results for case II show that the canard at its up location leads to a better aerodynamic performance of the fighter model. The results by Soltani et al. (2010)[22] and Hummel et al. (1989)[8] show that at high angles of attack, the upper-canard was found to induce the most favorable flow field on the wing or as for the low-canard configuration, minimum suction is developed on the wing; thus this configuration has a lower performance as compared with the high-canard configuration.

4.3 Results for case III

Different horizontal positions of the canard with respect to the wing, i.e., forward, mid and rear are investigated. The trends of the lift coefficient with angle of attack for the mentioned locations of the canard are shown in Fig.11. It is evident that the maximum lift enhancement occurs at the forward position of the canard and the minimum one is obtained for the rear position. Figure 11 verifies that considerable aerodynamic benefits as a result of the forward position of the canard caused by the appropriate interference of the wing vortices and canard downwash are obtained.

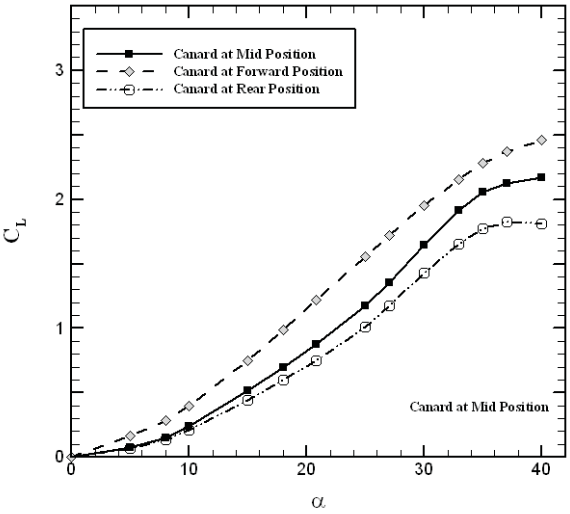

Figure 11. Variations of the lift coefficient for different horizontal positions of the canard.

Variations of the drag coefficient with angle of attack for different horizontal positions of the canard are shown in Fig.12. The maximum and minimum drag enhancement occur in the forward and the rear positions of the canard, respectively, due to higher induced drag; Fig.12.

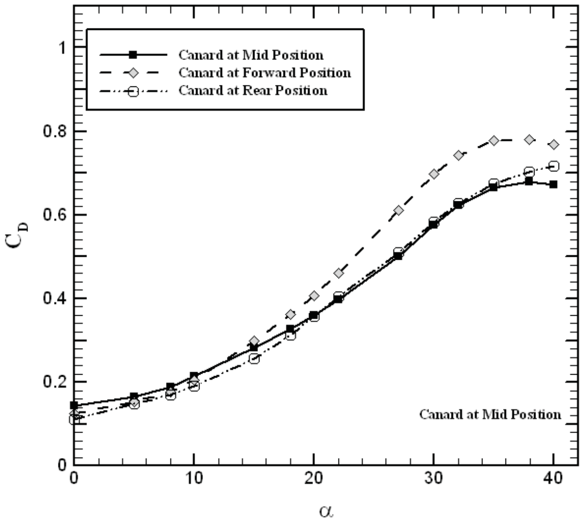

Figure 12. Variations of the drag coefficient for different horizontal positions of the canard.

In Fig.13 behaviors of the pitching moment coefficient with different angles of attack are shown. It is obvious that for all configurations of case III, with an angle of attack of more than 16, the model is stable, however, at higher angles of attack, the stability is decreased. The results indicate that the maximum stability occurs in the forward position of the canard due to the maximum distance and the lift obtained for this configuration. The lowest amount of stability is achieved for the model with the canard at the closest position of the main wing.

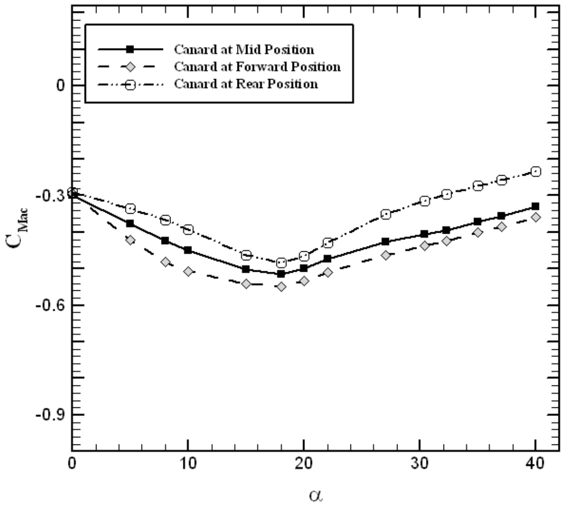

Figure 13. Variation of the pitching moment for different horizontal positions of the canard.

In Fig.14, a variation of the aerodynamic efficiency of the wing-body model at different horizontal locations of the canard is shown. The findings demonstrate that the canard, when located at forward position has the more aerodynamic efficiency in comparison with the other horizontal locations.

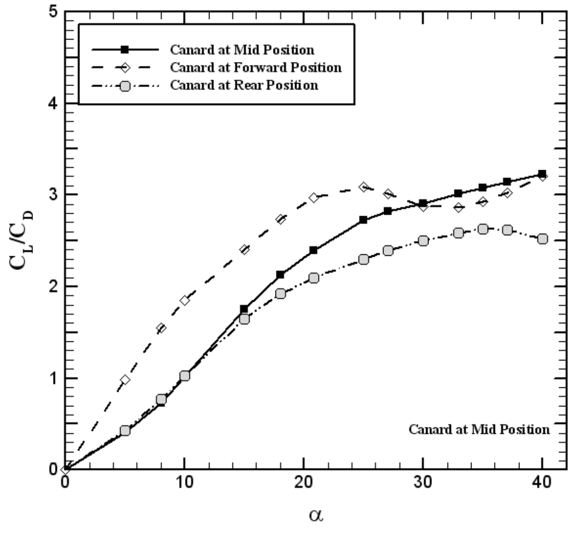

Figure 14. Variations of the aerodynamic efficiency for different horizontal positions of the canard.

In Fig.15, the drag polar sketches of the wing-body model for different horizontal positions of the canard are presented. It is evident that the canard at the rear position has the lowest effects as compared with the other locations. The canard at its forward has a slightly higher lift.

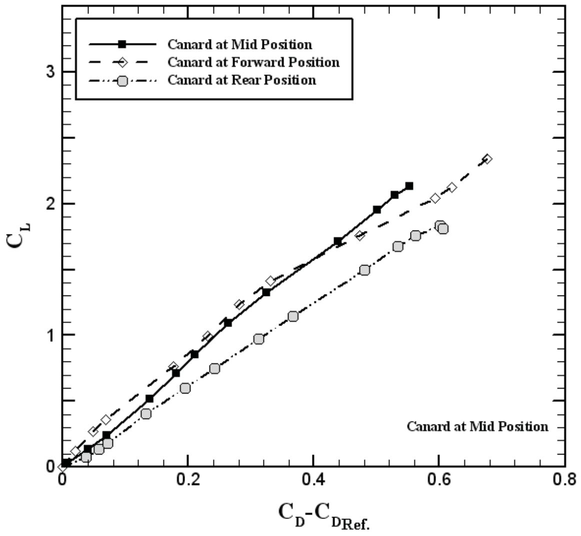

Figure 15. Drag polar for different horizontal positions of the canard.

The findings for the case III show that the best position of the canard is the forward one. The results by Soltani et al. (2010)[22] show that higher suctions on the wing of wing-body configurations were achieved with the wing at moderate to high angles of attack, as the wing-canard distance was increased, i.e. the forward position of the canard (e.g. Soltani et al. 2010)[22]. Their results show that with rear portion, the amount of the suction peak for the canard-on configuration has been reduced. This implies that the domain of favorable influence of the canard is mostly restricted to the front and middle portions of the wing. At the rear portions of the wing, near the trailing edge, the amount of suction is roughly half of that of the front region. For the most forward position of the canard, by increasing the horizontal distance between the canard and the wing, higher suction is achieved for moderate to high angles of attack. It seems that the upper far position for the canard is a proper choice for the best performance at high angles of attack among the wing-canard-body configurations (e.g. Soltani et al. 2010) [22] that is in agreement with outcomes of this research.

5 Conclusion

1. Experiments are performed to study effects of the canard location on the flow aerodynamics of a wing-body configuration. Different horizontal and vertical positions of the canard on the model with respect to the wing are considered. Aerodynamic forces, aerodynamic efficiency and drag polar at different flight conditions and different canard settings were compared in this investigation. A 6-component balance in a subsonic wind tunnel is utilized for this study. The wing and the canard used for this study have triquetrous shapes and they have flat leading edges. The results indicate that:

2. The canard has a very effective role on the performance of a fighter model and increases the lift and the aerodynamic efficiency of the fighter. It is due to the remarkable increase in the wing suction peak for the canard-on configurations.

3. The results for different vertical positions of the canard indicate that the canard at up location leads to a better aerodynamic performance of the fighter model and the upper-canard was found to induce the most favorable flow field on the wing.

4. The findings for different horizontal positions of the canard prove that the best horizontal position of the canard is the forward state. In this position, higher suctions on the wing of the wing-body configurations were achieved at moderate to high angles of attack.

5. it can be concluded that the canard at up or forward position with respect to the wing-body is an appropriate choice for the best performance at moderate to high angles of attack from among the various wing-canard-body configurations.

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