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Analysis and Investigation of Aerodynamic Performance of Different Canard Configurations in FSW-Aircraft

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Abstract

Analysis will be done to compare the aerodynamic performance of different cases of canard configurations for FSW (Forward Sweep Wing) aircraft. This will include no-canard case, Forward Sweep Canard (FSC) configuration and Backward Sweep Canard (BSC) configuration. The effect on aerodynamic characteristics due to canard will be investigated as canard can immoderately amend the surface flow pattern of main wing. This will reveal the vortex interaction and mutual coupling between the canard and main wing; lift characteristic and drag characteristic in respect to all the given cases. Configurations of different cases will be expressed in terms of velocity vectors and pressure patterns. This investigation will further examine the consequences due to high angle of attack and low angle of attack. The alternating results owning to canard shape, high angle of attack and low angle of attack on aerodynamic performance of different cases will be illustrated.

Keywords: *Canard-FSW (Forward Sweep Wing), Forward Sweep Canard, Backward Sweep Canard, mesh, Vortex Shedding*

I. INTRODUCTION

Canard refers to an arrangement in which a small forewing is placed ahead of the main wing of a fixed-wing aircraft to provide extra stability or control. It is the secondary wing which is located in front of the main wing. Canard enhances the surface flow patterns of main wing which benefits the aerodynamic characteristics. The main advantage of canard configuration is to delay vortex breakdown, strengthen leading edge vortex, reduce shock between leading edge vortex and upper surface of main wing, and effectively control separation of boundary layer on leading edge of main wing and to provide better lift characteristics. A Forward Swept Wing (FSW) is an aircraft wing configuration in which leading edge sweeps forward and quarter-chord line of wing has a forward sweep. Forward- swept wings make an aircraft harder to fly, but the advantages are mainly down to maneuverability. Aircraft with forward- swept wings are highly maneuverable because air flows over a forward-swept wing and toward the fuselage, rather than away from it. It provides better stall characteristics at higher angle of attack and lower wave resistance.

The canard plays vital roles in the FSW configuration, where the interference of vortices generated by the canard and the main wing leads to better lift and stability characteristics. The canard vortex can effectively control separation of the boundary layer on the leading-edge of the main wing. It develops an effective control on the vortex over the main wing.

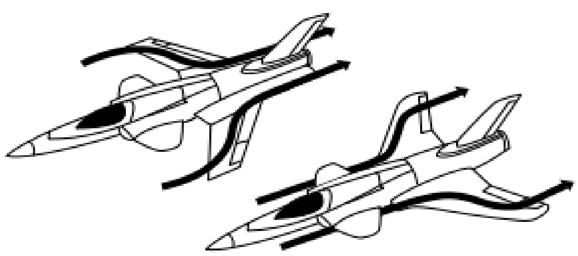

Fig. 1 Air flowing over swept wing

II. OBJECTIVES

The aircraft using canard-FSW configuration has less maneuverability and aerodynamic performance, so it was used to a lesser extent. Hence, by changing airfoil and making some modifications, analysis and investigations will be carried out to achieve good aerodynamic performance. By using EPPLER 398 instead of using WORTMANN FX63-137, better lift characteristics and drag characteristics will be obtained.

There will be comparison between the aerodynamics properties like lift-characteristics and drag characteristics for different cases of canard-FSW (Forward Sweep Wing) configuration. This cases includes no-canard case, forward sweep canard and backward sweep canard. The mutual coupling and vortices between the canard and FSW will be investigated at different angle of attack. Analysis and comparison of airfoil will be done and their lift characteristics and drag characteristics will be determined at different angle of attack. This airfoil includes WORTMANN FX63-137 and EPPLER 398.

III. AIRFOIL SELECTION

A. Geometry

Created geometry of EPPLER 398 and FX63-137 airfoil by using formatted points data in ICEM CFD and given domain parameter according to size of the geometry length. Here we created C-grid domain for airfoil because here geometry will rotate around its axis so that flow will tangential to the geometry with respect to different angle. The C-grid handles the flow resolution better in the wake when the flow gradients are concentrated directly behind the airfoil. Domain will be 5L from leading edge in forward, upward and downward side and 10L from leading edge in backward side.

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B. Basic airfoil shape

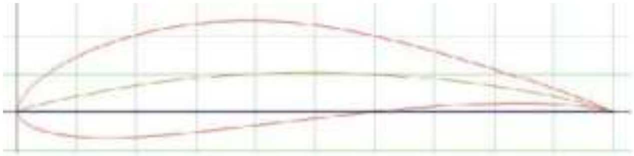


Fig. 2 Basic airfoil shape EPPLER 398

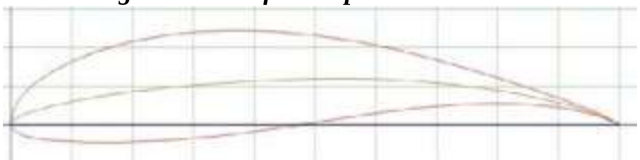
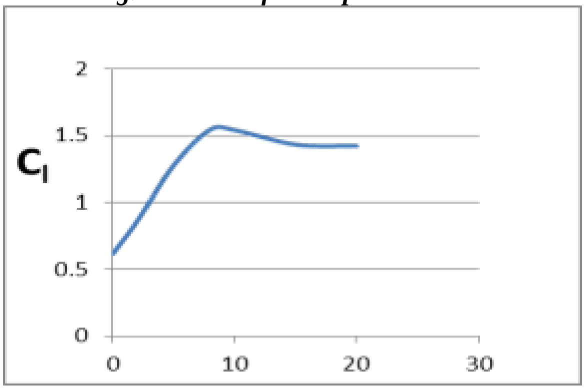
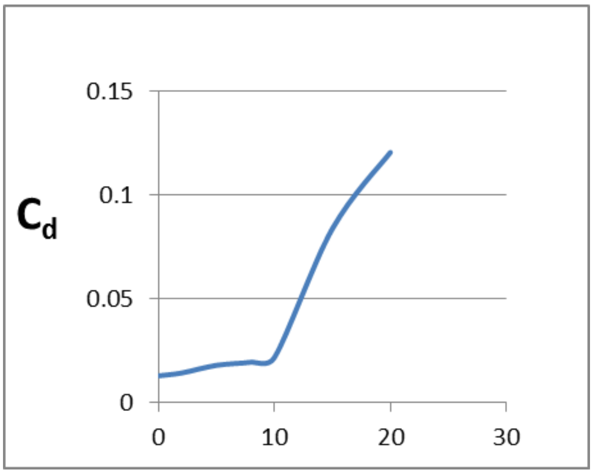


Fig. 3 Basic airfoil shape FX 63-137



Angle of attack

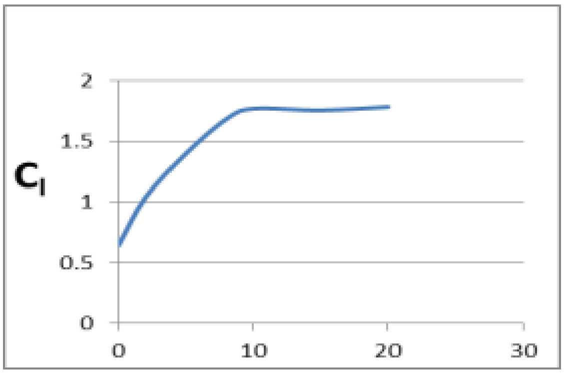
(a)Lift coefficient



Angle of attack

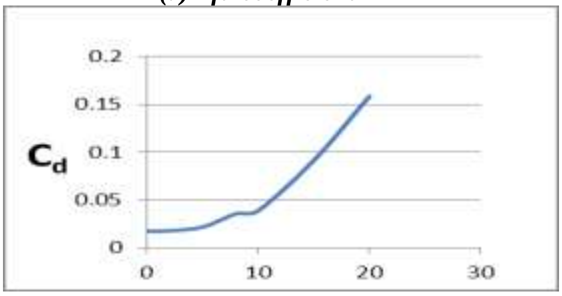
(b)Drag coefficient

Fig. 4 Lift characteristics and Drag characteristics of EPPLER 398



Angle of attack

(a)Lift coefficient



Angle of attack

(a) Drag coefficient

Fig. 5 Lift characteristics and Drag characteristics of FX 63-137

Fig. 4 and Fig. 5 depicts that there is minor difference in the value of C_l and C_d at different Angle of Attack for both airfoil. We choose EPPLER 398 due to its large pitching moment, thin trailing edge and gentle stall characteristics.

IV. GEOMETRY CREATION AND MESHING

A. Design Parameters

Table I Parameters of aerodynamic experimental mode

Geometric Parameters	FSW	FSC/BSC
Span(m)	0.0374	0.00219
Root Chord(m)	0.115	0.032
Tip Chord(m)	0.056	0.0105
Aspect ratio	5.12	4.73
Root -tip ratio	0.487	0.33
Forward/Backward swept angle(degree)	-21,-34	46,26

B. Types of models

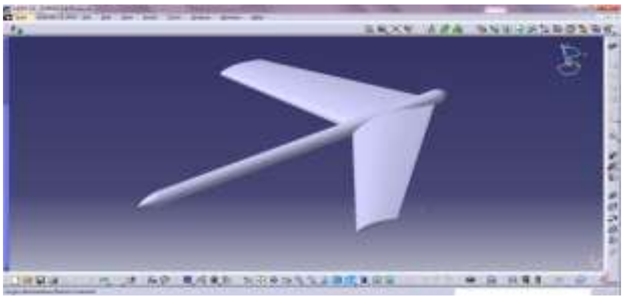


Fig. 6 3D model of Forward Swept Wing aircraft

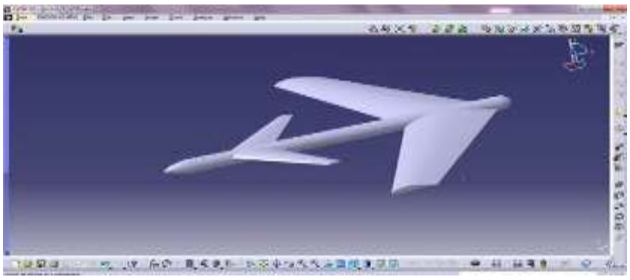


Fig. 7 3D model of Forward Swept Wing Aircraft with Backward Swept Canard

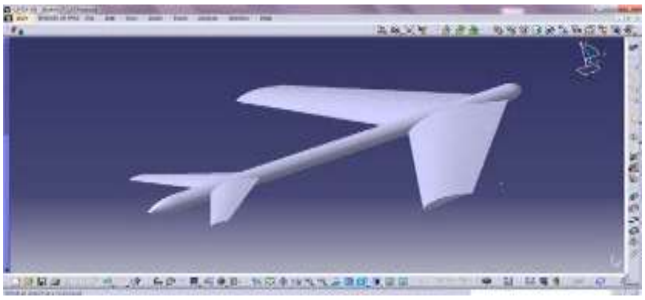


Fig. 8 3D model of Forward Swept Wing aircraft with Forward Swept Canard

The velocity of inlet, Reynolds number *Re* and temperature are set to be 20 m/s, $Re = 1.6\times10^5$ and 300 K respectively. Because of computational limits, 3D models are transferred to 2D models. 3D models are prepared using CATIA V5 and 2D models are prepared using ICEM CFD. Unstructured type of meshing is done. Simple iteration is adopted with k- ε turbulence model and wall functions.

C. Meshing

Mesh Type	Triangular
Mesh Method	Patch Independent
Total number of Nodes	17000
Total number of Elements	4,60,173
Mesh Quality	0.76

Table II Meshing

Fig. 9 Geometry of EPPLER 398 with meshing in ICEM CFD with domain

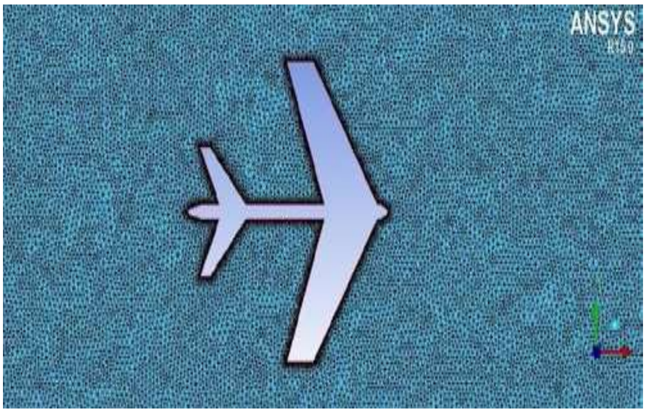


Fig. 10 2D model of FSW aircraft with FSC with meshing in ICEM CFD with domain

V. RESULT AND ANALYSIS

A. WORTMANN FX 63-137airfoil

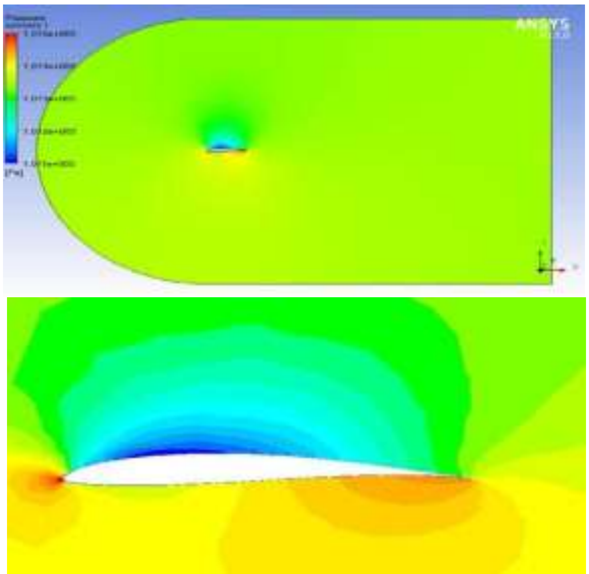


Fig. 11 Pressure contour of WORTMANN FX 63-137

In WORTMANN FX63-137, maximum pressure of $1.015*10^5$ Pa is obtained near the trailing edge and at the tip of the airfoil. Minimum pressure of $1.011*10^5$ Pa is obtained on the upper surface of the airfoil. On lower surface of the airfoil, there is pressure of $1.014*10^5$ Pa.

B. EPPLER 398 airfoil

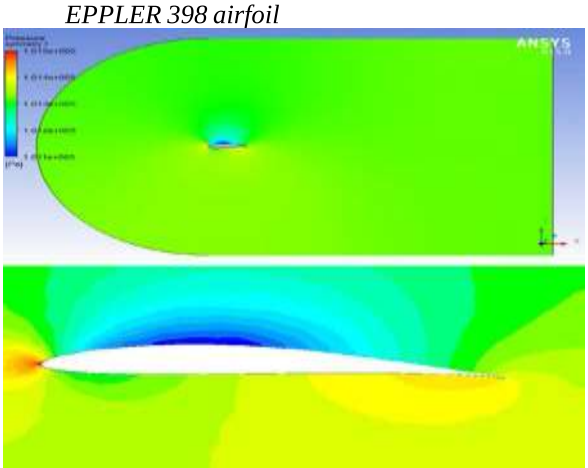


Fig. 12 Pressure contour of EPPLER 398

In EPPLER 398, maximum pressure of 1.015*10^5 Pa is obtained at the leading edge of the airfoil. Minimum pressure of 1.011*10^5 Pa is obtained on the upper surface of the airfoil. On lower surface of the airfoil, pressure between 1.013*10^5 Pa and 1.014*10^5 Pa is obtained.

C. Forward Sweep Wing with no-canard case

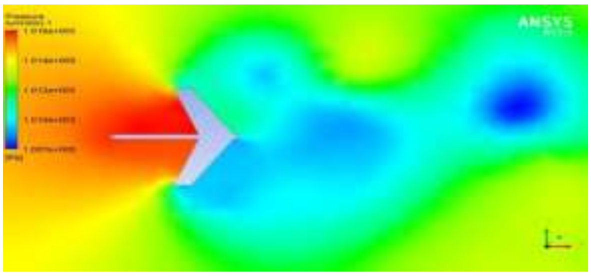


Fig. 13 Pressure contour of Forward sweep wing aircraft

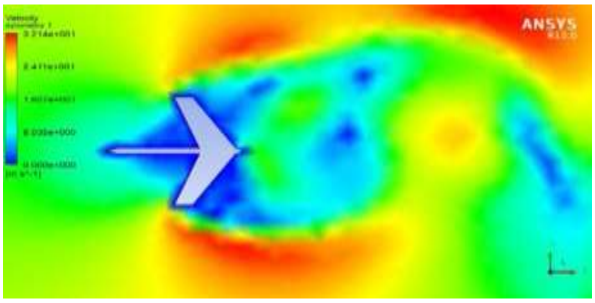


Fig. 14 Velocity contour of Forward sweep wing aircraft

In FSW aircraft without canard, maximum pressure of 1.05*10^6 Pa is obtained at the leading edge of the wing. Pressure is lesser on the upper surface of the wing and higher on the lower surface of the wing. Stagnation velocity is obtained at the leading edge of the wing. Because of this pressure difference, vortices are generated at the tip of the wing. The vortices generated at the tip will be carrying forward to form circulation before it leaves the tail of the aircraft. This circulation will re-circulate the flow and at some portion minimum pressure of 1.007*10^5 Pa is obtained. This will results in Vortex Shedding.

Vortex Shedding is an oscillating flow that takes place when a fluid such as air flows past a cylindrical body at certain velocities, depending on the size and shape of the body. In this flow, vortices are created at the back of the body and detach periodically from either side of the body.

D. Forward Sweep Wing with Backward Sweep Canard

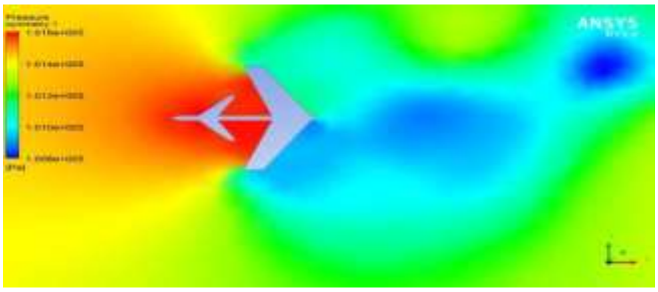


Fig. 15 Pressure contour of Forward sweep wing aircraft with Backward sweep canard

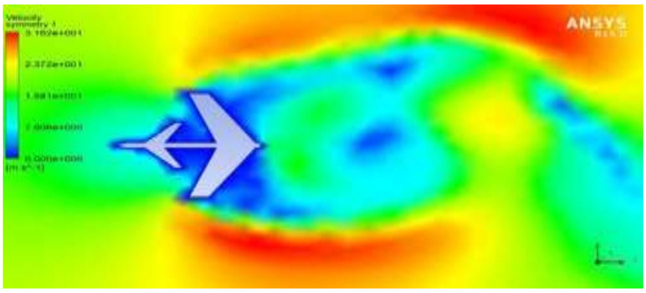


Fig. 16 Velocity contour of Forward sweep wing aircraft with Backward sweep canard

In FSW aircraft with BSC, maximum pressure of 1.05*10^6 Pais obtained at the leading edge of the canard. Because of the pressure difference, vortices are generated at the tip of the wing. Stagnation velocity is obtained at the leading edge of the canard. Velocity is higher on the upper surface of the wing and lesser on the lower surface of the wing. The vortices generated at the tip will be carrying forward to form circulation. This circulation will re-circulate the flow and at some portion minimum pressure of 1.008*10^5 Pa is obtained, which will results in Vortex Shedding. As compared to without canard case, this case is more efficient.

E. Forward Sweep Wing with Forward Sweep Canard

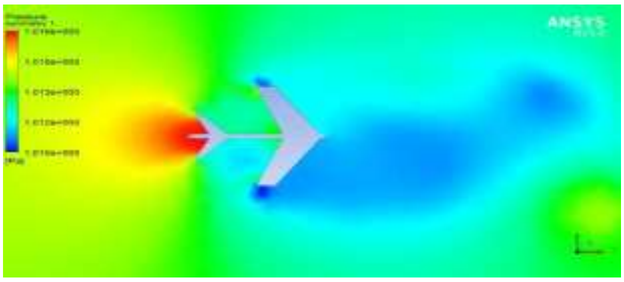


Fig. 17 Pressure contour of Forward sweep wing aircraft with Forward sweep canard

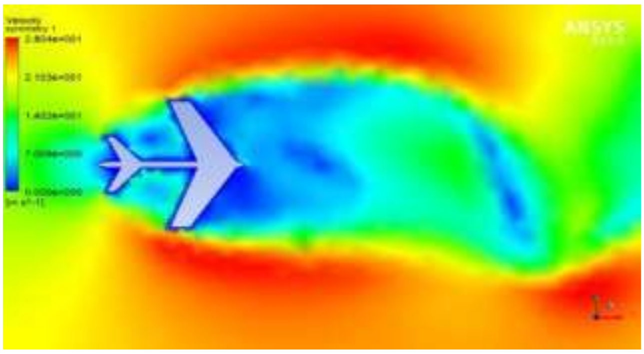
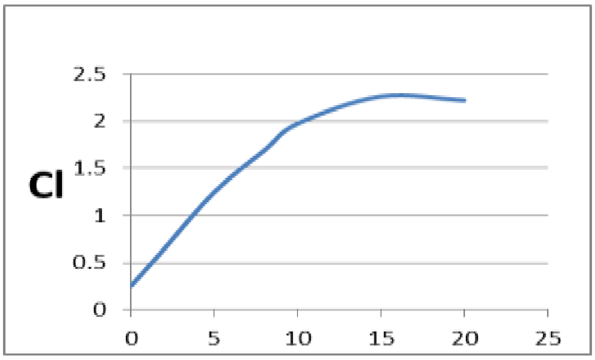


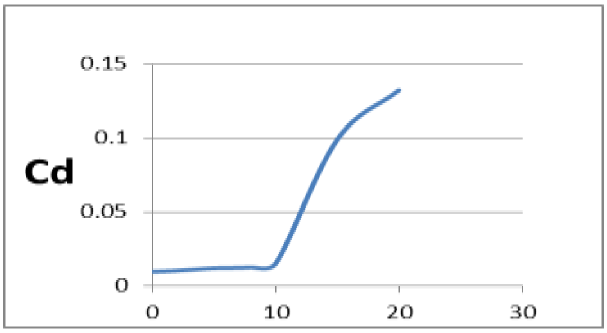
Fig. 18 Velocity contour of Forward sweep wing aircraft with Forward sweep canard

In FSW aircraft with FSC, maximum pressure of 1.016*10^6Pa is obtained at the leading edge of the canard. Pressure reduces to 1.012*105 Pa behind the canard. Stagnation velocity is obtained at the leading edge of the canard and at trailing edge of the wing. Because of the pressure difference, vortices are generated at the tip of the wing. The vortices generated at the tip will be carrying forward to form circulation. This circulation will re-circulate the flow and at some portion minimum pressure of 1.010*10^5 Pa is obtained, which will results in Vortex Shedding. This case is less efficient than backward canard case.



Angle of attack

(a)Lift coefficient



Angle of attack

(b)Drag coefficient

Fig. 19 Lift characteristics and Drag characteristics for canard and wing configuration

The drag characteristics do not show clear changes when α ≤ 10°. On the one hand, the Canard-FSW configuration can enlarge the surface area of the entire aircraft so as to increase friction resistance, on the other hand, the dynamic pressure of flow around the main wing after passing the canard is lower than that without passing a canard, and the effective angle of attack of the main wing is reduced owing to the downwash effect so as to decrease the drag coefficient. The two effects cancel each other and make the drag to be almost unchanged. But with the increase of angles of attack, the rise of lift-related drag becomes more and more dominating and finally produces larger net drag coefficient.

We can see that a strong concentrated vortex is generated above the surface of closed-couple main wing. This vortex is induced by the pressure difference between the upper surface and lower surface, which generates a vertical velocity component and drives the flow to separate and wrap up from the leading edge. The vortex induces negative pressure on the upper surface of the main wing, which can provide substantial vortex lift. These contributions account for a very large proportion in the total lift force and the lift curve shows nonlinear effects.

VI.CONCLUSION

Out of the three cases which include no-canard case, forward canard case and backward canard case, backward canard case is more effective. Higher value of C_l is obtained in Backward- FSW configuration.

Circulation and vortex shedding is captured at the trailing edge of the wing. In FSW, as the tip of wing is ahead of the root, the vortices generated at the tip will be carrying forward to form circulation before it leaves the tail of the aircraft. This circulation will re-circulate the flow and at some portion stagnation pressure is obtained.

It is observed that C_d remains unchanged below 10 Degree Angle of attack. This is because of two processes. On one hand, surface area of the whole aircraft increases, thus dynamic pressure so as to increase friction resistance, on the other hand, the dynamic pressure of flow around the main wing after passing the canard is lower than that without passing a canard, and the effective angle of attack of the main wing is reduced owing to the downwash effect so as to decrease the drag coefficient. The two effects cancel each other and make the drag to be almost unchanged.

At smaller angle of attack the aerodynamic performance depends upon the upwash and aerodynamic interference. At higher angle of attack the aerodynamic characteristics depends on the shape of canard and features of vortices above the main wing.

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