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Study of Vortex Interactions between two aerodynamic lifting Surfaces

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Abstract: This Paper deals with the study of vortex interactions between two lifting surfaces of an Aircraft using Computational fluid dynamics. The analysis deals with the effect produced on the wing(aft surface) by the placement of the canard (forward surface) owing to the vortices produced by the latter. Analysis has been done on Powerful CFD tools, GAMBIT and Ansys Fluent involving cases with wing placed at certain distances from the canard (Horizontally and vertically) in order to study the effect of Relative placement of the two surfaces in The Effective lift.

I. Introduction

The Advent of Canards began right with the first Airplane catching its way in the sky embarking the First flying Machine bestowed upon the Mankind by the Diligent and persistent efforts of the Wright Brothers. Canards were in Vogue for Several years until its complexities was discovered, one major being the reduction in effective lift due to the Vortex Interactions between the Canard and Wing. The Following study Explains the problems of Vortex Wake in Aeronautics and how the positioning of the two lifting surfaces affect the effective Lift Generated by an Aircraft , thereby energising the Effective lift despite the Vortexes generated by the Canard.

A. The Vortex Wake Problem in Aeronautics:

The vortex wake is a physical problem of great interest to a variety of disciplines, including Aeronautical engineers, fluid dynamists and air traffic administrators. The importance of this phenomenon has grown in recent years, as revealed by FAA/NASA interest in the cause of some aircraft accidents which have been partially attributed to the action of the vortex Pair located in the vortex wake on the aircraft in question.

The level of interest in this problem has been high since the inception of routine air transport, however, as shown by the contents of a recent bibliography of vortex research done over the last 70 years. The emergence of vortex wakes as a potential hazard and its relative importance is directly related to the advent of large high speed aircraft and their increased use in the Aviation industry. With their inherently high wing loading, these aircraft produce stronger, hence more dangerous, vortex wakes, especially near airports where their sustained lift

Coefficient must be kept high at lower speeds. The problem presents itself not as just a potential hazard to aircraft, but as a logistical, and thus economical, Problem as well. Due to the inherent motion of the vortex pair within the wake, the location of vortices generated by one aircraft coupled with the background circulation encountered at airports is difficult to predict. The nature of the vortex wake makes it difficult for pilots to handle in an encounter, as well. A pilot may direct the aircraft out of part of the wake which is imposing a roll onto the aircraft into part of the wake which imposes down-wash. Additionally, the vortex wake tends to separate into two individual vortices upon reaching the ground, each vortex then acting independently from the other and possibly increasing the likelihood of a random encounter with a vortex where none was expected. In situations where aircraft are in close proximity to one another, i.e. airports, this unpredictable motion results in high safety factors, which are manifested as arbitrarily (and possibly unnecessarily) large separation distances between aircraft. Aircraft landing or taking off behind one another must maintain a separation distance based on the weight class of both aircraft. Parallel runways must be placed a specified distance apart from an adjacent runway as well to be considered safe from the vortex wakes of aircraft on parallel approaches or landing strips.

B. Vorticity

The vorticity is defined as the curl of the velocity Vector: Thus each point in the fluid has an associated vector vorticity and the whole fluid space may be thought of as being threaded by vortex lines which are everywhere tangent to the local vorticity vector. These vortex lines represent local axis of spin of fluid particle at each point. In two dimensions, vorticity is the sum of angular velocities of any pair of mutually perpendicular, infinitesimal fluid lines passing through the point in question. For rigid body rotation, everybody perpendicular to the axis of rotation has the same angular velocity: therefore the vorticity is same at every point and twice the angular velocity.

Flow past an Airfoil:

Airfoils are streamlined (raindrop-type shape) surfaces designed in such a way that air flowing around it produces useful motion. Airfoils set in a velocity field or moving in still fluids are subjected to pressure and viscous forces. Over the top of the airfoil the velocity of the flow is greater than the free-stream velocity. Following from Bernoulli's equation, the pressure over the top surface is negative. Velocity along the underside of the airfoil is less than the free-stream velocity and the pressure is positive. The overall effects of the flow around the airfoil are a total lift force, L , acting normal to the free-stream direction and a drag force, D , acting parallel to the free-stream direction.

D. Vortex Generation in an airfoil:

Lift is the force which holds an aircraft in the air. From a Newtonian perspective, lift is generated by turning a flow of air. The flow turning creates a downwash from the wing which can be observed in flight.

The **starting vortex** is a Vortex which forms in the air adjacent to the trailing edge of an airfoil as it is accelerated from rest in a fluid. It leaves the airfoil (which now has an equal but opposite "bound vortex" around it), and remains (nearly) stationary in the flow. It rapidly decays through the action of viscosity. Whenever the speed or angle of attack of an airfoil changes there is a corresponding amount of vorticity deposited in the wake behind the airfoil, joining the two trailing vortices. This vorticity is a continuum of mini-starting-vortices. The wake behind an aircraft is a continuous sheet of weak vorticity, between the two trailing vortices, and this accounts for the changes in strength of the trailing vortices as the airspeed of the aircraft and angle of attack on the wing change during flight. (The strength of a vortex cannot change within the fluid except by the dissipative action of viscosity. Vortices either form continuous loops of constant strength, or they terminate at the boundary of the fluid - usually a solid surface such as the ground.)

E. Vortex Interactions

The unsteady aerodynamic performance associated with the canard-wing interaction is of Particular interest. The presence of a canard in close proximity to the wing results in a highly coupled canard-wing aerodynamic flow field which can include downwash/upwash effects, Vortex-vortex interactions and vortex-surface interactions. For unsteady conditions, these Complexities of the canard-wing flow field are further increased. The effect of changing the position of the canard or deflecting the canard can drastically alter a canard-wing aerodynamic interaction. For example a canard positioned with a vertical offset from the wing will have varying locations of the canard wake and leading-edge vortex relative to the wing, both of which can significantly change the canard-wing flow field from that of the coplanar canard case. For the canard with a positive deflection angle, the stronger canard downwash and modified canard trailing edge location will also change the wing flow field relative to that of the coplanar case. All of these flow field changes can potentially affect both the aerodynamic performance as well as the stability and trim characteristics of a configuration, and need to be fully understood. The effect of changing the position of the canard or deflecting the canard can drastically alter a canard-wing aerodynamic interaction. For example a canard positioned with a vertical offset from the wing will have varying locations of the canard wake and leading-edge vortex relative to the wing, both of which can significantly change the canard-wing flow field from that of the coplanar canard case. For the canard with a positive deflection angle, the stronger canard Downwash and modified canard trailing edge location will also change the wing flow field Relative to that of the coplanar case. All of these flow field changes can potentially affect both the aerodynamic performance as well as the stability and trim characteristics of a Configuration and need to be fully understood.

Canard-induced downwash will weaken or delay formation of the wing leading edge vortex.

The presence of a canard will eliminate the wing vortex breakdown. At low to moderate Angles of attack, the fixed high-canard configuration exhibits improved steady-state lift and Drag over the mid-canard case. However, due to the interaction between the low-canard vortex and the wing surface, unfavorable lift and drag characteristics for the low-canard configuration are evident as angle of attack is increased. At low angle of attack, the low canard vortex passes under the wing surface and can induce lower pressures on the wing lower surface. At higher angles of attack, the canard vortex is split by the wing surface into upper and lower vortices. Toward the outboard wing, the wing vortex induces a large inward movement of the canard upper-vortex. When the fixed canard is positively deflected, a pronounced effect on aerodynamic performance parameters is observed, particularly for wing lift and configuration pitching moment. Visualization of the canard-wing-body flow field shows a complex flow structure consisting of several interacting canard and wing vortices. Specifically, at significantly large canard deflection angles, effective wing angle of attack transitions from negative to positive values causing the formation of both lower and upper surface leading-edge vortices.

Furthermore, due to the strength of these vortices, secondary vortices are present indicating Strong viscous effects. Many of the complex nonlinear behaviors of various canard configurations can be attributed to the canard and wing vortical flow fields. Most configurations are dominated by leading edge vortices from both

wing surfaces. Strong vortex strength will result in adverse pressure gradient induced separation and may cause strong secondary vortices. The canard leading edge vortex has direct influence on the surface pressures over the main wing and indirectly through its influence over the leading edge vortex. Any effect the canard may have over the main wing will be highly influenced by modifications in canard vertical height and deflection angle. As the attack angle of an aircraft increases the secondary separation line moves inboard, indicating the upward and inward movement of a wing vortex. In the presence of a canard surface there is a delay in the formation of the main wing vortex and the main wing vortex is further outboard and aft than without the canard surface. This is due to the interaction of the two vortices.

The main mechanism for canard-wing interaction is the canard's influence on the wing Leading edge vortex, which involves the influence of canard downwash and canard leading edge vortex. Both will have a significant effect on the formation and trajectory of the wing leading edge vortex. Outboard of the canard-tip span line the leading edge vortex is the primary mechanism for influence over the flow field about the main wing. As the canard leading edge vortex passes over the main wing it will interact with the main wing leading edge vortex. The two vortices will rotate counter clockwise and induce a relative downwards and inwards motion of the canard vortex and, in turn an outwards motion of the main wing vortex. Had the canard not been present the main wing flow field would be much less complex. The wing vortex trajectory would be expected to follow an upwards and outwards path. The flow field may be further complicated by a counter clockwise rotating secondary vortex. Canard-induced downwash will weaken or delay formation of the wing leading edge vortex. The presence of a canard will eliminate the wing vortex breakdown. At low to moderate Angles of attack, the fixed high-canard configuration exhibits improved steady-state lift and Drag over the mid-canard case. However, due to the interaction between the low-canard vortex and the wing surface, unfavorable lift and drag characteristics for the low-canard configuration are evident as angle of attack is increased. At low angle of attack, the low canard vortex passes under the wing surface and can induce lower pressures on the wing lower surface. At higher angles of attack, the canard vortex is split by the wing surface into upper and lower vortices. Toward the outboard wing, the wing vortex induces a large inward movement of the canard upper-vortex. When the fixed canard is positively deflected, a pronounced effect on aerodynamic performance parameters is observed, particularly for wing lift and configuration pitching moment. Visualization of the canard-wing-body flow field shows a complex flow structure consisting of several interacting canard and wing vortices.

II. CFD ANALYSIS

The physics explained above was explained through the Analysis that Consisted of two airfoils separated by a fixed horizontal distance and varying vertical distance and vice versa. The aim here was to find lift and drag coefficients of the airfoil s1223 under standard sea level values for the free stream properties of air flowing at a free stream velocity of 20m/s. The characteristic lengths (chord) of the airfoils are 38cm. Accordingly we define the farfield conditions. In an external flow such as that over an airfoil, we have to define a farfield boundary and mesh the region between the airfoil geometry and the farfield boundary. It is a good idea to place the farfield boundary well away from the airfoil since we'll use the ambient conditions to define the boundary conditions at the farfield. The farther we are from the airfoil, the less effect it has on the flow and so more accurate is the farfield boundary condition.

A. Boundary Conditions

The rectangular farfield is divided as two equal airfields so as to use lesser computing power and get faster results. These are named as farfield 2 and farfield 3. The inlet region is named as Farfield 1. The airfoil is given the boundary type of wall as air would not pass through it. The farfield 1 and farfield 2 have a Velocity inlet boundary type and the other two have pressure outlet boundary type. This is because we give the inlet conditions in terms of velocity components of free stream air velocity and we expect Results in terms of forces (pressure).

B. Computational Method

Since the interaction between the vortices of the two surfaces is to be studied we need to make use of a turbulence model, so the k- ϵ model is used and we do not use the energy equation but only solve using the momentum, velocity equations and the continuity equation. Also we change the discretization method to PRESTO and Second Order Upwind to get more Accurate results. All the residuals values have been set to 1e-5 to obtain good quality of results.

Keeping the Horizontal Distance between the airfoils same, the vertical distance was varied as shown, as a result it was observed that more the distance between the foils better is the value of the coefficient of pressure

Horizontal Distance (cm)	Vertical Distance (cm)	Cp
30	30	-4.74
30	25	-7.83
30	20	-9.42

Similarly keeping the vertical distance constant the horizontal distance was varied and the following data was obtained, which again proved that farther are the foils from each other, better are the lift characteristics

Horizontal Distance (cm)	Vertical Distance (cm)	Pressure coefficients
21	30	20.51
31	35	22.12
41	20	25.64

CASE1:

This case deals with a situation where the horizontal distance between the airfoils is kept constant and vertical distance is varied , as depicted by *Figure 1 and figure 2*. As it can be observed in the two images, the increase in the vertical separation between the lifting surfaces tends to create a high pressure region below the aft surface (this can be seen as the red below the wing has increased) thereby increasing the effective lift .

CASE2:

Here, as depicted in *Figure 3,4 and 5*, the vertical distance between the airfoils is kept constant, and the horizontal distance is increased by 10 cm in each case. This increase in distance effects in more red(high pressure) below the wing, thereby increasing the effective lift

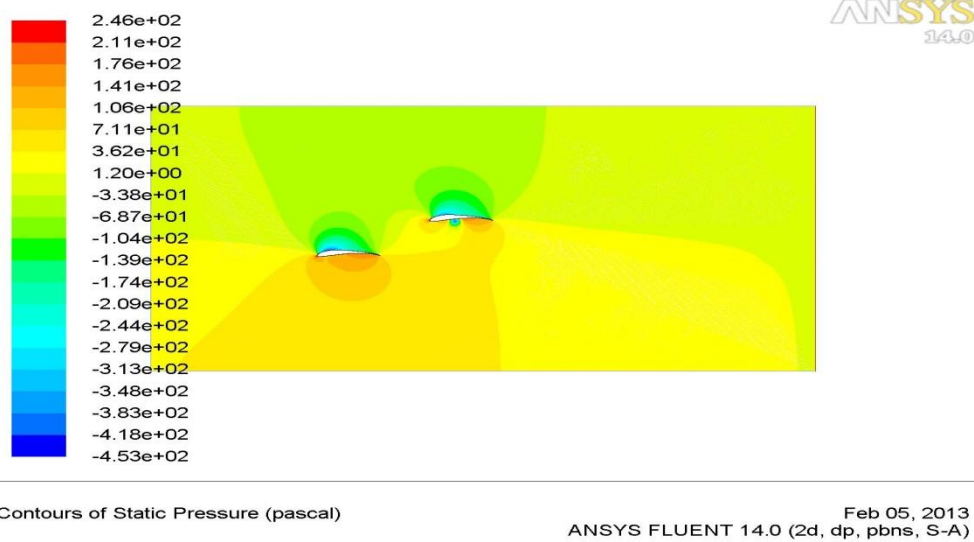


Figure 1

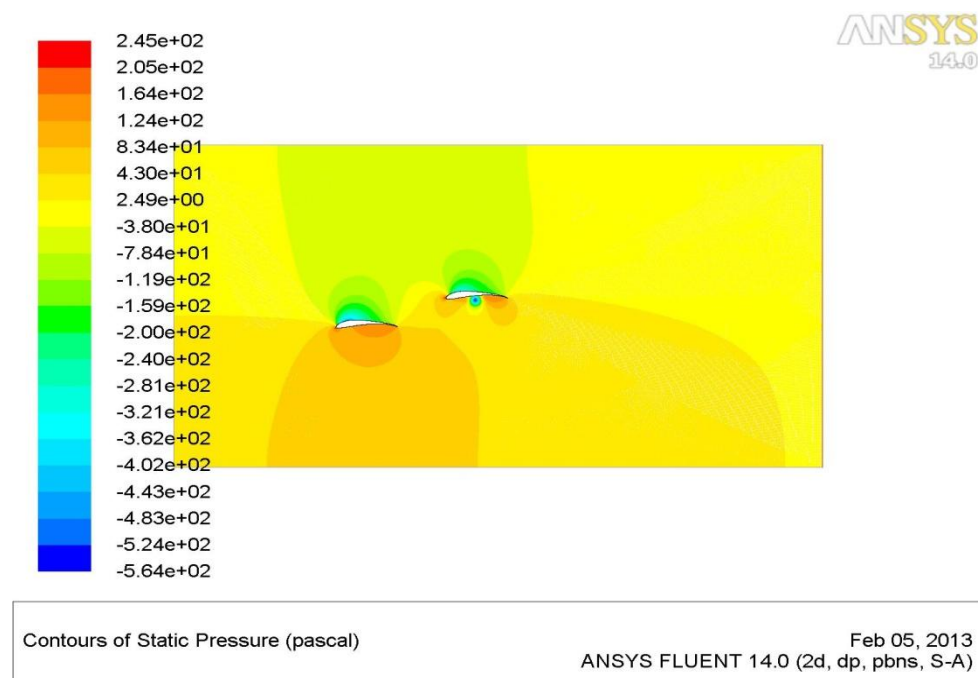


Figure 2

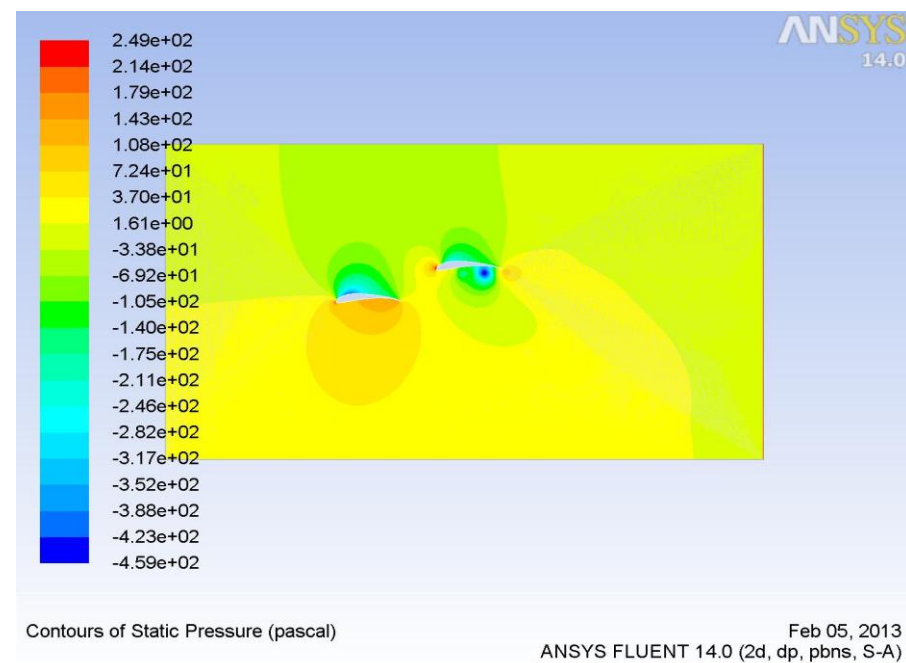
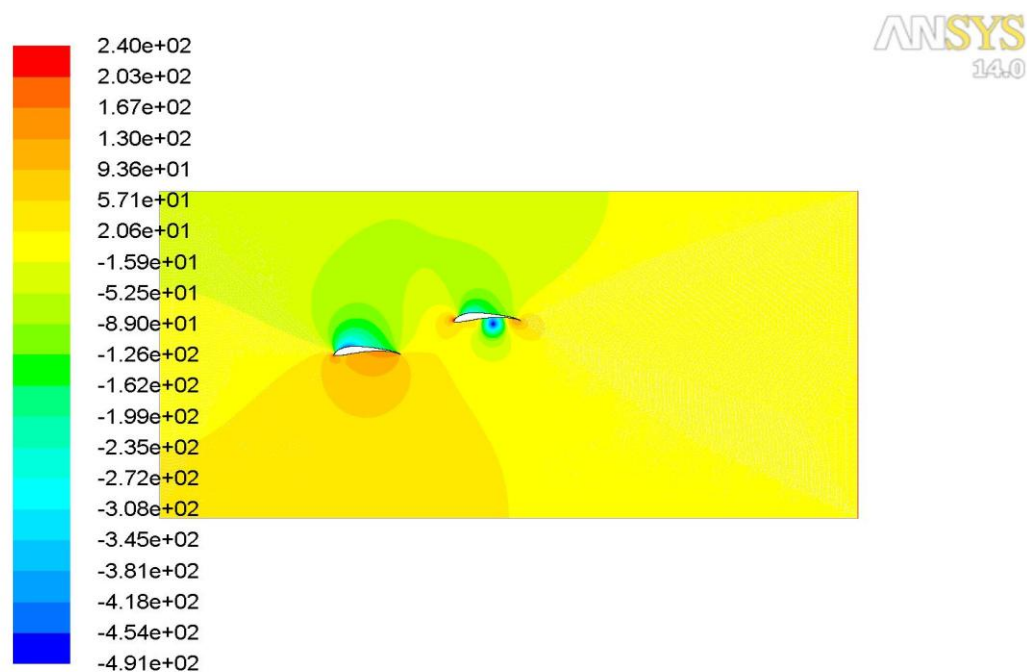


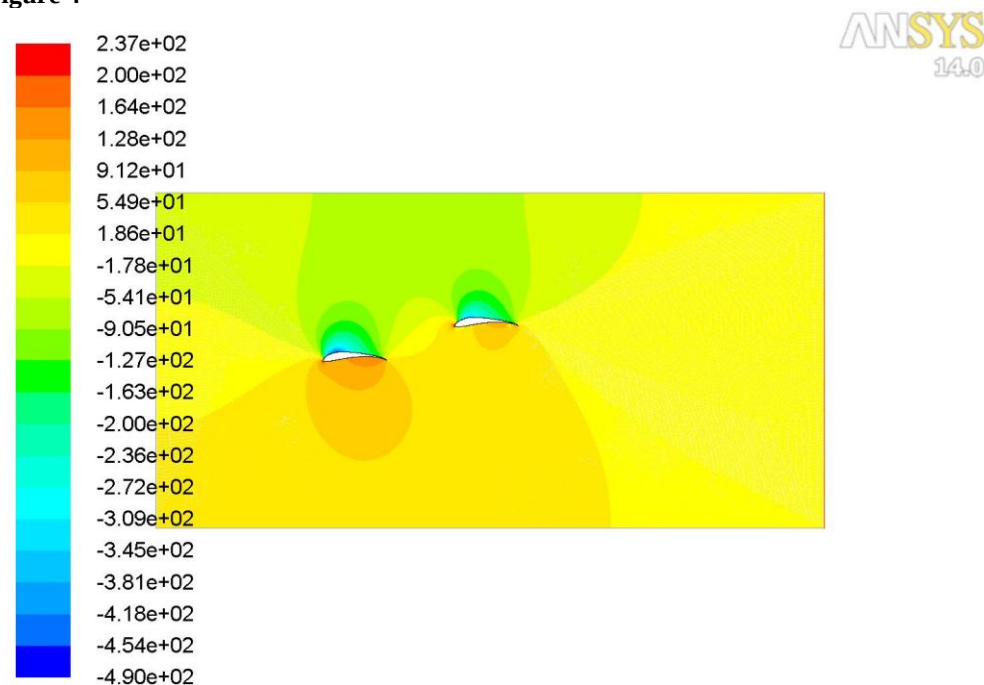
Figure 3



Contours of Static Pressure (pascal)

Feb 05, 2013
ANSYS FLUENT 14.0 (2d, dp, pbns, S-A)

Figure 4



Contours of Static Pressure (pascal)

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ANSYS FLUENT 14.0 (2d, dp, pbns, S-A)

Figure 5

III. Conclusion

A common phenomena observed in a canard configuration of an Aircraft is loss in net Lift due to the interaction of the vortices produced by the canard with the wing surface. This interference apart from reducing the lifting capacity of the wing also makes the ailerons ineffective. From the analysis performed and explained above it is observed that a canard configuration can give good lift characteristics provided the spacing of the canard and wing are well taken care of and a position is chosen which instead of making the wing lose on lift energizes the flow and improves the Aerodynamic efficiency.

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