Influence of Canard on the Longitudinal and Lateral-Directional characteristics of a Delta configuration at Low speeds

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Abstract: This paper analyses the effect of canard on a highly swept delta wing configuration. Extensive CFD studies were carried out to design a canard to meet desired aircraft instability level. This finalised canard shape was tested in a low speed wind tunnel and matched the trends obtained from CFD. The detailed pitching and lateral directional characteristics were studied from Wind tunnel tests and found to be satisfactory. Canard-Wing vortex matching studies helped in obtaining a good pitching moment trend and increased lift at high angles of attack.

Keywords: Computational Fluid Dynamics, Delta Wing, Canards, Wind tunnel.

CFD	=	Computational Fluid dynamics
RANS	=	Reynolds Averaged Navier-Stokes
C.G	=	Centre of Gravity
AOA	=	Angle of Attack
AOSS	=	Angle of Side Slip
CL	=	Coefficient of Lift
CD	=	Coefficient of Drag
CPM	=	Pitching moment coefficient
Cn_{β}	=	Yawing moment derivative
Cl_{β}	=	Rolling moment derivative
$Cn_{\beta,dynamic}$	=	Dynamic directional stability parameter
C_p	=	Pressure coefficient

1 Introduction

Modern fighter aircrafts have highly swept delta wings to meet supersonic performance requirements. In order to meet the contrasting performance requirements at subsonic and supersonic conditions, additional aerodynamic surfaces like canards are used. Additionally for improved subsonic performance, all fighter aircrafts maintain a desired level of instability. This paper is about a highly swept delta wing configuration, whose fuselage length was increased by 1000mm to increase internal fuel for better range and endurance. When additional fuel was added to a basic delta wing aircraft, the aircraft C.G shifted forward by 3.5%, To bring the instability level back to that of the basic configuration, a pair of canards were integrated in the increased fuselage length. Additionally this paper analyses the influence of a canard with increased fuselage length on the aerodynamic characteristics of a highly swept delta wing configuration from low speed CFD simulations and wind tunnel tests.

Three configurations are analysed in this paper, viz., a basic delta wing configuration (DELTA), basic delta wing with fuselage increased by 1000mm (DELTA + PLUG) and basic delta wing with 1000mm increased fuselage integrated with a pair of canards (DELTA + PLUG + CANARD). Numerous canard shapes have been explored and one final chosen shape was tested in wind tunnel and compared with CFD simulations. The basic shape of the delta wing has two sweeps (50° and 62.5°) with an airfoil based on 6400X series. The additional plug of 1000mm was added ahead of C.G and added with feasible amount of internal fuel which resulted in the forward shift of C.G by 3.5% of MAC. All detailed CFD simulations and wind tunnel tests were carried out on 1:10 scale model of the above three configurations. The basic delta wing configuration (DELTA configuration) had a 40mm modular part in the fuselage which was replaced by a 140mm plug (scaled equivalent of 1400mm in full scale) to arrive at the second configuration (DELTA + PLUG). The canards were integrated to the 140mm plug part to arrive at the third configuration (DELTA + PLUG + CANARD). The three tested configurations are shown in Fig.1. All CFD and wind tunnel tests were carried out on the three configurations with missiles carried in each of the Outboard missile hardpoint.

The Computational Fluid dynamics (CFD) studies were carried out with different grid densities for the above three configurations. The grids were generated on ANSYS ICEMCFD and RANS simulations were carried out in CFD++. Sufficient grid densities were created to capture the vortex characteristics of wing and canard. CFD simulations were carried out on a RANS grid with about 1million surface triangles and 48million total tetrahedral and prismatic cells with 35 layers of only prism. The Wind tunnel tests were carried out in the low speed HAL (Hindustan Aeronautics Limited) tunnel [cross section of 2.74mx1.83m] at 40m/s velocity.

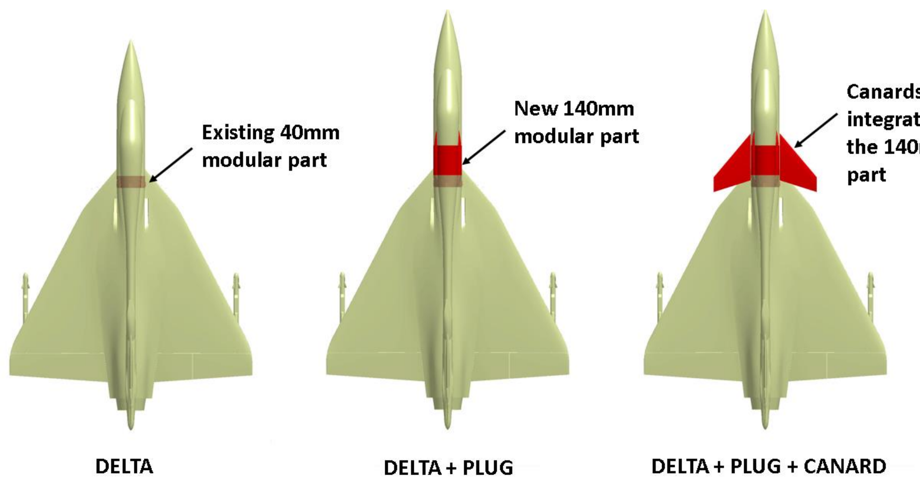

Figure 1: Three configurations tested in Wind tunnel (1:10 scale).

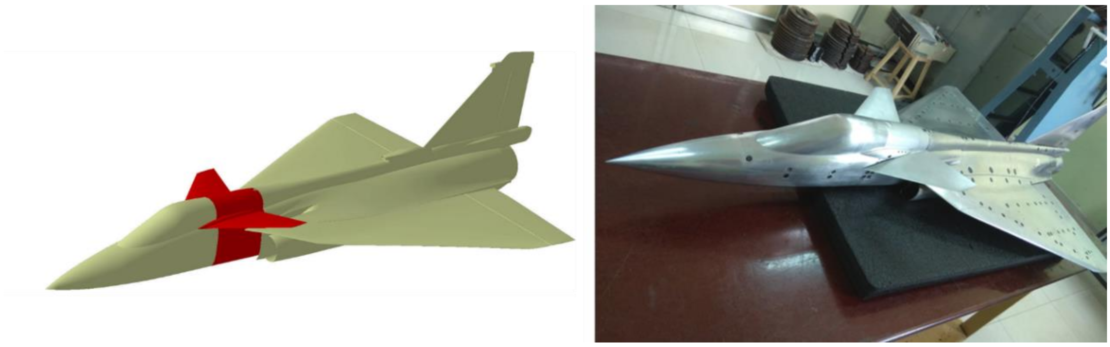

Figure 2: DELTA+PLUG+CANARD configuration used in Wind tunnel tests (shown without missiles).

The scaled model integrated with the canard (DELTA+PLUG+CANARD) configuration for CFD and the actual scaled model tested in wind tunnel is shown in Fig.2. The basic wing had leading edge slats and therefore the wind tunnel tests were carried out for zero deflection as well as full deflection of the leading edge slats. The CFD simulations were also carried out at the same Mach on the same scaled model as tested in the Wind tunnel. The basic grid details used for CFD simulation is shown in Fig.3.

The canard shape used for these tests has a leading edge sweep of 54° and a biconvex airfoil. The design of canard considered targeted aerodynamics objectives with various constraints and the shape was evolved through a comprehensive design procedure. Numerous wind tunnel studies carried out around the world for a delta-canard configuration was used in arriving at the basic design space. In the open domain significant amount of wind tunnel tests were carried out by different teams [Ref.1-15] out of which the main reference during the design of canards were based on the work of 4 teams as listed below.

- David. W. Lacey team at David W. Taylor Naval Ship Research And Development Centre
- Blair. B. Gloss team at Langley Research Centre (LRC), NASA.
- P.F.Covell from Langley with General Dynamics Team from Fort Worth Division
- W.Kraus at Messerschmitt-Bolkow-Blohm (MBB) Gmbh

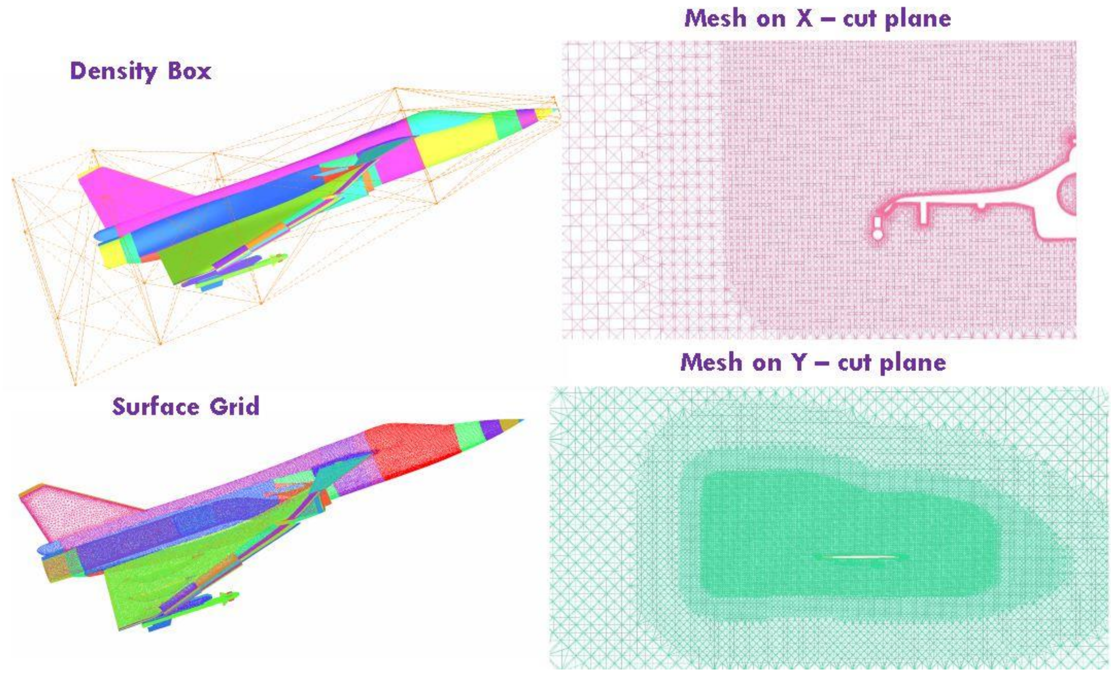

Figure 3: Basic grid details used for the CFD studies.

2 CFD studies

A parametric canard framework was created using In-House scripts with variation in root chord, span, tip chord, leading edge sweep angle and dihedral of the canard. All the canard shapes were integrated with DELTA configuration and were analysed using RANS computations. The vortex flow around the canard and its interaction with the wing vortex was studied in detail. Out of the numerous shapes studied from CFD, one chosen shape was tested in wind tunnel. One of the primary design parameters, namely the canard area was fixed to match the original instability level. The main aim of the Canard-Wing vortex matching studies is to get a linear pitching characteristic across a range of angle of attacks. The trends from wind tunnel results matched the CFD trends across the desired AOA range as shown in Fig.4. This was possible only by adopting an interactive procedure for parametric shape modification wherein new canard shapes were derived based on the vortex contours studied from CFD, The delta effect of canard on the lift and pitching characteristics matches satisfactorily with the CFD simulations as shown in Fig.5. The delta increase in lift due to canard was obtained from subtracting the lift of the DELTA+PLUG configuration from that of the DELTA+PLUG+CANARD configuration. Since the horizontal location of the canard is closer to the wing, there is a reduction in wing lift which is the main cause of small increase in ΔCL. However at high angles of attack, the canard-wing interference is reduced and the vortex lift dominates due to merging of canard and wing vortices, which explains the rapid increase in ΔCL.

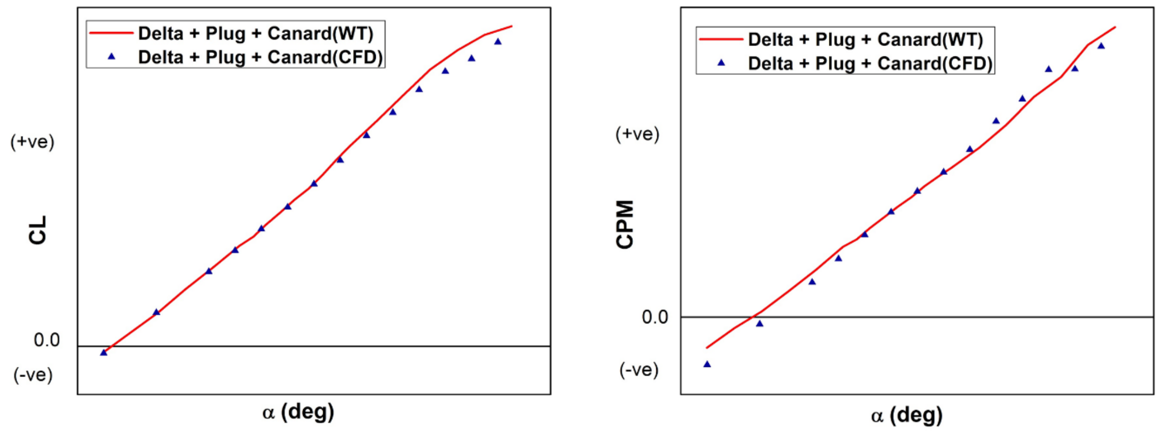

Figure 4: CFD and Wind tunnel results for the DELTA+PLUG+CANARD configuration.

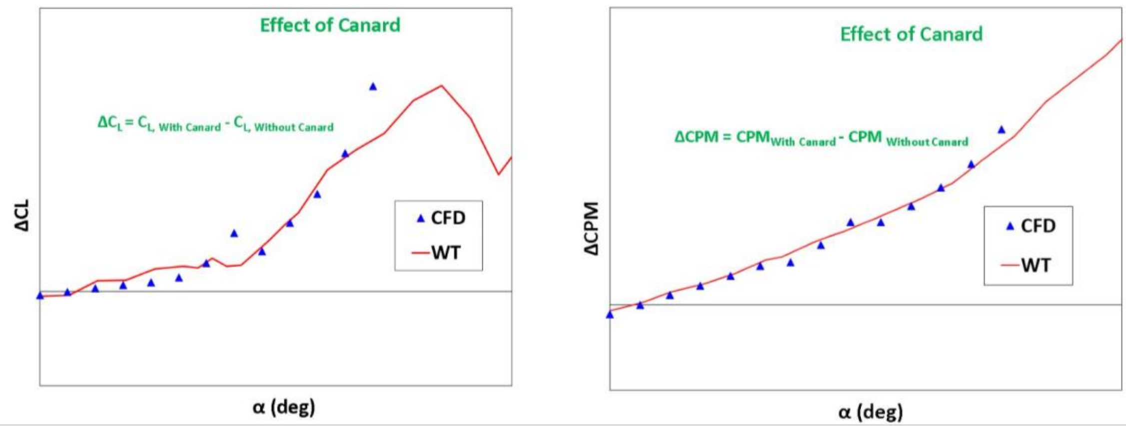

Figure 5: CFD and Wind tunnel results of the delta effect of canard.

3 Basic pitching characteristics

The lift, drag and pitching moment characteristics for the three configurations from the wind tunnel tests are shown in Fig.6 for full slat deflections. The addition of plug does not affect the lifting characteristics, while the canard increases lift at high angles of attack. Similarly the canard is beneficial at high angles of attack as seen from the drag polar. The pitching characteristics indicate that the effect of plug follows the similar trend as the delta configuration. The addition of canard increases the instability level for the same C.G as the basic delta configuration but it eliminates the pitch up tendency. However shifting the C.G forward by 3.5% rotates the pitching moment to match with the original instability level of the basic delta configuration. This satisfactory match in the instability levels from wind tunnel tests based on the shape chosen from CFD studies stood out as a significant validation for our CFD procedure

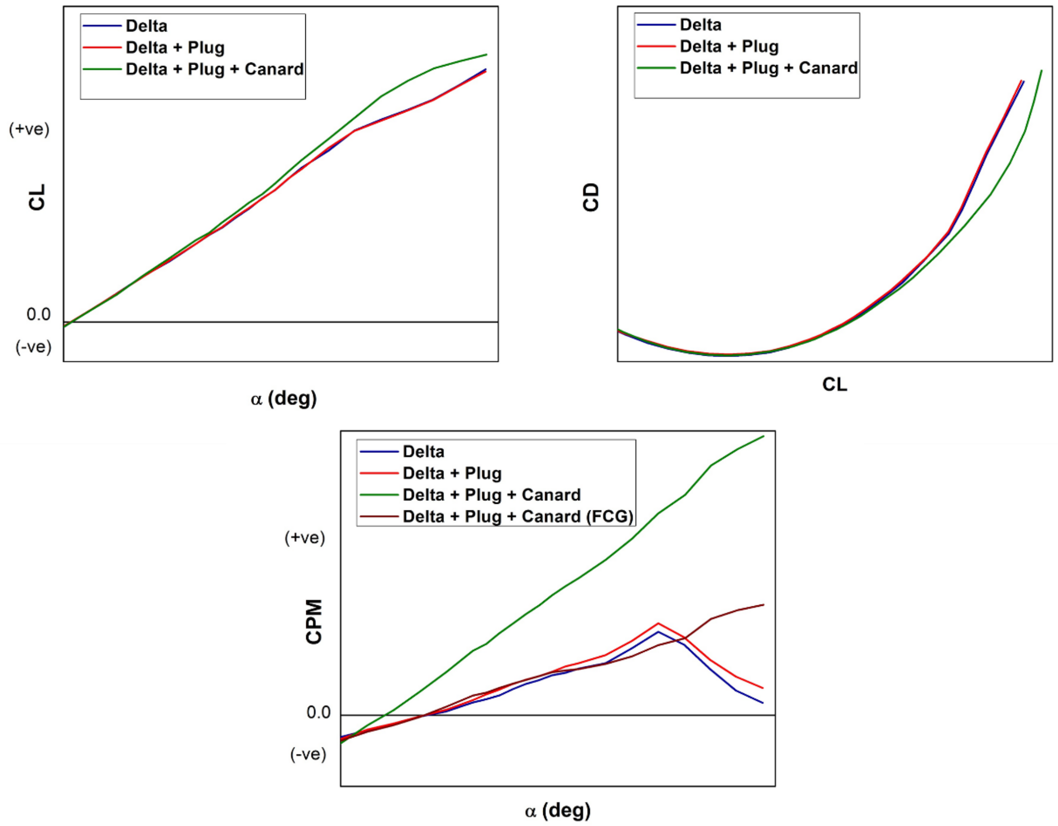

Figure 6: Basic aerodynamic characteristics with full slat deflections from Wind tunnel tests.

Another important feature than can be observed is that the integration of canard does not result in a stable break in the pitching characteristics. The canard carries the pitching moment curve linearly even at high angles of attack. This can be understood by studying the vortex contours from CFD simulations as shown in Fig.7. The surface pressure contours can be used to understand the strength of the attached leading edge vortex. It can be seen that as the angle of attack increases, the leading edge vortex gets getting stronger and stronger without showing signs of any separation or distortion. This canard vortex merges with the wind leading edge vortex and strengthens it even at high angles of attack. The comparison of pressure contours on the surface and on the wing slices are shown for DELTA and DELTA+PLUG+CANARD configuration is shown in Fig. 8.

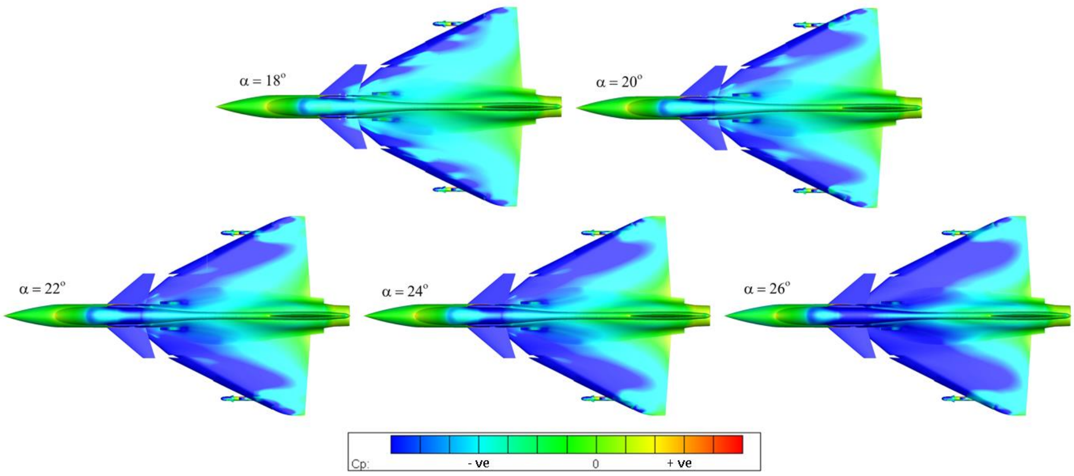

Figure 7: Surface pressure contours from CFD for DELTA+PLUG+CANARD configuration.

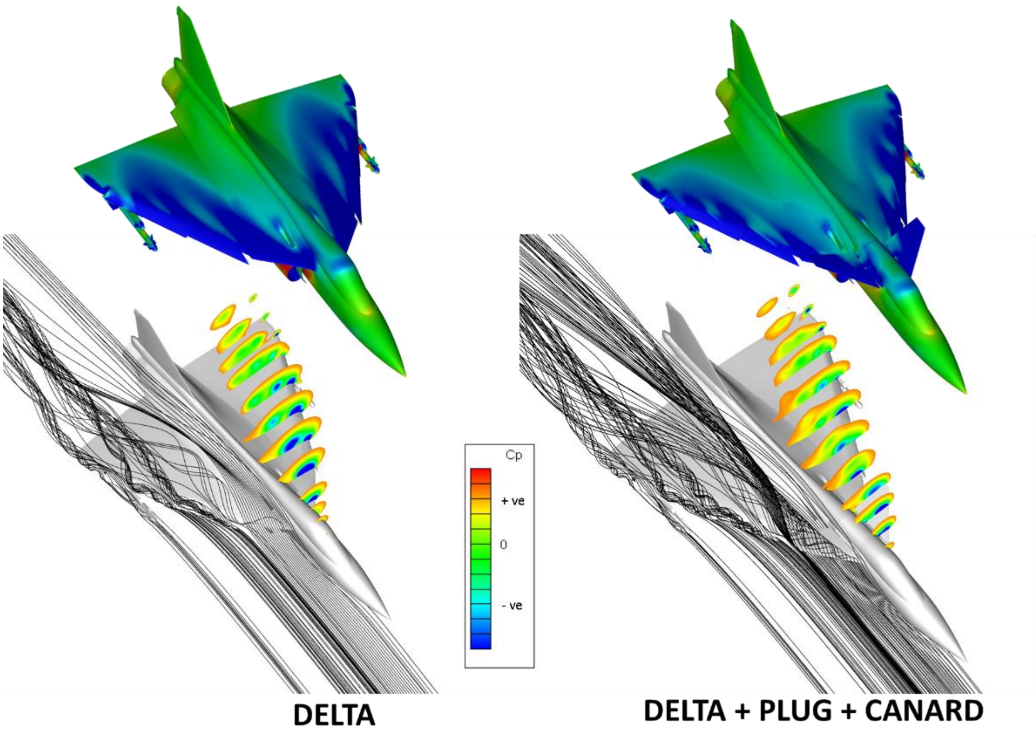

Figure 8: Surface pressure contours from CFD for DELTA and DELTA+PLUG+CANARD for AOA=18°.

4 Lateral directional characteristics

The lateral directional characteristics from wind tunnel tests for the three configurations are shown in Fig. 9 [AOSS=10°]. The increase in the length of the front fuselage by 140mm gives a sharp reduction in yawing moment derivative as expected. However, the presence of canard further aggravates it and leads to a large loss in directional stability. It was studied in CFD and found that the presence of canard results in a large high pressure region in the front fuselage which degrades the yawing moment derivative. The rolling moment derivative on the other hand is higher due to the addition of lift from canard and this helps in the dynamic directional stability parameter to be substantially better as in Fig.9.

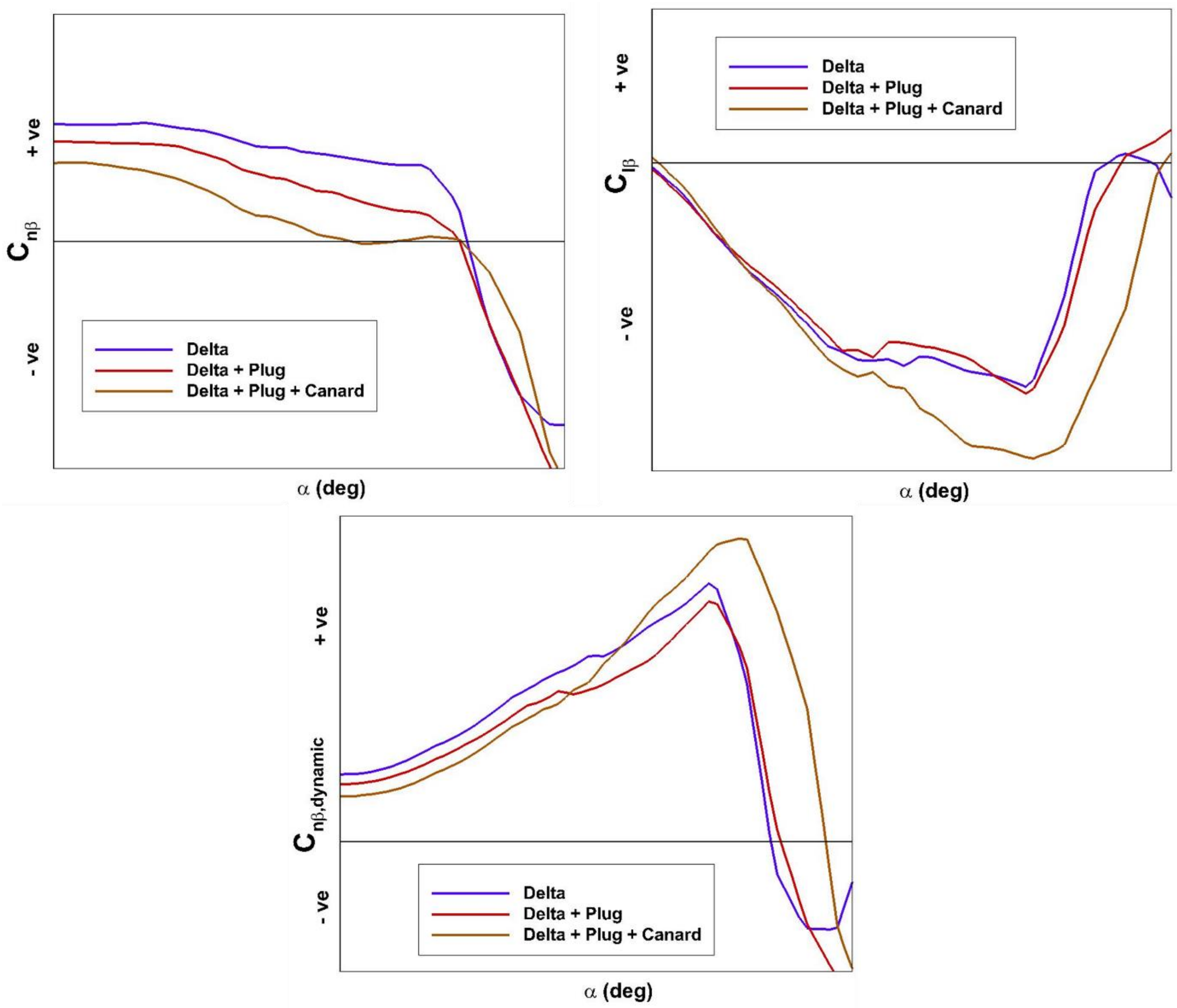

Figure 9: Lateral directional characteristics from Wind tunnel tests.

5 Conclusion

The changes in aerodynamic characteristics of a Delta configuration was studied with the integration of a longer fuselage and a canard from CFD and wind tunnel tests. The CFD results matched satisfactorily with the Wind tunnel giving a boost in confidence of recovering back the instability level to that of the original configuration. Though the yawing moment derivative worsened with canard, the improvement in dynamic derivative was substantial. It was observed that canard and wing vortex matching at medium to high angles of attack provided benefits in terms of improving high AOA characteristics for the canard configuration.

6 Acknowledgements

The authors wish to acknowledge the support provided by Dr. Santhosh Koruthu, Technology Director for Aerodynamics and Performance at ADA. The authors also acknowledge the effort of Shri. Balaji who helped in design, fabrication and integration of the canard and plug to the existing wind tunnel model. The support provided by Shri. Koner, Shri. Sudhir (HAL Wind tunnel) and Shri. Venugopal for Windtunnel testing is acknowledged. The computational support provided by Mugilvanan A, Shibin D.S. and Prasanna P is also acknowledged.

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