Analysis of Low Speed Aerodynamics of Double Delta Wing

Swaraj Singh[1], jayanta sinha[2]
[1,2]*Amity Institute of Aerospace Engineering, Amity University, Noida, Uttar Pradesh*

Abstract- **Wilbur Wright has famously noted that "The desire of flying is an idea handed down to us by our ancestors who looked enviously on the birds soaring freely through space on the infinite highway of the air." My paper addresses that curiosity of finding out the flow around a flying object, here, in this research work, double delta wing. In this research work, numerical as well as experimental investigation was performed on 80/56.867-deg double-delta wing to obtain lift and drag coefficients. Low speed aerodynamics was analyzed on this type of wing configuration. For the double-delta wing study, both numerical and experimental investigation was carried out, and the results from both numerical and experimental predications were compared to the experimental data found in existing literature. "The results of the comparison of lift and drag coefficients show good agreement with the experiments." In general, "the comparison shows good agreement" with the different CFD predictions as well as experimental studies and theoretical calculations.**

Index terms- **computational fluid dynamics, double delta wing, turbulence models, subsonic, hypersonic**

I.INTRODUCTION

A wing of an aircraft plays an integral part in any flight operation. Ancient Chinese used kites with curved surface to demonstrate that they are better than the kites with flat surface. Leonardo da Vinci, during 1486-1490, introduced the idea of flapping a pair of wings up and down. Lilienthal and Cayley, in late 1800s, demonstrated that a curved surface produces more lift than a flat surface. Wilbur and Orville Wright, the forefathers of flight, during early 1900s, constructed a fixed wing aircraft by the use of ailerons. Wright brothers' accomplishments revolutionized transportation on planet earth. Well, most of what the brothers accomplished was original work, however, the findings of several 19th-century experimenters provided helpful pieces to the puzzle and saved the brothers to chase many unfruitful boulevard of research. A wing is a surface used to create aerodynamic forces during flight. They have a shape called airfoil shape, a streamlined cross-sectional shape producing lift.

II. VORTEX BREAKDOWN

Recent research work has been in the area of high-angle of attack aerodynamics on delta-shaped wings. As discussed earlier, lift "increase as the angle of attack increases. Unfortunately, there are limits to the advantages provided by the delta wing vortices [1]. As the angle of attack increases, there is a abrupt breakdown in the vortex structure. This process is known as vortex bursting. As a result, there is stagnation in the core axial flow and an expansion in radial size [2]. Once this is reached, there is no increase in the lift aft of the burst point.
Therefore the research and development of breakdown of these vortices is important when it comes to the performance of the delta wing or its types.

Vortex Breakdown can be classified into two types:
1. Bubble or asymmetric type
2. Spiral type
In bubble type, there is rapid expansion of the core forming a bubble-like structure which is nearly asymmetric [3]. On the other hand, there is a deformation in the vortex centerline without any noticeable growth in the core size. There have been intensive research in order to control the delta wing vortices, like the use of blowing [4][5], suction [6][7], flaps [8][9][10], canards [11].
"Thus flow separation takes place at leading edge near apex and therefore primary vortices are formed on the upper surface [12]." When it comes to double delta wing, having two distinct sweep angles of its leading edge is more advantageous in terms of

aerodynamic performance. The advantage of double delta wing over single delta wing is that the vortices produced from "highly swept first leading edge i.e. strake, stabilizes the vortices produced downstream at the second or main leading edge." This delays the vortex breakdown to higher angle of attacks. By adding extra lifting surface, i.e. highly swept strake, additional leading edge vortices are produced. These vortices are same as the main wing vortices [13]. The vortices generated by strake also contribute to the increase in "maximum vortex lift over the wing," especially at "low Mach numbers. The aim of this study is to study vortex breakdown pattern in double delta wing, to find pressure coefficient distribution over double delta wing. The objective of this research work is to analyze low speed aerodynamics on Double Delta wing and to compare the results of experimentation with that of the simulated results. Also, to validate the data found in existing literature on Delta wing, with the numerical investigations on the delta wing geometry.

III. PROJECT DESIGN AND IMPLEMENTATION

Design: Design of the double delta wing was done on ICEM CFD. The below table provides design parameters of the double-delta wing.

Table 1: Design specifications of the double-delta wing

Parameter	Delta
Leading-edge/in-board sweep, Λ_{le}/Λ_i	80 deg
Out-board sweep, Λ_o	56.67
Root chord, c_r	0.3 m
Wing span, b	0.2963m
Wing area, S	0.0444525m^2
Aspect ratio, A	1.975
Thickness, t	0.01 m
Bevel angle	16.808 deg

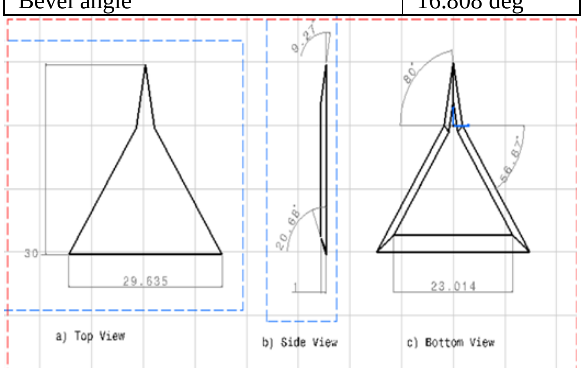


Figure 1: Schematic Diagram of Double-Delta wing a) Top View b) Side View c) Bottom View

Grid Generation: As discussed in earlier section that the geometry was created in ICEM CFD. Surfaces were created on the geometry and on the domain. Parts of the geometry were named as follows: UPPER, LOWER, EDGE, and REAR, representing upper, lower, edge and rear surfaces of the geometry respectively. Parts of the domain are as follows: INLET, OUTLET and FARFIELD, representing inlet, outlet and farfield, of the domain respectively. A body is created in between domain and the geometry, namely, AIR, representing the medium in which the aircraft is travelling. Total number of elements in the mesh setup is 200149, which is coarse mesh. Mesh type is tetra/mixed and the mesh method used is robust (Octree).

Table 2: Maximum part size

Part	Max. Size
Edge	3
Farfield	7
Inlet	7
Lower	3
Outlet	7
Rear	3
Upper	2

Density box was also created around the close proximity of the geometry. The size of which was kept unity and density ratio was given a value of 3.5, which describes the tetra growth away from the density-ratio.

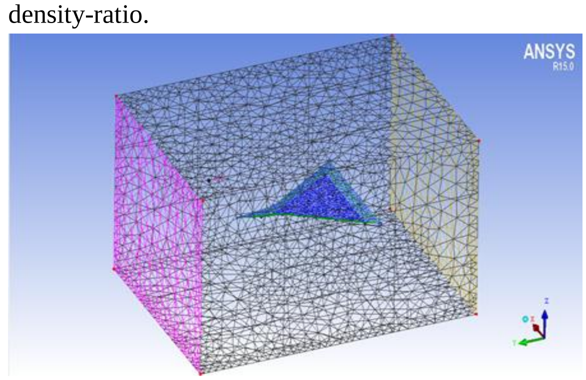
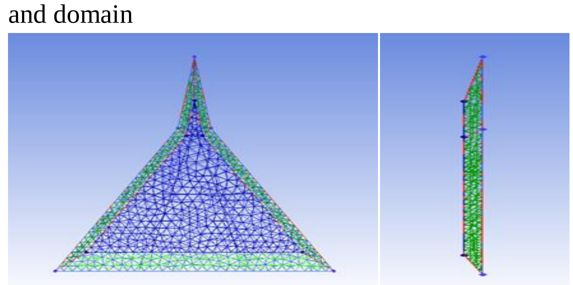
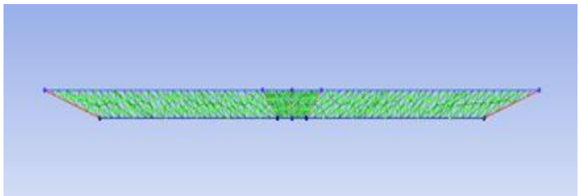


Figure 2: Mesh setup of 80/56.867-deg delta wing and domain



a) Bottom view b) Side View



c) Back View

Figure 3: Grid Distribution over the 80/56.867-deg Double-Delta Wing, (a) Bottom View, (b) Side View, (c) Back View

The above set of figures (Fig 2, Fig 3 (a), 3 (b), 3 (c)), shows grid distribution on the delta wing and domain surrounding the same.

Numerical Investigations: The next step is the simulation process of the flow over the wing. For double-delta wings, which are built for supersonic flights, the low speed aerodynamics is much standard subsonic flight investigations, merely due to absence of shockwave formation [14]. Again this is performed in ANSYS FLUENT. The initial conditions that were used are:

- Mach number = 0.04
- Gauge pressure = 0 (Pa)
- Temperature = 300 (k)
- Turbulent kinetic energy = 0.63375 (m2/s2)
- Specific dissipation rate = 4338.57 (1/s)

For different angle of attacks, X, Y and Z component of velocity were adjusted accordingly.

Table 3: Boundary conditions

Name	Type
Outlet	Outflow
Farfield	Outflow
Upper	Wall
Lower	Wall
Edge	Wall
Inlet	Velocity-inlet
Rear	Wall

Table 3 shows the boundary conditions on the corresponding parts of the system under study. The number of iterations for the simulations was 1000. The turbulence model uses Transition SST model, which is much more accurate when compared to other models.

IV. RESULTS AND DISCUSSIONS

Experimental Facility: Experiments were conducted on 80/56.867-deg Double-Delta wing in the wind tunnel facility at Amity University, Noida, India. The aim for doing so was to visualize the flow over the wing and to find pressure coefficient distribution around the wing. Two experiments were performed on 80/56.867-deg Double-Delta wing at different angles of attack, first to visualize flow around the wing and secondly to find pressure distribution on the wing. For flow visualization, the wing was made of black acrylic material. The choice of this material and color was to better observe the flow over the wing. For Cp distribution experiment, the material of the wing was chosen to be wood. The choice of wood was made solely on the basis of the fact that this material is relatively easy to work on, as compared to its metal counter parts. The dimensions are as per the design done on the software. Figure 4 shows the image of the 80/56.867-deg Double-Delta wing.

Flow Visualization Results:

Oil flow visualization was performed on the 80/56.867-deg Double-Delta wing at various angles of attack, which are, -10º, 0º, 5º, 10º, 15º, 20º, 30º. A mixture of Titanium Oxide, which is white colored powder, oleic acid and lubricating oil, was prepared. Firstly, oleic acid was heated in water bath at boiling temperature of water. Then 5-10 drops were added in a small bowl, along with 1 table spoon of titanium oxide and 5 drops of lubricating oil.

Figure 4: Image of 80/56.867-deg Double-Delta wing.

This mixture is stirred regularly throughout the experiment in order to maintain adequate viscosity. This mixture is then sprayed with the help of a small brush over the surface of the wing. Kerosene was used to clean the surface after each run of the wind tunnel so that next run of spraying can be done on the wing. The rated velocity of the wind tunnel was 26m/s. The following figures show the oil flow visualization done on the wind tunnel.

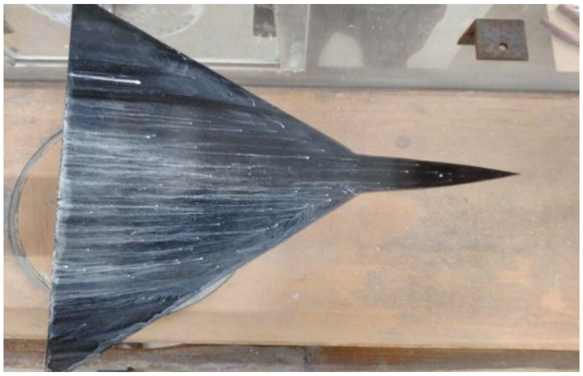


Figure 5: Flow at 0º angle of attack.

Figure 6: Flow at 5º angle of attack.

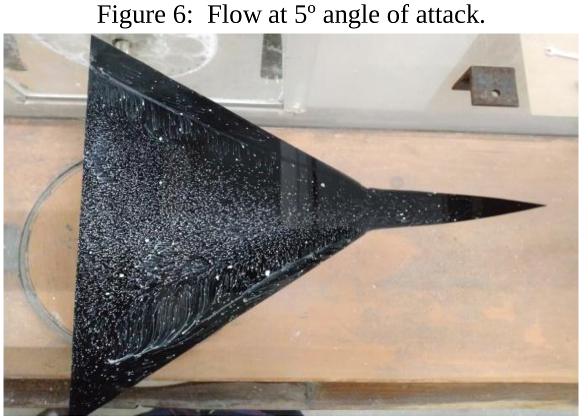


Figure 7: Flow at 10º angle of attack.

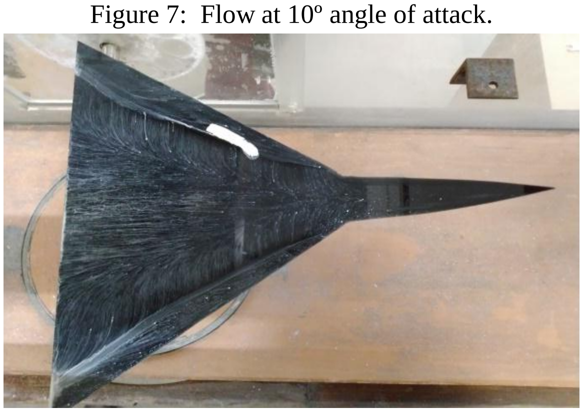


Figure 8: Flow at 15º angle of attack.

Figure 9: Flow at 20º angle of attack.

Figure 10: Flow at 30º angle of attack.

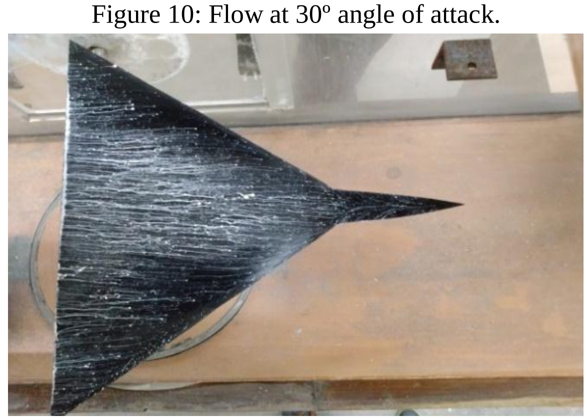


Figure 11: Flow at -10º angle of attack.

The above set of figures shows how the fluid flows over the 80/56.867-deg Double-Delta wing at different angle of attacks. It can be observed that the wing vortex is generated at the strake end and has an inward impression. The wing vortex is the secondary vortex region. The two vortices namely, primary and secondary, can be distinguished up to trailing edge at 5º angle of attack. Hence these set of vortices are appeared to moving in outboard direction and this movement increases as the angle of attack increases. Although the primary (strake) vortices have more outboard curvature than the wing vortices, which tends to remain straight at 10º angle of attack. These secondary (wing) vortices are disrupted as there is an increment in the value of angle of attack.

Double-Delta Wing simulation results:

For performing experiments on the 80/56.867-deg Double-Delta wing, a wooden model was made. In order to calculate pressure head using a manometer, 12 points were chosen that were required be drilled using a 2.5mm drill bit. A total of 12 holes were made. A plastic pipe of the same diameter as that of the hole, i.e. 2.5 mm, was used. This pipe was a connection between the model and the manometer. One end of the pipe was connected to the model and the other end was connected to the manometer. The manometer pipes contained a fluid called Ethyl alcohol, which have a density of 780kg/m3 at 20º C. Since ethyl alcohol is lighter than water, it can easily react to any changes in the pressure in the manometer pipes.

Figure 12 and Figure 13 shows the coefficient of pressure distribution with taping for 50% and 75% chord at 30º angle of attack respectively. It is obvious from the graph that there is good agreement between experimental and simulated value of Cp.

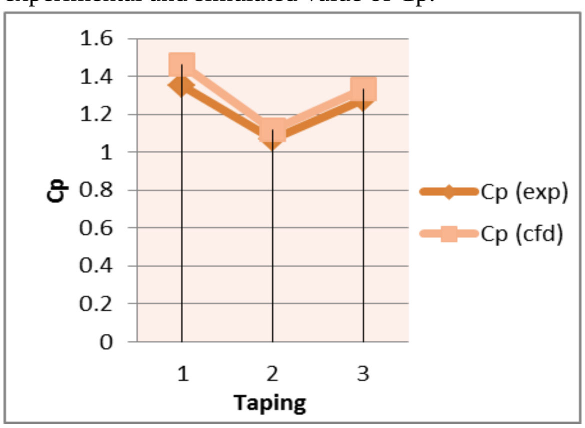


Figure 12: Cp distribution for 0.5c at 30º AOA

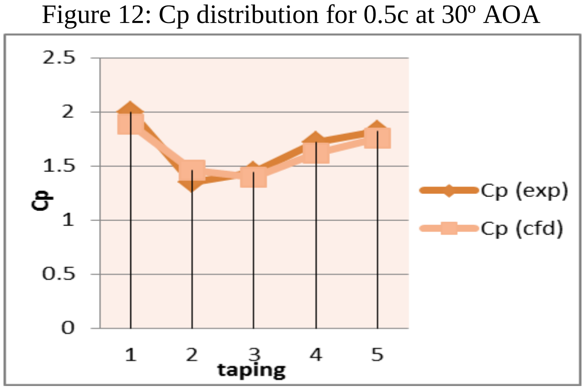


Figure 13: Cp distribution for 0.75c at 30º AOA.

Vortex Breakdown Pattern:

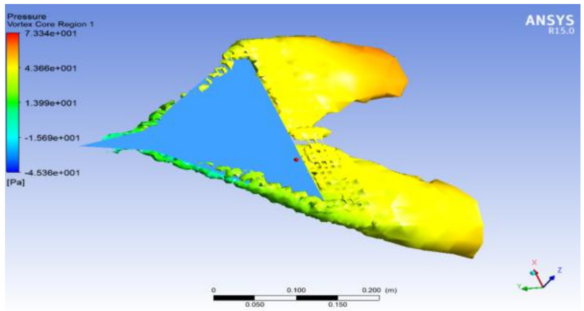


Figure 14: Vortex region over 80/56.867-deg double-delta wing at 0º AOA.

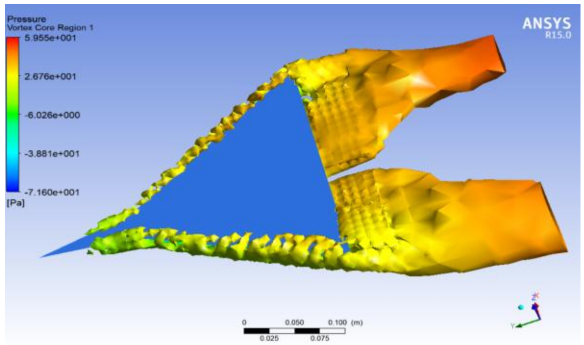


Figure 15: Vortex region over 80/56.867-deg double-delta wing at 5º AOA.

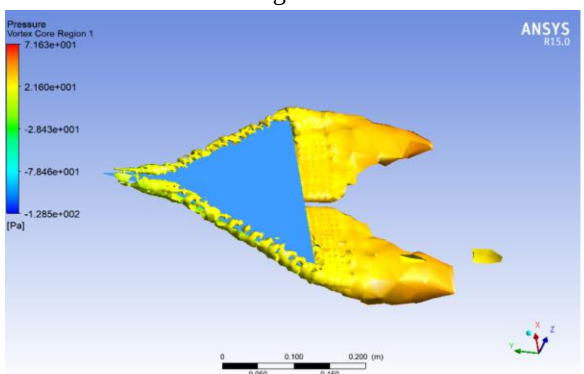


Figure 16: Vortex region over 80/56.867-deg double-delta wing at 10º AOA.

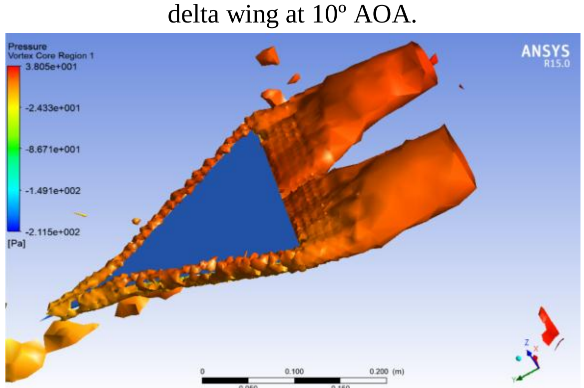


Figure17: Vortex region over 80/56.867-deg double-delta wing at 20º AOA.

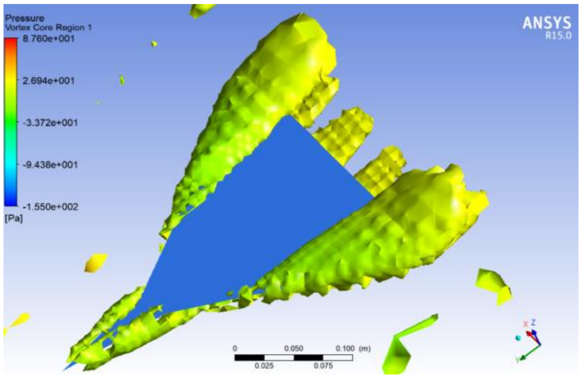


Figure 18: Vortex region over 80/56.867-deg double-delta wing at 30º AOA

Figure 14 to 18 shows vortex core regions over 80/56.867-deg double-delta wing at 0º, 5º, 10º, 20º, and 30º angles of attack. The method by which these vortex regions were generated was Absolute Helicity with level 0.1 for each vortex region contour. The absolute helicity vortex which is being displayed is created by a mixture of effects from the walls, the curve on the wing, and the interaction of the fluids. If I had chosen the vorticity method instead, wall effects would have dominated. At 30º angle of attack, there are strong vortices on the upper surface of the wing, which in turn indicates the region of vortex breakdown, a phenomenon which describes the deceleration of the vortex core and an increase in the vortex core diameter [16].

Effect of leading edge shapes: Measurements of the forces acting on the wing shows that as angle of attack increases, there is an increase in both lift and drag of the double-delta wing [15].

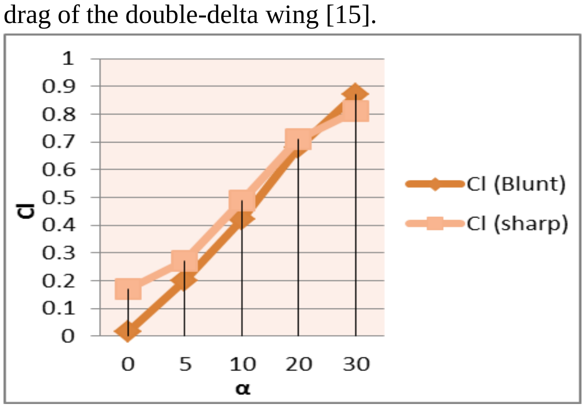


Figure 5.35: Cl vs. α curve for sharp and blunt double delta wing.

Coefficient of lift of 80/56.867-deg and 81/45-deg double-delta wing were calculated and compared. The former had a sharp leading edge whereas the latter one had a blunt leading edge with a bluntness ratio close to 1. The effect of leading edge shapes shows that the double-delta wing having blunt leading-edge, then it will delay the primary separation at the leading edge, resulting in further delay in the vortex lift. Therefore a blunt-shaped leading edge of a double-delta wing will produce more lift at higher angle of attack.

Hence various numerical investigations and experiments suggest that there is an increment in the suction pressure with increase in the leading edge bluntness.

V. CONCLUSION

Study of low speed analysis of aerodynamics over 80/56.867-deg double-delta wing was done. The aim of this study was to visualize vortex breakdown pattern over the double delta wing and to find pressure coefficient distribution over the double delta wing. The objective of this dissertation work was to analyze low speed aerodynamics over the double delta wing. Also to compare the results of the experiments and simulation on double delta wing and finally to validate the results of the delta wing simulations with existing research work. The experimental and simulated results of the low speed analysis of the double delta wing hold good relation with each other.

REFERENCES

[1] "Roy Y. Moose, Boon-kiat lee, Shigeo hayashibara and L. scott miller," "Diamond, cropped, delta, double delta wing vortex breakdown during dynamic pitching", AIAA Journal, Vol. 35, No. 3.

[2] "Ericson G. E.," "Water tunnel studies of leading edge vortices", "journal of aircraft, vol. 19, no. 6, 1982, page no. 442-448."

[3] Vidyadhar Y. Mudkavi, "The phenomenon of vortex breakdown", NAL, May 2015.

[4] "Seginer A. and Saeomon M.," "Performance augmentation of a 60-deg delta aircraft configuration by spanwise blowing", "journal of aircraft, vol. 23, no. 11, 1986, page no. 801-807."

[5] Wood N.J., and Robert L., "control of vertical lift on delta wing by tangential leading edge blowing", journal of aircraft, vol. 25, no. 3, 1988, page no. 236-243.

[6] "Parmenter K., and Rockwell D.," "Transient response of leading edge vortices to localized suction", "AIAA journal, vol. 28, no. 6, 1990, page no. 1131-1133."
[7] "McCormick, S., and Gursul, I.," "Effect of shear layer control on leading edge vortices", "AIAA paper, 96-0541, Jan-1996."
[8] "Marchman, J.F.," "Aerodynamics of inverted leading edge flaps on delta wings", "journal of aircraft, vol. 18, no. 12, 1981, page no. 1051-1056."
[9] Karagounis, T., Maxworthy, T., "Generation of separated vortices over a delta wing by means of leading edge flaps", "AIAA paper 89-0997, March 1989."
[10] "Gursul, I. Yang, H. and Deng, Q.," "Control of vortex Breakdown with leading-edge devices", "AIAA paper, 95-0676, Jan 1995."
[11] "Hayashibara, S., Myose, R.Y., and Miller, L.S.," "The effect of a 70-deg swept canard on the leading edge vortices of a 70-deg swept delta wing during dynamic pitching", AIAA paper 97-0613, Jan. 1997.
[12] "Shabudin mat, I.S. Ishak, Tholudin mat lazim, shuhaimi mansor, mazuriah said, abdul basid abdul rahman, ahmad shukeri mohd. Kamaludim and romain brossay," "Development of delta wing aerodynamics research in universiti teknologi Malaysia low speed wind tunnel".
[13] P.E. Olsen and R.C. Nelson, "Vortex interaction over double delta wings at higher angles of attacks", AIAA journal, 1989, pp. 238-248.
[14] Sukanta Saha, Bireshwar majumdar, "Modeling and simulation on double delta wing", "International journal of Advanced Computer Research, Vol. 3, No. 1, Issue 8, March 2013."
[15] "B. Ashwin kumar, P. kumar, S. das, and JK Prasad," "Effect of leading edge shapes on 81/45 double delta wing at slow speeds", Journal of aerospace engineering, Imech 2017.
[16] Lance W. Traub, "Simple prediction method for the laoction of vortex breakdown on delta wing", journal of aircraft, vol. 33, no. 2.