Numerical Investigation of high attack angle flow on $76^0/45^0$ Double-Delta wing in Incompressible Flow

Hesamodin Ebnodin Hamidi, and Mojtaba Rahimi

***Abstract*—**Along with increasing development of generation of supersonic planes especially fighters and request for increasing the performance and maneuverability scientists and engineers suggested the delta and double delta wing design. One of the areas which was necessary to be researched, was the Aerodynamic review of this type of wings in high angles of attack at low speeds that was very important in landing and takeoff the planes and maneuvers. Leading Edges of the wings,cause the separation flow from wing surface and then formation of powerful vortex with high rotational speed which studing the mechanism and location of formation and also the position of the vortex breakdown in high angles of attack is very important. In this research, a double delta wing with $76^o/45^o$ sweep angles at high angle of attack in steady state and incompressible flow were numerically analyzed with Fluent software. With analaysis of the numerical results, we arrived the most important characteristic of the double delta wings which is keeping of lift at high angles of attacks.

***Keywords*—**Double delta wing - High angle of attack – Vortex breakdown – Incompressible flow

I. INTRODUCTION

THE desire for increased speed, maneuverability and efficiency has dominated the evolution of military aircraft. These goals have resulted in aircraft designs that incorporate swept wings and highly swept wing leading-edge extensions (LEX).The flow field surrounding slender aircraft at large angles of incidence is dominated by the vortices generated on the forebody, leading-edge extensions, wing and control surfaces. At high angles of attack, the vortices can undergo a transition process known as vortex breakdown. When vortex breakdown occurs over a lifting surface, the aerodynamic loading can change suddenly. More dramatic chances in loading occur when breakdown reaches the apex of the lifting surface and the flow becomes fully separated. The nonlinear lift created by the vortex is reduced in the region aft of vortex breakdown [1].The main results of this first of a kind flow visualization data indicate that, for the static conditions of the model, the mutual induction effect of strake and wing vortex cores on each other leads to their intertwining . This interaction point moves upstream with increasing angle of attack (AOA) but at higher AOAs the strake vortex bursts even before the interaction. The AOA range for coiling-up of the vortices is 10-25 degrees [2].Verhaagen and Allan [3,4] studies was conducted to provide data for the purpose of understanding the vortical flow behavior and for validating Computational Fluid Dynamics methods. Flow visualization tests have provided insight into the effect of the angle of attack and Reynolds number on the vortex-dominated flow both on and off the surface of the double-delta wing. Sohn and Chung [5] are shown the strake modification can greatly alter the vortex flow pattern around the delta wing. It also suggests that an actuator efficiently realizing the strake shape modification can be used as an effective tool for the active flow control of the vortex flow.

In the present study, the vortex formation, interaction, and breakdown characteristics of double-delta wings were numerically investigated. The cases of were investigated at the angles of attack of 10,15, 25,30 ,35 and 40 degs. It is hoped in the present numerical study performing that the aerodynamic load characteristics of the double-delta wing could be explained with the flow physics observed.

II. DOUBLE-DELTA WING MODEL

The double-delta wing models are shown in Fig. 1.the wings sharped leading edges and rectangular trailing edges.The dimensions of the doubledelta wing model are as follows: in-board leading edge sweep Λ *i* = 76 degrees, out-board leading edge sweep angle Λ*o* = 45degrees, root chord *c* = 0.5 m, wing span *b* = 0.5 m, , bevel angle = 8.5 degree and thickness *t* = 0.02 m.

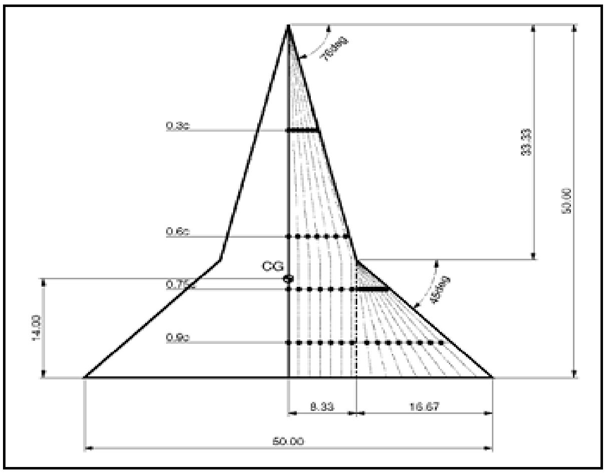

Fig. 1 Schematic of double-delta wing model

Assistant Professor, Department of Mechanical and Aerospace Engineering,(hebnodin@ihu.ac.ir)
Msc student, Department of Mechanical and Aerospace Engineering, (mr.mojtabarahimi@gmail.com)

III. THE COMPUTER PROGRAM

The present study involved numerical investigation of the aerodynamic loads and vortex flow on 76/45-deg double-delta wings using FLUENT (v6.3.26), a state-of-the-art commercial computational fluid dynamic (CFD) solver. FLUENT was used not only to obtain the aerodynamic loads on the numerical models but also to determine how closely it can be used to model the delta wing vortex dynamics. FLUENT can simulate a large variety of flow problems from subsonic to hypersonic, viscous and inviscid conditions. The geometry for the CFD analysis is modeled using the GAMBIT (v2.2.30) software associated with FLUENT.

IV. MESH GENERATION

Use of hexahedral cells and H-type topology were used to mesh the computational domain. Figure 2 and Figure 3 shows the different views of the computational grid around the double-delta wing that was generated using GAMBIT. The regions above and below the double-delta wing were meshed using the Hex/Map option whereas the rest of the regions were meshed using the Hex option.

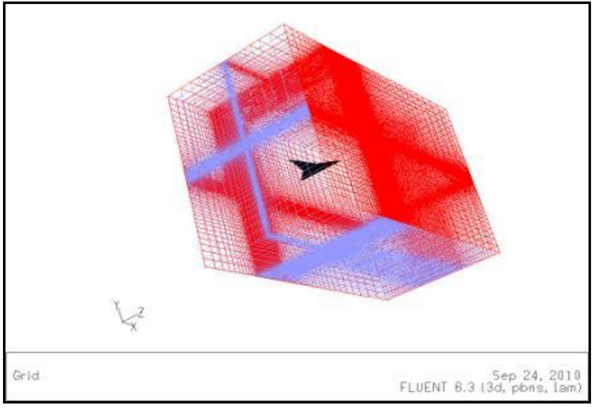

Fig. 2 Entire computational domain

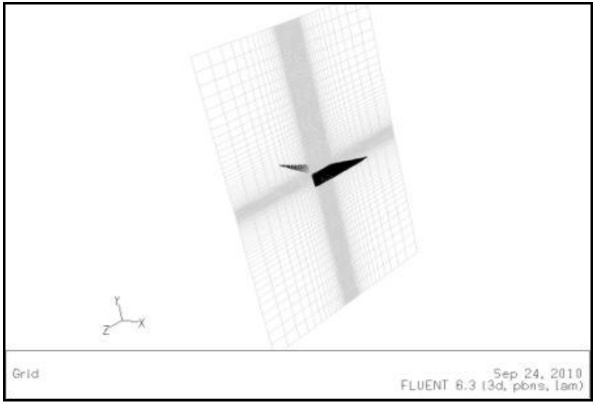

Fig. 3 A perspective view of the section mesh

V. BOUNDARY CONDITION

In this study we have considered double-delta wing model. The air flow comes into domain from these side-inlet face and it exit from end of domain. The mentioned mesh has been shown in Fig.2. As the boundary conditions, .velocity inlet. for side-inlet domain and .outflow. for the exit area have been considered. A initial conditions has been showed in table I.

TABLE I
INITIAL CONDITIONS

AIR FLOW	
Temperature	300K
Gage pressure	1atm
Velocity	30m/s

VI. SOLVING PATTERN

Initially, the use of wall functions approach on a mesh consisting of tetrahedral cells was constructed using the size function (automated grid generation) functionality available in GAMBIT. In this case, two different size functions were defined: one to capture the effects near the wall such that $y+ = 30$ at the wall, and the second to economize the number of cells in the outer region that extended to the far field boundary. In this case, the Laminar model, with the vorticity-based production option, was used since it is able to keep the resolution at a low level of complexity especially in regions of high velocity gradient. Moreover, the pressure based and implicit formulation was used to iteratively arrive at a converged solution. FLUENT runs using the wall-function approach with size function functionality suggested that for accurate resolution of aerodynamic loads, a mesh size of 2-3 million cells is needed. Since such a computational resource was not available, the computational effort switched focused on the near wall modeling approach in which the wall-adjacent cell height was of the order of $y+ < 3$ and at least 10 cells were used within the viscous sub-layer. Initially the firstorder upwind schemes were used in conjunction with a relaxation factors between 0.4-0.7. After 500-600 iterations, the second-order discretization schemes were employed. The convergence criteria used to monitor solution convergence was based on a two to three order-of-magnitude drop in the value of the residuals of mass, momentum.Typical grids were of the order of 1.2 to 1.3 million cells. Due to coarse nature of initial grids, grid adaptation was typically carried out to achieve a value of $y+$ below 3. Adapted grids typically consisted of approximately 20- 30% more cells.

VII. RESULTS

This section gives a brief description of the main results of the study. Figure 4 shows a Contour of velocity magnitude at AOA=35 and Figure 5 shows a velocity vectors at AOA=35 and Figure 6 shows a Contour of vorticity magnitude at AOA=35.The results of the theory were based on the theory proposed by Polhamus [6]. Figure 7 shows a Lateral velocity distribution for different angle of attack. Similarly Figure 8 shows a Longitudinal velocity distribution.

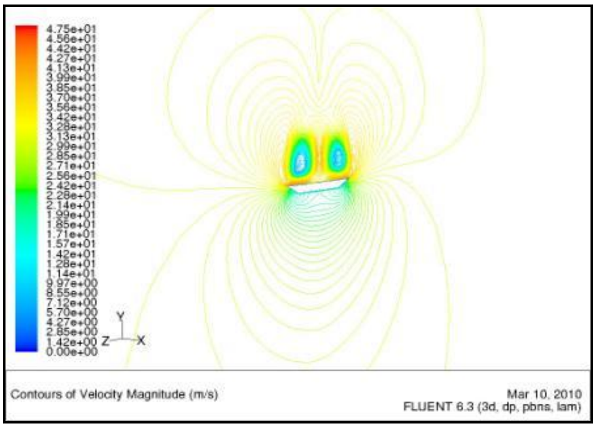

Fig. 4 Contour of velocity magnitude at AOA=35

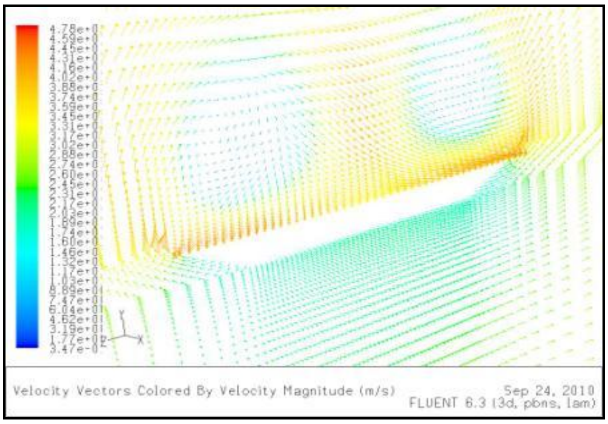

Fig. 5 Velocity vectors at AOA=35

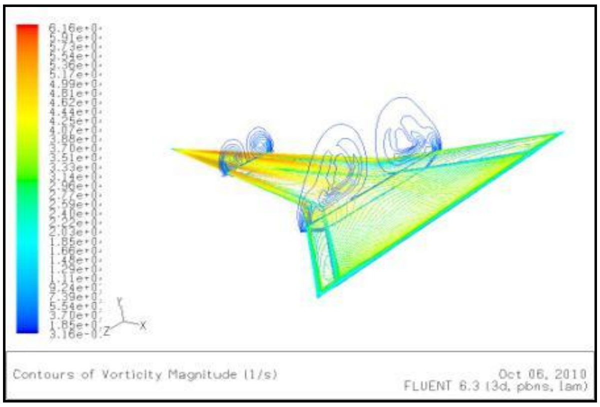

Fig. 6 Contour of vorticity magnitude at AOA=35

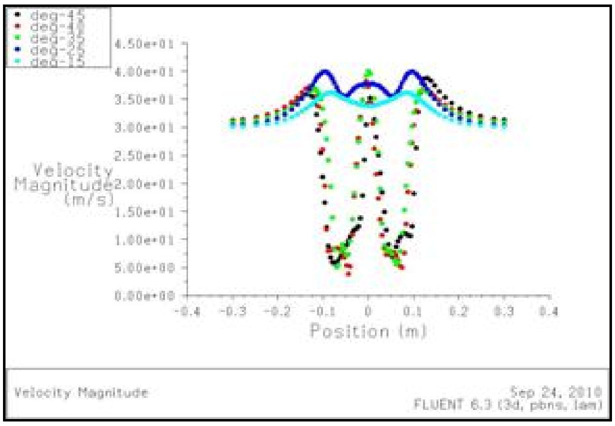

Fig. 7 Lateral velocity distribution for different Angle of attack

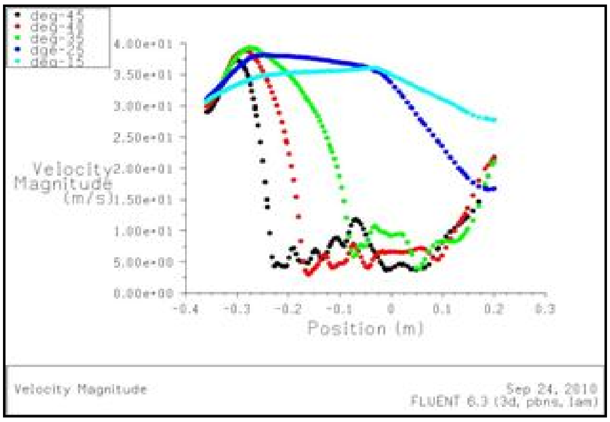

Fig 8 Longitudinal velocity distribution for different angle of attack

Figure 9 shows a Pressure coefficient distribution at upper and lower surface. Finally, Figure 10 shows a Diagram of lift coefficient vs AOA. The vortex breakdown occurs nearly trailing edge for the mentioned double-delta wing at α = 30 deg. The amount of lift coefficient in different AOA are shown in Table II.

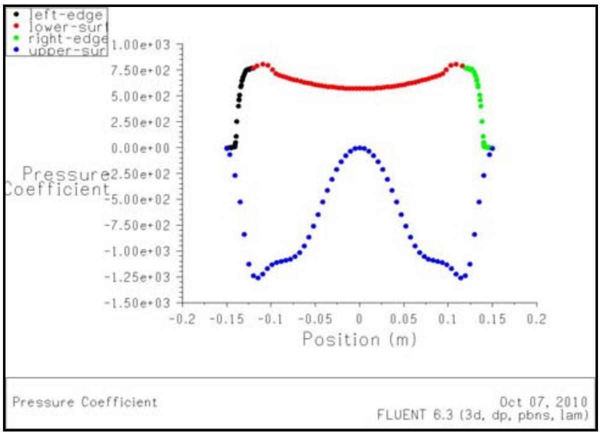

Fig. 2 Pressure coefficient distribution at upper And lower surface

TABLE II
THE AMOUNT OF LIFT COEFFICIENT IN DIFFERENT AOA

Angle of attack	10	15	25	30	35	40
Lift coefficient	0.307	0.46	0.79	0.98	1.05	0.87

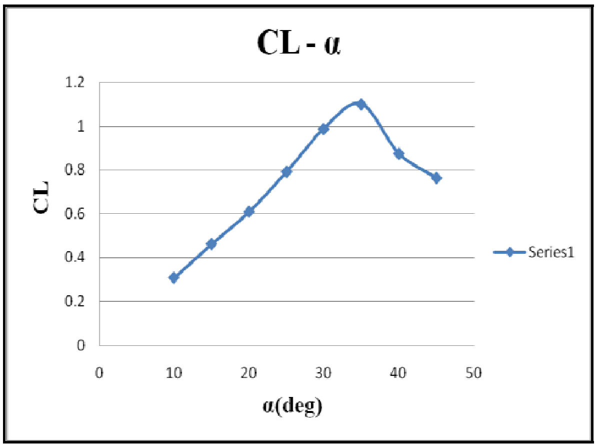

Fig 3 Diagram of lift coefficient vs AOA

VIII. CONCLUSION

In this study, an numerical investigation was carried out to obtain lift data on 76/45-deg double-delta wing at hight angle of attack and the vortex formation, interaction, and breakdown characteristics of double-delta wings were investigated too. The lift trajectory has been non-linear and stall occured approximately at 35 deg so loss of lift coefficient. The vortex breakdown has been arrived to trailing edge at 30 deg and lift coefficient have maximum amount and with increasing of angle of attack occur separate flow of on the wing. In upper of 35 deg, solution are unstable at convergency and loss of accuracy of results.About vortex interaction ,by increase angle of attack the primary and secondary vortex trajectory has nearly terajectory and interaction together absolutly.

REFERENCES

[1] Robert C. Nelson and Alain Pelletier,"The unsteady aerodynamics of slender wings and aircraft undergoing large amplitude maneuvers" ,_Progress in Aerospace Sciences 39 185-248,_April 2003.
[2] Sheshagiri K. Hebbar, Max F. Platzer and Feng-Hsi Li, “A Visualization Study Of The Vortical Flow Over A Double Delta Wing”, AIAA-93-3425, 1993.
[3] N.G. Verhaagen, L.N. Jenkins, S.B. Kern and A.E. Washburn, “A Study Of The Vortex Flow Over A 76/40-deg Double Delta Wing”, AIAA-2002-3455, 2002.
[4] M.R. Allan, K.J. Ba dcock, G.N. Barakos, and B.E.R ichards, ”Steady RANS_Simulations of A70° Delta Wing”, May 2003.
[5] Myong H. Sohn and Hyoung S. Chung,“ Effects of Strake Planform on the Vortex Flow of a Double-DeltaWing”, AIAA 2006-3498, June 2006.
[6] Polhamus e.c, “Vortex Lift Reasearch Early Contributions and Some Curent Challenges” NASA Conference Publication 2416, Vol.1 ,1986