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## Cover Page Footnote

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**Abstract:**

Many aircraft, like fighters and bombers, are delta-winged aircraft. These aircraft have the features of generating greater lift at low angles of attack even at low Reynolds's number. Highly swept-wing aircraft experience greater lift due to the generation of the leading-edge vortex at a high angle of attack flight. The vortex brakes down phenomena are noticed which leads to the decrease of the vortex lift and leads to the instability of the aircraft. This paper deals with an analysis of the flow on the delta wing with the existing literature and compares its benefits over the conventional wings using experimental and computational methods. The critical angles, pressure, and velocity variations are observed along with chord and span wise locations.

Keywords: Delta wing; Aerodynamic characteristics; Leading edge vortices; Pressure velocity variation; Wind tunnel.

## 1**INTRODUCTION**:

The efficient airfoils of the conventional aircraft wing design concept is based on low drag at cruising speed and great stability. However since the post WW II, the need of great maneuverability and quickness has been felt, in relation to the combat, pre and post stall operation and short landing and take-off characteristics. This demands considerable improvements in the aerodynamic characteristics of wing. The type of aircraft is supposed to be operated at changed angles of attack (AoA) and different sideslips conditions. The delta wing generates lifting force with the development of even leading edge vortices (LEVs), and also primary and secondary separation vortices, and vortex breakdown over the wing surfaces. The total lift generated by these types aircraft depends on the potential lift and leading edge vortices induced lift. These vortices create strong suction peak near the leading edge inboard and the static pressure drops significantly within this zone, which in turn increases the lift.

Broad theoretical, computational and take-off studies have been performed by Chu and Luck ring, Gurusul. Guglieri and Quagliotti, to reveal the fundamental mechanism of such detached vortex flow [2,3]. These lift enhancing LEVs are stable up to moderate AoA and burst along the protected side at higher AoA due to large positive pressure gradient in the vortex axis. The vortex collapse on delta wing is too unsteady event and it generate sudden changes on the flow variables causing severe structural aero elastic vibrations. The abrupt failure process is followed by a sudden reduction of fluid elements along the axis of the vortex and radically outward expansion in the cross flow plane. High AoA flight condition and associated failure of vortex process might cause an unwanted portent known as buffeting, due to the interaction between the vertical stabilizer and the unsteady wake. Moreover, the asymmetry of vortex breakdown for higher AoA triggers instabilities about the roll axis [4]. The interaction of these vortices with the aircraft fuselage can cause different instabilities and the control, may become less effective. Delta wing aircrafts glide at low subsonic speed during landing. take-off, manoeuvring to dodge interruption and a major part of reconnaissance mission etc. The need to generate high lift requires high angles of attack of the aircraft."The subsonic aerodynamic characteristics of sharp edged delta wing differ significantly from its supersonic behaviour. Study of supersonic delta wings at subsonic condition has often been a precursor to design breakthrough" [2].

## 2. **LITERATURE REVIEW**:

The passive bleeding study was performed, which uses passage exclusive the wing to allow the fluid flowing from the positive pressure side to the negative suction side by using intrinsic pressure difference, to a non-slender delta wing angle of sweep of 45 degree. The low speed wind tunnel of lower subsonic range was used to undertake the experiments using the six component balance to measure the aerodynamic forces and to measure the flow characteristics the paint pressure measurement, Particle Image Velocimetry (PIV) were used. The delta wings with tow sweep back angles like $13^0$ and $23^0$were used with4 different Ratio of the bleed opening like 0.35, 0.60, 0.85 and 1.00 have been tested. At high AoA>18 degrees, the separation appeared. The significant amount of increase in coefficient of pressure and vorticity was notices due to the passive bleeding which also recovered the leading edge vortices on the wing [1].

A sweep delta wing with 65 degrees sweep (VFE-2) with shrill leading edge at20degrees is studied by the DDES method. The results obtained are given herewith: there is inversely action ride height decreasing, the aerodynamic forces like lift, drag and negative pitching moment all increase nonlinearly; although the LEVs over the shielded side dominates the aerodynamic forces, the most of the aerodynamic force increments in SGE are from the leading edge side [2]. In another study, the aerodynamic property and vortex flow analysis is done of a reversed delta wing, of diverse shapes, were investigated. It was observed that the trailing edge of the delta wing plays very tiny role in generation of the lift, however, this triggers the disruption of the multiple vortex filament over the wing in span wise direction [3].

In a recent study, the parametric study by considering thickness to chord ratio, on overall aerodynamic characteristics and flow structure of a $45^0$ swept delta wing is examined using laser-lit smoke flow visualization, surface pressure measurement, PIV, and force measurements by balance. Analysis is carried out in a low subsonic wind tunnel using delta wing configuration with different t/c ratios ranging from 2- 15and AoA varying from 0 to $30^0$.It is observed by this experiment that the thickness to chord ratio ensures the breakdown of LEVs and at low AOA the lift coefficient is found high with increase of t/c [4].

A new study of the shedding of frequency in queasy static associated with vortex teeming on delta wings has been performed. This study will be beneficial in beginning the excitation frequency on aircraft with delta wings at moderate to high AOA, if differences in some of the quantities can be determined [5].An expression for the semi empirical expression to analyze the cross flow wake width at intermediate AOA has been progressed. This tentative expression is likely to observe the excitation frequencies clearly. "With regard to the experimental investigation of a non-linear limit cycle oscillation (LCO) in roll on an 80 ° swept delta wing the conclusions are: Although the LCO is a non-linear phenomenon the experimental measurements are consistent with an approximate, quasi-steady linear theory. Measurements was done at low speeds in the wind tunnel, for the amplitude and frequency parameter over a range of velocity and model inertia in roll, despite difficulties with bearing friction” [6].

A review of Vortex control concepts employed for slender and non-slender delta wings were done. Augmentation of lift coefficient, production of the forces and its moments for flight control system, and weakening of buffeting was done as per objective of flow control methods. Significant features of flow control comprise flow separation, flow reattachment, vortex generation, , vortex collapse, and vortex instabilities. The existence and comparative status of these portents strongly rest on on the wing sweep angle from the center. For example, on slim wings, reattachment does not commonly arise. For slim delta wings, vortex breakdown control is the prime goal of flow control techniques. “Delay of vortex breakdown is possible with the modifications to the swirl level and pressure gradient” [7]. For un-slender delta wings, one of the discrete structures is that reattachment of the separated flow is likely and can be employed. As active flow control methods mostly trust on shaky excitation.

The experimental and computational analysis were performed to investigate the active lift features and the unstable flow arena for a semi-span without lean delta wing in sinking fluctuations. Two pitch rates with abridged frequencies at k is 0.069 and 0.55 were tested in the range between 0 and $60^0$, which showed different unsteady phenomenon. According to the results of the force calculations, it was established that the abridged frequency had important effects on the dynamic lift performance of the wing. In the low plunging rate case when k = 0.069, the hysteresis loop of lift could embraced the lift slope of still wing, for which, at the same AOA, the pitch up process provided a greater coefficient of lift value than for the still case. Furthermore, as the wing pitched down stroke the CL rate converted lower than in the still situation [8].

An investigation on the double delta wing with leading edge extension (LEX) is undertaken to find the effect of the occurrence of a main body on the vortex flow through parallel estimation of the pressure and to visualize the fluid flow. From the wide investigation of the fresh information obtained from the subsonic wind tunnel measurements, the subsequent inferences are reached: The shrill-edged $65^0$ double-delta wing with LEX has sustained smooth flow and well-systematized vortex structure due to the robust collaboration of the wing vortex and the LEX vortex, which afterward results in the occurrence of the center body having a minor effect on the flow pattern and the wing-upper-surface pressure distribution [9]. “The off-surface flow visualization captured essential features of the development and interaction process of the wing and LEX vortices depending on the chord positions, and provided consistent physics of flow phenomena corroborating the wing surface-pressure distribution characteristics” [10]. In another import ant work, they used the modern tools like SA-DES and a hybrid fourth-order scheme to make research on the extensively separated flows of the 76 / 40 degrees-D wing. The standard tests depicted the robust competence of current numerical for turbulent modeling[11]. Computational investigations have been made for the D-D wing at AoA from 10 to 35 degrees. Evaluations were completed with the investigational results by Verhaagen The results indicated that the geometry allows modulation of the trailing edge pressure field such that vortex breakdown can be delayed and lift restored at high incidence [12-15]. Propeller actuation was observed to cause large moment excursions especially for low advance ratios. The propeller was observed to increase suction levels on both the windward and leeward surfaces such the lower surface suction decreased the achievable lift enhancement [16,20].

A computational study was performed by Rajat Singh and Dwivedi [20-21]to find the effect of area rule on the delta wing aircraft also the effect of bio inspired wing and aerodynamic characteristics were studied. The delta wing also produces the leading edge vortices as the dragonfly wing having the corrugations on the wing [22-23]. Present work is a review on the delta wing aerodynamic performance, which is used for the modern fighter and bomber planes. Different work by different researchers are put together and compared so that the researchers can get most of the information on this topic in one paper.

## 3**METHODOLOGY**:

The methodology can be divided as per the nature of the work. Normally computational work and experimental work.

### 3.**1 COMPUTATIONAL WORK:**

The enhancement of the heat transfer can be obtained near the generator due to boundary layers (BL) thinning at 29 degree. For larger AOA, the heat transfer rates can be enhanced by local growth of turbulence. At large AOA, the heat transfer enhancement strong common flow down vortices and secondary flows near the wall (small distance between vortices) enhance heat transfer persistently over the plate. Among all the reviews, the most common method is based on computations and done with DDES (delayed detached eddy simulations) RANS (Reynolds averaged Navier strokes) method, these methods are performed both in static and dynamic way.

The aero-elastic response of a 3-D wing in transonic flow was measured using coupled Numerical and finite element analysis (FEA) approach and the signal processing methodologies were used for obtaining time domain responses. The computation depicts a judicious promise of pressure spreading with help of the testing in wind tunnel, and a qualitative imitation of the external separation was found. Although there is a quantitative variance obtained, it is inspiring that the computation successfully forecasted the important point like the testing at AoA = 22.5◦. And for the location of the vortex breakdown, we also obtained a match to some degree with experiment. A numerical method based on the rigid moving mesh and DDES technique was implemented to simulate the unsteady vortex breakdown flows around a DDW subjected to a pitching motion.

### 3.2**EXPERIMENTAL WORK:**

Experimental work is undertaken in a subsonic wind tunnel having with a 12 bladed two fans contra-rotating placed in series with OD of 600mm and powered by 2 motors each with10hpinduction motors. Wind tunnel having the test section of 600 mm x 600 mm in width and height with 1200 mm in length. The 15m/s is the maximum velocity which could be achieved by this tunnel which corresponds to a dynamic pressure of 140pa. The wind speed is measured using a pivot static tube with digital anemometer with accuracy of ±0.50 of the obtained value. The input air is guided by one layer of square honey comb and also two layers of steel wire mesh located upstream of the settling chamber placed downstream to the break the larger eddies and to reduce the turbulence level further downstream. However, the flow is still turbulent with low intensity in all the places of the test section. A contraction ratio of the cone is 9:1in area which meets the requirement of test section tangentially. Transparent Plexiglas's detachable panels are fitted on the both side of the walls of the test section for easy flow visualization study (Fig.1 ).

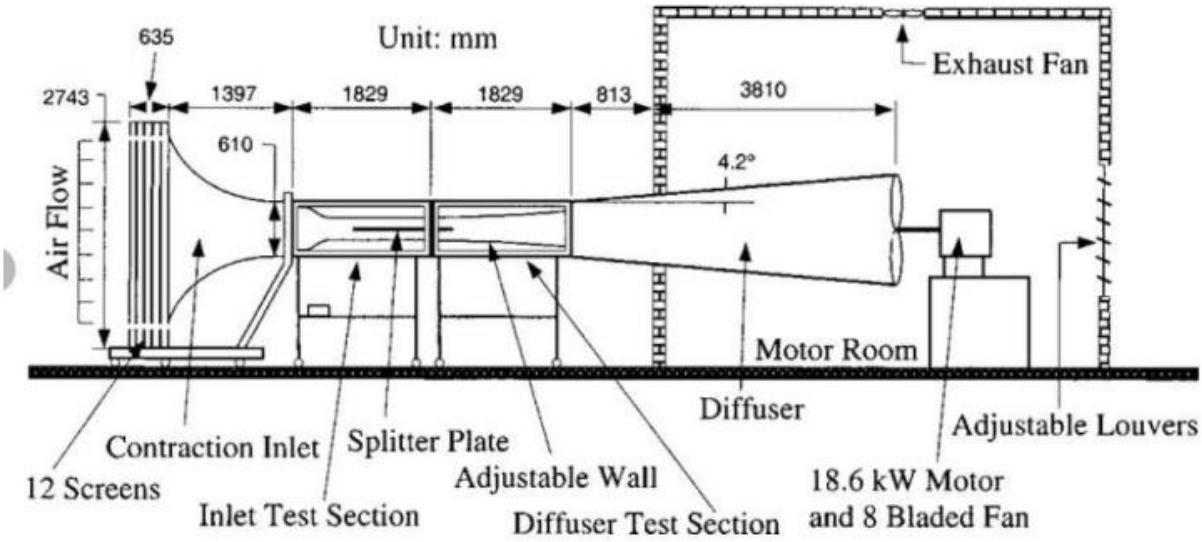


Fig.1. Wind tunnel setup [14]

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**4RESULTS AND DISCUSSION:**

After completion of the literature survey following results are made

- The qualitative and quantitative comparison of flow visualization for 65 degree sweep delta wing has been analyzed by using subsonic wind tunnel with oil powder mixture and compared with CFD results.
- RANS built steady state Numerical investigation has been performed for boundary conditions as done in wind tunnel testing. The turbulence model (SST k- )near the wall which gives low Reynolds number (Re)explanation is observed to be the good optimal aspect for accuracy as in the limit of available computational time and resources. The lines of the surface skin friction is predicted from Numerical results are given in Figure 2. Present work shows a well thoughtful on the development of the spiral or twisted vortex as given in Figure 2 below. The location of the breakdown of the obtained vortices is expected from CFD is 73-82 degree of AoA.
- The CFD result predicts worthy promise in both types of results i.e. qualitative and quantitative form in compared with the experimental outcome in terms of surface skin friction pattern arrangements and vortex breakdown position (Fig 3).

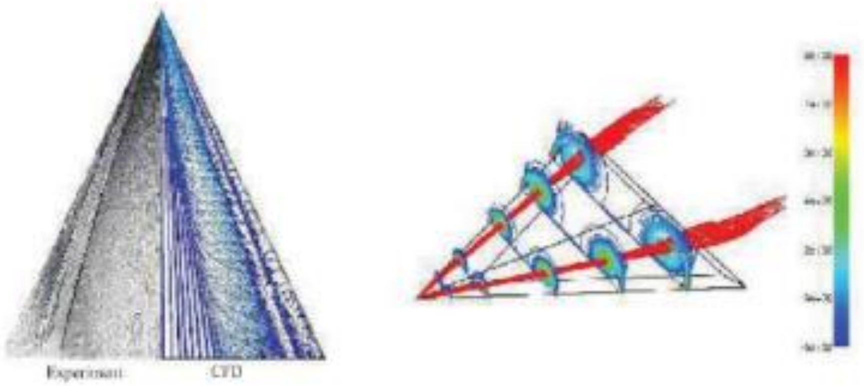


Fig 2. Skin Friction topology at 15 degree AOA [17]

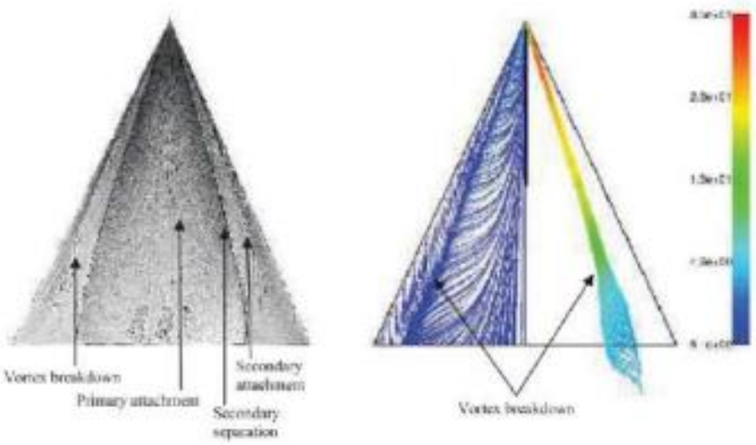


Fig 3. Skin Friction topology at 20 degree AOA [18]

## 5.**CONCLUSION:**

By above discussions, few main conclusions are drawn as given below:

1. Surface flow topology shows distinct features like primary attachment, secondary attachment and separation lines.
2. Surface flow visualization study shows the onset of vortex breakdown at the trailing edge for $15^0$AoA.
3. Vortex breakdown occurs at $20^0$ AoA on the leeward side over the wing.
4. Experimental results are comparable with the validated data.
5. Numerical result shows good agreement with the experiment.
6.

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