Aerodynamics Characteristics of Compound Delta Wing at Sea Level

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Abstract: Compound delta-wing aircraft are in the top tier for great maneuverability and satisfactory take-off and landing speeds and low distance as delta wing have a property of vortex generation at different speeds, during flight the property of vortex generated depends on factors like the coefficient of lift, coefficient of drag and shock wave impact absorption upon varying speed from subsonic speed and supersonic speed with changing attack angle is studied by flow visualization of the wing in Ansys Fluent using 'k-ℇ 2nd equation model' to simulate mean flow characteristics for turbulent flow conditions. Vortex generation is studied for flow physics at Subsonic speed and Supersonic speed at sea level over Pressure and Density based respectively. The flow velocity at Subsonic is 260m/s and 686m/s for Supersonic. During the experiment, we observed that the vortex flow generation of observable output starts forming at 5° angle of attack following a powerful vortex at 10° leading to a shortfall powerful vortex at 15° for both subsonic and supersonic speeds but as velocity is more in the supersonic state the vortex is denser and more stable and provides better shock absorption while transitioning on higher attack angle and lift force is very sensitive for the supersonic state as drag is substantially increased with speed.

Nomenclature

- CL: Coefficient of lift
- CD: Coefficient of drag
- α: Angle of attack
- L: Lift force
- D: Drag force

1. Introduction

Compound delta wing is mainly known for the unique ability to create vortex which can benefit the flight performance and stealth operational improvement for conventional and non-conventional aircraft. The vortex can be affected by drag and lift variation by a great deal. The problem associated with delta wing is that more wing area causes more drag increase rather than lift, better aspect ratio of L/D improvement has been the point of concern of most research teams. The other most important aspect of aeronautical engineering is to shorten the landing and take-off distance and speed, have more armament and cargo weight, and most important aerodynamics efficiency.

The flow in leading-edge delta wing is described as a movement in a spiral motion flow from the lower to the upper surface [1]. The wing causes flow separation that results in the pressure difference between the top and bottom of the wing [1].
T. Lee and his team studied the reverse delta wing to study the vortex breakdown further reported that, in addition to the lowered lift and drag forces, the 65°-sweep reverse delta wing also exhibited a delayed stall compared to its delta wing [2].

Flow separation will start at the leading edge from the apex a distortion of flow will be observed from the leading edge which wraps up in a spiral vortex. These vortices produce a pair of large primary vortices along the chord of the wing whose nature depends on the angle of attack, Mach number, and wing configuration for certain frequencies of undergoing conditions [2]. In compound delta wing at lower attack angle air flows is similar to a conventional wing but does not produce much lift but as the angle of attack increases the property of vortex generation upon the delta wing starts to appear, the vortex starts forming and the airflow starts separating as the air around spins very fast which creates a low-pressure region that provides an extra lift [3].

A multi-performance aircraft that needs to partake in many different operations can take advantage of this effect and maneuver this property by changing the angle of attack with speed to achieve better maneuverability and stable flight at heavy load conditions.

This study aims to computationally find out the angle of attack for aircraft with compound delta wings to produce a steady and uniform flow separation point to increase the maneuverability of the aircraft and improve the future scope for transportation.

2. Experimental Design Modelling and Methodology
The geometry of the delta wing is modeled in SOLIDWORKS the profile of the wing is shown in Figure 1 [4]. The geometry of the wing as shown in Figure 1 is derived from the model counterpart of military aircraft, with a leading-edge angle of 50° (first sweep) and 62.5° second sweep angle and 4° forward sweep trailing angle compound delta wing model with edge bevelled at an angle of 14° for 53 cm to study the vortex.

The flow fields are assumed to be symmetric on the centerline of the wing [5]. Therefore, the computational domain covers only half of the wing [5].

Figure 1. Geometry of wing
To simulate mean flow conditions over compound delta wing ‘k-ℇ 2nd Equation Model’ is used in Ansys Fluent to perform CFD flow experiment and numerical calculations [6]. The traditional meshing of rectangular domain is used with Boolean tetrahedral meshing using with the cell count of 2317894, the simulations were run on subsonic speed(260m/s) condition using pressure-based model since at low speed the air instead of compressing just slides away around the edges and density-based model for Supersonic speed(686m/s) as in the high-velocity phase the sudden shock leads to the compression in the air and insight over the flow structures of delta wing pressure distribution for attack angle of 5°, 10° and 15° is studied.

3. Result and Discussion

Pressure distribution of surface contours was obtained which are shown by Figure 2 to Figure 7, coefficient of lift and coefficient of drag was acquired to discuss characteristics of delta wing in Figure 8 to Figure17. The flow visualization result of the leading-edge wing was obtained at a different angle of attack for both subsonic speed and supersonic speed and the results are discussed below:

3.1 Flow Visualization for Subsonic

In Figure 2, at 5° angle of attack faint profile of the vortex is observed at edges which formed the primary vortex although the lift was not quite improved and the density of the primary vortex was quite low [7]. Due to the pressure drag which caused the air to separate fast which made a delay in the formation of the vortex. In Figure 4, at a 10° angle of attack, as the attack angle increased the flow separated faster, and a powerful vortex is observed over the edge tailing to the primary vortex which has a higher density, and the lift was increased. In Figure 6, as the attack angle was high the pressure drag was increased and caused the flow to separate faster but due to high wave impact, at 15° a powerful vortex is observed but the vortex diminished near the middle of the wing showing the low density and the lift increase was quite significant but drag was also increased in multiples which compromised the stability of the vortex.

3.2 Flow Visualization for Supersonic

In Figure 3, at 5° a slight powerful vortex is formed from the edge towards the chord line and a lift increase of 7 times was observed with very high drag due to higher speed and pressure drag and faster flow separation but was lower than the subsonic counterpart. In Figure 5, as the flow separated faster and shock lead to compression of air, at 10° attack angle a very powerful vortex is originated from the edge creating a powerful primary vortex with high density and the wing is found to have a lower lift to drag ratio than the subsonic counterpart with a lift increase of about 6 times. In Figure 7, at 15° due to higher angle of attack, the compression of air around the wing was increased and pressure drag also increased which helped in early vortex generation to create a powerful but short vortex in contact with leading-edge and diminished in the middle of the wing but the drag increase was quite large which resulted in a lower L/D ratio.

3.3 Pressure Distribution of Wing

The pressure distribution of the wing shows quite a similarity between subsonic speed and supersonic speeds for the same angle of attack but at supersonic speed, the pressure is observed to be denser than the subsonic speed [8], the difference in pressure density can be observed upon the wings. Figure 2 to Figure 7 shows the pressure distribution on the contour of the wing as the speed increases for the various angle of attacks as the angle of attack increases vortex starts forming and starts to become denser and after the attack angle increases above 13° the vortex starts to distort due to shock separation [9]. The pressure distribution on the wing is shown below:
In Figure 2, at 5° attack angle pressure is seen at the leading edge with density along the chord with most density at the trailing edge, and vortex is seen to be faint in the case of subsonic speed, and in Figure 3, a slight powerful and sustaining vortex is seen in supersonic speed with little lesser pressure on edge as compared to subsonic speed but higher pressure on trailing edge [10].

In Figure 4, at 10° attack angle showed a stable and dense vortex formation at subsonic speed, and in Figure 5, denser vortex at supersonic speed with lesser pressure density at leading-edge than for the attack angle of 5° and more density at trailing edge is observed.
In Figure 6, at $15^\circ$ attack angle, a powerful vortex is formed upon the leading edge and faints just in between the wing with high pressure at the trailing edge, although in Figure 7, the pressure density is observed to be high up on the sweeping edge, and very little pressure is observed at the leading edge.

3.4 Variation of Values

The graphs showing the variation of values between the subsonic and supersonic is shown below:

In Figure 8, the coefficient of lift is seen to increase gradually same in subsonic speed and supersonic speed in Figure 9, a little linear and smooth increase is observed in supersonic speed.
In Figure 10, the coefficient of drag in subsonic is seen to increase in steep variation whereas in Figure 11, for supersonic speed the variation is seen to be smoother and more stable. Thus, concluding that for higher speed the transition in the attack angle comes with a stable density increase of the vortex.

In Figure 12, drag force is found to be increasing with the magnitude incrementation of attack angle and in Figure 13, at the supersonic level drag is seen to increase at a high rate with attack angle and following a linear slope in higher attack angle.

In Figure 14, the highest value of lift/drag ratio is high in subsonic speed, and in Figure 15, the peak value of lift/drag is low, this states that the drag is more when the speed is low.
In Figure 16, the lift force is seen to be in constant variation in accordance to speed and angle of attack at subsonic speed the drag is seen to increase steeply whereas in Figure 17, for supersonic speed the lift increase is somewhat constant and linear and the value is quite high as compared to subsonic. Thus, the vortex is denser and more stable.

4. Conclusion
The study of flow visualization is done on subsonic and supersonic flow on compound delta wing at an attack angle of 5° to 15°. The results were discussed using the flow profile and pressure density upon the wing.

The result concludes that the formation of the primary vortex is highly dependent on the angle of attack. An increase in the angle of attack can boost the upstream movement hence, the formation of the primary vortex towards the aft portion of the wing. The lift force was seen to be very sensitive concerning attack angle and not consistent with the range of attack angle. A wide increase in lift force is observed with the increase of attack angle and drag force is also found to increase violently with the lift force. The result of lift by drag is found to be proportionally inverse to the attack angle. This could be concluded as the density of the vortex remains consistent with the higher angle of attack from 5° to 12° and the L/D ratio is superior.

For future scope of improvement regarding the stability of flight the plane should be operated in between the attack angle of 5° to 12°. A forward sweep should be added at the tail of the wing with strake to control the flow separation and to decrease the shock caused by variation in the angle of attack and speed.

The present physics study of compound delta wing for subsonic and supersonic flow can be helpful to study more about vortex formation.

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