Effects of Leading-Edge Figure on Aerodynamic Characteristics of 65° Delta Wing

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Effects of leading-edge figure on Aerodynamic Characteristics of 65° Delta wing

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Abstract

Delta wing is used for hypersonic flying object. The specific feature of delta wing by comparison with normal wing is that, the lift is created not only by potential flow but also by vortex flow. There are two vortexes along the leading-edge. If the wing is in stability regime, the lift creating by the vortexes helps increase total lift and stall angle of attack is reached to 40°. The creation of vortex is impacted by the figure of leading-edge. The paper presents the result of dependence of aerodynamic parameters and vortexes on the figures of leading-edge by using Ansys software. As the result, the paper brings some evaluation and optimal choice for the figure of leading-edge in the stage of design the wing.

Key Words: : delta wing, vortex, gambit, ansys, angle of attack….

1. Introduction

The aerodynamic characteristics of triangular wing (delta wing) for airplane are very interesting topic and contain many different features in comparison with normal wing. As we know delta wing is often applied in hypersonic flying object. However in take-off and landing case the lift of the wing is added by two vortexes line in upper wing, which help its lift force significantly increase. In steady case lift force associated with the existence of the separated leading-edge spiral vortices (vortexes lift) widens to 50% of total lift at average angle of attack [2]. Many others research indicated that lift over an airfoil reaches maximum at angle of attack about 10-15°. With increasing angle of attack the lift force dramatically dropped due to separation flow. Increasing angle of attack assisted to raise the mobility of airplane and to widen the range its utilization. One way to enhance performance of fighter airplane at high angle of attack is to use the delta wing. The separation flow in a delta wing occurs all range angle of attack, creates by two vortexes at leading-edge. In steady case these vortexes produce a low- pressure region in leading-edge of upper wing. As the result lift of a delta wing is grown up. The separation angle of attack is also increased. For a 70° degree delta wing continues to grow its lift up to an about 40° angle of attack. Nonetheless with increasing angle of attack and difference figure of leading-edge, the core and structure of vortexes dramatically change. The other research should be done to make the phenomenon clearer. The calculating method by using Ansys software is an excellent way to simulate the phenomenon.

Edward C. Polhamus [1] in his research demonstrated that lift force in a delta wing can be calculated as the sum of a potential- flow lift and the vortexes lift. He has done many experimental tests, compared with previous research and presented two experimental coefficients… The two lifts for thin delta wing in his theory are depended strictly in angle of attack and wing aspect ratio:

$$C_L = K_p \sin\alpha\cos^2\alpha + K_V \cos\alpha\sin^2\alpha \qquad (3)$$

Where K_p and K_v are two experimental coefficients. Their value is defined as following figures:

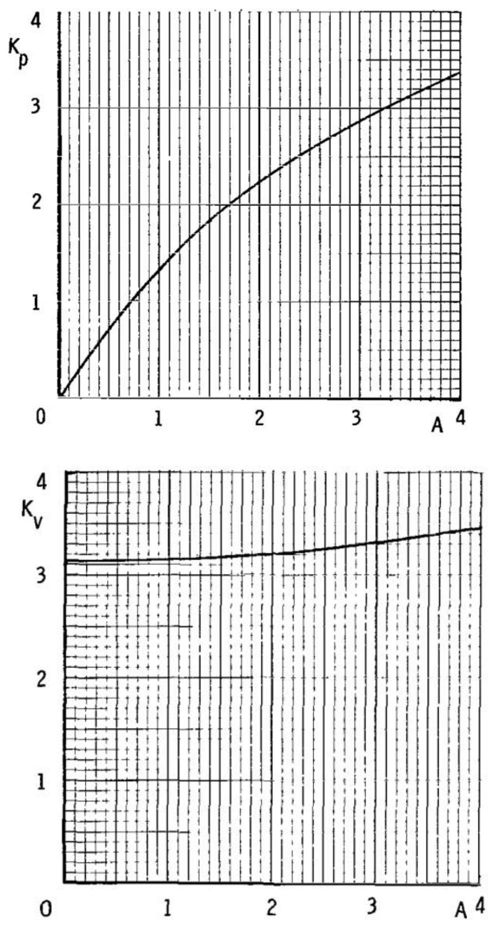


Figure 1: Dependence of coeeficients K_p and K_v in wing aspect ratio

However the theory is only applied for the thin wing in standard conditions. In real conditions there are many factors that could be influenced in the lift coefficient, for example: speed of free flow, figure of leading- edge, Reynolds number, flow conditions… In research of Ahmad Z. AL-Gami [3] lift coefficient of 65 degree delta wing rises up to 35° angle of attack.

The paper presents some investigations of a 65 degree delta wing with different kinds of leading-edge by using numerical method. The result is also compared with theory method created by Edward C. Polhamus in his method. As the result of paper, the best way to design a delta wing in steady flow will is presented. The velocity of the flow is small (v=15m/s) which appears in take-off and landing regime. The figure of leading-edge and delta wing is showed in the following picture.

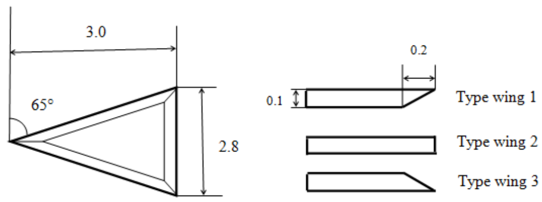


Figure 2: Delta wing and type of leading-edge

2. Computation setup

2. 1. Equation Navier-Stockes

To investigate, we use equation Navier-Stockes for turbulence, viscous and incompressible flow with Averaged Reynolds number. With the steady flow, equation Navier- Stockes for mass and momentum can be written as [6]:

Equation of mass:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

Equation of momentum:

$$\rho\left(\frac{\partial e}{\partial t} + \vec{V}.grad(e)\right) = \vec{p}_x.\frac{\partial \vec{V}}{\partial x} + \vec{p}_y.\frac{\partial \vec{V}}{\partial y} +$$

$$+\vec{p}_z.\frac{\partial \vec{V}}{\partial z} - div\vec{q} \qquad (2)$$

Equation for surroundings of the wing:

$$\frac{\rho du}{dt}=\rho X-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[\mu\left(2\frac{\partial u}{\partial x}-\frac{2}{3}div\vec{V}\right)\right]+$$
$$+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\right]$$
$$\frac{\rho dv}{dt}=\rho Y-\frac{\partial p}{\partial y}+\frac{\partial}{\partial y}\left[\mu\left(2\frac{\partial u}{\partial y}-\frac{2}{3}div\vec{V}\right)\right]+$$
$$+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right] \quad (3)$$
$$\frac{\rho dw}{dt}=\rho Z-\frac{\partial p}{\partial z}+\frac{\partial}{\partial z}\left[\mu\left(2\frac{\partial w}{\partial z}-\frac{2}{3}div\vec{V}\right)\right]+$$
$$+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)\right]$$

Where: X, Y, Z- component of force in the x, y, z directions; u, v, w- velocity in the x, y,z directions; ρ – air density, μ- viscosity;

The equation of Navier-Stokes is applied for numerical method. Before that we used Gambit software to create mess for numerical area. The results depend strictly on kind of mesh which was created.

2.2 Method of creating mesh.

In the paper, the calculating area is a rectangular parallelepiped which size: length x width x height = 15 x10 x10. Near the wing the mesh was created with high density for simulating the complicated phenomenon and getting the good calculating results.

The whole calculating region is divided into 600.000-800.000 cells. The zones in upper and lower wing are meshed by Cooper/Hex type. The rest zones are mesh by Map/Hex type. This type is easy to create in the rectangular parallelepiped area. The mesh for three types of leading-edge figure is demonstrated in the figure:

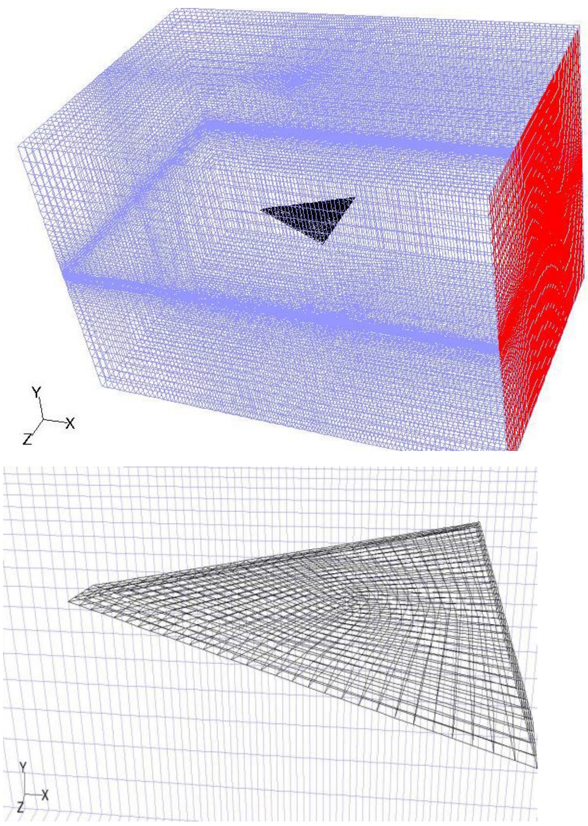


Figure 3: Mesh around delta wing

2.3 Calculating model

The most economical options available in FLUENT are the different methods for the solution of the Reynolds- averaged Navier-Stokes equations for the mean flow quantities, with all the scales of the turbulence being modeled. There are many methods that could be applied for the flow over airfoil with different degree of accuracy and different calculating time such as: Spalart-Allmaras, k-ε, k-ω…

In the paper we used the Shear-Stress Transport Model k-ω. The SST k-ω model was developed by Menter to effectively blend the robust and accurate formulation of the k-ω model in the near- wall region with the free-stream independence of the k-ε model in the far field. To achieve this, the k-ε model is converted into a k-ω formulation. It is effective method with high degree of accuracy. The model could be applied in low Renolds turbulence model and do not add any extra damping functions

The SST k-ω model is the same as the standard k-ω model with some difference, included: the bending function is designed to be one in the near wall region, which activates the standard k-ω model, and zero away from the surface, which activates the transformed k-ε model. It also incorporates a damped cross-diffusion derivative term in the ω equation, as well as the modification in turbulent viscosity for the transport of the turbulent shear stress and changing value of constants parameters. The turbulence kinetic energy k and the specific dissipation rate ω are defined as following equations [7].

Turbulence kinetic energy:

$$\frac{\partial k}{\partial t}+U_j\frac{\partial k}{\partial x_j}=P_k-\beta^* k\omega+\frac{\partial}{\partial x_j}\left[(\nu+\sigma_k\nu_T)\frac{\partial k}{\partial x_j}\right] \quad (4)$$

Specific Dissipation rate:

$$\frac{\partial \omega}{\partial t}+U_j\frac{\partial \omega}{\partial x_j}=\alpha S^2-\beta\omega^2+\frac{\partial}{\partial x_j}\left[(\nu+\sigma_\omega\nu_T)\frac{\partial \omega}{\partial x_j}\right]+$$

$$+2(1-F_1)\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i} \quad (5)$$

Where closure coefficients and Auxilary relations are:

$$\nu_T=\frac{a_1 k}{\max(a_1\omega, SF_2)};F_2=\tanh\left[\left[\max\left(\frac{2\sqrt{k}}{\beta^*\omega y},\frac{500\nu}{y^2\omega}\right)\right]^2\right]$$

$$P_k=\min\left(\tau_{ij}\frac{\partial U_i}{\partial x_j},10\beta^* k\omega\right);$$

$$F_1=\tanh\left\{\left\{\min\left[\max\left(\frac{\sqrt{k}}{\beta^*\omega y},\frac{500\nu}{y^2\omega}\right),\frac{4\sigma_{\omega 2}k}{CD_{k\omega}y^2}\right]\right\}^4\right\};$$

$$CD_{k\omega}=\max\left(2\rho\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i},10^{-10}\right);$$

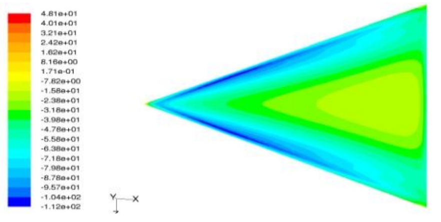
$$\alpha_1=\frac{5}{9};\alpha_2=0.44;\beta_1=\frac{3}{40};\beta_2=0.0828;\beta^*=0.09;$$

$$\sigma_{k1}=0.85;\sigma_{k2}=1;\sigma_{\omega 1}=0.5;\sigma_{\omega 2}=0.856;$$

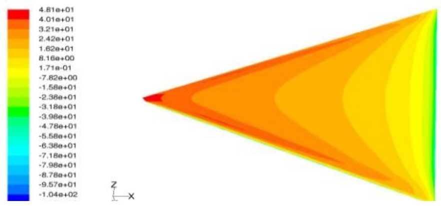
3. Result and discussion

3.1 Distribution of pressure in upper and under wing.

With the speed of free flow 15m/s, angle of attack α=10°, the pressure in the under wing has no special, while in the upper wing, there are two regions with low pressure (figure 4). In low speed the regions are steady, which help increase lift of the wing.



Upper wing



Lower wing

Figure 4: Distribution of pressure in the wing

3.2Lift coefficient in different wing and different methods

From figure 4, it can be seen clearly that, lift coefficient of a delta wing increase significantly to 40° angle of attack and reaches to 1.6. Method of Edward C.Polhamus obtains a good result and nearly coincides with the wing 2. The wing 3 gives the lowest lift coefficient in the investigating zones, while the lift coefficient of wing 1 closes with the experimental method, which was investigated by Ahmad Z. Al-Gami, Farooq Saeed and Abdullah [3]. For the thin delta wing in low speed the change of leading-edge figure has a litte effect on the lift coefficient. It is recommended to design a delta wing without any leading-edge shape

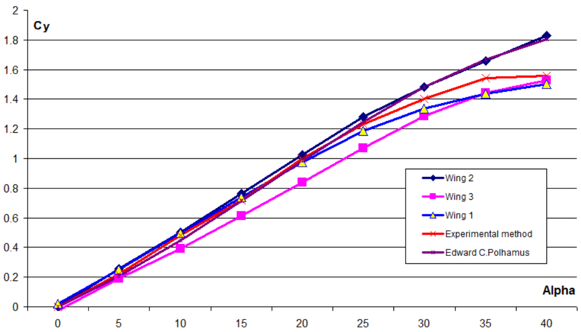


Figure 4: Depend of lift coefficient on angle of attack in different case of leading-edge figure

3.3 Vortexes in different wing.

Change the type of wing will impact in the vortexes in upper surface. As demonstration in the figure 5, the vortexes are impacted strongly in the wing 3. The figure showed change pressure of the different wing at 10° angle of attack in cross-section 2/3. The vortexes' core line of the wing 3 locates near the corner of the triangle, which make vortex less stable. Accordingly, lift force of wing 3 have the lowest value by comparison with wing 1 and wing 2.

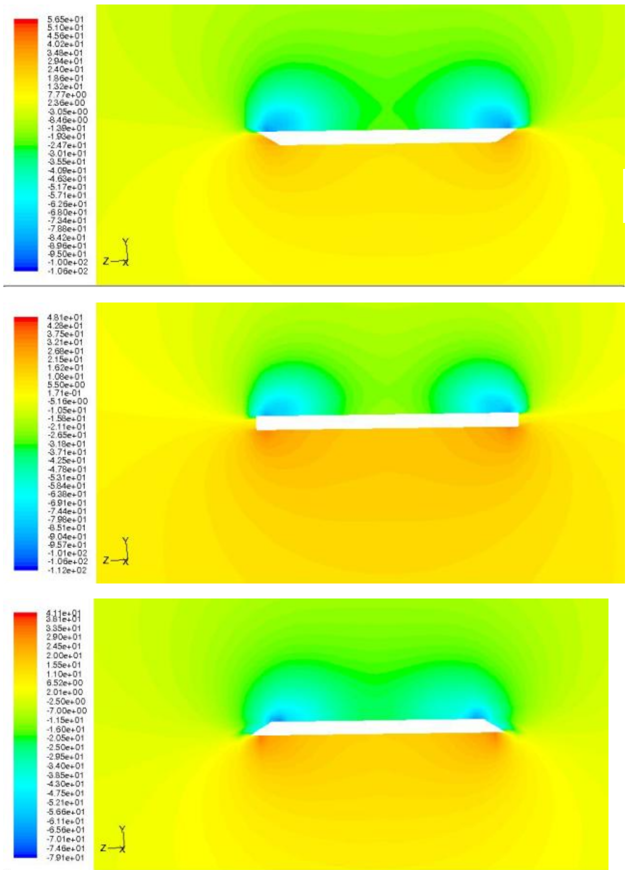
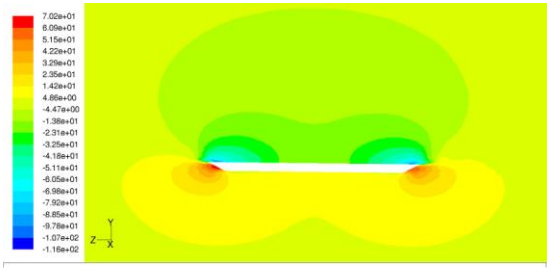


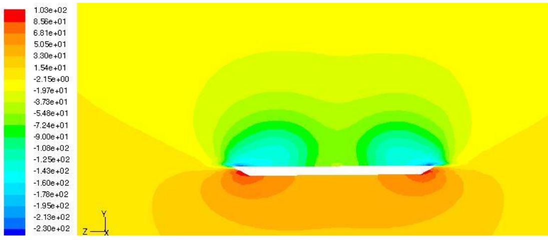
Figure 5: Distribution of pressure in different cases of leading-edge type (wing 1, 2, 3*)*

3.4 Influence of angle of attack on the construction of vortexes line.

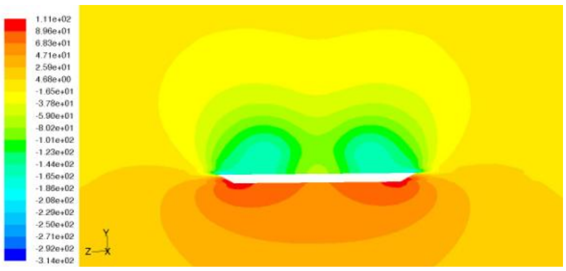
With increasing of angle of attack the vortexes line are widened and impacted one with other. However, when angle of attack is smaller than 40°, the vortexes are stable, which help the lift of wing continue to increase



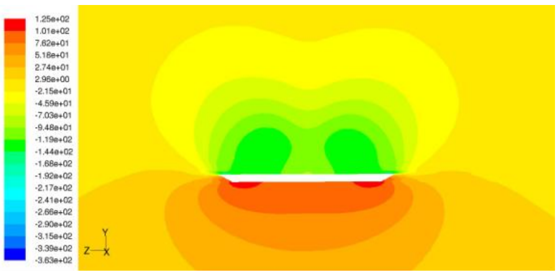
Angle of attack $\alpha=5°$



Angle of attack $\alpha=20°$



Angle of attack $\alpha=30°$



Angle of attack $\alpha=40°$

Figure 6: The vortexes line in upper delta wing 1 with different angle of attack.

4. Conclusion

As the result of investigation in the paper, we could make some conclusions:

For delta wing, there is additional lift force, which is created by vortex line in upper wing. In the stable case, the vortexes assist to increase lift of the wing and separation angle of attack.

The wing with rectangular angle gives the highest lift coefficient with the thin wing, while the wing with an acute angle in the lower wing has the smallest lift coefficient. For the thick wing, it is better to choice a wing with acute angle in the upper.

The method brought good result in investigation lift of delta wing, with litter difference comparison with experimental method and theory method created by Edward C.Polhamus.

The result of the paper make a huge reference for process of designing wing.

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