A Computational Study of Inlet Turbulence on Delta Wing Flow

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Abstract

Effect of turbulence flow to dynamic characteristic of high sweep-back angle Delta wing was performed in subsonic flow. Numerical method (SIM), based on CFD methods using ANSYS/FLUENT software, was carried out to study this phenomenon. At low Reynolds number, air velocity 2.5m/s, Delta wing was investigated with a range of attack angle from 0 to 40^o within three cases of turbulent intensity, which varied from 0.5% to 15% due to parameter of square grid. Decay of turbulence intensity with and without grid was considered. Change of dynamic characteristic of Delta wing caused by different change of turbulence intensity at inlet flow was also observed. Finally, interaction between turbulent flow and vortex on upper wing was clarified.

Keywords: Turbulent Effect, Delta Wing, Vortices, ANSYS FLUENT, Square Grid.

1. Introduction

The concept of Delta wing was first proposed in the 1931s as new model design for the new generation of aircraft; see [1] for broader history of Delta wing. From this, Delta wing has been employed for most of high performance and high velocity aircraft, because it has a long root chord, so that its wing thickness can be relatively large even with a small thickness. Furthermore it has an advantage that the drag can be reduced in supersonic flight due to swept-back leading edge [2-3]. Investigation on the aerodynamics of Delta wing was traditionally driven by the demand of aeronautical application. In recent year, study of turbulent flow generated by square gird was investigated by many researchers [4-7]. They remarked that turbulent flow affected strongly to dynamic characteristic of object, for example, for airfoil, it made increasing stall angle and lift coefficient [4]. Turbulent flow affected shear layer near solid surface by changing thickness of boundary layer, point of transition, separation, and skin friction [5]. For Delta wing, turbulent flow reduced lift coefficient, lift curve lope and maximum lift coefficient [6]. Different effect of turbulent flow to airfoil and Delta wing might be due to special characteristic of Delta wing, which was apparition of vortices upon the Delta wing. These vortices were shed from the leading edges of the wing, which rolled up spirally into strake vortices and flow downstream over the wing. Aerodynamic characteristics of Delta wing such as lift or drag coefficient which was affected dramatically by vortices. Therefore, interaction between turbulent flow and vortices might decide main characteristics of Delta wing [8-10].

In research of Nguyen et al. [10], the inlet turbulence effect was studied numerically using ANSYS FLUENT software and experimentally in subsonic wind tunnel using I-type single hot-wise probe within air velocity 2.5 m/s and attack angle 20^o The turbulence intensity increased from 0.5% to 15% with increasing size of grid.

The aim of this research was continuously developed the research of Nguyen et al [10] using ANSYS/FLUENT software with attack angle varied from 0 to 40 degree. And, the turbulent effects were carried out with two different square grids at inlet flow and without grid.

2. Numerical method

The turbulence model was SST (Shear Stress Transport) k-ω model. This model was two-equation eddy-viscosity model. The use of a k-ω formulation in the inner parts of the boundary layer made the model directly usable from the wall through the viscous sub-layer. Hence, the SST k-ω model could be used as a Low-Reynolds turbulence model without any extra damping functions. The SST formulation also switched to a k-ε behavior in the free-stream and thereby avoided the common k-ω problem that the model was too sensitive to the inlet free-stream turbulence properties. The SST k-ω model was often merited for its good behavior in adverse pressure gradients and separating flow.

A 65^o high sweepback angle Delta wing (Fig. 1), with a semi-span s = 0.2 m and chord length c =

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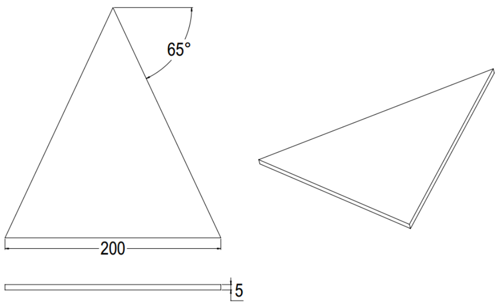
0.214 m, was used as test model. In regard reference [10], the flow became homogeneous from x = 0.4 m for different square grids in both numerical and experimental results. So on, x = 0.4 m was chosen as position to install Delta wing.



(Unit: mm)

Fig. 1. Delta wing model

In order to generate different turbulence intensities in the test section, the grids screen with different density and grid bar dimension were put after the intake just before the test section. The grid dimension was listed in Table 1. Representative turbulence intensity for different grids and no grid were 0.5% (No-Grid), 10% (medium grid) and 15% (large grid).

The blockage ratio, σ, was estimated as follow:

$$\sigma = \frac{L^2 - (L-d)^2}{L^2} \tag{1}$$

Where:

L: dimension of square grid

d: dimension of aluminum bar

Table 1. Dimension of Grids

	L (mm)	d (mm)	σ	I (%)
No-Grid	-	-	-	0.5
M-Grid	50	10	0.36	10
L-Grid	75	15	0.36	15

Turbulent intensity, I (%), was defined as:

$$I = \frac{u'}{U} \tag{2}$$

Where u' is the root-mean-square of the turbulent velocity fluctuations and U is the mean velocity. If the turbulent energy, k, is known u' can be computed as:

$$u' = \sqrt{\frac{1}{3}\left(u_x'^2 + u_y'^2 + u_z'^2\right)} = \sqrt{\frac{2}{3}k} \tag{3}$$

U can be computed from the three mean velocity components U_x, U_y and U_z as:

$$U = \sqrt{U_x^2 + U_y^2 + U_z^2} \tag{4}$$

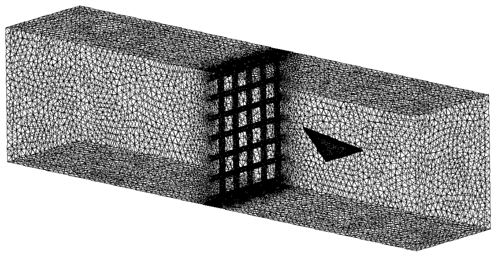
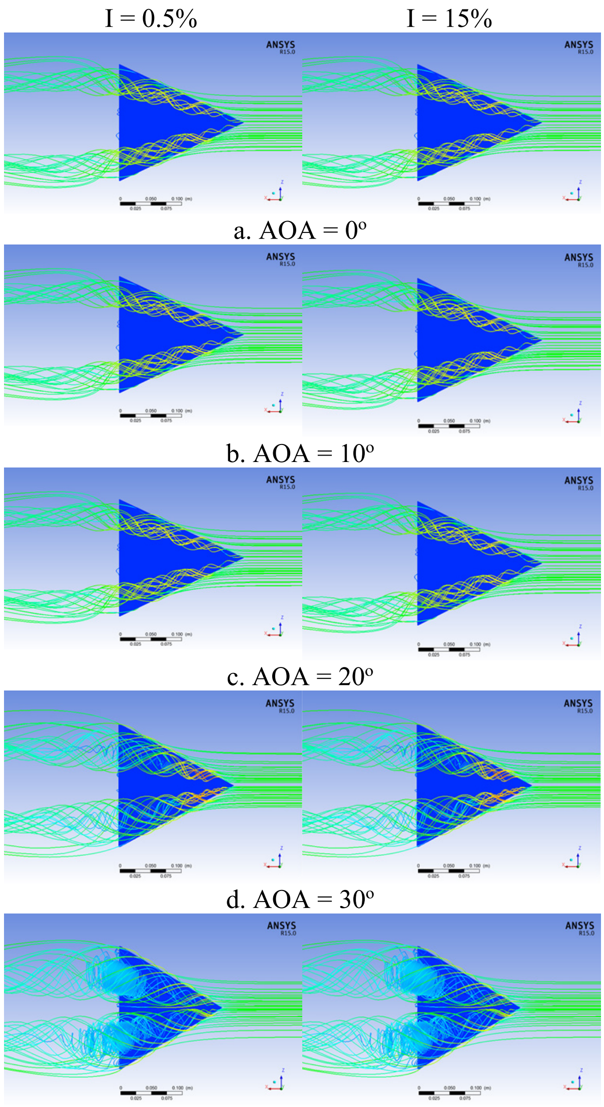


Fig. 2. Meshing grid



a. AOA = 0°

b. AOA = 10°

c. AOA = 20°

d. AOA = 30°

e. AOA = 40°

Fig. 3. Streamline

The models was meshed by MESH tool in FLUENT software. Computational domain was discretized with a tetrahedral unstructured mesh of one million elements, which was shown in Fig. 2. The quality standards for computational mesh such as orthogonal quality, skewness and aspect ratio were good according to document of ANSYS.

3. Results and disscution

Regarding Fig. 3, there was no remarkable phenomenon on the lower surface while on the upper surface, there were two different parts. One was the vortices which were shed from the leading edges of the wing, which created a large pressure difference that induced a lift for delta wing. Other was attached flow on the wing that caused another lift for delta wing. These remarks due to the lift force theory of delta wing that lift force of delta wing included potential lift force and vortices lift force [2] [8-10].

These remarks were also observed for both case of turbulence intensity 0.5% and 15% (Fig. 3) with attack angle varied from 0 to 40°.

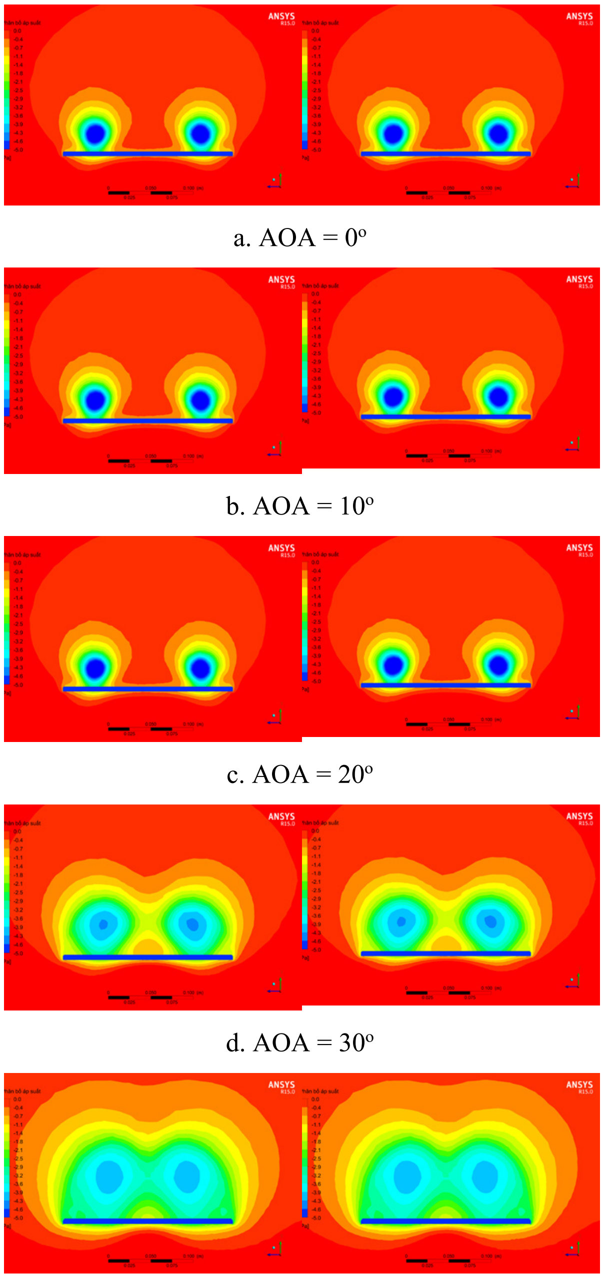
When attack angle increased, these vortices became stronger and seemed to be progressed far from the wing's surface. The pressure in the core of these vortices were low and increased when attack angle increased (Fig. 4).

Without grid at the inlet, these vortices was stronger affected the entire upper surface of Delta wing until attack angle 20°. But from attack angle 30°, these vortices was affected a part of upper Delta wing and then broke down. This breakdown of vortices was rapidly when attack angle was increased.

With square grid or with inlet turbulence flow, this attack angle was about 20°. It seemed that the turbulent flow from inlet interacted with vortices upon Delta wing and broken down these vortices. [10].

Influence of attack angle to aerodynamic characteristics of Delta wing was resumed in Fig. 5. The lift force (Fig. 5a) and drag force (Fig. 5b) increased with increase of attack angle. From attack angle 30°, the drag force continuously raised up, but the lift force was decreased. The aerodynamic characteristics of attack angle below 20° were the same for different inlet turbulence flow. The quantitative difference was observed from attack angle 20°. In plus, the lift force was found maximum at attack angle about 30-35° for case no inlet turbulence. While this attack angle was observed about 20° with inlet turbulence intensity 15%. It could be explained that the inlet turbulence interacted with vortices upon the Delta wing and decreased the stall angle of the wing [10].

I = 0.5% I = 15%



a. AOA = 0°

b. AOA = 10°

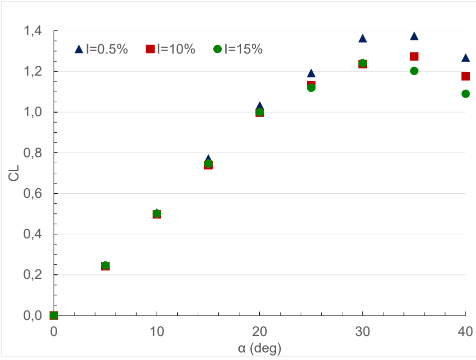
c. AOA = 20°

d. AOA = 30°

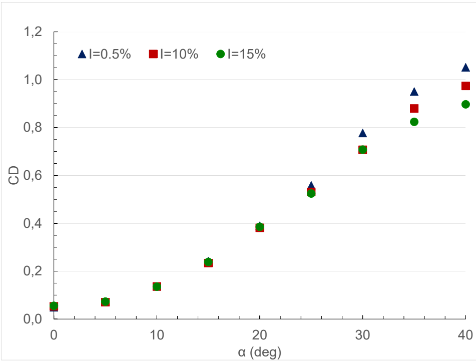
e. AOA = 40°

Fig. 4. Distribution of pressure x/cr= 0.9

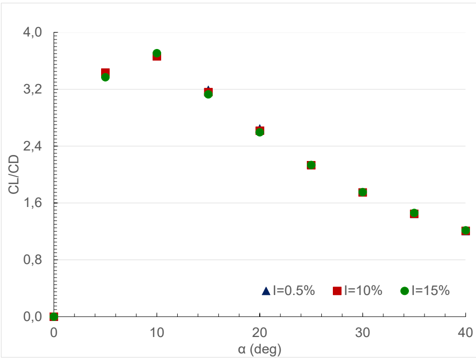
In summary, although the behavior of flow was different when the inlet turbulence was changed, the aerodynamic quality of Delta wing was found out the same (Fig. 5c).



a. Coefficient of lift



b. Coefficient of drag



c. Aerodynamic quality

Fig. 7. Aerodynamics characteristics

4. Conclusion

In this study, turbulent flow was generated by two square grids. The major results were summarized as below:

• The inlet turbulence interacted with vortices upon Delta wing, broken down these vortices and made a negative influence to aerodynamic quality of Delta wing.

• The inlet turbulence affected weakly the lift and drag force of the wing with attack angle below 20°. But, from attack angle 20°, the influence of this inlet turbulence became significantly.

• The inlet turbulence seemed to reduce the stall angle of Delta wing.

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