Simulation of Turbulent Flow around an Airfoil by using κ-ε Model: Angle of Attack Effects

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Abstract
In this paper, unsteady turbulent flow around an airfoil has been studied. Navier-stokes equations solved by Simple C algorithm exerted to specified structured and unstructured grids. Turbulent models used are two-equation *κ-ε* standard model. Equations solved by staggered method and discretization of those done by upwind method. Results show that lift and drag coefficients are increasing functions of the angle of attack.

Keywords: Turbulent flow, *κ-ε* model, airfoil, angle of attack, lift, drag.

1. INTRODUCTION

Simulation of the turbulent flow around airfoil is an up to date problem. This problem is complex and difficult to solve numerically, because many phenomena occur in this flow. Flows around aerodynamic shapes at low-to-moderate Reynolds numbers have a complex nature known as large separation bubble (LSB) [1] characterized by boundary layer separation, flow transition to turbulence, flow reattachment In many engineering applications involving a fully turbulent flow, turbulent quantities can be predicted using conventional turbulence models. While the simulation at high Reynolds numbers has been difficult, some groups have turned to simulate the flow for lower Reynolds numbers [2, 3].

Fundamentally, an airfoil generates lift by diverting the motion of fluid flowing over its surface in a downward direction, resulting in an upward reaction force by Newton's third low [4]. While this is an acceptable qualitative way of looking at airfoils, understanding the design of applicable systems such as airplanes, helicopters, and turbine blades requires a quantitative method of analyzing fluid flow and lift.

The present work aims to study the angle of attack effects on the turbulent flow around an airfoil using the commercial software FLUENT. The *κ-ε* model is derived from the Navier-Stokes equations and it is one of the simplest models of turbulence with two-equation models in which the solution of two separate transport equations allows the turbulent velocity and length scales to be independently determined.

2. GOVERNING EQUATIONS

The most important equations such as conservation of mass and momentum used by the software's solver are listed as follows:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla . \rho v = 0$$

Conservation of momentum:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_j}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\nu \frac{\partial u_i}{\partial x_j}\right)$$

Transport equations for *κ* and *ε*:

$$\rho \frac{Dk}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + G_k + G_b - \rho\varepsilon - Y_m$$

$$\rho \frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_i}\left(\alpha_\varepsilon \mu_{eff} \frac{\partial \varepsilon}{\partial x_i}\right) + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon} p \frac{\varepsilon^2}{k} - R$$

where κ is the specific turbulence kinetic energy and it is defined as the variation in the velocity fluctuations. ε is the turbulence dissipation of small velocities (eddies), in other words, the rate at which the velocity fluctuations are dissipated. G_k represents the generation of turbulence kinetic energy due to the mean velocity gradients, G_b is the generation of turbulence kinetic energy due to buoyancy, Y_m represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate. σ_k and σ_ε are the inverse effective Prandtl numbers for κ and ε respectively.

3. RESULTS

An airfoil is the shape of a wing or blade or sail as seen in cross-section. In fluid dynamics, angle of attack (AOA, or α) is the angle between a reference line on a lifting body (known as the chord line of an airfoil) and the vector representing the relative motion between the lifting body and the fluid through which is moving (figure 1).

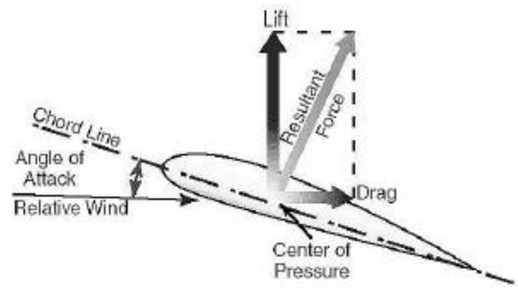

Figure 1. Resultant forces on an airfoil.

The leading edge is the part of the wing that first contacts the fluid. The trailing edge of an aerodynamic surface such as a wing is its rear edge, where the flow separated by the leading edge rejoins. Lift force is the component of the surface force that is perpendicular to the oncoming flow direction. This force can be determined using the following equation:

$$L = \frac{1}{2}\rho U_\infty^2 A C_L$$

where L is lift force, U_∞ is is the velocity of the uniform flow, C_L is the lift coefficient, and A is platform area.

Drag force refers to force which acts on a solid object in the direction of the relative flow velocity. This force can be determined using the following equation:

$$D = \frac{1}{2}\rho U_\infty^2 A C_d$$

where D is lift force, and C_d is the lift coefficient.

The airfoil was modeled in the software package GAMBIT. The geometry of the airfoil has been shown in figure 2. A fine mesh is needed in the closer regions of the airfoil. Figure 3 shows the mesh around the airfoil (MS (1)-0313).

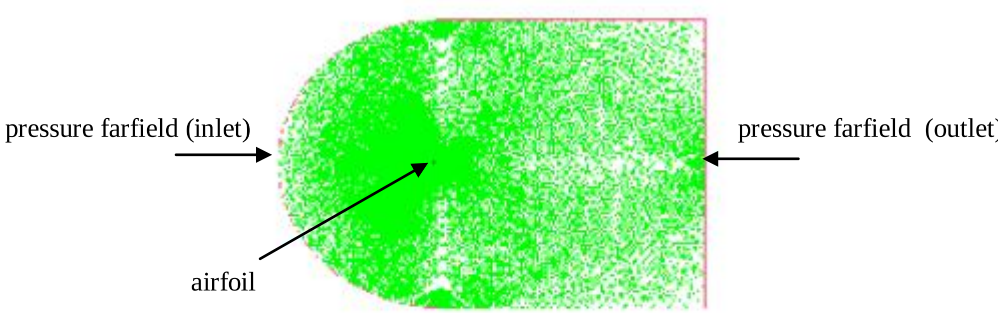

Figure 2. Geometry of the airfoil.

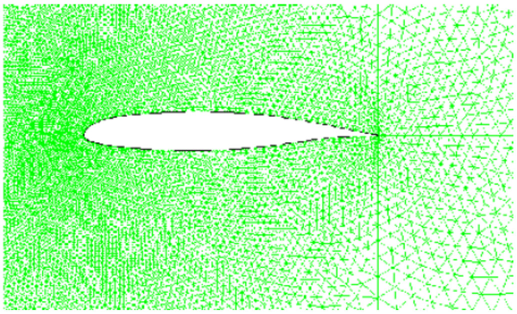

Figure 3. Mesh around the airfoil (MS(1)-0313).

The magnitude of the lift generated by an airfoil depends on the shape of the airfoil and how it moves through the fluid. For thin airfoils, the lift is directly proportional to the angle of attack for small angles (within +/- 10 degrees). As an airfoil moves through the fluid, fluid molecules stick to the surface. This creates a layer of fluid near the surface called boundary layer. Figure 4 shows the variation of lift coefficient with the angle of attack. One can see that the lift coefficient increases with increasing the angle of attack. Figure 5 shows the variation of drag coefficient with the angle of attack. The drag force increases with increasing the angle of attack. The increases in the angle of attack increases lift and drag forces. Depending on the angle of attack, there will be a force backward (induced drag) and a force upward (lift). If the angle of attack is small, the drag and the lift are comparatively small.

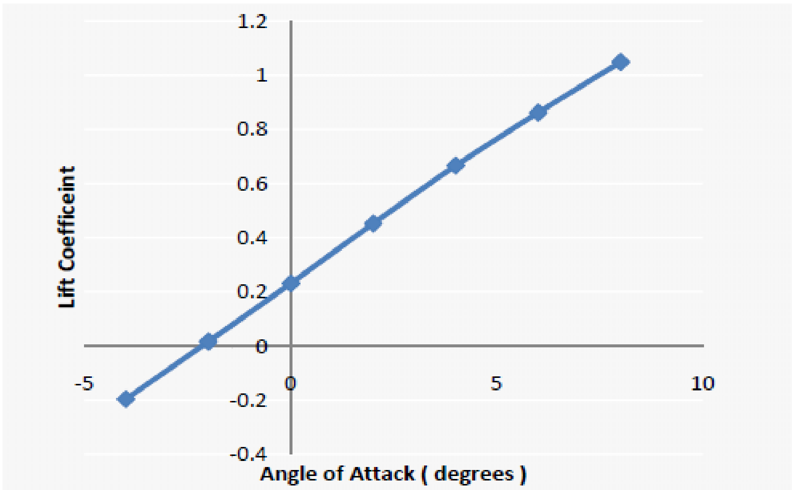

Figure 4. Lift coefficient versus angle of attack ($Re = 4\times10^6$).

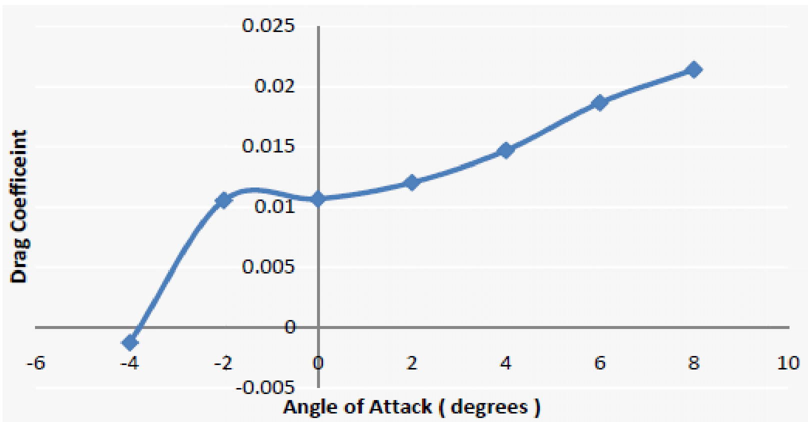

Figure 5. Drag coefficient versus angle of attack ($Re = 4\times10^6$)..

4. CONCLUSIONS

In this paper, unsteady turbulent flow around an airfoil has been studied. Navier-stokes equations solved by Simple C algorithm exerted to specified structured and unstructured grids. The present work aims to study the angle of attack effects on the turbulent flow around an airfoil using the commercial software FLUENT. Turbulent models used are two-equation κ-ε standard model. Equations solved by staggered method and discretization of those done by upwind method. Results show that lift and drag coefficients are increasing functions of the angle of attack. Depending on the angle of attack, there will be a force backward (induced drag) and a force upward (lift). If the angle of attack is small, the drag and the lift are comparatively small.

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