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Simulation of Viscous Flows Around A Moving Airfoil by Field Velocity Method with Viscous Flux Correction

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Abstract. Based on the field velocity method, a novel approach for simulating unsteady pitching and plunging motion of an airfoil is presented in this paper. Responses to pitching and plunging motions of the airfoil are simulated under different conditions. The obtained results are compared with those of moving grid method and good agreement is achieved. In the conventional field velocity method, the Euler solver is usually used to simulate the movement of the airfoil. However, when viscous effect is considered, unsteady Navier-Stokes equations have to be solved and the viscous flux correction must be taken into account. In this work, the viscous flux correction is introduced into the conventional field velocity method when non-uniform grid speed distribution is occurred. Numerical experiments for the flow around NACA0012 airfoil showed that the proposed approach can well simulate viscous moving boundary flow problems.

AMS subject classifications: 65Z05,65M04

Key words: Gust response, unsteady Navier-Stokes equations, field velocity method, viscous flux correction.

1 Introduction

In the field of Computational Fluid Dynamics (CFD), there are two categories of numerical methods for simulating moving boundary flow problems. One is the moving grid method [1–3], which constantly updates the grid according to the position of object. In this type of methods, the unsteady Navier-Stokes (N-S) equations are solved with the help of Arbitrary Lagrangian-Eulerian (ALE) technique. The major limitation of moving grid method is the regeneration of mesh at every time step, which may consume much time and reduce computational efficiency. To overcome this drawback, a

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pseudo grid-deformation approach was developed [4]. This approach calculates the grid speed through analytical expression of grid movement. The method is feasible to simulate rotational motion of the object. However, to simulate axial motion of the object, the volume change of grid cells should be considered. Another type of approaches for handling moving boundary problems is the field velocity method [5–8], which adopts the grid speed technique to simulate the velocity change of flow field. This method is especially suitable for calculation of step change of airfoil, and has been successfully applied to calculate the gust response of the airfoil/wing [9–12].

The conventional field velocity approach described above is usually used to calculate the indicial response [7, 8, 13]. It is a method for incorporating unsteady flow conditions via grid movement in CFD simulations. This approach provides a unique feature for directly calculating aerodynamic responses to step changes in flow conditions. Physically, the grid velocity can be interpreted as the velocity of a grid point in the mesh during the unsteady motion of the boundary surface. An impulsive change in the angle-of-attack can be perceived as an impulsive superposition of a uniform velocity field to the free stream. The magnitude of the normal velocity is determined by the magnitude of the indicial change for the angle-of-attack. This method effectively decouples the influence of pure angle-of-attack from that of a pitch rate because the airfoil is not made to pitch, and also because the step change is enforced over the entire flow domain uniformly. A similar methodology can be used for simulating responses of an airfoil to step changes in pitch rate and interaction with traveling vertical gusts or convecting vortices [13, 14]. In addition, the field velocity approach is also used to prescribe the effects of the trailed vortex wake from the other rotor blades [15–17], which reduces a lot of computational time as compared to the full wake capturing method. However, the observations from the time dependence study [15] strongly suggests that the consistent evaluation of time metrics for satisfying the geometric conservation law is critical for obtaining smooth and accurate solutions in time.

Based on the field velocity method, a novel technique is developed in this paper to simulate unsteady pitching and plunging motions of an airfoil by using a fixed grid. In the present work, the unsteady N-S equations are solved to describe the flow field. In the meanwhile, it is necessary to add a viscous flux correction to consider the gust responses when the grid speed is not uniform in space. In addition, to model the pitching motion, a rotational velocity is added to the grid to simulate the rotational speed of airfoil, and a vertical velocity to the grid to represent the angle change of airfoil. To model the plunging motion, only a vertical velocity is required. The present method is validated by its application to simulate the airfoil movement with different motion modes. The obtained results show good agreement with those of moving grid method. This demonstrates the capability of present field velocity method for simulation of moving boundary flow problems, and the ability to consider the gust response.

The paper is organized as follows. In Section 2, the viscous flux correction-based field velocity method is described in details. In Section 3, the proposed method is applied to simulate various moving airfoil problems to demonstrate its feasibility for