An Unstructured Mesh Technique for Rotor Aerodynamics

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Abstract: An unstructured mesh method has been developed for the simulation of steady and time-accurate flows around helicopter rotors. A dynamic and quasi-unsteady solution-adaptive mesh refinement technique was adopted for the enhancement of the solution accuracy in the local region of interest involving highly vortical flows. Applications were made to the 2-D blade-vortex interaction aerodynamics and the 3-D rotor blades in hover. The interaction between the rotor and the airframe in forward flight was investigated by introducing an overset mesh technique.

Keywords: Unstructured mesh, Solution-adaptive technique, Unsteady flows, Rotor aerodynamics

1. INTRODUCTION

The flow fields around helicopter rotors are very complicated, particularly in forward flight, because rotor blades encounter unsteady periodic free stream and are subjected to time-varying wake. The interaction between the vortical wake and the rotor blades is the main source of rotor aeroacoustic noise and aeroelastic vibration. Addition of an airframe underneath the rotor further amplifies the complexity, requiring the solution of unsteady time-accurate three-dimensional flows involving multiple bodies in relative motion. Accurate capturing of the wake and the interaction between the rotor and the airframe is one of the most challenging problems, even using the state-of-art techniques in computational fluid dynamics.

In the present study, an unstructured mesh method has been developed for the simulation of complicated rotor aerodynamic problems involving blade-vortex interaction (BVI), wake capturing, and rotor-airframe interaction. A solution-adaptive mesh refinement technique was coupled to the flow solver for the enhancement of the solution accuracy. The present method has been applied to several rotor aerodynamic problems for validation.

2. NUMERICAL METHOD

The governing unsteady Euler equations were discretized using a second-order accurate cell-centered finite-volume method in conjunction with the Roe's flux-difference splitting scheme [1]. An implicit time integration algorithm based on the linearized second-order Euler backward differencing coupled with dual-time stepping was used to advance the solution in time. The linear system of equations was solved at each time step using a point Gauss-Seidel method.

In order to reduce the large computational time, a parallel algorithm based on a domain decomposition strategy was adopted. The load balancing between processors was achieved by partitioning the global computational domain into local subdomains using MeTiS libraries. The Message Passing Interface was used to transfer the flow variables across the subdomain boundary.

To handle the relative motion between the rotor blades and the airframe, an overset mesh technique has been coupled to the flow solver. A time-accurate or quasi-unsteady solution-adaptive mesh refinement technique [2, 3] was also adopted to reduce the numerical dissipation and to enhance the accuracy of the solution.

3. RESULTS AND DISCUSSION

3.1 2-D Blade-Vortex Interaction

The first application of the present method was made to the two-dimensional blade-vortex interaction at a transonic speed. In Fig. 1, the instantaneous mesh and the corresponding pressure contours are presented. It is shown that the present unstructured dynamic mesh adaptation technique well predicts the migration of the vortex and the unsteady shock behavior, along with the mutual interaction between the two. The shock wave bifurcation due to the interaction, the pressure wave generated from the leading edge of the airfoil, and its migration to upstream are also well captured.

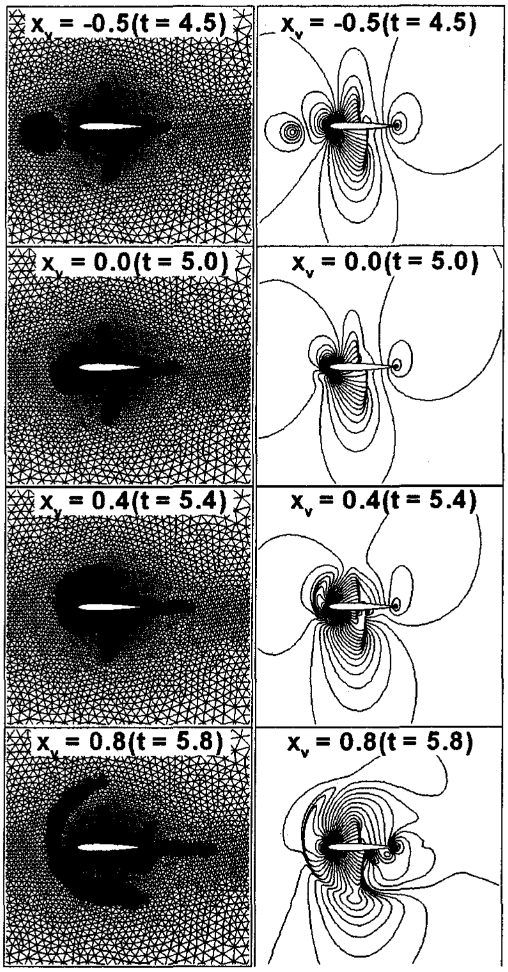

Fig. 1 Instantaneous meshes and the corresponding pressure contours in 2-D BVI at transonic speed

3.2 Isolated Rotor in Hover

The second application was made to an isolated Caradonna-Tung rotor in hover operating at a transonic tip Mach number of 0.877. In Fig. 2, the vorticity contours along the blade tip vortex trajectory is presented. It shows that the tip vortex is well captured up to one revolution of the rotor using the present solution-adaptive mesh refinement technique, without too much numerical dissipation. In Fig. 3, the blade surface pressure distributions at several spanwise sections of the blade are presented. It shows that the predicted results compare well with the experiment [4] at all spanwise sections. The location and the strength of the shock wave are reasonably well predicted.

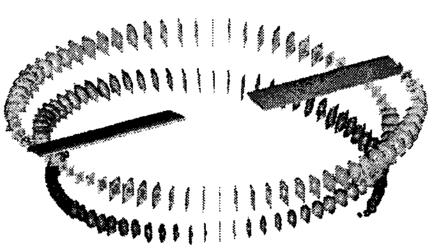

Fig. 2 Vorticity contours along the tip vortex trajectory of a hovering rotor.

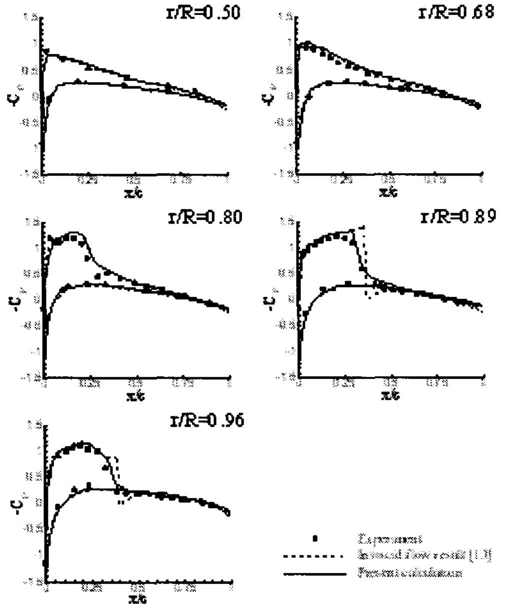

Fig. 3 Blade surface pressure distributions at a transonic tip Mach number.

3.3 Rotor-Airframe Interaction in Forward Flight

The next validation was made for the ROBIN (Rotor Body Interaction) configuration tested at the NASA Langley Research Center [5]. This configuration consisted of a four-bladed rotor and a generic airframe. In Fig. 4, the computational mesh is presented after the mesh adaptation. It shows that the cell refinement was made mostly around the rotor and the airframe where strong vortical flow exists. In Fig. 5, the predicted unsteady pressure variations are compared with experiment at two selected airframe surface points. It shows that the peak-to-peak magnitude of variation and the phase are in good agreement with experiment, demonstrating that the present method is an effective tool for the simulation of complicated unsteady flows involving mutual interaction of multiple bodies.

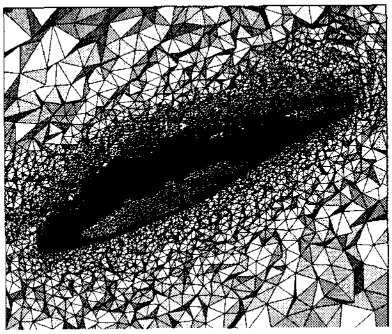

Fig. 4 Unstructured mesh around the ROBIN rotor-airframe configuration.

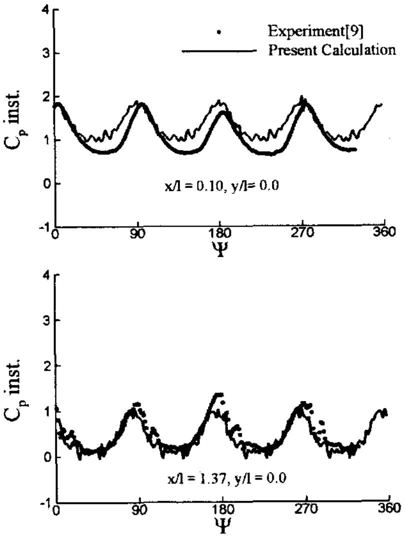

Fig. 5 Unsteady pressure variations at selected two airframe surface points.

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