A conservative adaptive scheme for the two-dimensional airfoil-vortex interaction problem

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Abstract: Preliminary computations for the vortex-airfoil interaction problem are shown. The Arbitrary Lagrangian-Eulerian formulation of the Euler equations is used to describe the fluid behaviour. An unsteady adaptive grid strategy is adopted to better capture the flow features, e.g. shock waves, and to reduce the numerical dissipation of the vortex.

Keywords: Adaptive Grids, Airfoil-Vortex Interaction, ALE Formulation.

The computation of the dynamic loads over an airfoil caused by the interaction with external vortices is a challenging task. Numerical simulations of this kind of flow fields are of interest since in rotorcraft the blade-vortex interaction (BVI) could be a relevant source of noise and vibration [1]. However, suitable techniques must be adopted to avoid the desctruction of the vortices by the numerical dissipation [2, 3], a well known phenomenon of schemes based on the shock-capturing approach. In the present work grid adaptation is performed to locally increase the grid quality and reduce the spacing, thus reducing the numerical dissipation introduced by the scheme. A combination of node displacements and local topology modifications (edge-swapping, node insertion/removal) is adopted. The Arbitrary Lagrangian-Eulerian (ALE) formulation of the Euler equations, in which the control volumes are allowed to change in shape and position as time evolves, is used to describe the behavior of the flow. The governing equations are discretized by a node centered finite volumes approach in which the grid velocities are corrected to take into account the grid modifications performed by the adaptation scheme. The overall scheme allows to compute the solution at the current time level by simply integrating the governing equations, without explicit interpolation of the solution, i.e. in a conservative manner. Moreover high order time integration schemes, e.g. standard BDF techniques, can be implemented very easily. [5].

Preliminary computations of the interaction between a compressible vortex and a NACA0012 airfoil are presented in order to assess the validity of the proposed approach. A transonic asymptotic Mach number of 0.8 is considered, the initial miss distance is set to $-0.26c$, with c airfoil choord, the vortex radius is $0.05c$ and the vortex Mach number is 0.16. The initial grid spacing is chosen to be proportional to the distance from the solid walls and then adapted to the Mach gradient of the steady solution. The vortex is then inserted in the flowfield at a distance of 5 chords from the leading edge and an additional refinement is perfored inside the vortex radius. As result the area of the elements located inside the vortex is equal to $1.3c \cdot 10^{-5}$. At every time step the vortex core is identified as the minimum of vorticity. The unsteady computations are

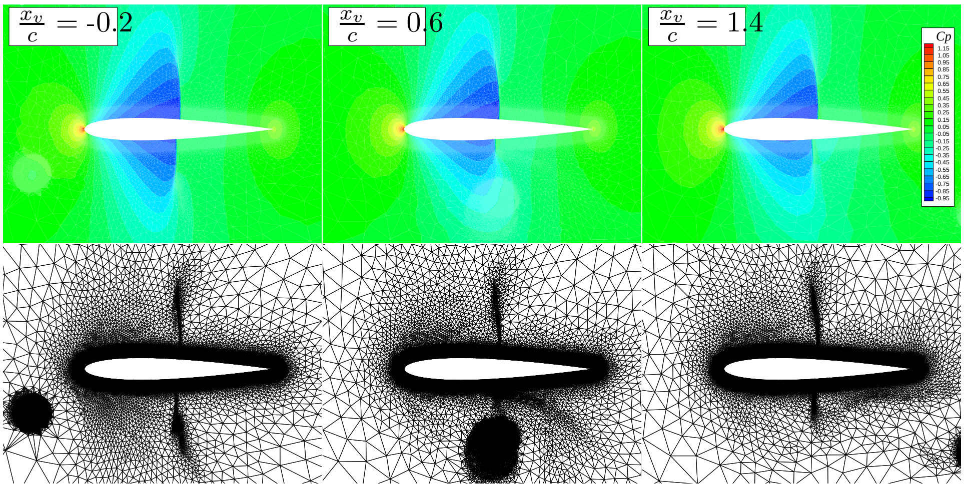

Figure 1: Pressure coefficient contours and computational at several time steps, i.e. different core horizontal coordinates z.

carried out according to the following procedure:
i. Core displacement: the grid close to the vortex is deformed to follow its movement.
ii. Predictor: the solution $\tilde{u}^{n+1}$ is computed from the solution at the previous time step.
iii. Adaptation: the grid is adapted over the predicted solution.
iv. Correction: the solution u^{n+1} is computed from u^n over the adapted grid.
The first step allows to reduce the numerical dissipation, since the grid around the core almost rigidly follows the vortex in a Lagrangian fashion. The predictor phase is necessary to adapt the grid over the solution and the correction phase allows to take the topology modifications into account in a conservative way. The evolution of the computational grid is shown in Figure 1. It must be noted that significant changes in the mesh are caused by the almost-rigid displacement the vortex. However, the overall quality of the mesh does not decrease. The results in terms of pressure coefficient values in the flowfield are also shown in Figure 1. The displacement of the shock waves can be observed.

References

[1] R. Singh and J. D. Baeder, Adaptive Euler Simulation of Supercritical Interaction of Airfoil and Vortex. *16th AIAA Computational Fluid Dynamics Conference*, June, 2003, Orlando, FL, USA.

[2] L. Tang and J. D. Baeder, On the significance of transonic effects on aerodynamics and acoustics of blade-vortex interactions. *2nd AIAA/CEAS Aeroacoustics Conference*, 1996.

[3] W. S. Oh, J. S. Kim, and O. J. Kwon. Numerical Simulation of Two-Dimensional Blade-Vortex Interactions Using Unstructured Adaptive Meshes. *AIAA Journal*, 40(3):474-480, 2002.

[4] A. Guardone, D. Isola, and G. Quaranta. Arbitrary lagrangian eulerian formulation for two-dimensional flows using dynamic meshes with edge swapping. *Journal of Computational Physics*, 230(20):7706–7722, 2011.