Dynamic Mesh Deformation for the Preconditioned Implicit Adaptive Non-Linear Frequency Domain Method (adaptive NLFD)

Ali Mosahebi and Siva Nadarajah
ali.mosahebimohamadi@mail.mcgill.ca

CFD Lab, Department of Mechanical Engineering, McGill University, Montreal, Canada.

December 9, 2011

Abstract: In the present study a preconditioned implicit adaptive Nonlinear Frequency Domain method (adaptive NLFD) has been implemented for the Navier-Stokes equations on deformable grids. Although the computational time for periodic flows is drastically reduced by using the NLFD approach over classical time marching schemes, implementing the adaptive NLFD concept leads to an even faster numerical algorithm. To be able to simulate unsteady problems with a large amount of movement, the concept of dynamic or moving/deformable grid is implemented for the adaptive NLFD method. In order to accelerate the convergence rate, the nonlinear LU-SGS technique, which is an implicit time marching method, as well as local time stepping and multigrid techniques are implemented. Finally, a novel low mach number preconditioning technique is developed for the adaptive NLFD method, where the preconditioning is implemented in the frequency domain instead of the time domain. Results will be presented for 2D oscillating cylinders and plunging airfoils and are compared with previous numerical results as well as experimental data.

Keywords: Computational Fluid Dynamics, Nonlinear Frequency Domain Method, Dynamic Mesh Deformation, Preconditioning.

1 Introduction

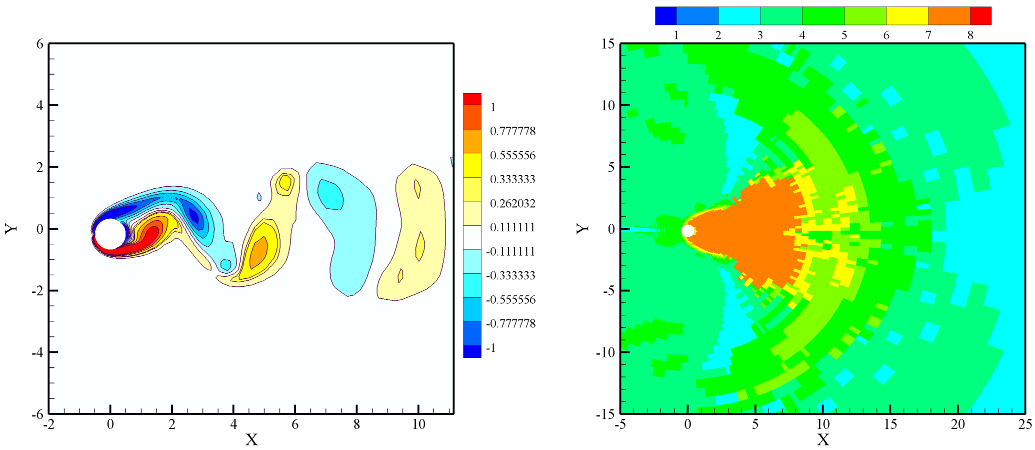
Periodic phenomena widely appear in physical fluid flow problems where the flow contains repeating patterns in time. In the case of periodic problems, usually one is most interested in the periodic steady state solution when the initial transient behaviors vanish. However, because of the hyperbolic nature of the governing equations, simulation of the unsteady part of the solution is inevitable. For many cases, the time associated with the initial transient portion is much larger than the time period. Therefore, most of the computational resources are spent on resolving the initial transient before reaching the desired periodic steady state.

A significant improvement in execution time can be obtained using NLFD approach which originally was introduced by Hall *et* al[1] and McMullen[2]. However, for a better computational efficiency, the adaptive concept was developed for 2D viscous flows by the present authors [3]. In this study, the nonlinear LU-SGS technique together with local time-stepping and multigrid technique are employed to accelerate the convergence to a periodic steady state solution. These techniques are extended to the adaptive NLFD method, where different cells have dissimilar number of modes and therefore have to be treated individually.

Finally, an innovative preconditioner is developed for the present method, where the preconditioning should be performed in the frequency domain. Therefore, the compressibility problems for high amplitude and/or high frequency flutters, would be eliminated.

2 Results

Figure 1(a) presents the vorticity contours for the flow around a vibrating stationary cylinder at $Re = 100$. In figure 1(b) the mode distribution contour for the same case is presented. It shows that more modes are required for the cells which are at the wake of the cylinder while the rest of the domain needs less number of modes for the same level of accuracy.



(a) (b)

Figure 1: Flow around an oscillating cylinder (y-direction) with oscillation amplitude of $\dfrac{A}{D} = 0.2$ at $Re = 100$ and $F = 1$; (a) The vorticity contour (b) The mode distribution contour.

Figures 2(a) and 2(b) shows the Mach number distribution contours for the flow around a stationary cylinder at inflow Mach numbers of M=0.3 and M=0.01, respectively. From this figure, it is observed that the employed preconditioning technique preserves the accuracy of the solutions.

References

[1] K. C. Hall, J. P. Thomas, and W. S. Clark. Computation of unsteady nonlinear flows in cascades using a harmonic balance technique. Technical report, 9th International Symposium on Unsteady Aerodynamics, Aeroacoustics and Aeroelasticity of Turbomachines, Lyon, France, September 2000.

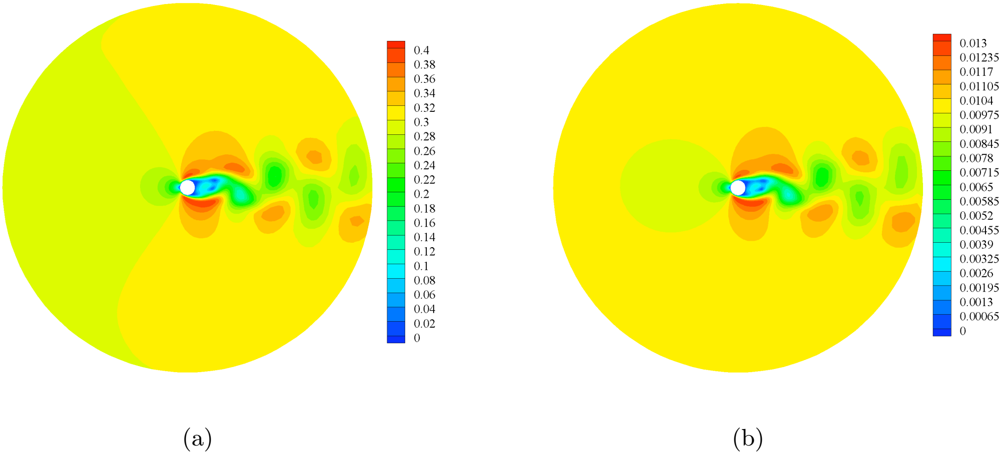


Figure 2: Mach distribution contours for the flow around a stationary cylinder; (a) M=0.3, (b) M=0.01

[2] Matthew McMullen. *The Application of Non-Linear Frequency Domain Methods to the Euler and Navier-Stokes Equations*. Ph.d. dissertation, Department of Aeronautics and Astronautics, Stanford University, Stanford, CA, March 2003.

[3] Ali Mosahebi Mohamadi and Siva K. Nadarajah. An adaptive non-linear frequency domain method for viscous periodic steady state flows. Technical report, 48th AIAA Computational Fluid Dynamics Conference, January 2010.