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A New Immersed Boundary Method for Aeroacoustic Sound Prediction around Complex Geometries

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A high-order, sharp-interface immersed boundary method for aeroacoustic sound prediction around complex geometries is proposed. The present immersed boundary method sharply resolves the interface of immersed boundaries with a ghost-cell approach, and the boundary conditions on the body surface are applied using a high-order approximating polynomial with a least-square error minimization. For the efficient computation of flow induced noise around complex geometries at low Mach numbers, the present immersed boundary approach is applied to the hydrodynamic/acoustic splitting method where the flow field around complex geometries is computed by the immersed boundary, incompressible flow solver, and the acoustic field is then predicted by the linearized perturbed compressible equations (LPCE) employing the present immersed boundary method. The present method is validated for canonical acoustic wave scattering problems and a fundamental flow induced noise problem by comparing the results with the analytical solutions and the result of direct simulation performed on a body-fitted grid.

I. Introduction

In recent years, much progress has been made in computational aeroacoustics (CAA) and CAA has been applied to various engineering applications such as airplane, automobile, turbo machinery noise, and also used for some bio-medical engineering applications. CAA with practical, complex geometries however remains a challenge. Most high-order numerical methods used in CAA are very sensitive to the quality of computational grid and boundary condition formulation, but it is usually difficult to generate computational grids of good quality around general, complex geometries found in practical applications. There have been a couple of approaches to resolve this matter. A high-order overset grid method[1,2] has been developed to solve compressible flow and acoustics over a complex geometry. However the level of geometric complexity that this solver can handle is still limited. High-order discontinuous Galerkin method[3-6] could be an alternative method to solve aeroacoustic field around complex geometries, but these methods are known to be very costly. Immersed boundary method[7] (IBM) is a highly versatile approach to deal with complex geometries. With IBM, all the equations can be solved on a Cartesian grid, and also the grid does not need to be re-generated for moving or deforming bodies. Due to this flexibility many different kind of immersed boundary methods are used in compressible and incompressible flow solvers. The key to the immersed boundary method is the treatment of boundary condition at the immersed surfaces. In most IBMs for compressible equations, however, the formulation of wall boundary condition is locally only first-order accurate (one counterexample is the method of Ghias et al.[8]). Such low-order boundary formulations are not appropriate for acoustic field computation, since they may cause excessive dispersion/dissipation errors. Also the sharpness of interface would be very important in order to limit the phase and amplitude errors on the wave interacting with the immersed boundary. Recently, Liu & Vasilyev[9] applied the Brinkman penalization method, which is an immersed boundary method based on a porous media model equation, to the compressible Navier-Stokes equations and considered an acoustic wave scattering problem. In this method, however, the interface of immersed boundary is not sharp, and it causes both phase and amplitude errors depending on modeling parameters[9] which control the sharpness of interface.

In the present study, we propose and test a computational methodology to solve aeroacoustic problems with complex bodies using a sharp interface, higher-order immersed boundary method. The immersed boundary method applied in this study is based on the ghost cell method for incompressible flows proposed by Mittal et al.[10] (also found in Ghias et al.[8] for compressible flows) and extended to higher-order method using an approximating

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