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The Modified Ghost Fluid Method Applied to Fluid-Elastic Structure Interaction

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Abstract. In this work, the modified ghost fluid method is developed to deal with 2D compressible fluid interacting with elastic solid in an Euler-Lagrange coupled system. In applying the modified Ghost Fluid Method to treat the fluid-elastic solid coupling, the Navier equations for elastic solid are cast into a system similar to the Euler equations but in Lagrangian coordinates. Furthermore, to take into account the influence of material deformation and nonlinear wave interaction at the interface, an Euler-Lagrange Riemann problem is constructed and solved approximately along the normal direction of the interface to predict the interfacial status and then define the ghost fluid and ghost solid states. Numerical tests are presented to verify the resultant method.

AMS subject classifications: 65M06, 65N85, 74F10, 35L65, 35L67, 35Q74

Key words: Fluid-elastic structure interaction, Euler-Lagrange coupling, Euler-Lagrange Riemann problem, ghost fluid method, modified ghost fluid method.

1 Introduction

Fluid-structure interaction (FSI) is one important field of scientific interests [17]; it covers numerous applications including acoustics, explosive loading of structures, fluid induced vibration of floating/offshore structures, sloshing of liquids in open and closed containers, wind load on buildings, flutter of aerodynamic vehicles, etc. In this work, our focus is on the numerical treatment of compressible fluid-elastic structure interaction.

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There are several difficulties and challenges encountered in the numerical simulation of FSI. The first issue is how to treat the coupling between the fluid domain and solid domain. The second is numerical instability, especially when the structure is under a strong impact. The third is to faithfully take into account the nonlinear interaction occurring at the interface.

In treatment of the first issue [18, 19], there are several ways as founded in the literature and these can generally be categorized as three approaches, namely, the loose Euler-Lagrange coupling, full Lagrange coupling and half-way Euler-Lagrange coupling. The loose Euler-Lagrange coupling is a weak coupling and very popular, where the fluid domain and the solid domain are solved by a fluid solver (usually an Eulerian solver such as a finite difference method) and a solid solver (usually a Lagrangian solver such as a finite element method), respectively. In this approach, the interaction between fluid and structure is achieved by applying respective boundary conditions to the individual solver separately. More specifically, the fluid is usually solved first with the structure assumed (unphysically) rigid, and then the structure is solved via imposing the force boundary conditions, which is obtained from the fluid solver, on the structure surface. The interface location obtained from the solid solver serves as the new boundary for the fluid solver in the next round of computation. If one intends to allow mesh along the interface, mesh regeneration has to be applied in the fluid domain at least in the vicinity of the interface. If the mesh is fixed for the fluid solver, special technique of treating irregular grid cells for the fluid solver is then required. The loose Euler-Lagrange coupling is relatively simple and convenient in numerical implementation. In addition, existing fluid and structure codes can be easily coupled together to simulate FSI problems. Current commercial software like ABACUS-FLUENT, ANSYS-CFX, LSDYNA commonly available in the market are built on the idea of using independent fluid and solid solvers. On the other hand, because of the weak and loose coupling, the boundary conditions at the interface for both fluid and structure are not imposed accurately (at least not at the same moment). Strictly speaking, the nonlinear (wave) interaction at the interface (the third issue mentioned above) is unable to be taken into consideration faithfully. In addition, numerical instability (the second issue mentioned above) is another problem frequently encountered.

The full Lagrange coupling involves a fully implicit monolithic approach where the fluid and the solid domains are solved simultaneously for the unknown variables; the interface boundary conditions are imposed as part of the solution and even the interface location is assumed to be part of the unknowns. This leads to the seamless coupling between the fluid domain and the solid domain. The full Lagrangian coupling usually leads to a large and complex numerical system, which requires iteration to obtain its solution with (possible) treatment of preconditioning [7]. Theoretically, on one hand, the nonlinear (wave) interaction at the interface can be captured faithfully using the full Lagrangian approach. On the other hand, the numerical instability is another major issue for this approach especially when the interface is under strong impact and large deformation. Furthermore, mesh regeneration is always required in the full Lagrangian coupling. The Arbitrary Euler-Lagrange (ALE) method is the