Interface Treatment and Load Computation in Embedded Boundary Methods

Kevin Guanyuan Wang 1 and Charbel Farhat 1, 2, 3

1. Institute for Computational and Mathematical Engineering (ICME), 2. Aeronautics and Astronautics, 3. Mechanical Engineering, Stanford University

Introduction

N on body-conforming CFD grids in which wet surfaces of various obstacles are embedded are gaining popularity in many scientific and engineering applications under different names including the immersed, embedded, fictitious domain, and Cartesian methods. These methods can be attractive because they simplify a number of issues ranging from meshing the fluid domain to formulating and implementing Eulerian-based algorithms for fluid-structure applications with large structural displacements and/or deformations. Unfortunately, embedded boundary methods also tend to complicate other issues such as enforcing the fluid-structure transmission conditions in general, and the computation and transfer of the flow-induced loads on the wet surfaces of obstacles in particular.

Purpose and Hypothesis

The purpose of this work is to develop robust methods for discretizing the transmission conditions associated with fluid-structure applications in the context of embedded boundary methods. Because the main application is currently underwater implosion, the flow is assumed to be inviscid. However, extension to viscous flows is possible and under investigation.

Computational Framework

The key components of the proposed computational framework include: (a) an interface tracker that computes intersections between the fluid grid and the structural wet surface; (b) a Riemann problem based single-phase flux solver; (c) an analytical approach for enforcing the kinematic transmission condition at the embedded fluid-structure interface, which is based on the analytical solution of the one-dimensional fluid-structure Riemann problem; (d) an algorithm for enforcing the equilibrium transmission condition at the embedded fluid-structure interface; and (e) staggered and yet numerically stable explicit-explicit time-accurate algorithms for efficiently solving the coupled fluid-structure equations.

Applications

All proposed algorithms are implemented in parallel within AERO-F, AERO-S (or XFEM), and MATCHER suite of fluid-structure computational modules. Three applications are considered for verification and performance assessment. In Figure A, a steady-state subsonic flow over an airfoil is considered for convergence analysis. In Figure B, forced-motion simulations under both ALE and embedded framework are performed for mesh conservation analysis. The last application (Figure C) is a large deformation underwater implosion problem with strong shock waves for which experimental data is available.

Conclusions

Despite the fact that it operates on a surrogate fluid-structure interface that is jagged and O(x/2) away from the real wet surface of the structure, the computational framework described here for enforcing the appropriate interface conditions and evaluate the flow-induced load on the structure converges faster than traditional approaches designed for body-fitted grids.

Acknowledgments

The authors acknowledge the support by the Office of Naval Research under Grant N00014-06-1-0505 and Grant N00014-09-C-015.

Bibliography


Further Information

For more information please contact Kevin Wang at kmewang@stanford.edu