Deforming Composite Grids for Fluid-Structure Interactions: Overcoming the Added-Mass Instability for Compressible Fluids and Elastic Solids

Domain-Adaptive High-order Accurate Algorithms for PDEs in Moving Geometry

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Abstract

Fluid-structure interaction (FSI) problems are multi-domain problems involving moving and deforming solids that are coupled to a neighboring fluid or gas. These problems are important in many fields of engineering and applied science and are often computationally challenging. Examples of FSI problems include the modeling of flow induced vibrations of structures (aircraft, undersea cables, wind-turbines, buildings), parachutes and airbags, blood flow in veins and arteries, acoustic lenses, thermal expansion in nuclear reactor cores, shock-structure interactions (blast effects), and weapons effects, to name just a few.

We describe a mixed Eulerian-Lagrangian approach for solving FSI problems. The technique, which uses deforming composite grids (DCG), is applied to FSI problems that couple high speed compressible flow with elastic solids. The fluid and solid domains are discretized with overlapping grids. Curvilinear grids are aligned with each interface and these grids deform as the interface evolves. The majority of the grid points generally remain fixed during the computation. The FSI-DCG approach allows large displacements of the interfaces while retaining high quality grids. The method provides a very efficient scheme (through the use of Cartesian grids) that can also accurately treat interfaces with boundary fitted curvilinear grids. The grids can be rapidly regenerated and remain of high quality even under large displacements and rotations of the solid domains. Traditional ALE (Arbitrary Lagrangian-Eulerian) approaches have difficultly treating problems with large displacements and rotations since the meshes can be come highly distorted or require many remeshing/remapping steps that can lead to loss of accuracy.

The governing equations in the fluid and solid domains are evolved in a partitioned approach. We solve the compressible Euler equations in the fluid domains using a high-order Godunov finite-volume scheme. We solve the linear elastodynamic equations in the solid domains using a second-order upwind scheme. We develop interface approximations based on the solution of a fluid-solid Riemann problem that results in a stable scheme even for the difficult case of *light* solids coupled to *heavy* fluids. This approximation, which extends the recent work of Banks and Sjögreen [1], seems to be the first-ever explicit, non-iterative, partitioned algorithm that over-comes the well-known added-mass instability for light solids. The FSI-DCG approach is verified for three problems with known solutions, an elastic-piston problem, the superseismic shock problem and a deforming diffuser. The overall FSI-DCG scheme is shown to be second-order accurate in the max-norm for smooth solutions.

References

[1] J. W. Banks, B. Sjögreen, A normal mode stability analysis of numerical interface conditions for fluid/structure interaction, Commun. Comput. Phys. 10 (2) (2011) 279–304.