Sharp Treatment of Multi-Material Interfaces in Fluid Dynamics

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ABSTRACT

A new method for high-order front evolution and sharp treatment of interfacial jump conditions on arbitrary meshes is introduced. Our interface tracking method is a hybrid of a Lagrangian marker tracking with a Discontinuous Galerkin projection based level set re-distancing. This Marker-Re-Distancing (MRD) method [1] is designed to work accurately and robustly on unstructured, generally highly distorted meshes, necessitated by applications within ALE-based hydro-codes. Since no PDE is solved for re-distancing, the method does not have stability time step restrictions, which is particularly useful in combination with AMR, used here to efficiently resolve fine interface features. The MRD is coupled with high-order reconstructed Discontinuous Galerkin fully-implicit all-speed fluid dynamics solver [2], using IMEX time discretization scheme ($ESDIRK_{3,4,5}$). We introduced a new sharp treatment of mix elements, which reconstructs multiple-per-element solution fields (one for each material present in the mix element). Reconstruction incorporates interfacial jump conditions, which are enforced in the least-squares sense at the interfacial marker positions provided by MRD. This "physics-based" reconstruction is designed to work with generally non-linear interfacial jump conditions, as occur in applications with temperature-dependent material properties and shock dynamics. The non-linear least-squares reconstructions are formulated in the narrow-band of interfacial elements, and solved with inexact Newton method. Since no explicit differentiation across the interface is involved in the assembly of residuals for mass, momentum and energy equations, the method is capable of capturing discontinuous solutions at multi-material interfaces with high order, and without Gibbs oscillations. Also, the method is conservative for mixture mass, momentum and energy, in difference to other known sharp interface methods, like GFM. The method performance is demonstrated on a number of numerical tests, including manufactured, well-known benchmarks, and several phase-change fluid dynamics problems relevant to the selective laser melting (SLM) applications.

REFERENCES

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