Proceedings of the 7th World Congress on Momentum, Heat and Mass Transfer (MHMT'22)
~~Lisbon, Portugal~~ Virtual Conference – April 07 – 09, 2022
Paper No. ICMFHT 130
DOI: 10.11159/icmfht22.130

Improvements on a Direct-ALE Scheme for Multiphase Flows with Thermodynamic Consistency

Vazquez-Gonzalez Thibaud[1]
[1]CEA, DAM/DIF, Arpajon Cedex, F-91297, France
thibaud.vazquez-gonzalez@cea.fr

Extended Abstract

In some highly demanding CFD simulations, it appears necessary to simulate multiphase flows involving numerous constraints at the same time, such as: large number of fluids, both isentropic and shocked compressible evolution, large heat sources, large deformations, transport over long distances, and highly contrasted equation of state stiffnesses. Fulfilling such a challenge in a robust and tractable way demands that thermodynamic consistency of the numerical scheme be carefully ensured [1]. This is adresses here over an Arbitrary Lagrangian Eulerian (or ALE) numerical scheme obtain by a three-step mimicking derivation [2]: i) to ensure a compatible exchange between kinetic and internal energies under isentropic conditions, a variational least action principle is used to generate the proper pressure forces in the momentum evolution equations, ii) to generate the conservative internal energy equation, a tally is performed to match the kinetic energy, and iii) artificial dissipation is added to ensure shock stability, but other physical terms could also be added (drag forces, heat exchange, gravity, etc.).

The resulting numerical scheme called GEECS (Geometry, Energy, and Entropy Compatible Scheme) involves the following features [4]: i) full conservation of mass, momentum and total energy at discrete level, ii) direct ALE formalism where mass, momentum and energy fluxes are taken into account directly into the discrete evolution equations without remapping procedures, iii) thermodynamic consistency of the pressure work obtained by application of a variational principle, and iv) pressure equilibrium through a simple and local procedure. Multiphase test cases performed in two-dimensions and using various strenuous grid motion strategies confirm the following properties : i) exact conservation at discrete level, ii) robust multi-material like behavior with small residual volume fractions, iii) stable multiphase behavior where each fluid has its own velocity in order to obtain drifting between fluids, and iv) versatility regarding grid motions (including supersonic shearing, linear interpolation of contact discontinuity, or randomly distorted mesh).

GEECS represents a proof of concept and a starting point for the application of mimetic ALE schemes for the simulation of multiphase flows, and as such only use a first order advection step using a rudimentary upwind scheme. In the present work, a simple yet effective second order extension is carried out using a MOOD technique (Multidimensional Optimal Order Detection) [4] for ensuring accurate and robust results at second order both in the Eulerian limit (when the mesh grid is fixed) and in the Lagrangian limit (when the mesh grid follow fluid motions).

References

[1] T. Vazquez-Gonzalez, A. Llor, C. Fochesato, "Ransom test results from various two-fluid schemes: is enforcing hyperbolicity a thermodynamically consistent option?" in *Internation Journal of Multiphase Flows*, 2016, vol. 81.

[2] T. Vazquez-Gonzalez, A. Llor, C. Fochesato, "A novel GEEC (Geometry, Energy, and Entropy Compatible) procedure applied to a staggered direct-ALE scheme for hydrodynamics" in *European Journal of Mechanics B Fluids*, 2017, vol. 65.

[3] T. Vazquez-Gonzalez, A. Llor, C. Fochesato, "A mimetic numerical scheme for multi-fluid flows with thermodynamic and geometric compatibility on an arbitrarily moving grid" in *Internation Journal of Multiphase Flows*, 2020, vol. 132.

[4] S. Clain, S. Diot, R. Loubère, "A high-order finite volume method for hyperbolic systems : Multi-dimensional Optimal Order Detection (MOOD)" in *Journal of Computational Physics*, 2011, vol. 230.