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A Front Tracking Method for the Simulation of Compressible Multimedium Flows

Haitian Lu[1], Ning Zhao[1,*] and Donghong Wang[2]

[1] *College of Aerospace Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu 210016, P.R. China.*
[2] *College of Science, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu 210016, P.R. China.*

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Abstract. A front tracking method combined with the real ghost fluid method (RGFM) is proposed for simulations of fluid interfaces in two-dimensional compressible flows. In this paper the Riemann problem is constructed along the normal direction of interface and the corresponding Riemann solutions are used to track fluid interfaces. The interface boundary conditions are defined by the RGFM, and the fluid interfaces are explicitly tracked by several connected marker points. The Riemann solutions are also used directly to update the flow states on both sides of the interface in the RGFM. In order to validate the accuracy and capacity of the new method, extensive numerical tests including the bubble advection, the Sod tube, the shock-bubble interaction, the Richtmyer-Meshkov instability and the gas-water interface, are simulated by using the Euler equations. The computational results are also compared with earlier computational studies and it shows good agreements including the compressible gas-water system with large density differences.

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1 Introduction

The dynamics of multimedium flow has become a research hotspot nowadays for its significant applications in many engineering fields. The investigation of the multimedium

*Corresponding author. *Email addresses:* `lhtgkzy@126.com` (H. Lu), `zhaoam@nuaa.edu.cn` (N. Zhao), `wangdonghong@nuaa.edu.cn` (D. Wang)

flow behaviors in the micro- and nanochannels [25], for example, can be applied to colloidal and interfacial systems, such as bioassays, microreactors, emulsification and encapsulation, etc.

As for the computation of multimedium flows, a relatively dominant part is the treatment of moving material interface and its vicinity. Among the numerical simulations used to compute the contact discontinuities based on Euler framework, two basic approaches may be distinguished. One is the shock capturing method and the other is the front tracking method. Early algorithms have treated the material interfaces with the γ-based model [14], the mass fraction model [1, 15], the volume of fluid [2] or a level set function [19, 21]. These algorithms, based on shock capturing methods, always yield a numerical diffusion of contact discontinuities over several nodes. However, for the front tracking method [8–10], fluid interfaces are explicitly tracked by connected marker points and a sharp interface boundary is maintained during the computation. In this method, a Riemann problem is constructed near the fluid interfaces to handle the sharp jump across the interface. Similar idea based on Riemann solutions can also be found in the study of Cocchi et al. [5]. In their algorithm, a Riemann problem is solved at material interfaces in the corrector step and the Riemann solutions are used to correct the results from the predictor step which generally generates spurious oscillations or numerical diffusion. The method proposed by Tryggvason et al. [28] is in fact a hybrid between front capturing and front tracking since a stationary regular grid is used for fluid flow and the interface is tracked by a separate grid of lower dimension.

The basic ideas of ghost nodes have more recently been used in the ghost fluid method (GFM) introduced by Fedkiw et al. [4, 6, 7]. In the GFM, the discontinuous physical variables, such as entropy, are extrapolated across the interface which can efficiently prevent pressure oscillations and reduce smearing of discontinuous variables. The GFM is robust and can easily handle fluids with different material properties. However, when the pressure or the velocity experiences a large gradient across the interface, the GFM cannot work well. Indeed, the ghost fluid states should consider the influence of both wave interaction and material properties on the interfacial evolution. This leads to the proposal of improved versions of GFM, for example, the modified ghost fluid method (MGFM) and the real ghost fluid method (RGFM). In the MGFM, Riemann problem is defined and solved approximately to predict interface states [17, 18]. The predicted interfacial states are then used to define the ghost fluid states. The RGFM described in [30] further predicts the flow states for the real fluid nodes just next to the interface because wave interaction at the interface can propagate upward and downward simultaneously. The RGFM enables a better imposition of interface boundary conditions and less conservative errors, especially for those critical problems of shock impendence matching.

The purpose of this paper is to simulate the multimedium flows in a more accurate and simple way. As is well known, the way to track the interface and define the interface boundary conditions plays the critical role in the numerical simulations. With legitimate concerns over these factors, we combine a front tracking method with RGFM (RGFM-FT) in this paper. Unlike the front tracking method in [29] where the marker points are