High-resolution Capturing of the interaction of Shock Wave with a Helium Bubble

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ABSTRACT

In this study, a robust MUSCL type AUSMD [1] along a approximated Riemann solver along with the Tangent of Hyperbola for Interface Capturing (THINC) [2] technique to reconstruct the solution function for both smooth profile and discontinuity. The two-fluid model of the reduced five equations in [3] is regarded as a model equation. This test case show the MUSCLwith THINC idea allows us to achieve the sharp capturing of the evolution of interfaces and shock-bubble interactions and demonstrate less numerical dissipations than the original MUSCL scheme did.

1. Introduction

Multi-fluid flows often feature interactions between shock waves and bubbles related to cavitation. Providing suitable dissipation to avoid spurious oscillations associated with capturing shocks and sharp interfaces is the challenge in high resolution solution of multiphase flows. The interface is allowed to diffuse on a small number of computational cells and a mixture model is given for this transition region. The conservation equations for the mass of each fluid and for the total momentum and energy of the mixture and an advection equation for the volume fraction of one of the two fluids is written by Allaire [4]. Using a higher-order spatial interpolation than previously used, which allows for a steeper representation of discontinuities, particularly contact discontinuities. Evaluating several approaches for sharp phase interface-capturing is for computations of multi-phase mixture flows. Attention is focused on algebraic interface-capturing strategies that fit directly within a finite-volume MUSCL-type framework. Boundary variation diminishing reconstructions that minimize the discontinuities (jumps) at cell interfaces in Godunov type schemes is motivated by the observation that diminishing the jump at the cell boundary can effectively reduce the dissipation in numerical flux. Benchmark tests are two-phase gas-liquid shock tube and Mach 1.22 shock wave + Helium bubble.

2. Numerical Methodology

To consider the multi-component flow equations, the reduced five equation model proposed by Allaire [4] is used. The interface between two fluids is represented by the discontinuity in the properties, and of the different fluid components. This volume-fraction function would be updated in each time step by solving an evolution equation of the form. For the sake of simplicity, we introduce the MUSCL with THINC reconstruction scheme to achieve the sharp interface of multi-component flows problems

3. Numerical results

Following the work of Shyue [3], a two-phase gas-liquid Sod's problem involving gas and liquid phases separated by an interface is solved. This is a simplification of the underwater explosion problem in a spherically symmetric geometry. This test includes the multiple interactions of strong shock waves, density discontinuities and rarefaction waves. The common problem to nearly all existing shock-capturing schemes is the overly smeared density discontinuities in the numerical solutions. In Figure1, we can find the numerical solutions of MUSCL+THINC in two phase flow problems, resolve discontinuous solutions with less numerical dissipation effect.

Next, we consider a well-studied shock-bubble interaction problem that involves the collision of a shock wave in air with a circular helium gas bubble. We note that this gives us one example that the (Helium) material interface is accelerated by a shock wave coming from the heavy-fluid to the light-fluid region, and the intricate interaction of the incident, transmitted, and reflected shocks with the accompanied expansion fan is clearly seen in Figure 2.. When shock wave impacts Helium gas bubble, the current scheme can achieve sharp resolution of the material interfaces; it resolves better resolution of instability on latter revolution of bubble interface.

4. Conclusion

In this paper, we implement MUSCL-THINC scheme to simulate compressible multiphase flows by solving the five-equation model. This scheme can resolve discontinuous solutions with much less numerical dissipation. By treating interface as another contact discontinuity rather than implementing interface-sharping techniques explicitly, the new scheme can realize thermos-dynamical-consistent reconstruction straightforwardly. The results of test cases show a remarkable improvement in the solution quality to the problems of interest. Compared with the high-order shock-capturing schemes, the new scheme shows competitive or even better numerical results but with less computational cost. This work provides an effective but simple approach to simulate compressible interfacial multiphase flows.

References

[1] Y.Y. Niu, *Journal of Computational Physics*, 308(2016), 389－410.

[2] Z. Sun, S. Inaba, F. Xiao, *Journal of Computational*

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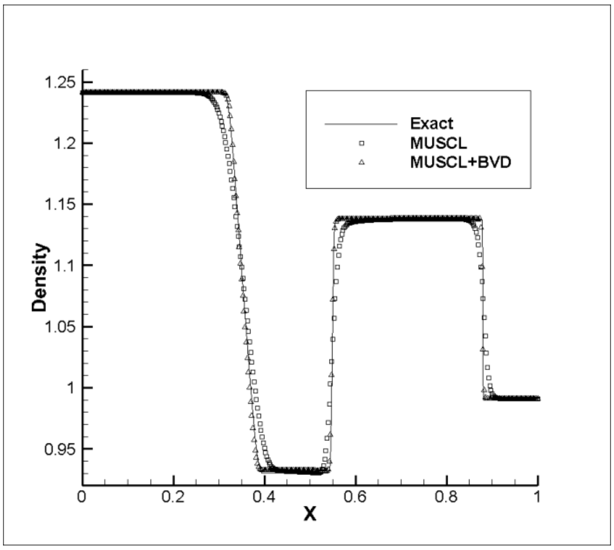
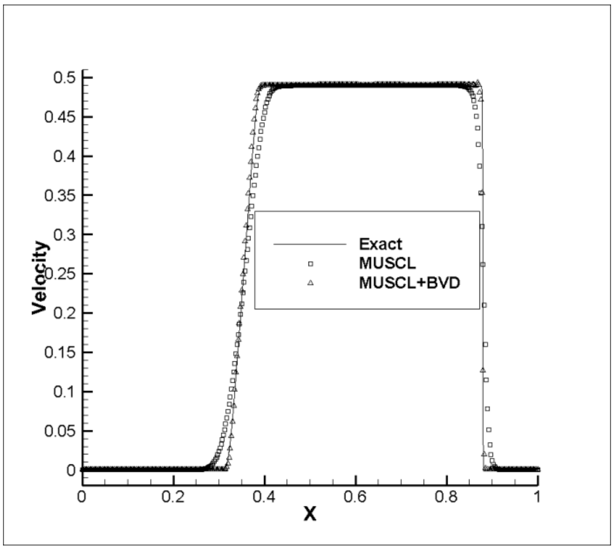
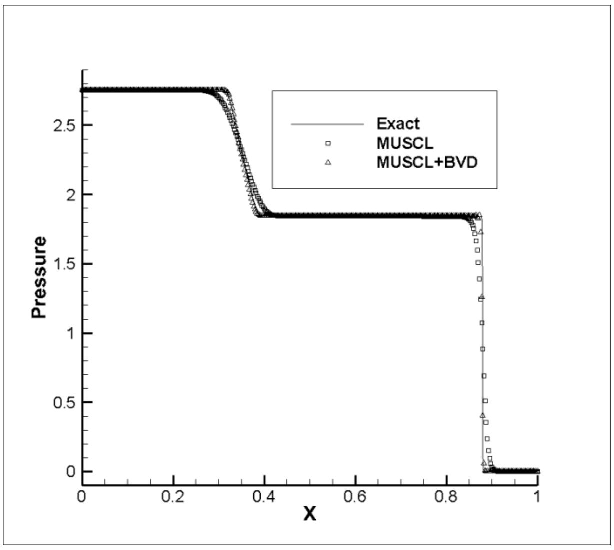
Physics, 332(2016), 309—325.
[3] K.M. Shyue, *Journal of Computational Physics*, 142 (1998), 208—242.
[4] G. Allaire, S. Clerc, S. Kokh, *Journal of Computational Physics*, 181(2002), 577—616.2002.



(a)



(b)



(c)

Fig. 1 Numerical solutions of the (a) density, (b) velocity and (c) pressure in the two-phase gas-liquid shock tube problem based on ASUMD at time t = 0.1 with 400 mesh points.

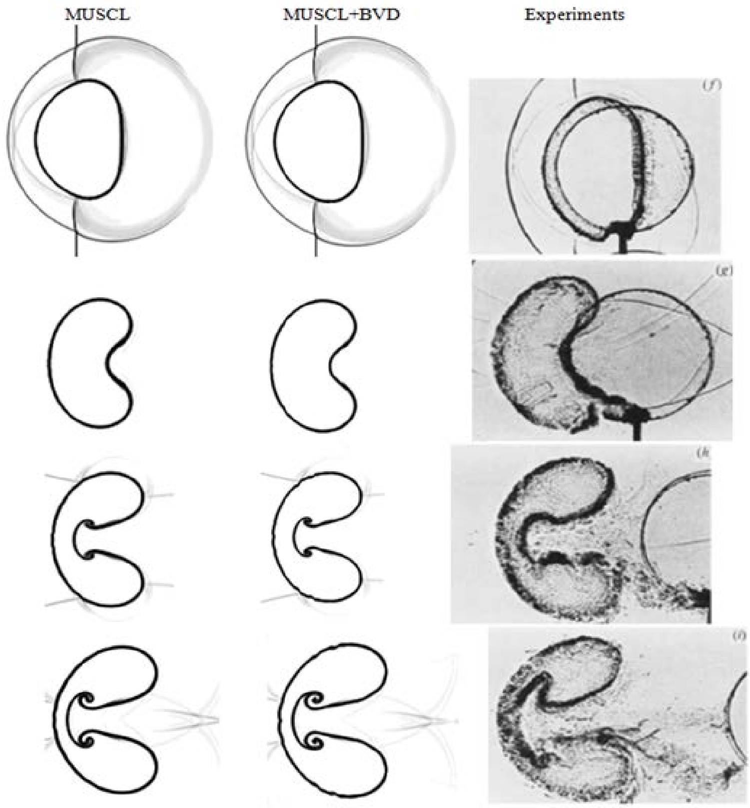


Fig. 2 Comparison between Schlieren plots from experiments (right) and numerical results (f) t = 102 μs , (g) t = 245 μs , (h) t = 427 μs , (i) t = 674 μs .