Amirkabir University of Technology
(Tehran Polytechnic)
Vol. 45, No.1, Summer 2013, pp. 1-3

Amirkabir Journal of Science & Research (Mechanical Engineering)
(AJSR - ME)

Two Dimensional Numerical Simulation of Shock-Bubble Interaction in Compressible Two-Phase Flows

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(Received 4 Jul 2011; Accepted 13 Nov 2012)

ABSTRACT

The main objective of this paper is the accurate interface capturing and study on the shock-bubble interaction in gas-gas and gas-liquid two-phase flows. For this aim, the HLLC Riemann solver and Godunov numerical method were used for the first time for the 5-equation Kapila model. Transient shock wave interaction with Helium-Air and Air-Water bubbles were simulated. Numerical results were compared with available experimental results. The results have excellent agreement with experimental and previous published numerical results obtained by methods that are more sophisticated. Results show that the present method is able to capture transient shock waves and materials discontinuities and interfaces instabilities accurately and without any diffusion and oscillation**.**

KEYWORDS

Two-Phase Flows, Compressible, Shock Wave, Godunov Numerical Method, Interface

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1- INTRODUCTION

Numerical simulation of multiphase or multi-component flow is a challenging subject with many applications in industry and in modeling natural phenomena. The models and numerical simulations presented in the recent literature present different levels of accuracy and complexity. In general, these types of methods can be separated into two categories by how each considers the interfaces:

Sharp interface method (SIM)

Diffuse interface method (DIM)

In the sharp interface methods, special effort is made to find the right location of the interface and to treat the interface explicitly. In the second group of numerical methods, DIM, the interface is modeled as a numerically diffused zone (area), which is similar to capturing a discontinuity in gas dynamics. In fact, it can be mentioned that this type of diffused interface is a kind of artificial diffusion that is created by numerical calculations.

One model that is based on diffuse interface is also known as the Kapila model [1, 2]. This model consists of two mass conservation equations, one momentum conservation equation, one energy conservation equation in the conservative form and one volume fraction advection equation in the non-conservative form.

The main objective of the present work is toaccurately simulate two-phase gas-gas and gas-liquid interfacial problems with less computational cost by using reduced five-equation models. In this study, the HLLC Riemann solver is used for numerical simulation of compressible two-phase flow.

2- TWO-FLUID MODEL AND NUMERICAL METHOD

The single speed, equal pressure, five-equation model is also known as this model, with the exclusion of heat and mass transfer as follows:

$$\frac{\partial \alpha}{\partial t} + \vec{u}.\vec{\nabla}\alpha = 0 \tag{1a}$$

$$\frac{\partial(\alpha_1\rho_1)}{\partial t} + \nabla.(\rho_1\alpha_1\vec{u}) = 0 \tag{1b}$$

$$\frac{\partial(\alpha_2\rho_2)}{\partial t} + \nabla.(\rho_2\alpha_2\vec{u}) = 0 \tag{1c}$$

$$\frac{\partial(\rho\vec{u})}{\partial t} + \nabla.(\rho\vec{v}\otimes\vec{u}) + \vec{\nabla}P = 0 \tag{1d}$$

$$\frac{\partial(\rho E)}{\partial t} + \nabla.((\rho E + P)\vec{u}) = 0 \tag{1e}$$

Where α, ρ, u, P, E, e are the volume fraction, density, velocity, pressure, total energy and internal energy, respectively.

In the present work, the stiffened-gas equation of state (SGS) is used. In this article, the Godunov numerical method was applied using the HLLC Riemann solver [3]. To achieve the second-order accuracy, the MUSCL method was used [3]. This method is conducted in three steps, which include data reconstruction, evolution and solving the Riemann problem. A structured grid is used in the present work

3- RESULTS

Three standard test cases that include an interface were considered in this article:

- Shock and helium bubble interaction, (fig (1)).
- Shock and air bubble interaction, (fig (2)).

As can be seen from Fig. 3, the numerical results obtained in this attempt exhibit very good agreement with experimental results.

4- CONCLUSIONS

A simple methodology based on the Godunov numerical method and the HLLC Riemann solver is applied with second-order accuracy to simulate compressible transient one- and two-dimensional two-phase flows in the presence of a shock wave. This numerical method, which is a subset of the diffuse interface method, uses a constant computational grid that is simple and easy to apply. The numerical results of 2D simulations were accurate with no numerical oscillation. The results are in good agreement with experimental results and previous numerical results obtained by more sophisticated numerical methods.

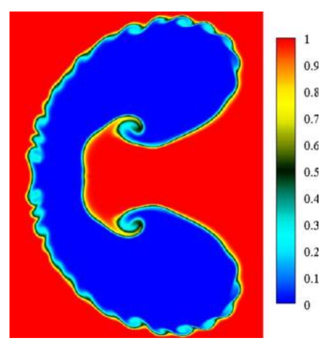

Fig. 1. Time evolution of the void fraction for the shock with M=1.22 and helium bubble interaction at t=432 μs.

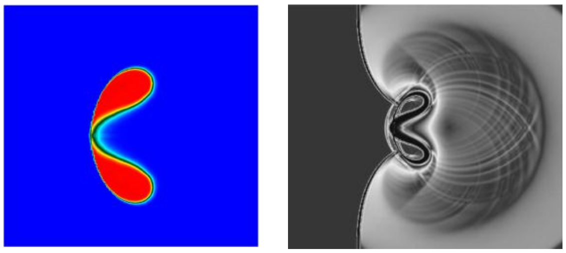

Fig. 2. Numerical results of the shock wave and water/air bubble interaction. Left: Contours of void fractions, Right: Numerical Schlieren-type results at t= 7.0 μsec,

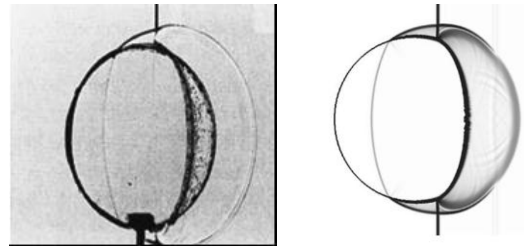

Fig. 3. Shock and air/helium bubble interaction. Left: shadow-photographs of Haas and Sturtevant (1987), Right: Numerical Schlieren-type results at t= 52 μsec,

5- REFRENCES

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