# 1320 レーザー誘起気泡と衝撃波に関する数値模擬

孫 明宇（東北大），小松 真（岩手医科大），齋藤 務（室蘭工大），高山和喜（東北大）

# Numerical simulation of laser-induced bubble and shock wave: Part 1, Construction of the conservative front capturing method for compressible multi-fluids

M. Sun, M. Komazu, T. Saito and K. Takayama

## Abstract

This paper reports our progress in the development of a numerical method to simulate the hydrodynamic phenomenon induced by a focused laser beam in water. As the first step, the present work is to construct a general conservative front capturing method for multi-fluids. The idea is to evaluate numerical fluxes on a fixed mesh but taking into account the interaction between the material interface in the cell and the waves initiated from cell interface. A 1-D dimensional numerical test is reported.

## Introduction

Numerical simulation of interfacial phenomenon between two compressible immiscible multi-fluids imposes a great challenge for researchers. For a fixed mesh, an interface generally stays in a mesh cell or a control volume because of its arbitrary shape and motion. There are mainly two approaches to solve the problem. One approach is to move the neighborhood grid points to the interface, and then the interfacial problem can be divided to two single phases with an interface moving the grid line, known as the front tracking method, e.g. Ball et al. (2000). It is not easy for a front tracking method to generate a mesh for an interface with topological change during its evolution. Another approach, giving up tracking the interface exactly, is to approximate the interface location by a scalar function that is solved independently. The level set method (Osher & Fedkiw, 2001) is probably the most popular one within this category. The method was extended to compressible flows by Fedkiw et al. (1999) by the so-called ghost fluid method. Recently, Liu et al. (2003) reported that the original ghost fluid method fails to accurately solve the problem of strong shock impacting on a material interface, and devised a modification by considering the wave interaction at the interface. A drawback of the level set method is that it may violate the conservation laws, because the advection of the set function is solved separately from the flow solver.

The lack of conservation may lead to a misprediction of wave location. In the problem of laser-induced underwater bubble formation, the bubble is started from a tiny nucleus, and its growth and collapse are governed by the mass and energy transfer through the interface and its thermal and hydrodynamic states inside. The conservation of mass and energy are expected to be essential in the process. Therefore, a new numerical technique that can treat the material interface while maintaining the conservation laws is required for such a problem. The present method follows the Godunov-type scheme that assumes a Riemann problem between two control volumes. The key idea of the present method is to incorporate the interaction with the interface in solving the Riemann problem.

## Approximate Riemann solver including a material interface in the neighborhood

In the Godunov method, the variables are taken as constant in each control volume, and they are evolved in time according to the net numerical fluxes through the neighboring faces. The numerical fluxes through each face are determined by solving a Riemann problem, or a Riemann solver. This approach has been successfully applied to a variety of problems with a single phase, or multi-phases with similar acoustic impedance.

The Riemann solver can be exact, or approximate. In either case, assuming two constant states on left and right sides, the solver can neglect any waves from the neighborhood before they arrives or if the Courant number is less than one. However, if there is an interface separating two phases with disparate acoustic impedances in the neighborhood, the wave interaction with the interface cannot be neglected. For the Riemann solver that neglects the interaction, the Courant number has to be limited by the arrival of the reflected wave from the interface. A sketch is shown in Fig. 1*a*. When the reflected wave arrives, denoted by *b,* is related to the distance from face O, where the Riemann problem is solved, to interface *i.* Since the interface can be anywhere in a cell, the Courant number can be limited to an unacceptable value.

In the present approach, the wave reflection from the interface is taken into account. The numerical fluxes are a sum of fluxes over time at $x=0$. An approximate two-wave system is constructed at the beginning, and then a three-wave system is considered at the inner interface. The motion of the interface is also coupled with the Riemann solver. According to the flow conditions at *O*, there are four cases for subsonic flows, two of them are shown in Fig.1, four cases for right supersonic flows. The treatment for left supersonic cases is not very clear, and can be most difficult. A difficulty encountered is how to get an equilibrium state for a cell having an interface inside, or how to force flow quantities of the cell satisfying the compatible conditions, i.e. pressure and normal velocity difference should be zero. The equilibrium state is required to avoid the complicated wave system starting from the interface.

Figure 2 gives a preliminary result of a shock tube problem. The contact region is sharply resolved.

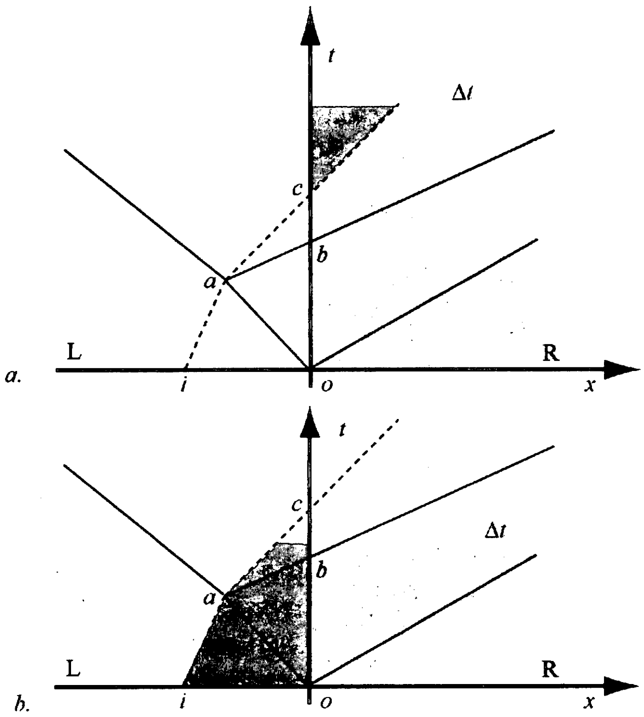


Fig. 1 Wave system for the Riemann solver

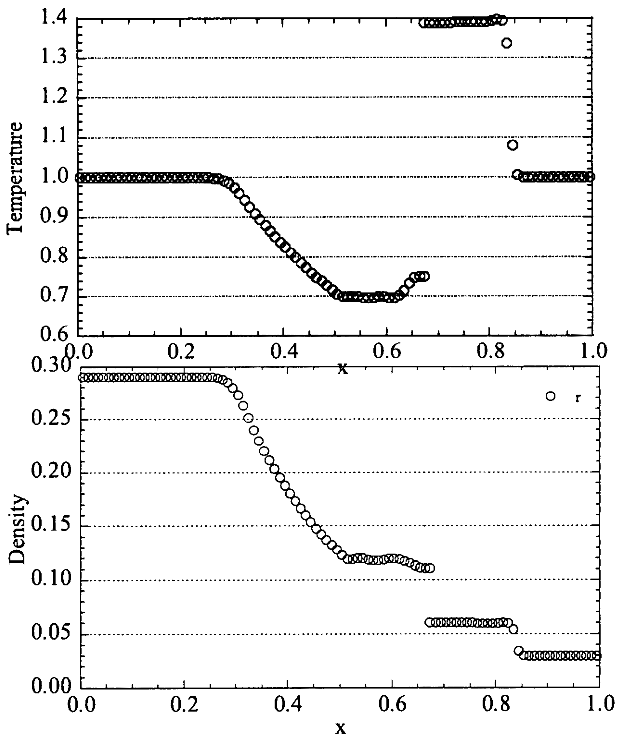


Fig. 2 Numerical result or a shock tube problem

## References

[1] Ball GJ, Howell BP, Leighton TG, Schofield MJ (2000) Shock-induced collapse of a cylindrical air cavity in water: a Free-Lagrange simulation, Shock Waves, 10: 265-276

[2] Osher S, Fedkiw RP (2001) Level set methods: An overview and some recent results, J. Comp. Phys., V169: 463-502

[3] Fedkiw RP, Aslam T, Merrimann B, Osher S (1999) A non-oscillatory Eulerian approach to interfaces in multimaterial flows (the Ghost Fluid Method), J. Comp. Phys, V152: 457-492

[4] Liu TG, Khoo BC, Yeo KS (2003) Ghost fluid method for strong shock impacting on material interface, J. Comp. Phys. V190: 651-681

[5] Toro EF (1999) Riemann solvers and numerical methods for fluid dynamics, second ed., Springer, Berlin