MULTI-MATERIAL EULERIAN METHOD AND ITS LARGE-SCALE COMPUTATION FOR 3D EXPLOSION AND SHOCK PROBLEMS

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Summary A multi-material Eulerian hydrodynamic numerical method that can effectively simulate 3D explosion and shock problems in engineering practice was developed in this study. The fuzzy interface treatment method was proposed for the mixed cells. The data dependency in the parallel algorithm of the multi-material Eulerian hydrodynamic numerical method was studied in order to simulate the large-scale engineering problems. As a test, the three dimensional numerical simulation of the formation of the shaped charge jet was performed. The numerical results are in good agreement with the experimental results, indicating that the proposed numerical method and parallel algorithm are valid.

INTRODUCTION

Eulerian method is very useful in simulating the flows with large distortions such as explosion and shock problems, because it use a fixed mesh and can eliminate the problems associated with a distorted mesh that are commonly encountered with a Lagrangian method [1]. Owing primarily to the limited processing speed and relatively small size of the local memory and storage in single computers, parallel computing is an indispensable technique for running large-scale simulations, which may arise from a combination of many millions of cells and many thousands of time steps, especially in the fields such as computing hydrodynamics, bioinformatics, and meteorology. This paper will focus on the Eulerian method, which is used to simulate explosion and shock issue. Operator splitting method was adopted to solve governing equations. For the difficulty of treating the three-dimensional multi-material interface, a fuzzy interface method was presented. Two key issues of the parallel algorithm of the Eulerian method were studied. As a test, the three dimensional numerical simulation of the formation of the shaped charge jet was performed.

NUMERICAL METHODS

Opeator splitting method

The Eulerian equations neglecting viscosity and heat conduction were used as the governing equations [2], which can be represened by a general form:

$$\frac{\partial \boldsymbol{\varphi}}{\partial t} + \boldsymbol{u}\cdot\nabla\boldsymbol{\varphi} = \boldsymbol{H} \tag{1}$$

where $\boldsymbol{\varphi}$ is a solution variable, and $\boldsymbol{H}$ is the source term.

In this study, the operator splitting method was adopted, by which Eq. (1) can be rewritten as follows

$$\frac{\partial \boldsymbol{\varphi}}{\partial t} = \boldsymbol{H} \tag{2}$$

$$\frac{\partial \boldsymbol{\varphi}}{\partial t} + \boldsymbol{u}\cdot\nabla\boldsymbol{\varphi} = 0 \tag{3}$$

Here Eq. (2) and Eq. (3) are called the 'Lagrangian' phase and the 'Eulerian' phase, respectively.

In the Lagrangian phase, the changes of the velocity and internal energy caused by the pressure and deviatoric stresses are calculated, and the cell is allowed to distort along with the material. The Eq. (2) is updated using a first order finite difference scheme, and the changes in three directions are calculated simultaneously by

$$\tilde{\boldsymbol{\varphi}}^{n+1} = \boldsymbol{\varphi}^{n} + \frac{\Delta t}{\Delta x}\left(\boldsymbol{H}^{n}_{i+1/2,j,k} - \boldsymbol{H}^{n}_{i-1/2,j,k}\right) + \frac{\Delta t}{\Delta y}\left(\boldsymbol{H}^{n}_{i,j+1/2,k} - \boldsymbol{H}^{n}_{i,j-1/2,k}\right) + \frac{\Delta t}{\Delta z}\left(\boldsymbol{H}^{n}_{i,j,k+1/2} - \boldsymbol{H}^{n}_{i,j,k-1/2}\right) \tag{4}$$

In the Eulerian phase (advection phase), the mass, energy and momentum transport across the cell edges are calculated.

Three-dimensional multi-material interface method

How to determine the multi-material interface and how to calculate the physical quantities in the mixed cells are the difficulties of three-dimensional multi-material Eulerian method. Many interface reconstruction methods, such as volume-of-fluid (VOF) methods, piecewise linear interface construction (PLIC) methods and level-set methods has been developed, but it is hard to extend these methods to handle the mixed cells with three or more materials to 3D case. In this paper, the fuzzy interface method was proposed [3]. In this method, the multi-material interface is not determined, and the volume ratio of materials is considered as fuzzy weight coefficient, by which transport quantities is determined. Meanwhile, the transport order is made by the priority. Fuzzy interface treatment methods can easy treat mixed cells involving three or more materials in 3D case, and the computational cost is low. Although the interface may

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become fuzzy after many time steps, parallel computing can overcome this disadvantage by increasing amount of cells and reducing cell size.

Key issues of the parallel algorithm of Eulerian method

In the Eulerian method, the cells are fixed, and materials transport among cells. The material interfaces must be determined and the quantities of transport between adjacent cells also must be calculated by the transport algorithm. The change of physical quantities of current cell will change ones of adjacent cells. It is difficult to discover the data dependence in algorithms and the relevance between subdomains, and these two issues just exist in Eulerian phase, which are key issues and difficulties of parallel realization.

NNUMERICAL TESTS

To test the resolution of the interface treatment algorithm proposed here, the formation of the shaped charge jet was investigated. In this case, the cone angle of the liner is 60°; the liner thickness is 2.4mm; the charge height is 33.2mm, and the charge diameter is 60.0mm. Point initiation was chosen as the way of initiation, and a simple combustion model was used to simulate the propagation process of detonation wave.

In this study, Pulse X-ray photography was used to observe the formation of the shaped charge jet, and to measure the velocity and diameter of the jet tip. The figure gained by Pulse X-ray photography was presented in Fig.1(a), and the numerical results were presented in Fig.1 (b). It can be concluded that the results of numerical simulation are agreement with the experimental one. Because of simple combustion model used, the length of jet at 25.5μs is shorter than experimental one. From these images, it can be seen that the interface among detonation product, metal and air is very clear, which shows that multi-material interface method used in this paper is effective.

For studying the effect of the angle of linear on jet performance, a group of numerical examples with different cone angles were designed. Geometric structure, computational domain and material properties are the same as above, and the cone angles of the liner were 60˚ 70˚, 80˚, 90˚, and 120˚, respectively. The tip velocity distribution along time was presented in Fig.2. It can be concluded that cone angle has great effect on jet performance. Under the same condition, the jet with a small angle is slenderer with high velocity, and the one with a large angle is shorter with low velocity.

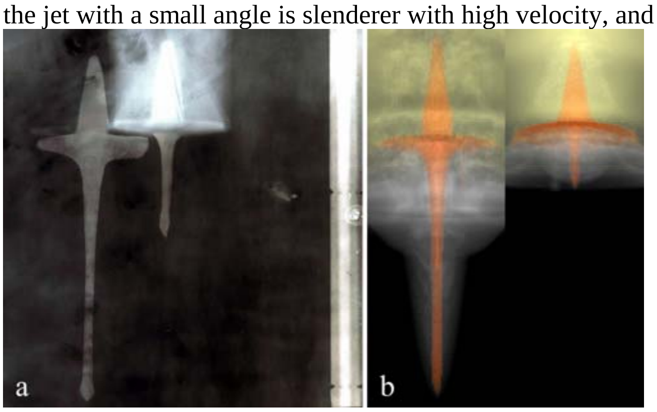

Fig.1 Numerical results vs. experimental results

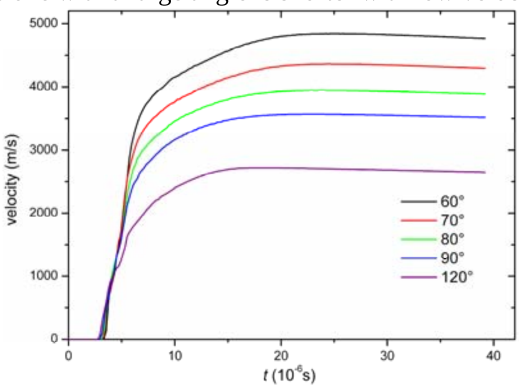

Fig.2 Velocity distribution of the jet tip versus time

CONCLUSIONS

(1) For the difficulty of three-dimensional multi-material interface method, a fuzzy interface treatment method was presented. From the result of shaped charge jet, the interface among detonation product, metal and air is very clear, which shows that the fuzzy interface method is effective.

(2) Two key issues of the parallel algorithm of the multi-material Eulerian method were studied in order to simulate the large-scale engineering problems.

References

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