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Two-fluid plasma numerical analysis of the interfacial instability induced by a collision-less shock wave
無衝突衝撃波によって誘起される界面不安定の二流体プラズマ数値解析

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The interactions between a collision-less shock wave and an isolated cylindrical bubble are investigated by solving the two-fluid equations. A second-order Riemann solver is employed to sharply capture the shock wave and the contact discontinuity. As a result, filamentation driven by the electron precursor introduces the turbulence in the plasma ahead of the shock wave.

1. Introduction

Fluid dynamical instability is one of the major mechanisms for building up the turbulence in plasma. The interactions between a shock wave and an isolated bubble, so-called the shock-bubble interactions have been studied so far with the aim of understanding the compressible turbulence in neutral gas. [1] For plasmas, the effects of the magnetic field on the deformation of a plane density discontinuity are investigated using the magneto hydrodynamic (MHD) simulation code. [2] Because the quasi charge neutrality is presumed in the MHD equations, the shock wave in un-magnetized plasma is not different from that in neutral gases within the MHD formalism. The present study deals with the shock-bubble interaction problems in un-magnetized and collision-less plasma in order to understand the shock compression in high-temperature plasma and relevant instability problems. The space-charge will play a fundamental role. Recently, Shumulak and Loverich solved the one-dimensional Riemann problem using a full system of two-fluid model of collision-less plasma. [3] Similar methods are employed in the present study.

2. Method

Two-fluid equations of collision-less plasmas are formulated in a normalized form. Here, the subscript *s* represents the species either electron (= *e*) or ion (= *i*). We have four conservation laws for each species. Nine equations including the Poisson equation for the electrostatic field are solved.

The system of the fluid equations is solved in the conservation form using a finite volume Riemann solver developed by reference to the upwind method developed in the previous study. [3] The numerical fluxes are evaluated using the Roe scheme. [4] The space and time accuracy is enhanced to the second order by using the MUSCL-Hancock method. [5] The fluid solvers have been verified by solving the Sod problems and the shock-bubble interaction problem in the neutral gases. [6] The present fluid solver captures sharply a shock wave and contact discontinuity within a few cells. Moreover, the bubble deformation processes could be reproduced without adding special treatment to capture the bubble-atmosphere interface.　Major difficulties in solving the two-fluid equations are originated from integrating the stiff source terms. A nine-step composition-method was selected to avoid unphysical oscillations at moderate grid size.

The computations are conducted for a singly ionized atomic hydrogen gas. The mass ratio m_i/m_e is kept constant at 1836.0. The half domain is discretized with 512 × 64 cells. In the initial condition, the diaphragm and the bubble are located. The diaphragm separates the high-pressure-room (HPR) and the low-pressure-room (LPR). The initial values in the LPR are $(N_e, N_i, p_e, p_i) = (1.0, 1.0, 5.28\times10^{11}, 9.58\times10^{6})$. Both the electron and ion fluids are initially at rest in both rooms. The ratio of the electron temperature to the ion temperature T_e/T_i is set at 30.0 uniformly over the calculation domain for the initial condition so that typical shock profile is formed. Across the interface between the bubble and the surrounding plasma in LPR, the pressure is not changed but the gas density is changed. Both N_i and N_e inside of the bubble are 0.1.

3. Results

Figure 1 shows the density contour of the ions and electrons. Because the length scale is close to the Debye length, the charge neutrality is not always satisfied. Electron precursor leaches out of the shock front. Besides, the hot electrons contained in the bubble are spreading out diffusing into the surrounding plasma. Before the shock front reaches the bubble, the electrons at the upstream interface of the bubble are pushed downstream by the electron precursor. Moreover, fine filaments appear at the downstream interface of the bubble. At first, the filaments extend both in the longitudinal and the lateral directions. At later times, the filaments extend further only in the longitudinal direction. The interval between two adjacent filaments almost equals to the Debye length. The current driven by the potential gradient at the upstream interface of the bubble penetrates the bubble through the downstream interface breaking up into fine filaments. Filamentation observed in the other PIC simulation of the collision-less shock wave is though to be oriented from the two-stream instabilities. The mushroom shapes appear at one of the leading tips due to the Rayleigh-Taylor instability.

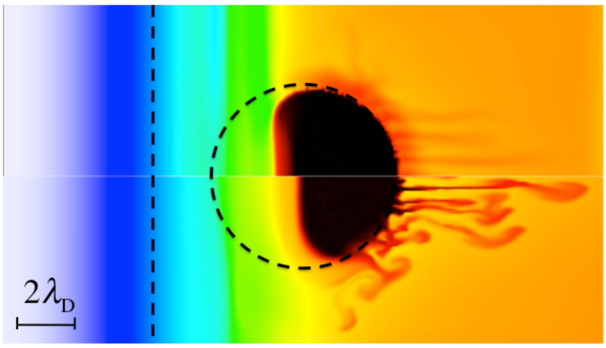

Fig.1 Filamentation from the bubble

4. summary

The shock-bubble interactions in un-magnetized and collision-less plasma are investigated. Filamentation driven by the electron precursor of the shock wave is observed. Baroclinic vortex generation is prevailed by the filamentation instability in the collision-less plasma.

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References

[1] D. Ranjan, J. Oakley, and R. Bonazza, "Shock-Bubble Interactions," Annu. Rev. Fluid Mech. **43**, 117 (2011).

[2] J.P.H. Goedbloed, R. Keppens, and S. Poedts, *Advanced Magnetohydrodynamics*, Cambridge University Press, Cambridge, 2010.

[3] U. Shumlak and J. Loverich, "Approximate Riemann solver for the two-fluid plasma model," J. Comput. Phys., **187**, 620 (2003)

[4] P.L. Roe, "Approximate Riemann Solvers, Parameter vectors, and Difference Scheme," J. Comput. Phys. **43**, 357 (1981).

[5] E.F. Toro, *Riemann Solvers and Numerical Methods for Fluid Dynamics*, Springer, Berlin, 2009

[6] K. Mori, "Blast-bubble interaction for a divergent case," to appear.