

Recent Progress of an Integrated Implosion Code and Modeling of Element Physics

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Abstract. Physics of the inertial fusion is based on a variety of elements such as compressible hydrodynamics, radiation transport, non-ideal equation of state, non-LTE atomic process, and relativistic laser plasma interaction. In addition, implosion process is not in stationary state and fluid dynamics, energy transport and instabilities should be solved simultaneously. In order to study such complex physics, an integrated implosion code including all physics important in the implosion process should be developed. The details of physics elements should be studied and the resultant numerical modeling should be installed in the integrated code so that the implosion can be simulated with available computer within realistic CPU time. Therefore, this task can be basically separated into two parts. One is to integrate all physics elements into a code, which is strongly related to the development of hydrodynamic equation solver. We have developed 2-D integrated implosion code which solves mass, momentum, electron energy, ion energy, equation of states, laser ray-trace, laser absorption radiation, surface tracing and so on. The reasonable results in simulating Rayleigh-Taylor instability and cylindrical implosion are obtained using this code. The other is code development on each element physics and verification of these codes. We had progress in developing a nonlocal electron transport code and 2 and 3 dimension radiation hydrodynamic code.

1. Introduction

Physics of the inertial confinement fusion is based on a variety of elements such as compressible hydrodynamics, radiation transport, non-ideal equation of state, non-LTE atomic process, and relativistic laser plasma interaction. In addition, implosion process is not in stationary state and fluid dynamics, energy transport and instabilities should be solved simultaneously. In order to study such complex physics, an integrated implosion code including all physics important in the implosion process should be developed. The details of physics elements should be studied and the resultant numerical modeling should be installed in the integrated code so that the implosion can be simulated with available computer within realistic CPU time. Therefore, this task can be basically separated into two parts.

One is to integrate all physics elements into a code, which is strongly related to the development of hydrodynamic equation solver. In the previous work, the integrated implosion code, ILESTA-2D[1] has been modified to be an implicit arbitrary Eulerian Lagrangian code (ALE) for the robustness and saving the computational time[2]. The most difficult problem was rezoning and remapping method in this ALE algorithm. An improvement of this method have been done to enable the code to clearly capture contact surface, ablation surface and shockwave, and successfully progressed. Nevertheless, the difficulty of the rezoning/remapping was still remained when we simulate complicated problem, such as non-linear Rayleigh-Taylor instability using the improved ILESTA-2D. Therefore, we applied the Cubic-Interpolated Pseudo-Particle(CIP)[3] method which has high-order accuracy in space and time. The feature of this new code is described in section 2.

The other is code development on each element physics and verification of these codes. We had progress in developing a nonlocal electron transport code and multi-dimension radiation hydro-

dynamic code. In this paper, we describe latest study on the nonlocal electron transport. Recent works showed that the nonlocal electron transport has important effects on the Rayleigh-Taylor instability in the laser implosion[4][5][6]. We developed the code that simulates the electron transport based on the Vlasov-Fokker-Planck equation. In this code, the electron distribution function is expanded into the zero-th and first order parts of Legendre polynomials, and they are solved at the same time. In this paper, outline of the hybrid code in which this nonlocal electron transport code is coupled onto ILESTA-1D and its simulation result is shown.

2. Integrated Implosion Code

2-1. Numerical Methods in Integrated Implosion Code

In the integrated implosion code, mass, momentum, electron energy, ion energy, equation of states, laser ray-trace, laser absorption, radiation transport, surface tracing and other related equations are solved simultaneously. The hydrodynamic solver is the most important and base algorithm. Because the scale ratio of the expanded plasma to the target shell thickness is extremely large, the implosion must be solved by Lagrangian coordinate to save the computational resources and to capture the large gradient values in the space phase clearly. Therefore, most of the ALE implosion codes are based on Lagrangian method in which the computational grids move along with the material. In general, computational grids are destroyed using the Lagrangian method. In order to continue the calculation stably, it requires the sophisticated and expensive rezoning/remapping algorithm. In case of complicated simulation, it needs graphical user interface for rezoning[7]. To avoid such problem, a simple hydrodynamic solver was developed using CIP method[3]. The CIP has some characteristics of Lagrangian method, though by fundamental formations are derived for Eulerian coordinate. To obtain pressure implicitly, we also applied C-CUP(CIP and Combined, unified procedure)[8], and this method enable to capture the ablation surface stably. This CIP method is applicable to track the materials.

2.1 Example Calculations

As an example, the laser-driven Rayleigh-Taylor (R-T) instability was simulated. A target of surface-rippled polystyrene ($\rho = 1.06\text{g/cm}^3$) was irradiated by green laser beam ($\lambda = 0.53\mu\text{m}$). The target thickness is $16\mu\text{m}$. Perturbation wavelength and amplitude are $30\mu\text{m}$ and $0.6\mu\text{m}$, respectively. In Fig 1., the density contours at $t=1.5\text{ns}$ is shown. New hydrodynamic code enables us to simulate the instability without complicated rezoning/remapping system, thus the bubble and spike structure is simulated clearly. The growth rates estimated from present code are shown in Fig.2, with experimental result[4]. Though the growth rate of the simulation almost agree with that of simulation result, they seem slightly low compared with the other codes, such as ILESTA-2D. This must be caused by the low laser absorption rate relatively compared with ILESTA-2D. This would be adjusted after further study.

To check the capability of the present code, a non uniform implosion was simulated also. A target of surface-rippled polystyrene ($\rho = 1.06\text{g/cm}^3$) was irradiated by green laser ($\lambda = 0.53\mu\text{m}$). The target shell thickness is $25\mu\text{m}$. The perturbation mode number and amplitude are 8 and $1.0\mu\text{m}$, respectively. In Fig 3., the density contours at $t=2.2$ (left) and $t=2.5\text{ns}$ (right) are shown. At $t=2.2\text{ns}$, bubble and spikes structure of nonlinear Rayleigh-Taylor instability caused by the acceleration were observed, and the target was almost broken up. On the other hand, at $t=2.5\text{ns}$, the target was decelerated by the high pressure in the center region and bubble and spike were grown to the opposite side as they were observed in acceleration phase. This feature was similar

to the experiment done by Beck *et. al*[10].

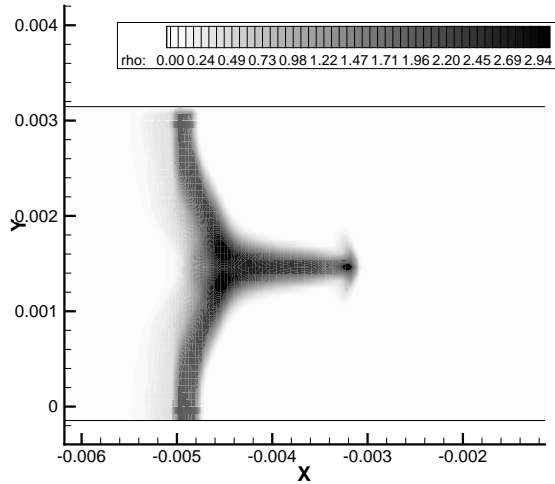


FIG.1. The density contours at $t=1.5\text{ns}$ using present code. The structure of nonlinear Rayleigh-Taylor instability is simulated stably

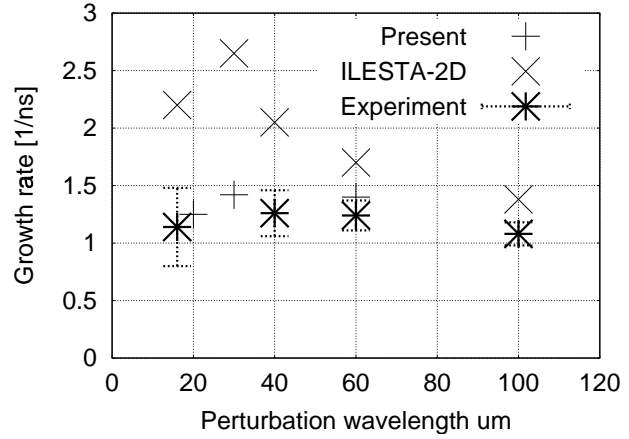


FIG.2. The dispersion relation of R-T growth rates.

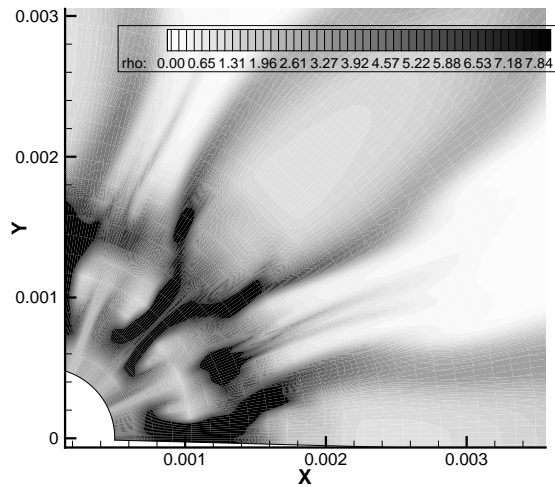
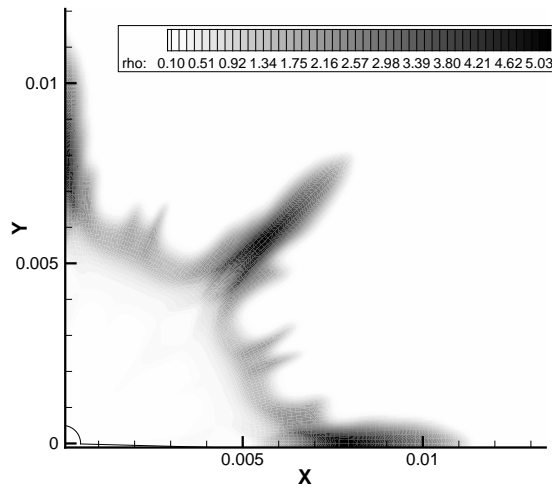


FIG.3. Simulated result of Rayleigh-Taylor instability in implosion. The density contours at $t=2.2\text{ns}$ (left) and $t=2.5\text{ns}$ (right) are shown. X and Y are the distance from the center in cm .

3. Nonlocal Electron Transport

It has been suggested that a kinetic effect on electron transport is important in analyzing target acceleration of relatively thin plastic foils. In such a case, it must be solved by the Fokker-Plank equation for thermal conduction. Generally, a Fokker-Planck code is not robust and consumes much CPU time. A new numerical method has been proposed recently where the electron distribution function is extended into the zero-th and first order parts of Legendre polynomials, and they are solved simultaneously. This method is more stable, and it is easy to couple this solver with conventional hydrodynamic equation. In order to study the effects of nonlocal electron transport on the hydrodynamics, the present code was combined with the integrated

implosion code, ILESTA-1D which is the 1D integrated implosion code.

Using this hybrid code, we consider the case when CH foil is accelerated by the laser ablation. In this case, the thickness of CH foil is $16\mu\text{m}$, overcoated with Al ($0.03\mu\text{m}$). The laser wavelength is $0.53\mu\text{m}$ and the pulse is a flat top square with 2.2ns duration. The laser absorption is calculated based on the inverse-bremsstrahlung for the Maxwellian limit. In Fig.4(a) we show the dynamics calculated by Spitzer-Härm model with a flux limiting factor $f=0.1$. The results based on the Fokker-Plank model are shown in Fig.4(b). Comparing the two models, an increase of the density scale length is seen for the FP case. These results are important for the estimation of the linear growth of the Rayleigh-Taylor instability.

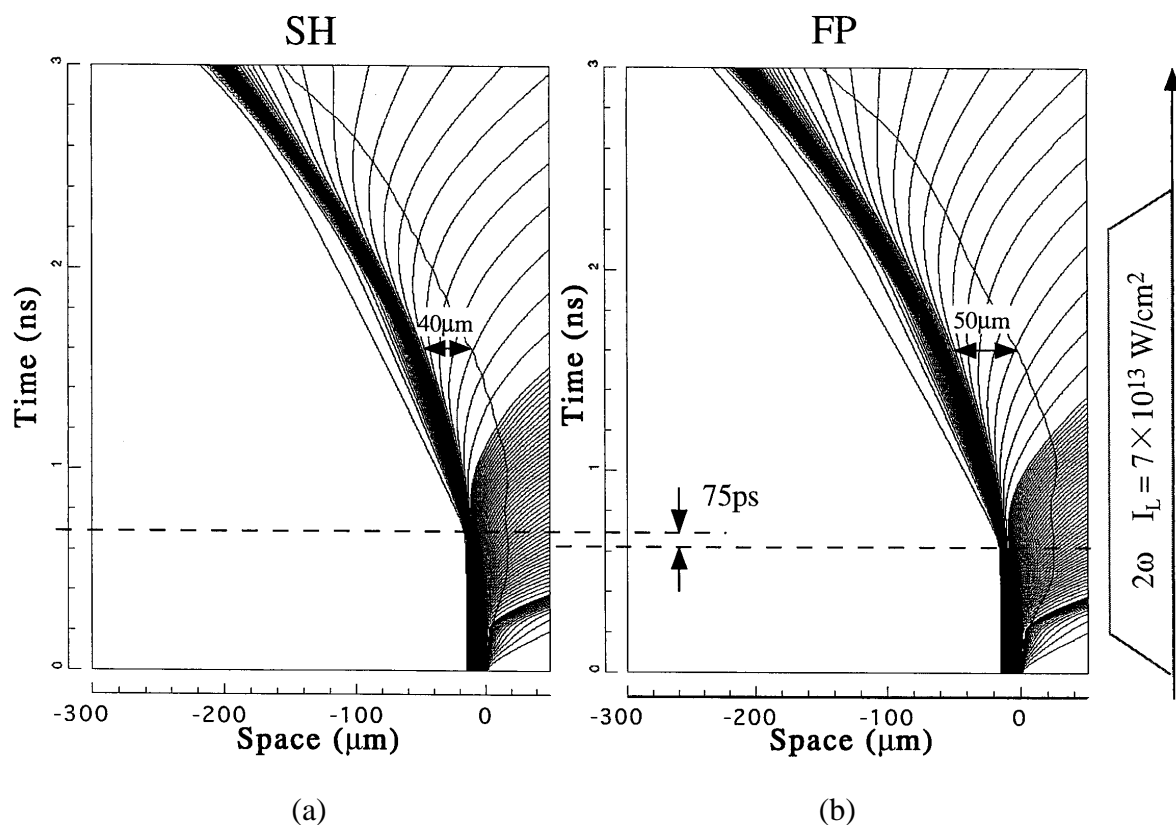


FIG.4. The radius-time diagram of SH model (a) and FP model (b). The critical surface for the laser wavelength $\lambda = 0.53\mu\text{m}$ is plotted in the figure with lines crossing Lagrangian fluid trajectories

4. Summary

In summary, the following status of our computational codes at ILE Osaka were reported. 1) The basic part of the new 2-D integrated implosion code is developed. This code can simulate not only Rayleigh-Taylor instability in laser-driven planar target reasonably but also implosions in ICF. 2) An hot electron transport code based on the Fokker-Planck equation is developed, and it was combined with the ILESTA-1D. The difference of simulated result between Spitzer-Härm model and the FP model is shown when a CH foil is accelerated by the laser ablation using this hybrid code.

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