20pC1-7

Hydrodynamic instability analysis on deceleration phase with implicit time-integration
陰的時間進行法を用いた爆縮減速相における流体不安定性解析

Takashi Shiroto, Naofumi Ohnishi, Atsushi Sunahara[A] and Shinsuke Fujioka[B]
白戸高志, 大西直文, 砂原淳[A], 藤岡慎介[B]

Tohoku University, 6-6-01 Aramaki-Aza-Aoba, Aoba-ku, Sendai 980-8579, Japan
[A]*Institute for Laser Technology, 2-6 Yamadaoka, Suita 565-0871, Japan*
[B]*Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita 565-0871, Japan*
東北大学工学研究科 〒980-8579 仙台市青葉区荒巻字青葉6-6-01
[A]レーザー技術総合研究所 〒565-0871 吹田市山田丘2-6
[B]大阪大学レーザーエネルギー学研究センター 〒565-0871 吹田市山田丘2-6

The backward Euler method was installed in a radiation hydrodynamics code to mitigate the Courant condition at the center of polar coordinate system for an ICF capsule. Parallelization with domain decomposition was conducted using Lis library that includes an algebraic multi-grid solver. Improved performance enables PC clusters to simulate the implosion dynamics. The effect of Rayleigh–Taylor instability on the deceleration phase was analyzed with the developed code.

1. Introduction

A time-step interval of hydrodynamic simulation is limited by the minimum mesh size for an explicit time-integration. Thus, it is difficult to compute at the center of the inertial confinement fusion (ICF) capsule. This fact leads us to hesitate to handle a singular point, resulting in a considerable effect on the estimation of implosion performances.

Another problem is the expensive computational cost of radiation hydrodynamics (RHD) simulation. Most of RHD codes [1,2,3] in Japan are parallelized only in the radiative transfer part, and the number of processors is strongly limited. Consequently, we have to employ expensive vector computers even if the simulation is two-dimensional (2D).

We installed the Euler implicit method in the hydro part to mitigate the Courant condition. Then, the code was parallelized by domain decomposition method. Analysis of the Rayleigh–Taylor instability (RTI) in a deceleration phase was performed with the developed RHD code.

2. Numerical Methods

RAICHO code [1] has been updated in this study. Governing equation is the Euler equation in the polar coordinates. Numerical flux of $(n+1)$ time step is required to implement the backward Euler method and is expressed in the following equation;

$$\tilde{\boldsymbol{F}}^{n+1} = \tilde{\boldsymbol{F}}^{n} + \Delta\tilde{\boldsymbol{F}} \tag{1}$$

The flux of n step $\tilde{\boldsymbol{F}}^{n}$ is calculated by the AUSM-DV while the difference $\Delta\tilde{\boldsymbol{F}}$ is estimated by the Roe scheme. The estimated flux is substituted into the discretized equation, forming a block sparse matrix. Thanks to MUSCL scheme, the flux has 2nd-order spatial accuracy. With an appropriate solver, we can obtain a time-integrated solution.

Laser absorption of the inverse-bremsstrahlung is considered in one-dimensional ray-tracing manner. Thermal conduction is solved by a diffusion approximation of the Spitzer–Härm type. Moment equations of the radiative transfer equation are solved in multi-group photon energy. The energy space of 3 keV is divided into 32 groups. Opacities are estimated based on the screened hydrogenic model.

Parallelization with the domain decomposition is performed to achieve further speed up of the code. The linear solvers are parallelized using Lis library [4], which includes algebraic multi-grid (AMG) preconditioner. The AMG method is useful in the case of a large-scale simulation.

3. Numerical Conditions

We set numerical conditions to direct-drive implosion with a large driver such as national ignition facility (NIF). A schematic diagram of the spherical capsule is shown in Fig. 1. The thickness of ablator and DT-ice are 45 μm and 230 μm, respectively. Diameter of the fuel shell is 3200 μm.

Temporal profile of the laser power is depicted in Fig. 2. Wavelength of the laser is 0.351 μm. Time duration at the maximum power is 5.7 ns, and the laser energy is approximately 1.6 MJ. Surface of the spherical shell does not have any perturbation, whereas spherical harmonic perturbation is added into spatial distribution of the laser power. Amplitude of the perturbation is 3%.

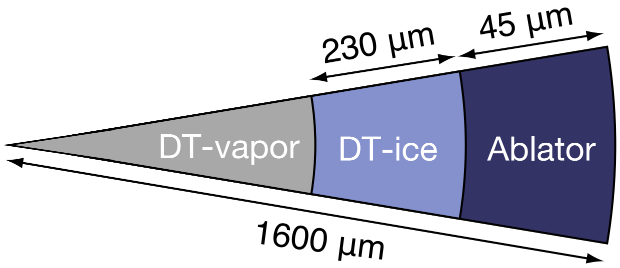

Fig. 1: Geometry of a spherical capsule.

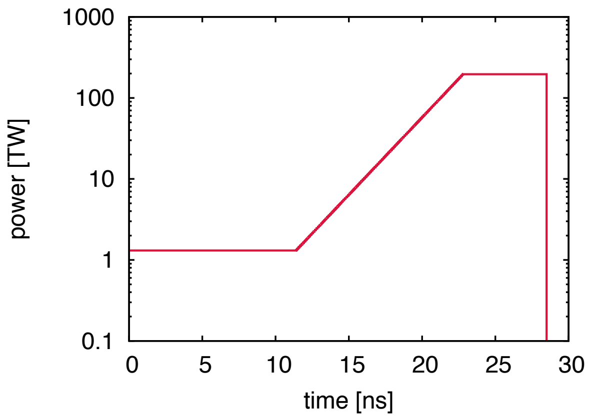

Fig. 2: Temporal profile of laser power.

4. Results and Discussions

We conducted 2D simulations and corresponding one-dimensional (1D) simulations. Table I shows the azimuthally-averaged areal density at the maximum compression. Although the RTI has been regarded as harmful, the results with perturbations have higher areal density than that of the non-perturbed one. This is because of the RTI on the deceleration phase. Fig. 3 depicts density contours with the perturbation at the maximum compression. Spike structures generated by the deceleration RTI penetrate into the center of the capsule, so the density becomes higher due to the spikes. This fact seems to differ from many experimental results. In this study, since only low mode perturbations such as P6 or P7 are considered, growth rate of the RTI is relatively small. Hence, the capsule shape at the acceleration phase is not severely broken up, and the outer surface is stabilized in the deceleration phase. In the cases of the higher mode perturbations, the higher growth rate may completely break up the original shape, and we cannot expect the improvement of the implosion dynamics. Since high-Z dope technique [5] can suppress the RTI especially at the higher mode, the larger-scale simulations are needed to consider the higher mode perturbations.

Table I. Azimuthally-averaged areal density $\langle \rho r \rangle$ at the maximum compression

	$\langle \rho r \rangle$ [g/cm^2]
1D	1.88
2D (P6)	2.32
2D (P7)	2.48

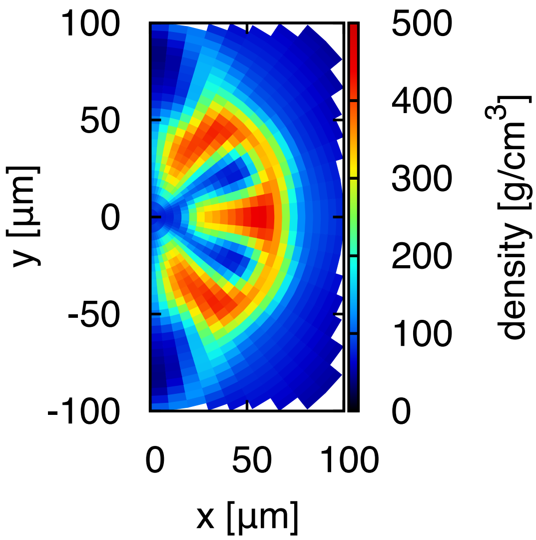

Fig. 3: Density distribution in the case of the P6 mode perturbation.

5. Conclusion

Implicit time-integration based on the backward Euler method was installed into the hydro part of our RHD code. Parallelization with domain decomposition was performed using a linear solver library, Lis. The RTI at the deceleration phase was resolved by the updated code, and low mode perturbation may enhance the fuel density at the maximum compression.

Acknowledgments

Computations were conducted on HC cluster of Cybermedia Center, Osaka University. We were given a great deal of efforts from Dr. Nishida on the installation of Lis library.

References

[1] N. Ohnishi: High Energ. Dens. Phys. **8** (2012) 341.
[2] H. Nagatomo et al.: Proc. Fusion Energ. Conf. (2002) IF/P-07.
[3] H. Nagatomo et al.: Fusion Eng. Des. **44** (1999) 187.
[4] A. Nishida: ICCSA 2010, Part II, LNCS **6017** (2010) 448.
[5] S. Fujioka et al.: Phys. Rev. Lett. **92** (2004) 195001.