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Growth of Rayleigh–Taylor Instability at Interface Between a Target and a Flyer.

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Abstract

Results on the analysis of Rayleigh-Taylor instability growth when a heavy flyer impacts with another heavy and relatively thick plane target at rest are presented. The hydrodynamics of the impact is simulated using a multi group radiation hydrodynamic code. A non-LTE atomic model is used to calculate multi group opacities and emissivities. Growth of perturbation at the interface is analyzed using the single-mode plane-wave perturbation method including non-linear saturation**.**

1. Introduction

In inertial confinement fusion (ICF), the ablation front of the imploding material is known to be hydrodynamically unstable. The Rayleigh – Taylor (RT) instability and its shock analog Ritchtmyer-Meshkov (RM) instability are the two main hydrodynamic instabilities associated with ICF studies. In this paper we summarize our main results on the analysis of RT instability growth when a heavy flyer impacts a heavy and relatively thick plane target at rest. The hydrodynamics of the impact is simulated using a multi group radiation hydrodynamic code. In section 2 of the paper we describe our atomic physics and hydrodynamic model and in section 3 we present some of our numerical simulation results on RT instability. Finally, we conclude the paper in section 4.

2. Atomic and Hydrodynamic Model

We use the screened hydrogenic atom model[1] to calculate the energy levels of partially ionized ions. The l splitting is included in the model. The population densities of neutral to fully ionized ions for any element are obtained by solving the steady state rate equations. The atomic processes considered are the collisional ionization, 3 body and radiative recombination and the die-electronic recombination. We have compared the average degree of ionization for gold by various models and we find that at higher temperatures, SAHA model over predict the ionization as compared to the non-LTE model. Absorption and emission coefficients consist of bound-bound, bound-free and free-free transitions. Thomson scattering and plasma oscillation contributions are also included. As an example, we plot in Fig. 1 the frequency dependent absorption coefficient for gold as calculated by the above model. Also shown by dotted line are the results from the code IONMIX[2]. The hydrodynamics is treated by solving the standard three conservation equations in 1- D Lagrangian geometry. The shocks are treated by Von-Neumann artificial viscous

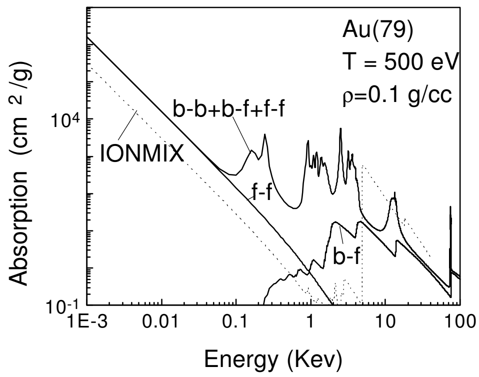

Fig. 1: Frequency dependent opacity.

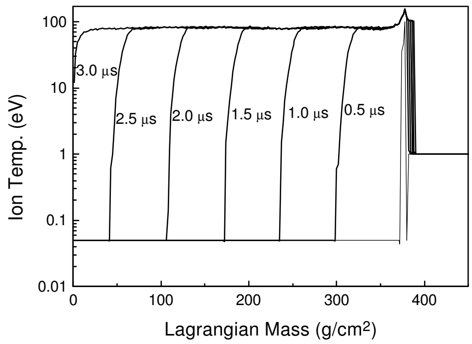

Fig.2: Space profiles of ion temperature

Pressure. Electron heat conduction is calculated using the flux limited Spitizer's formula. Radiation transport is treated by multi-group radiation diffusion approximation or by discrete direction S_N method[3]. Tabulated opacity and emissivity data are used[4].

3. RT Instability Growth Analysis

We considered a 20 cm thick uranium slab at room temperature and it is impacted by a 0.5 cm uranium flyer with a velocity of 5 cm/µs. The flyer is assumed at an initial temperature of 1 eV. The hydrodynamics of the impact is simulated using the model described in section 2. For the results presented in this paper, we solved radiation transport in 1 group diffusion approximation. A 3-term equation of state[5] is used for these studies. As a representative of hydrodynamic parameters, we show in Fig. 2 the space profiles of ion temperatures at the marked times. Shock wave takes about 3 µs to traverse the 20 cm of slab. A compression of 3.9 is observed which is close to the maximum compression of 4 for an infinite strong single shock in a plane geometry. The growth of hydrodynamic instability at the interface of target and flyer strongly depends on the inwards acceleration experienced by the interface. In Fig. 3 we show the time profile of the acceleration at the interface. We observe strong oscillations in the acceleration up to 3.0 µs. Similar oscillations are also reported by Vasey et al[6]. In Fig. 4 we show the time profile of Froude number used in Betti's formulation[7]. We analyze the growth of any perturbation at the interface using the single-mode, plane-wave perturbation model[8]. Non-linear saturation is assumed to occur when the amplitude of perturbation reaches a value of 50% of the mode wavelength. We

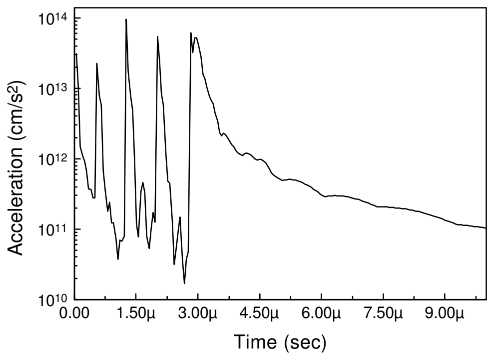

Fig.3: Acceleration at flyer-target interface.

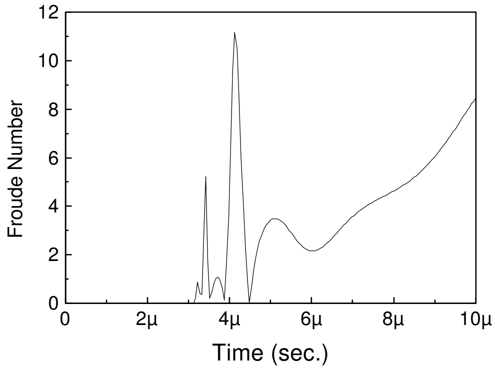

Fig.4: Froude Number.

considered the most dangerous mode number K = 0.32. The modes of smaller wave number grow slower while the larger wave number modes enter the non linear saturation regime. We used modified Takabe formula[9] and Betti[7] formulation to calculate the growth rates. Time variation of the growth rate is shown in Fig. 5. The solid and dotted lines respectively denote Betti's and modified Takabe's formulas. The oscillations in the growth rate correspond to the oscillations in the interface acceleration. After about 3 μs, stabilization is because of strong ablation flow through the interface as result of its reverse motion. In the unstable period, the two growth rates are nearly same while Takabe's modified formula gives much lower values as compared to Betti's formulation at later times. Using these growth rates, the growth of the perturbation with time was evaluated and in Fig. 6 we show time evolution of

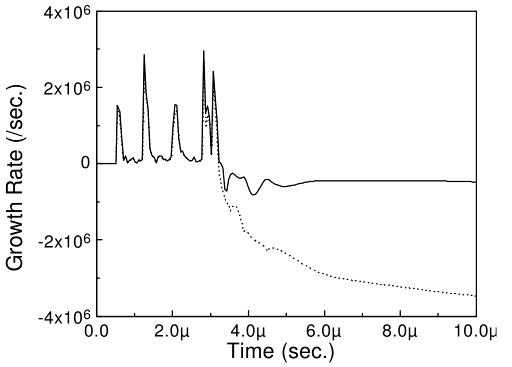

Fig.5: Growth rate at the interface.

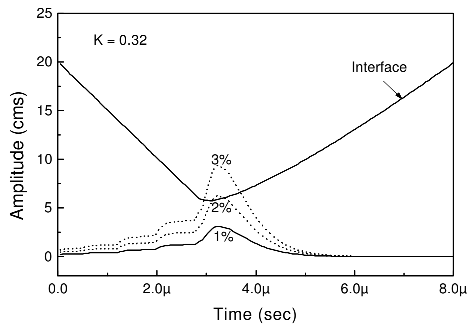

Fig.6: Growth of perturbation amplitude.

perturbation using the modified Ttakabe's formula. Also shown in this figure is the movement of flyer target interface. It moves inwards up to about 3 μs and then it reverts back. No estimate is made for the initial non-uniformity and therefore we have considered 3 cases. These cases assume initial perturbation amplitude of 1, 2 and 3 % respectively. The growth of the amplitude for these 3 cases is shown by solid, dashed and dotted lines in Fig. 6. We note that up to about 3 μs, the amplitude is lower than the compressed slab thickness for all the three cases indicating no danger. However, later on the amplitude of perturbation becomes more than the compressed region for the 3% initial perturbation. This in turn implies that if there are more than one type of material, the instability may lead to mixing of the regions and it may not be desired.

4. Conclusions

In conclusion, we may add that this study is only a representative one. The results, in general, depend on the velocity and size of flyer and also on the geometry used. We have carried out only single mode analysis in the frame of one-dimensional hydrodynamics. No mode coupling is included even in the non-linear regime. However, non-linear saturation of the growth rate is included. In general, 2 or 3 dimensional simulations are required to see the growth of any arbitrary initial perturbation on the interface.

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