Stability analysis of double ablation fronts in inertial confinement fusion

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The Rayleigh-Taylor instability (RTI) in inertial confinement fusion (ICF) is critical for the achievement of appropriate implosions. In the direct-drive approach, a shell of cryogenic deuterium and tritium (DT) is accelerated to high velocities (~400 km/s) by directed laser irradiation of the target surface. During this imploding acceleration phase, the compressed material is ablated off the surface (ablation front) into low-density expanding plasma. The plasma blowoff (light fluid) accelerates the compressed material (heavy fluid) radially inwards, and this is the standard situation for the occurrence of the Rayleigh-Taylor instability. In this work the linear stability theory of double ablation fronts is developed for direct-drive inertial confinement fusion targets, and the so-called electron-radiative ablation front (Shinsuke Fujioka *et al*., Phys. Rev. Lett. 92, 195001 (2004)) [1] is studied with a self-consistent model.

Actual target capsule designs comprise a core of thermonuclear fuel (mixture of DT gas) which is enclosed by two layers behaving as ablators, mainly the outer one. Inner layer (around a hundred of microns) is made up of cryogenic DT ice, which is often solidified around the thin main ablator (few tens of microns thickness). Selection of the material that provides the best performances to achieve the ultimate goal of ICF has been object of numerous studies in recent years. First experiences were carried out using a thin plastic (CH) overcoat. Both, cryogenic DT and plastic foam matrix form a wetted foam layer (CD) [2]. The small amount of CH in wetted foams leads to enhanced absorption of the laser light and better performance over pure DT ice targets. Since the thin CH overcoat is quickly ablated off in the early stages of the driving laser pulse, the main ablator is hydrogenic and the DT ice plays both roles of ablator and thermonuclear fuel. The choice of hydrogenic ablators is motivated by their relatively low density, that permits them achieve high ablation velocities with low in-flight aspect ratio, and therefore exhibit good hydrodynamic stability [3,4]. However, recent cryogenic implosion experiments on the OMEGA laser have shown that hydrogenic ablators exhibit a low threshold for the two-plasma decaying (TPD) instability leading to elevated levels of hot electron preheat for ignition-relevant laser intensities of 10^{15} W/cm^2 and 351 nm wavelength [5]. This preheat implies not achieving the onset of ignition requirements on high total area densities and high hot spot temperatures. If hydrogenic ablators are excluded as viable ablators due to excessive preheat, then alternative choices need to be explored. Two decisive facts motivate the study of using moderate-Z ablators such as SiO_2 and CH or CD doped with moderate-Z elements. Firstly, although the utilization of moderate-Z ablators can be suspected of worsening hydrodynamic stability, a recent work shows the contrary [1] indicating that the use of brominated plastic foils significantly improves the hydrodynamic stability properties by reducing the growth of the RTI. Secondly, a recent direct-drive implosion experiment in the OMEGA Laser Facility [6] using glass ablators (SiO_2) suggests that the use of this moderate-Z ablator reduces target preheat. Therefore, moderate-Z ablators are less affected by the TPD instability. A crucial peculiarity of ablation fronts formed from moderate-Z ablators is the importance of radiative energy flux that drives the appearance of a second ablation front. This structure of two separated ablation fronts, called double ablation (DA) front, was confirmed also in the simulations carried out in [1].

The one-ablation front linear theory of ablative RTI has been extensively studied over the past forty years [7]. Roughly speaking, linear models can be divided into two main types. First, there are the sharp boundary models (SBM). They consider the ablation surface as a zero-thickness interface and homogeneous flow at both sides of it. Problem is not mathematically closed and a closing assumption is necessary to solve it. Recent generalized SBM avoids this difficulty by keeping the model with one free parameter, the density jump across the ablation front [8]. This unknown parameter depends on the structure of the front and its determination requires the prescription of a characteristic length inherent to the ablation process. With an adequate choice of such a length, supported by the analysis of the sophisticated self-consistent models, the SB models yield results in good agreement with the numerical calculations and with the self-consistent models. The just-mentioned self-consistent models are the second type of analytic linear theories. These models start from studying the temperature and density profiles in the ablation front region, for, next, imposing over those profiles linear perturbations, which are analyzed, numerical [9] or analytically [10], in order to complete the study. Nevertheless, analytic theories of both types reported in the literature are all based on a temperature single-group model, which are not able to properly reproduce the hydrodynamic profiles of DA fronts. Therefore, existing models are not adequate to determine the RT growth rate of imploding shells with DA fronts. The aim of this work is to develop a first approach to a linear stability theory for DA fronts.

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