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Progress on Instability Experiments at the AWE HELEN Laser*

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Abstract.
We present an overview of the progress being made on the instability and mix experiments which are being performed at the HELEN laser at AWE. The first section of the paper describes the development of an experiment to measure the growth of Rayleigh-Taylor instability at the ablation front in radiation-driven high Z foils. Preliminary work has concentrated on single wavelength sinusoidal perturbations on thin foils of copper and gold. The second section describes an experiment designed to give a measurement of Richtmyer-Meshkov instability growth in targets in which a shock is driven down a plastic-walled tube containing low density plastic foams.

1 Rayleigh-Taylor Instability at the Ablation Front in High Z Foils

The effect of stabilizing mechanisms on the growth of Rayleigh-Taylor instability at an ablation front is a topic of considerable interest, particularly in the field of Inertial Confinement Fusion. In addition to the development of theoretical models [1], there has also been a thorough experimental investigation of the growth rates in radiation-driven foils using the NOVA laser at LLNL [2]. These experiments use low atomic number, plastic foils of similar material to that being considered for high gain ICF capsules. Although the data from these experiments have mainly been compared with detailed two-dimensional hydrocode simulations, they have also been compared with the analytic models such as that due to Takabe et al in [1]. Such models are useful in that they allow initial estimates of likely instability levels for a given target without the need for the detailed, time-consuming simulations. Despite the relative simplicity of the model

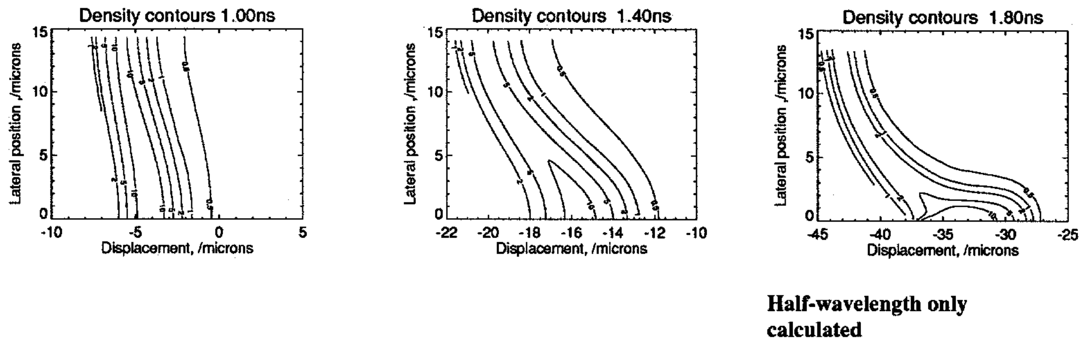

Figure 1: Density contours show the growth of the perturbation and the onset of non-linearity.

approach, reasonable agreement has been seen between the experiment and the theory for these low Z foils.

In a number of other laser experiments however, the target being driven may be a foil of higher atomic number where the transport of radiation from the source of the drive to the ablation front is fundamentally different. In the high Z target the radiation transport through the ablated material will be diffusive, whereas in the low Z case the radiation penetrates through the essentially transparent ablated material directly to the ablation front. Differences in calculated growth rates between directly and indirectly driven targets have been attributed to the different effect of electron thermal conduction rather than radiation transport. The aim of this work is to investigate whether a difference in radiation transport mechanism has any effect on the processes stabilizing the instability growth.

A series of experiments has been designed in which a 3-4 μm copper foil is accelerated by a radiation drive from a gold hohlraum heated by two 900ps, 450J laser pulses. The first set of experiments will use single wavelength sinusoidal perturbations formed on the side of the foil facing the source of the drive. These perturbations will have wavelengths in the range 30–50 μm, and amplitudes in the range 0.1–0.5 μm. Diagnosis of the experiment will be primarily by face-on X-ray back lighting, although other measurements will be made to check, for example, the foil trajectory and therefore its acceleration history. The perturbation growth has been calculated in two ways, by direct two-dimensional simulation and by applying the Takabe model, using input data from a one-dimensional simulation.

The two-dimensional simulations were performed using a Lagrangian code, using 25 zones per half wavelength in the y-direction and 53 zones in the x-direction. Figure 1 shows the density contour plots at different times for a 4 μm foil with an initial perturbation of 0.5 μm. With this large initial perturbation the early onset of non-linearity

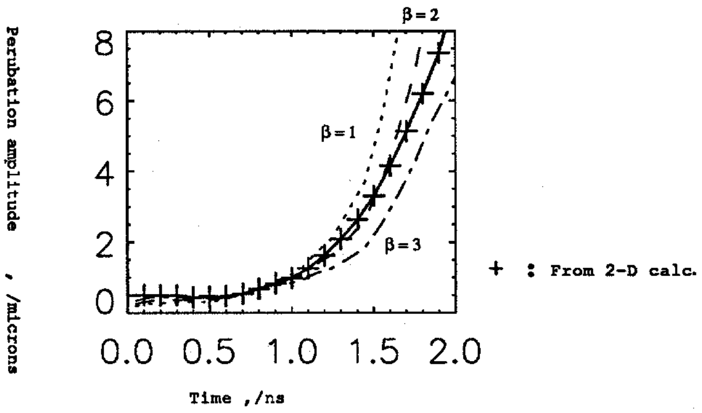

Figure 2: Comparison of perturbation amplitudes from the 2D simulation with those obtained using the analytic growth rate formula $\gamma = \alpha\sqrt{kgA} - \beta \mathrm{kv_a}$ where $\alpha = \frac{1}{\sqrt{1+kL}}$.

can clearly be seen with a distinct "bubble and spike" structure apparent by 1.8ns after the start of the laser pulse.

The perturbation amplitudes extracted from this simulation have been compared with those predicted by the Takabe formula with three different values of the ablative stabilization multiplier, b. For ease of comparison the Takabe amplitudes have been adjusted to take into account stretching caused by the decompression of the foil in flight. These data are shown in Figure 2. Significant growth can still be seen even after the onset of non-linearity.

Predictions of the likely backlighter transmissions through the target can easily be obtained by post-processing the density profiles given by the 2D simulation, as shown in Figure 3. A good diagnostic resolution will be required to follow the instability growth into the non-linear regime due to the formation of the narrow spike.

2 Richtmyer-Meshkov Experiments

The growth of Richtmyer-Meshkov instability in the non-linear and fully turbulent regimes is currently the subject of widespread investigation, both experimental [3] and theoretical [4]; although a simple scaling law has been obtained for the case of Rayleigh-Taylor growth in a smoothly accelerating system, this has not been possible for the impulsively-driven Richtmyer-Meshkov instability. Some of the recent work [4] predicts different scaling laws for the growth of the spikes and the bubbles, making it impossible to describe the overall mixing zone width as a simple power law of time.

An experiment is being designed for the AWE HELEN laser, in which we aim to mea-

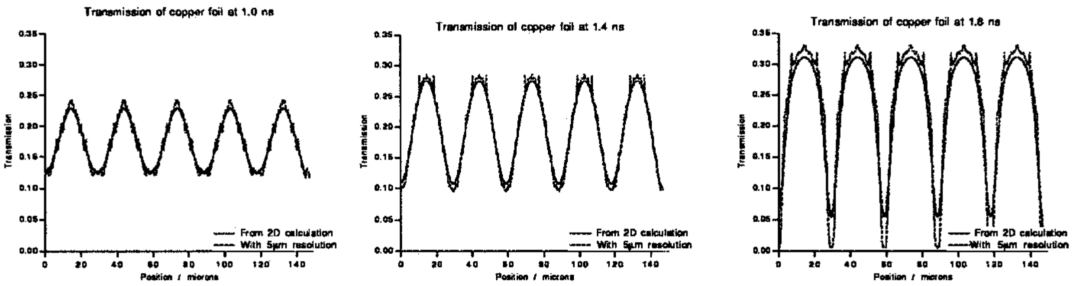

Figure 3: Predicted transmission profiles for the 4μm copper foil with a 3.3 keV backlighter.

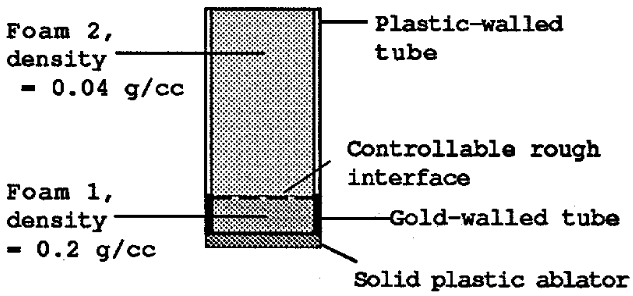

Figure 4: Target design for the planned Richtmyer-Meshkov experiment.

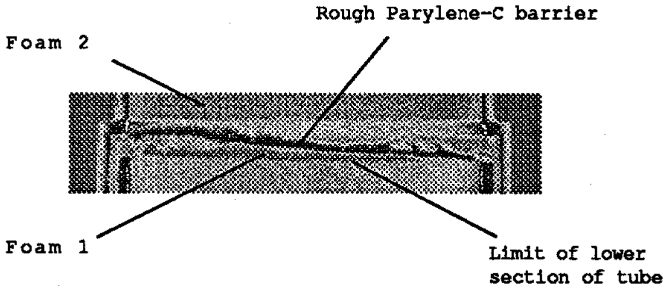

Figure 5: Sub-region of a radiograph of a Richtmyer-Meshkov target showing the region around the rough interface.

sure the Richtmyer-Meshkov mix developing at the interface between two low-density foams. The ultimate aim of the experiment is to use point projection spectroscopy to measure the material distribution within the turbulent mix region [5]. In this way it should be possible to address issues such as the relative growth of bubbles and spikes. Foams, not full-density material, are used to give acceptable X-ray transmission through the relatively wide target, necessary to reduce problems due to two-dimensional effects. The target design is shown in Figure 4.

Radiation drive from a gold hohlraum heated by two 900ps, 450J laser pulses will drive a shock from the solid plastic ablator into a foam-filled tube. This first section of tube contains the higher density, doped foam which is contained within gold walls to reduce lateral energy losses and maintain the shock planarity. The shock will then cross a well characterized rough interface into a region of lower density foam, doped with a second material. The second section of the tube has plastic walls to allow X-ray diagnosis at photon energies of around 3 keV. This target is a challenging fabrication problem, with the main areas of concern being the formation, control and characterization of the interface, and the production of suitably doped foam.

In order to generate mix regions many times wider than the diagnostic spatial resolution it will be necessary to use a large amplitude perturbation on the interface - the current design uses a 3D random perturbation with an rms amplitude of around 5 μm. This is formed at the interface by creating a suitable surface on a thin barrier, characterizing this, and forming the two foams against it in situ, as shown in Figure 5. Characterization of foam surfaces created in this way have shown good replication of the original surface, and this technique has the further benefit that it prevents diffusion of foam dopants across the interface. The barrier can then either be removed chemically with little damage to the foams, or left in place, for example, to be used as a tracer layer.

The choice of suitable materials as dopants for the foams has proved to be difficult. Such materials should have absorption edges in the energy range 2.5–3.5 keV, and be easily incorporated into the foam, preferably chemically. The preferred combination is for one foam to be doped with chlorine, which is an established process, and for the other to be doped with rhodium. Research into the production of a rhodium-doped foam is continuing.

In parallel with the target fabrication research effort, current experimental work is focusing on the detailed design of the tube in order to control the planarity of the incident shock at the interface, and of the interface as it moves down the tube. An intermediate target design, involving a thin, high opacity, tracer layer on the rough interface will be used to develop the target fabrication techniques independent of the doped foam production. This type of target will allow a measurement of the overall mix width and can easily be used with a smooth interface to check the gross hydrodynamics of the target, in particular the planarity of the interface. The use of such a tracer layer in combination with a dopant in one of the foams is also being considered to give more information on the mix distribution without the use of a second doped foam.

3 Conclusions

We are continuing to use the AWE HELEN laser to pursue a number of interesting fields in instability research. At present the main areas of interest are in the growth of Rayleigh-Taylor instability at the ablation front in high Z foils, where the physical processes of the ablation are different from those in the low Z foils more commonly studied, and in the growth of turbulent mixing zones due to Richtmyer-Meshkov instability.

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