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K. S. Budil, B. A. Remington, S. V. Weber, D. R. Farley,
S. Murray, T. A. Peyser

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Nonlinear Rayleigh-Taylor and Richtmyer-Meshkov Mixing Experiments at Nova

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Lawrence Livermore National Laboratory

The evolution of the Rayleigh-Taylor (RT) and Richtmyer-Meshkov (RM) instabilities in the nonlinear regime of growth was investigated in indirect-drive experiments on the Nova laser. The RT experiments investigated the evolution of both single- and multimode perturbations at an embedded interface, isolated from the effects of ablation. This "classical" geometry allows short wavelength ($\lambda \sim$ 10-20 μm) perturbations to grow strongly, in marked contrast to prior results at an ablation front. The RM experiments studied singly- and doubly-shocked perturbed interfaces in both face-on and side-on geometries.(U)

Introduction

Hydrodynamic instabilities are present in physical systems ranging from inertial confinement fusion (ICF) capsules to supernovae. In particular, the Rayleigh-Taylor (RT) instability(Chandrasehkar,68) wherein a heavy fluid is accelerated by a light fluid, can be found in a variety of situations. For ICF the imploding capsule goes through two phases of instability. Initially, the ablating outer surface of the capsule is RT unstable. Later, during the deceleration phase of the implosion, the inner fuel-pusher interface becomes unstable.(Lindl and Mead,75; Verdon *et al.*,82; Bodner,74; Lindl,95) Astrophysicists seeking to explain the early appearance of spectral signatures from heavy elements produced at the core of an exploding star believe that large growth of RT bubbles and spikes at composition interfaces allows the heavier elements to penetrate through the outer layers of the star much earlier than would be expected just from 1D expansion plus diffusion.(Muller *et al.*,91; Herant and Woosley,94)

The Richtmyer-Meshkov (RM),(Richtmyer,60; Meshkov,69) or shock-driven instability is also present in numerous physical systems, often in conjunction with RT and Kelvin-Helmholtz, or shear, instabilities. When a shock wave passes a perturbed interface, it imparts an instantaneous acceleration which can cause mixing. The instability exists whether the shock passes from the higher density fluid to the lower density fluid or the inverse, however, any perturbations will invert phase under the influence of a shock passing from heavy to light.

Herein we describe experiments studying the evolution of a multimode initial perturbation at an RT-unstable interface isolated from the effects of ablation as well as a new experiment to study the development of the RM instability at a perturbed interface which has been double shocked.

Rayleigh-Taylor Experiments

Motivation

We have performed a series of experiments to investigate the evolution of multimode perturbations at an RT-unstable, embedded interface. At an ablation front, the growth of a collection of initial modes can be described by a model proposed by Haan.(Haan,89) The growth is divided into two stages: (1) a linear regime where growth is exponential and (2) a nonlinear regime characterized by an asymptotic, constant bubble velocity. Because ablation will stabilize the shortest wavelengths and the longer-wavelength modes may not have particularly large amplitudes, this model, which neglects mode coupling, reasonably describes the evolution of a wide, smooth initial spectrum.

However, in the case of an embedded interface, isolated from the influence of ablation, short wavelength modes $\lambda \sim$ 10-20 µm grow strongly.(Budil *et al.*,96) For this case, where growth of longer wavelengths can be due primarily to seeding via mode coupling rather from their initial amplitudes, the development of the mixing region should lose dependence upon the initial conditions.(Young,84; Haan,91) The bubble front penetration is given by $\eta_{bubble} = \alpha A g t^2$ and the front evolution can be described in statistical terms from the dynamics of the individual bubbles plus two-bubble merger.(Young,84; Haan,91; Ofer *et al.*,96; Layzer,55) As the coupling proceeds, longer and longer wavelength structures will begin to dominate the flow resulting in an *inverse cascade*.

Experimental configuration

In the experiments described herein, a gold cylindrical hohlraum was utilized to generate an x-ray drive to ablatively-accelerate the sample foil. The sample foils consisted of a 40 μm thick brominated polystyrene (CH(Br)) ablator backed by a 15 μm thick Ti payload. The perturbation being studied was placed at the CH(Br)-Ti interface and consisted of either two, ten or twenty cosine modes superimposed in phase. The experimental configuration is illustrated in Figure 1.

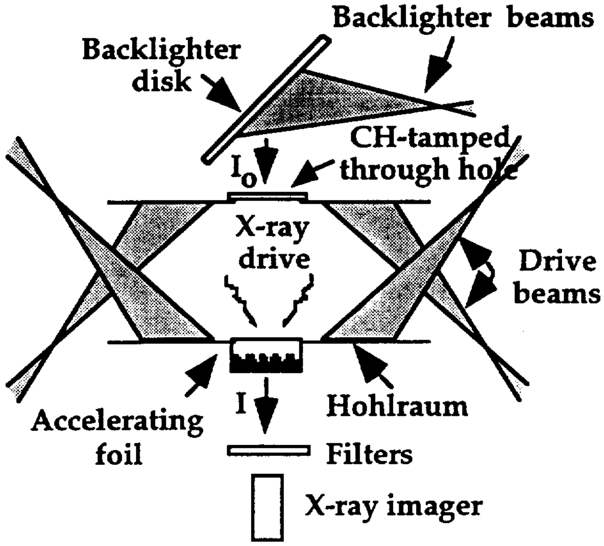

Figure 1. Experimental configuration for the classical Rayleigh-Taylor instability studies.

An iron foil was irradiated to generate Fe He-Kα x rays at 6.7 keV to back-illuminate the target and the radiographs were recorded with a gated x-ray framing camera.(Budil *et al.*,96) The radiographs were then Fourier-analyzed to determine perturbation amplitude in ln(exposure) ∝ δ(OD) as a function of time, where OD represents optical depth.

Bubble Merger Experiment

In an effort to directly observe the competition between neighboring bubbles in *physical* space rather than Fourier space, as discussed by Alon *et al* (1995), we designed a target consisting of two harmonic wavelengths ($\lambda = 20$ μm, $\eta_o = 1$ μm and $\lambda = 10$ μm, $\eta_o = 1$ μm) superimposed in phase. This corresponds to an alternating series of larger and smaller bubbles side-by-side, and the size and shape of each of the bubbles can be directly observed. For comparison, each target also had, in separate bands, the two corresponding single mode patterns. Results from this experiment are shown in Figure 2.

By 4 ns the amplitude of the 10 μm mode has begun to decrease in the bubble merger pattern (Figure 2a), whereas the amplitude of the 10 μm single mode (a separate band measured on the same target) is still increasing at that time (Figure 2b). The central, smaller bubble appears to be giving way to its larger

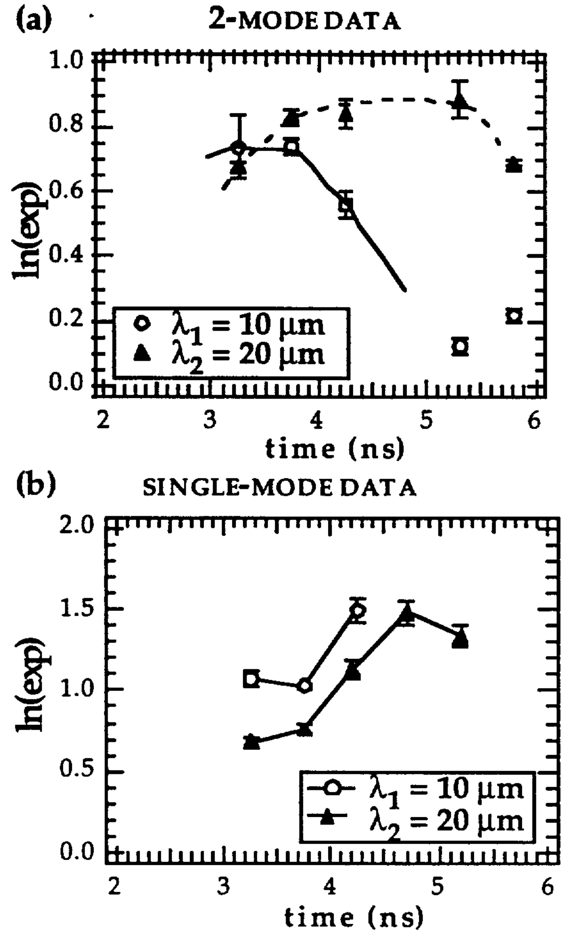

Figure 2. (a) Fourier amplitudes in ln(exposure) corrected for instrument response for the bubble merger 2-mode pattern. Solid and dashed curves are added to guide the eye. (b) Same only for the corresponding single mode patterns. Please note the suppressed origin along the time axis in plots (a) and (b).

neighbor as the experiment progresses. We may be seeing the initial stages of bubble competition and merger. However, as the bubbles grow in our experiment their amplitudes begin to approach the thickness of the titanium layer, which may impede the bubble competition process.

Richtmyer-Meshkov Experiments

Motivation

A great deal of work has been directed toward the study of planar, perturbed interfaces under the influence of a single, strong shock.(Peyser *et al.*,95 and references therein) Now the interaction of a highly mixed, or perhaps turbulent layer with a shock wave is beginning to be studied in detail. We have begun an experimental campaign to extend the work of Peyser *et al.* (1995) to the interaction of a strong shock wave with an evolving mix layer.

Experimental configuration

In the experiments described herein, gold cylindrical hohlraums were utilized to generate an x-ray drive to ablatively launch a shock into a miniature shock tube. A schematic of the experimental configuration is shown in Figure 3. Four Nova beams are incident into each

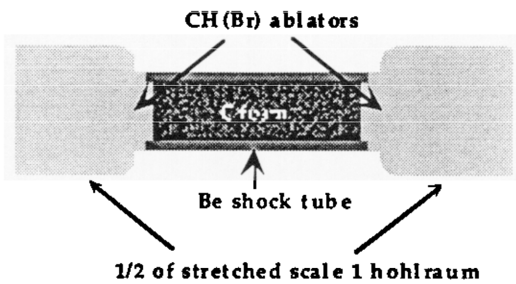

Figure 3. Experimental schematic for the double shock experiment.

half hohlraum, thus generating two independent shock waves moving in counter-propagating directions. By a simple surface area scaling argument it can be shown that one-half of the available energy into a one-half-scale hohlraum generates approximately the same peak radiation temperature (~220 eV) as the corresponding full-scale experiment (8 beams into a scale-1 hohlraum). The package is diagnosed by focusing the remaining two Nova beams onto a Ti disk to generate a 4.7 keV x-ray backlighter source.

The shock tube is a 2 mm long Be cylinder. Into each end a 300 μm thick brominated polystyrene (CH(Br), 1.22 g/cm^3) ablator is inserted and the central section is filled with low density (0.1 g/cm^3) carbon foam.

Drive Characterization

To date, two preliminary drive characterization studies have been carried out. A measurement of the radiation drive generated in the half-hohlraum geometry was made using both a time-resolved measurement of the shock breakout from a wedged Al witness plate and a filtered x-ray diode array (Kornblum *et al.*,86). This measurement confirmed the predicted scaling and showed a radiation temperature profile which peaked at approximately 210 eV (albedo-corrected).

A second measurement was made by side-lighting a mix package with a flat (unperturbed) interface and recording the interface trajectory at a series of times. This is a diagnostic of the planarity of the shock which crosses this initially planar surface and a reasonably planar shock is observed.

Conclusions

We have performed experiments studying the deep nonlinear, RT-growth of an initially multimode perturbation in a geometry where the perturbations are isolated from the effects of ablation. The early stages of the bubble competition process have been observed. Results from other initial perturbations will be discussed as well. We have also begun an experimental campaign to study the evolution of a mixing layer under the influence of a second shock. Preliminary experiments have measured the radiation drive and shock planarity for the novel, counter-propagating geometry.

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University of California • Livermore, California 94551