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SHOCK-HYDRODYNAMICS EXPERIMENTS ON THE NOVA LASER

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Shock-hydrodynamics Experiments on the Nova Laser

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Abstract: We have conducted shock-induced hydrodynamics experiments using the Nova laser at Lawrence Livermore National Laboratory. The laser provides a high-enthalpy source by depositing its energy (about 22 kJ) in a small gold cavity called a *Hohlraum*. The *Hohlraum* serves as a driver section, launching very strong ($M \approx 20$) shocks into millimeter-scale cylindrical "shock tubes." The flow is imaged radiographically by an electronic framing camera, using a laser-generated x-ray source. Several topics have been addressed with this configuration, including shock-induced mixing at density interfaces (seeded with a variety of perturbations); the development of high-speed, shaped-charge-like jets; the effects of geometry on the planarity of the generated shocks; and shock-shock interactions which develop in the flows. In this paper, we describe the general configuration of our experiments, present an overview of the high-speed jet work, discuss some of our findings, and compare our results with computer simulations we have conducted.

Key words: jet, mixing, Richtmyer-Meshkov, Nova laser, compressible flow

1. Introduction

We are investigating shock-induced hydrodynamics with experiments conducted on the Nova laser, at Lawrence Livermore National Laboratory (LLNL). Understanding shock-induced flows, including the Richtmyer-Meshkov instability (Richtmyer 1960, Meshkov 1969) which occurs at shocked density interfaces, is of interest in inertial confinement fusion, astrophysics, and other applications. In particular, in this paper, we describe experiments involving high-speed jets generated at a density interface with a hemispherical perturbation. Additional material described in the ISSW oral presentation, regarding an investigation of the mixing region growth that results from the passage of a shock across a density interface with an initial sawtooth perturbation, is not included here, but has been documented in Phys. Rev Lett. (Peyser *et al.* 1995).

2. Experiment Description

The experiments are conducted using the Nova laser facility. Nova has ten separate beam lines, each capable of delivering approximately 2.8 kJ of energy in pulses 1 ns long, at a wavelength of 353 nm. The beams are focused into a 5 m-diameter target chamber, which contains a target positioner holding the target, alignment systems, and various diagnostics.

In our experiments, we use the Nova laser as a high-enthalpy source to drive our miniature shock tubes, and to produce diagnostic x rays. A small gold cylindrical can, called a *Hohlraum*, serves as the shock tube driver section (see Fig. 1). The hohlraum dimensions are 3200 μm long by 1600 μm wide, with 1200 μm diameter holes in both ends and a 45 μm wall thickness. Our miniature shock tube is mounted on a 700 μm hole on the side of the hohlraum. The shock tube wall is made of beryllium, about 700 μm in internal diameter with 100 μm-thick walls. The working fluid in the shock tube is brominated plastic (2% by atomic fraction) in the end closest to the hohlraum, and low-density carbon foam (0.1 g/cc) in the remainder of the tube. The shock tube length, 2 mm, and external diameter, 0.9 mm, are about the same size as the letter "i" in the word "DIME" on the backside of a U.S. dime.

The figures are not incorporated electronically. All of the figures have previously undergone classif/review/release in the presentation which was the basis for this (proceedings) paper.

Figure 1. Schematic of the experiment.

The sequence of events in one of the experiments is as follows. Eight of Nova's beams are focused into the interior of the gold *Hohlraum* can, rapidly heating the interior of the *Hohlraum* to a temperature of about 230 eV (over 2 million K). The plastic-filled end of the shock tube, exposed to the high temperature through the hole in the side of the *Hohlraum* it is mounted over, begins to rapidly ablate, driving a strong shock (10's of Mbar's) down the axis of the tube. As the shock propagates down the tube, it crosses the interface between the brominated plastic and the low-density carbon foam. In the jet experiments, the interface is flat, except for a 150 μm-radius, hemispherical hole in the plastic side (filled with foam), centered on the tube axis.

In the shock-induced mixing region experiments described below, the interface has 60 degree linear sawtooth perturbations machined into the otherwise flat plastic side of the interface, and the carbon foam is flat and placed in contact with the sawteeth points. The shock tube and associated parts are made with advanced micro-machining techniques developed at LLNL (Louis *et al.* 1995).

The primary data collected in these experiments are x-ray images. To provide the x-ray illumination to capture these images, the remaining two of Nova's ten beams, which are not used to heat the *Hohlaum*, are delayed in time and strike a titanium foil located several millimeters behind the shock tube, as viewed from the diagnostic camera. The interaction of the intense laser light with the metal produces x rays (of about 4.9 keV), providing a backlighting source. The x-ray transmission through the flow is attenuated by a factor which is a combination of path length, type of material, and density. The beryllium tube and unshocked carbon foam are relatively transparent to x rays of that energy, while the brominated plastic and higher density materials are more opaque. Therefore, the jet of brominated plastic appears as a dark feature on a lighter background. Images of the resulting flow are captured using an electronic framing camera (Louis *et al.* 1995), which is basically an x-ray pinhole camera, capturing 2-dimensional images with about 100 ps exposures. The data is recorded on film, and later digitized on a densitometer, including wedge corrections.

3. High-Speed Jet: Experimental and Numerical Results

For the high-speed jet experiments, as described above, we place a hemispherical protrusion at the density interface, which, when struck by the shock, inverts and forms a jet. Two-dimensional, axisymmetric numerical simulations of the jet flow have been conducted using the code CALE. CALE is an arbitrary Lagrangian-Eulerian code that was developed at LLNL. A calculated temporal sequence of the jet behavior, depicting material boundaries, is shown in Fig. 2. Since this is a depiction of material interfaces, densities, and the shock, are not represented. The shock is travelling from top to bottom in the figures. At 0 ns, the initial geometry is evident, and 5 ns after the laser begins to heat the *Hohlraum* the shock is crossing the hemispherical protrusion, causing it to invert. By 10 ns, the hemisphere has fully inverted and is froming a jet, which continues to develop through later times. The sides of the jet, subject to shear, form roll-ups by the Kelvin-Helmholtz instability. Such roll-ups, when viewed in transmission, appear in the data as dark horizontal bands.

Using the known opacities of the materials, the simulation was post-processed to create simulated radiographs, which can then be compared directly with the experimental data. A comparison of data with the results from the simulation is shown in Fig. 3. Cosmetic differences between the two sets of images include the presence of noise, the inclusion of reference grids, and the non-uniformity of the x-ray illumination, all in the experimental data. Features of interest in the experimental data include the jet's bow shock (particularly evident at 10.6 ns), the dark bands of the vortical structure around the head of the jet, swirls of material at 14.8 ns and trailing tendrils from the sides at 19.7 and 21.9 ns, and the growth and thinning of the neck

Figure 2. Material boundaries of the high-speed jet experiment calculated with CALE.

of the jet, particularly at 21.9 ns. Differences between the simulation and the data include faster growth (longer neck) and later development of the swirl features in the simulation.

Using data from a series of separate experiments, four jet features were identified in each picture: the bow-shock location, the tip of the jet material, the center of the dark band from the vortical roll-up, and the "shoulder" or material to the side at the base of the jet. The axial positions of these four features were measured from each data image, and the results are compared in Fig. 4 to the measurements from the simulated x-ray images of the calculation. One datapoint for the shoulder at 19.5 ns was out of the frame. The time is measured from the beginning of the 1.0 ns laser drive pulse, and the shock crosses the hemispherical protrusion around 5 ns. Axial position is measured from the end of the brominated plastic closest to the *Hohlraum*, withthe tip of the hemisphere initially at 250 μmand the flat around it at 400 μm.

The agreement between the simulation and the data is, depending on the context, between excellent and fair. The feature locations from the calculation agree within 5-10travel distance with those from the data, with the exception of the earliest-time data, and the spacing between features at a particular time is also quite similar. The datapoints at 11.5 ns and 19.5 ns are significantly less advanced than the calculation, however. It should be noted that the drive energy delivered by the laser in each

Figure 3. X-ray images from CALE calculation and experimental data.

experiment is subject to variations of +/- 10lower sets of data were, in fact, lower than the others. One possible approach to correct for this uncertainty in the initial drive would be to assume the shock location is an accurate indicator for the drive condition, and to shift the data points in time to where they agree with the simulated shock location. We do not present such an adjustment here.

4. Conclusions

We have presented results from our shock-induced fluid dynamics experiments conducted on the Nova laser facility. For this paper, we have focused on our high-speed-jet data and compared it to two-dimensional CALE calculations. The distinct features present in the jets provide good fiducials for comparison with the calculations. The CALE simulations are found to agree in major respects, but differ in some details. We also note that the roll-up observed in the data is possibly the first such direct observation of the Kelvin-Helmholtz instability in this (plasma) regime.

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Figure 4. Comparison of jet feature locations from calculation and experiment.

References

Richtmyer RD (1960) Taylor instability in shock acceleration of compressible fluids. Commun Pure Appl Math 13:297.

Meshkov EE (1969) Instability of the interface of two gases accelerated by a shock wave. Sov Fluid Dyn 4:101.

Peyser TA, Miller PL, Stry PE, Budil KS, Burke EW, Wojtowicz DA, Griswold DL, Hammel BA, and Phillion DW (1995) Measurement of radiation-driven shock-induced. mixing from nonlinear initial perturbations. Phys Rev Lett (to appear).

Louis H, *et al.* (1995) Fusion Technology (to appear).

Louis H, Demiris A, Budil KS, Miller PL, Peyser TA, Stry PE, ~~and~~ Wojtowicz DA, and Omotakis PE

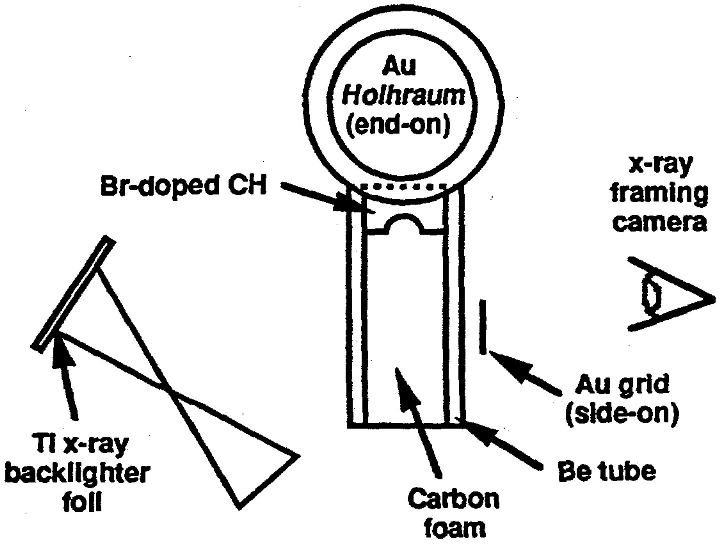
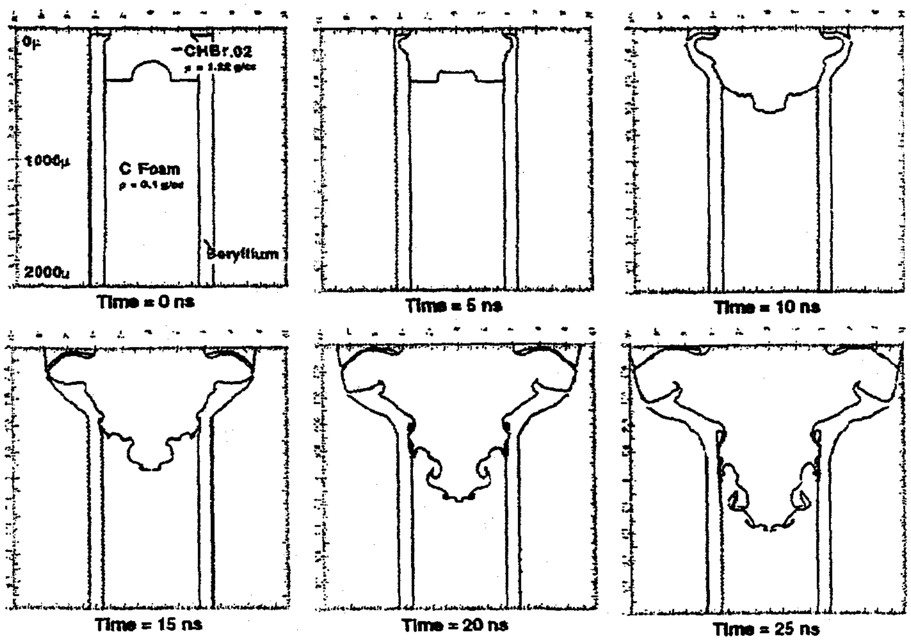


Figure 1 - ISSW paper 188 (Miller, et al.)



Time = 0 ns

Time = 5 ns

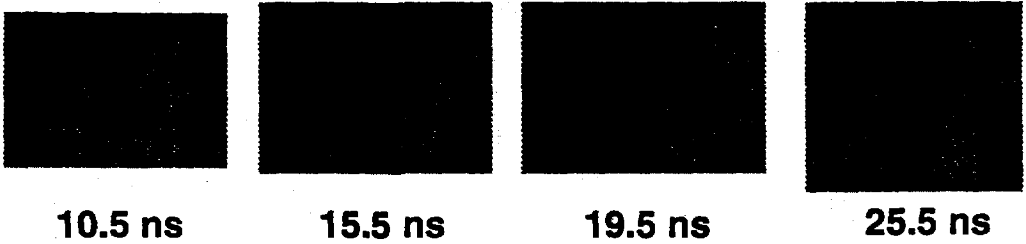
Time = 10 ns

Time = 15 ns

Time = 20 ns

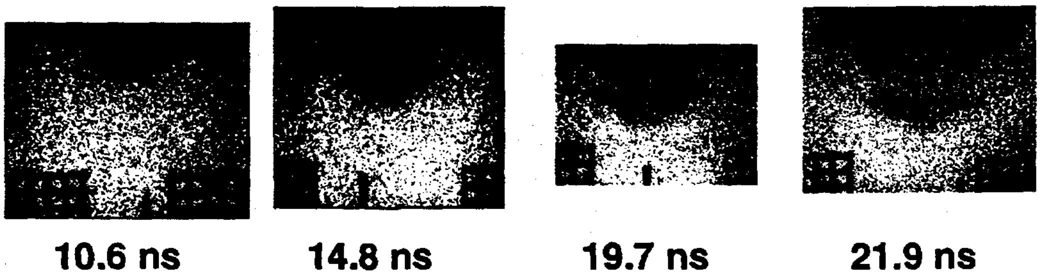
Time = 25 ns

Figure 2 - ISSW paper 188 (Miller, et al.)



Simulated radiographs from CALE

10.5 ns 15.5 ns 19.5 ns 25.5 ns



Data radiographs

10.6 ns 14.8 ns 19.7 ns 21.9 ns

Figure 3 - ISSW paper 188 (Miller, et al.)

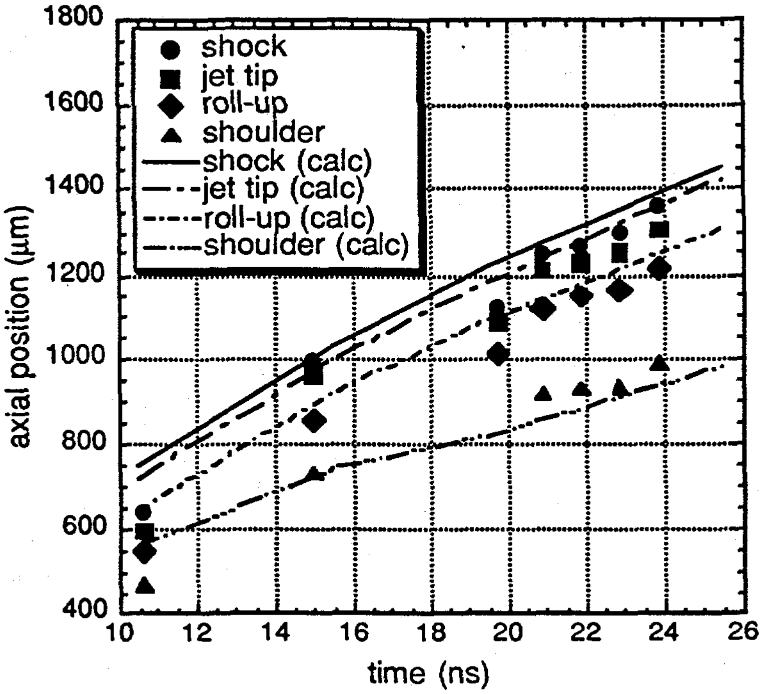


Figure 4 - ISSW paper 188 (Miller, et al.)