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Turbulent Mix Experiments and Simulations

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Hydrodynamic instabilities produce material mixing that can significantly degrade weapons performance. We investigate the Richtmyer-Meshkov[1] (RM) and Rayleigh-Taylor[2] (RT) instabilities in the turbulent regime in two experimental venues. RM experiments are conducted on the Nova laser with strong radiatively driven shocks (Mach > 20) in planar, two fluid targets. Interfacial perturbations are imposed with single sinusoidal modes to test linear theory and with three dimensional (3D) random modes to produce turbulent mix. RT experiments are conducted on a new facility, the Linear Electric Motor (LEM), in which macroscopic fluids are accelerated with arbitrary temporal profiles. This allows detailed diagnosis of the turbulence over a wide range of conditions. The Nova experiments study the high compression regime whereas the LEM experiments are incompressible. The results are compared to hydrodynamic simulations with the arbitrary Lagrangian-Eulerian code (CALE)[3]. The goal is to develop and test engineering models of mix.

I. RM experiments on Nova

The Nova experimental configuration[4] is shown in Fig. 1. In order to produce a spatially uniform drive, eight laser beams (28 kJ at 0.53 μm) are converted to soft x-rays inside a hohlraum (~ 2-3 mm diameter, 3-4 mm length). A 3 ns laser pulse generates a quasi-Plankian x-ray drive with a peak radiation temperature of ~ 140 eV. A HIGH and LOW drive is used in our experiments with different size hohlraums. The target is mounted on the hohlraum wall and radiographed in-flight from the side and face-on using x-rays generated by striking backlighter foils with two independent laser beams. A gated x-ray imager (GXI) obtains 2D radiographs and an x-ray streak camera obtains 1D images streaked in time.

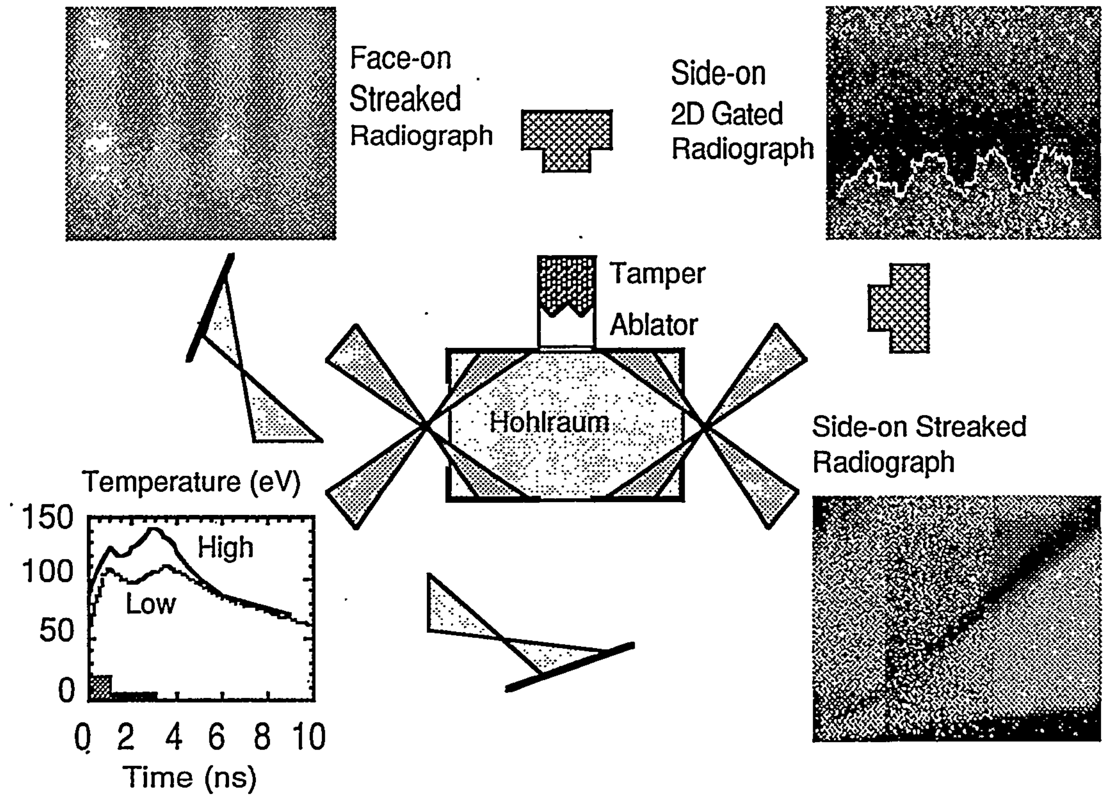

Figure 1: Experimental configuration and sample data

The target consists of a berylium (Be) ablator (1.7 g/cm^3) and a foam tamper (0.12 g/cm^3). The shock originates in the ablator and couples to the tamper while exciting perturbations imposed at the ablator/tamper interface. The shock characteristics (speed and compression) are obtained from streaked side-on radiographs as shown in Fig. 1 taken with a smooth interface. For the single mode instability experiments, the perturbations are 2D and the foam is opaque while the Be ablator is transparent. The growth of the pertubations is observed directly with 2D gated radiographs while a continuous record in time is obtained with streaked face-on radiographs as shown in Fig. 1. By varying the hydrodynamic parameters (shock strength, density ratio, and amplitude and wavelength of the initial perturbations), we can rigorously test the different calculations[1,5] and CALE simulations.

Turbulent mix is investigated by replacing the single modes with 3D random interfacial perturbations. To facilitate radiographic diagnosis, we modified the target because the interface can tilt or become bowed late in time and this confuses the diagnosis. Thus, we introduce tracer layer in the center of the target where the problems are minimal. The turbulent mix width is observed to increase in time following a power law that supports analytical estimates[6].

II. RT experiments on the LEM

The Nova experiments are unique because they utilize a radiation drive to generate very strong shocks and high compression. However, the targets are small and turbulence is difficult to characterize over a wide range of spatial scales. Thus, we built a linear electric motor[7] (LEM) to accelerate large fluids for diagnostic clarity and with an arbitrary acceleration profile as shown in Fig. 2. These experiments extend the seminal AWE "rocket rig" experiments[8] that have been important in calibrating mix models.

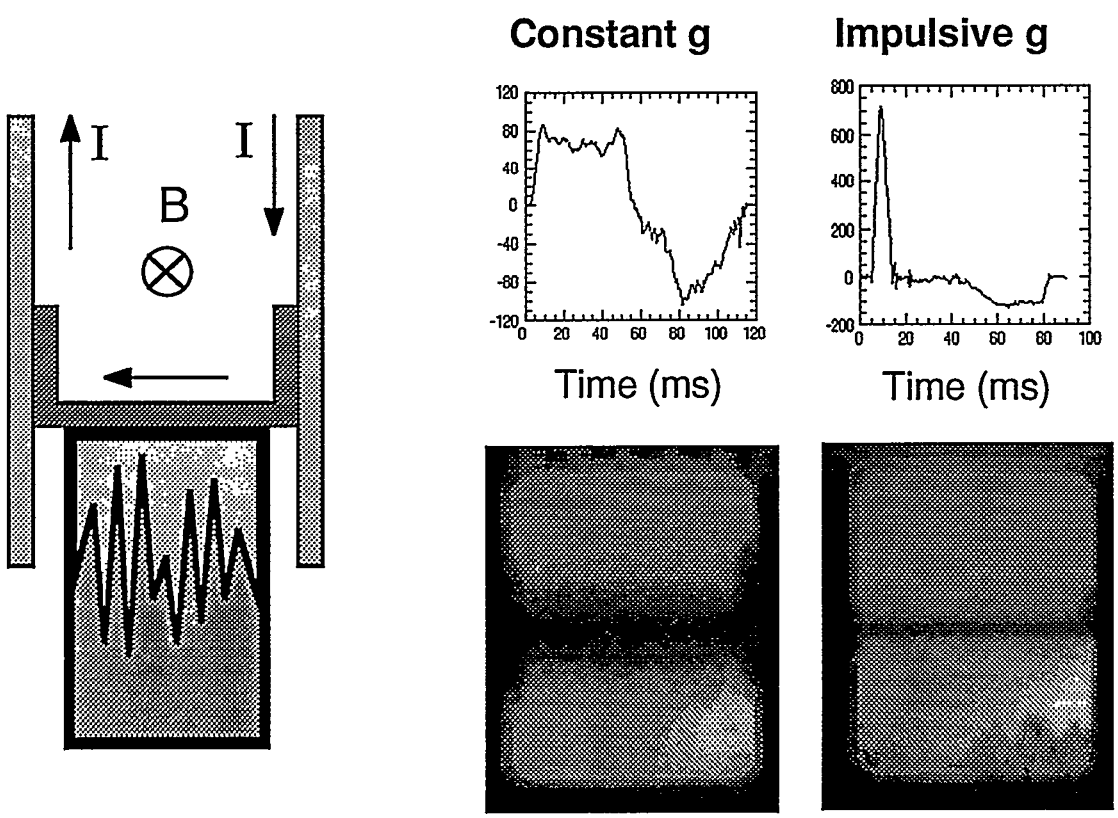

Figure 2: LEM configuration, acceleration profiles and shadowgraphs for constant and impulsive cases

The LEM consists of linear electrodes that conduct current through a sliding armature. This current and that flowing through an augmentaion coil (not shown) produce a magnetic field as shown in Fig. 2. The product of the rail current and the magnetic field produces a downward force that can be programmed by varying the two current pulse shapes. The power is supplied by 16 independent circuits from an electrolytic capacitor bank with a total of 5.6 farad at 450 volt. The cell has a total mass of ~ 2 kg and fluid dimensions of ~ 10 cm

Two acceleration profiles are shown in Fig. 2. A constant profile with g ~ 70 g_0 (g_0 is earth's gravity) is obtained for ~ 45 ms with 12 and 20 kamp in the rail and coil circuits, respectively. After 70 ms, the cell enters a mechanical brake which is open for diagnostic access. An impulsive profile with peak g ~ 700 g_0 is obtained for 10 ms by increasing the rail and coil currents to 28 and 54 kamps, respectively. These profiles are designed to produce the same maximum velocity of ~ 30 m/s. Sample shadowgraphs are shown below each profile at the same displacement z = 80 cm for A = 0.22 (Freon/water). The turbulent mixing zone is the dark region in the center and clearly shows the importance of the acceleration profile. The dark region at the bottom of the impulsively accelerated case is due to cavitation in the Freon because the pressure drop accross the Freon exceed 15 psi for g > 150 g_0 .

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