Investigating Turbulent Mix in HEDLP Experiments

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Abstract. Mix is an important issue in High Energy Density Laboratory Plasmas (HEDLP), specifically Inertial Confinement Fusion (ICF) implosions. In ICF, shock waves traverse fuel capsule defects and material interfaces, and due to hydrodynamic instabilities transitioning into turbulence, these shocks can initiate mix between shell and fuel, degrading yield. To this end, a series of laser-driven mix experiments has been designed for the OMEGA and NIF laser facilities to investigate the turbulent mixing of materials proceeded by reshock and shear, which initiates Richtmyer-Meshkov and\or Kelvin-Helmholtz instabilities on a tracer layer. The experiments are designed to understand if the Besnard-Harlow-Rauenzahn (BHR) mix model that has been implemented in LANL's RAGE hydrodynamics code has coefficients that are properly determined for an HEDLP environment.

1. Introduction

Los Alamos National Laboratory has been engaged in Inertial Confinement Fusion (ICF) research in support of ignition on the National Ignition Facility (NIF). As part of this effort, we are studying the effects of material mixing inside of ICF capsules which can degrade the fusion yield. One of the areas we have focused on as part of our research is the effect of instabilities and their transition to turbulence on mix. Much of this mixing becomes relevant to ICF implosions following the shocks crossing the material boundaries in a fuel capsule, as well as in other applications like shocks in supernovae implosions. Shown in Figure 1 is a representation of two typical regions where instabilities in an implosion reside. Rayleigh-Taylor (RT) and Richtmyer-Meshkov (RM) [1, 2] instabilities can be initiated during the initial phase of the implosion. In the current point design for ignition, four shocks traverse the capsule and converge on the center of the capsule to heat and ignite the fuel. Strong shocks can cause the instabilities to progress rapidly into the turbulent regime when traversing these regions under the right conditions. Figure 1 shows two regions of interest, one subject to the RM instability labeled as the "Re-Shock Region" and another region subject to the Kelvin-Helmholtz (KH) [3, 4] instability labeled "Shear Region". The re-shock region is characterized by a shock traversing the material interface, in this case the capsule shell and ice/fuel boundary, subjecting it to RM initially; then a reflected shock hits the layer again from the opposite direction, causing the layer to be recompressed and quickly transition into a turbulent mix regime [5]. The shear region is characterized by two flows in opposite directions, one light (the fuel), and one heavy (the capsule shell), subjecting the region to KH shear instability, when one shock passes or when two shocks pass in opposite directions. This subjects the layer to intense shear forces, causing the initial instability to transition into a turbulent regime. To this end, we have developed the *Reshock/Shear* platform for the Omega laser system to study these interactions in detail and compare the conditions to one particular turbulence model, the Besnard-Harlow-Rauenzahn (BHR) mix model [6, 7], which has been implemented in RAGE [8].

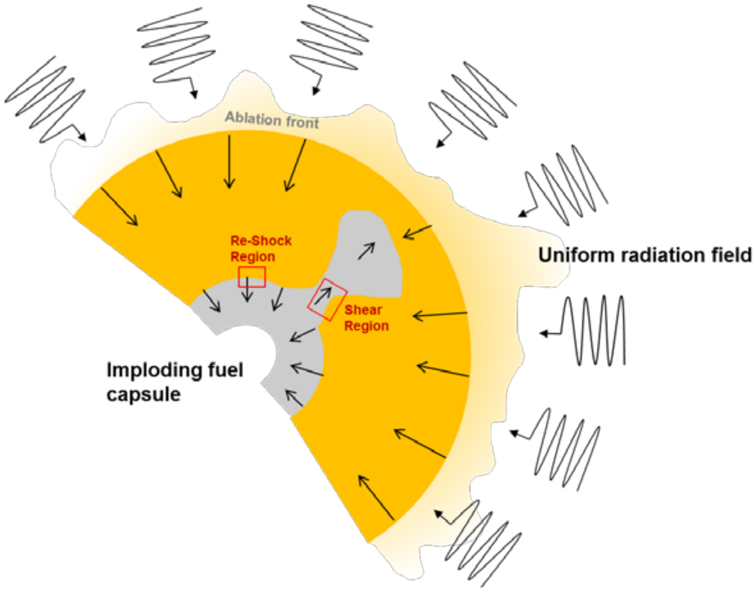

Figure 1. Schematic of half of an imploding ICF capsule, with DT gas at the center (white), DT ice (grey), and the capsule wall/ablator (orange).

2. The (Re)Shock/Shear Platforms

The Omega campaigns on reshock and shear have been successful in helping us understand the BHR mix model in the context of high energy density laboratory plasma (HEDLP) experiments, by measuring the expansion of a tracer layer as it mixes into the surrounding material. These campaigns used a single platform target exterior that is changed on the interior of the shock tube to be in any of four *Reshock* or *Shear* configurations [9]. The Omega *Reshock* campaign [9] has shown that the BHR model successfully models shock and reshock evolution in the HEDLP regime, even though the model's parameters were set from non-HEDLP hydro conditions [7]. The Omega *Shear* campaign [9, 10] has revealed similar results in the shear geometry, and revealed the dependence of the KH instability on the initial scale length parameter. Additionally, the results revealed indirect evidence of turbulent self-heating via thermal-turbulence coupling [11]. Drawing on the success of this platform, we are extending these experiments to the NIF. We have designed the platform and are currently carrying out experiments, including an ultra-large area x-ray backlighter benchmarking [12, 13].

The *Shear* experimental platforms for Omega and NIF are shown side-by-side in Figure 2. The NIF laser system is capable of delivering up to1.8 MJ, which is 45 times that of the Omega laser system. This allows for much larger experimental volumes, higher drives, and more energy deposited into the system to perform HEDLP experiments. Unlike the Omega experiments, which used direct laser-ablation to produce the shocks in the shock tubes, the NIF experiments use halfraums on the ends of the tube to indirectly drive the ablator with x-rays and produce the shocks, as this allows much longer support times for the shocks (past 10 ns) and gives greater flexibility over the shock strengths and convective Mach numbers.. This source temperature, currently designed for ~ 260 eV, can be tuned by changing the laser energy delivered to the halfraums.

Figure 3 shows the NIF setup of the shock-tube (gold) and iron backlighter (blue), with the UV laser beams in a variety of colors. Only the *outer cone* beams, those at 44.5 and 50 degrees, are used for driving the halfraums, and the *inner cone* beams, those with 23.5 degrees are used for driving the backlighter, with the exception of two *outer cone* beams (50-degree) used to flatten out the backlighter uniformity for a total of 136 kJ of laser energy on the backlighter.

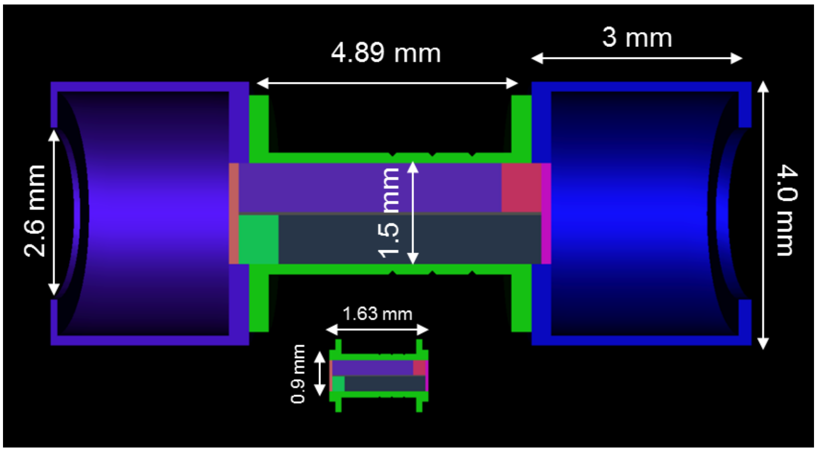

Figure 2. Relative dimensional comparisons of the *(Re)Shock/Shear* platforms for both Omega (bottom) and NIF (top). The NIF platform is indirectly driven by two halfraums (blue) on either end, which push the Rexolite ablators (orange and pink) with 260 eV radiation, instead of directly by the UV laser beams at Omega. The NIF platform, encased in a 250 μm thick Rexolite tube instead of a Be tube (green), is 3 times longer with a 194 times greater volume, allowing for longer experiments and fewer edge effects. The shocks are blocked from propagating on the opposite halves by dense gold plugs (red and light green); such that shocks propagate from opposite directions on either half of the tube. The interior shows the counter-propagating *Shear* geometry, with two foams (purple and dark grey) separated by a tracer layer (light grey).

3. NIF experiment design

The experiment was designed using the hydrocode RAGE, initially using conditions similar to the Omega experiments for comparison. The halfraum drive temperature is chosen to drive a shock of 110 km/s near the Omega experimental conditions. The Reynolds number is designed to be 6E5 (ΔΔ·) and 5E6 (ΔV), with a Zhou's [5] turbulence transition time calculated to be between 3 and 6 ns after the shocks cross. This means that in the NIF experiment, with the shock crossing time of ~17 ns into the experiment, the experiment will be fully turbulent ~23 ns into the experiment. Compared to the Omega experiment, where the shocks cross at 6 ns and the transition time was 5-10 ns after this, meaning it is not fully turbulent until >14 ns. In the Omega experiments, due to the size of the tube, the experiment ends by shocks reflecting off the end plugs back into the tube center at 20 ns. Thus, the

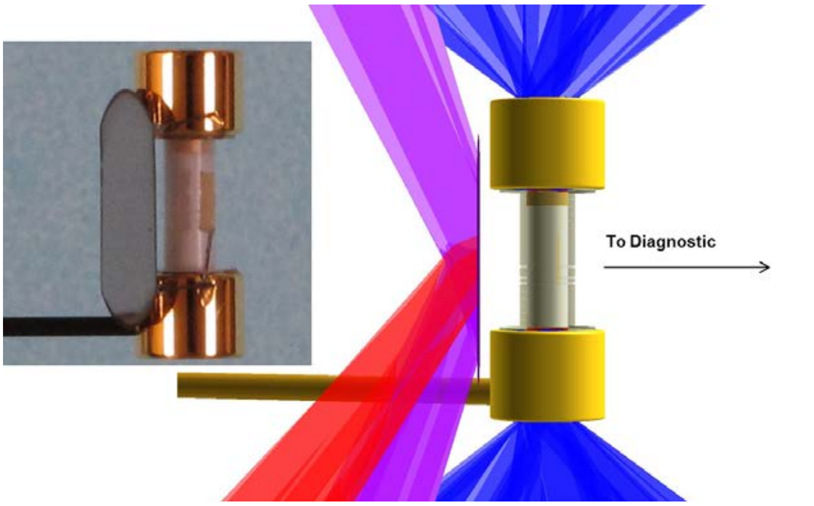

Figure 3. A visual representation of the NIF Shock/Shear setup. The main target (gold) sits at the center of the target chamber supported on a stalk from the left, with halfraums on top and bottom, which are driven by 60 top and 60 bottom *outer* cone beams (blue beams) with 310 kJ each of the halfraums. Two *outer* quads (red) and five *inner* quads (violet) are pointed at the backlighter foil (purple edge-on) driving it with ~163k J of laser energy to produce the radiograph. (*image inset*) The target as actually built.

fully turbulent data set is limited to the last 4 ns. With the NIF platform, we anticipated having at least 7 ns of data, which should be possible to extend even later with the longer delay capabilities of the backlighter beams on NIF, past 30 ns.

Figure 4 shows simulated radiographs using a 6.7 keV Fe x-ray backlighter to follow the expansion and mixing of an aluminum tracer layer initially 20-μm thick. The shocks are produced in 60 mg/cc foams inside two halves of a Rexolite cylinder from opposite directions, kept from propagating from both directions by dense gold plugs, shown in Figure 2, and as dark squares below in Figure 4. These shocks are driven by shooting 310 kJ of laser energy into each halfraum end, which is then converted into the indirect soft x-ray bath heating and ablating a Rexolite end cap, launching the shocks into the tube with a peak pressure of 143 Mbar at approximately 11 ns after the lasers arrive at the target. The shocks propagate at ~Mach 2 from opposite ends and cross around ~17 ns at the center of the tube. This produces a shear on the Al tracer layer at a rate greater than 5 ns^{-1} from a ΔV of 200 μm/ns and a 40 μm initial layer width. This will cause the KH-like shear instability to transition into turbulence 5 ns later, based on the Zhou criteria. These figures of merit will be compared to the experiment to understand whether the BHR model is capturing the NIF experiment, with different conditions than those of the Omega experiment.

Figure 4(right) shows the mix width evolution for the radiographs presented on the left. One can see the evolution of the width as it starts to expand slowly due to pre-heat. Then, at 17 ns, the shocks cross and compress the layer slightly. After that, it begins to re-expand slowly due to the KH instability. Next, the layer begins to turn turbulent. Energy is then extracted from the mean flow, and converted to turbulent kinetic energy. After the transition to fully developed turbulence around 25 ns, the layer growth due to mixing proceeds at an increased rate, instead of reaching hydrodynamic equilibrium which would stop the expansion. This later time expansion is governed only by the turbulence evolution, and not by the initial conditions of the model, which is ultimately the area we would most like to explore in the NIF experiments.

4. Conclusions

The design and simulated results of the Shear platform on the NIF have been discussed in the context of measuring the width of a tracer layer as it undergoes shear instabilities and transitions into turbulence. This experiment will test the extension of the BHR turbulent mix model into a strongly HEDLP regime, where the turbulent energy in the tracer layer is greater than that of the surrounding material, allowing the layer to continually expand, instead of reaching hydrodynamic equilibrium with the surrounding material on the time scale of the experiment.

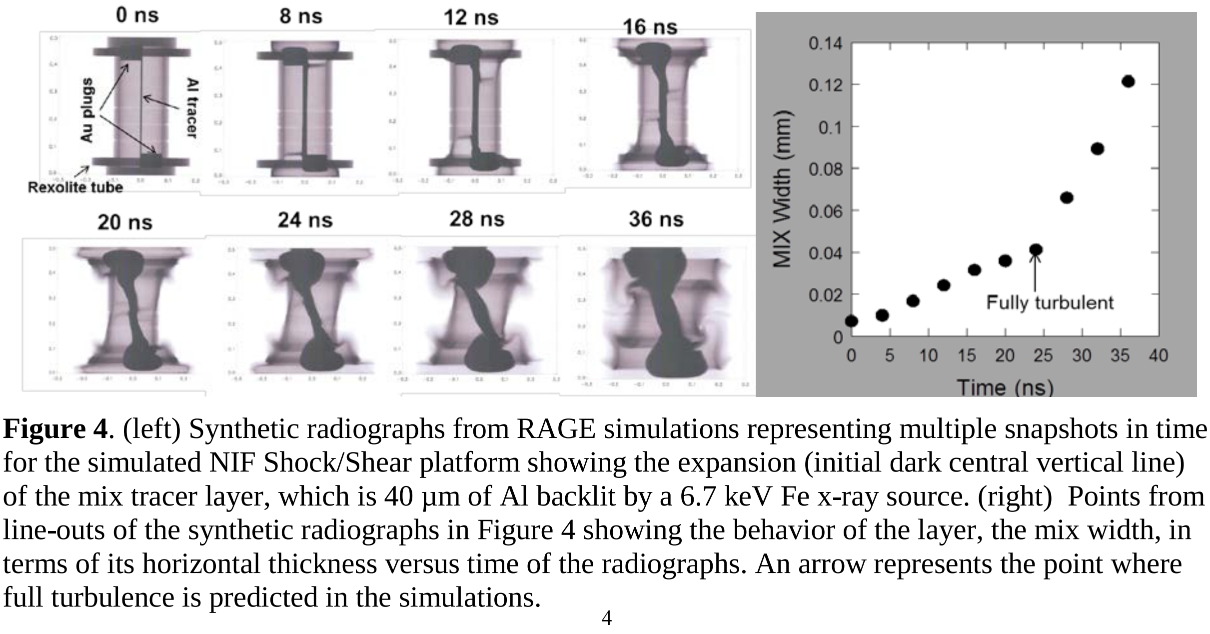

Figure 4. (left) Synthetic radiographs from RAGE simulations representing multiple snapshots in time for the simulated NIF Shock/Shear platform showing the expansion (initial dark central vertical line) of the mix tracer layer, which is 40 μm of Al backlit by a 6.7 keV Fe x-ray source. (right) Points from line-outs of the synthetic radiographs in Figure 4 showing the behavior of the layer, the mix width, in terms of its horizontal thickness versus time of the radiographs. An arrow represents the point where full turbulence is predicted in the simulations.

5. References

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