Simulated Refraction-Enhanced X-Ray Radiography of Laser-Driven Shocks

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X-ray radiography is a useful diagnostic in inertial confinement fusion (ICF) implosions to obtain shock positions by imaging shock waves. Specifically, it has been demonstrated that refraction-enhanced x-ray radiography[1] (REXR) can infer shock-wave positions of more than one shock wave, launched by a multiple-picket pulse in a planar plastic foil. REXR relies on the density gradient across a shock front that deflects x rays from their trajectory through refraction. It also accounts for the attenuation of the x rays as they travel through a denser medium with lower transmission by tracking their intensities. The benefit of this technique over existing x-ray postprocessors such as *Spect3D*[2] is that it includes x-ray refraction.

REXR is successful in overcoming some of the limitations of a velocity interferometer system for any reflector (VISAR) by locating shock waves before shocks merge and during the early time and the main drive of the laser pulse. VISAR does not provide any information about the shock wave early in time because of a time lag associated with the critical surface formation for the diagnostic to work. During the main drive, the high intensity of the laser leads to x-ray photoionization of the target ahead of the shock front. This blanks out the VISAR signal, preventing it from determining the shock wave's location.[3]

A point-projection radiography system was used to image a shock wave in a planar plastic foil on OMEGA [Fig. 1(a)]. The laser drive was comprised of a square pulse with ~350 J of energy that generated the shock wave in the foil. For the x-ray radiography, x rays of 5.2-keV energy corresponding to the He_α emissions of vanadium were projected from a 10-μm pinhole to image the shock wave onto an x-ray framing camera. The framing camera started to acquire the image at 8.63$\pm$0.1 ns after the start of the laser pulse that generated the shock. The target was placed in the middle, 14 mm away from the pinhole and 533 mm away from the x-ray framing camera. This setup was simulated using the hydrodynamic code *DRACO* and the density profiles obtained from it were used to generate the simulated radiograph in Fig. 1(b). Figure 1(c) shows that the relative degree of transmission in the unshocked plastic, shocked plastic, and shocked aluminum with respect to the vacuum was in good agreement between the experiment and REXR. REXR showed that it is necessary to incorporate refraction and attenuation of x rays along with the appropriate opacity and refractive-index tables to interpret experimental images.

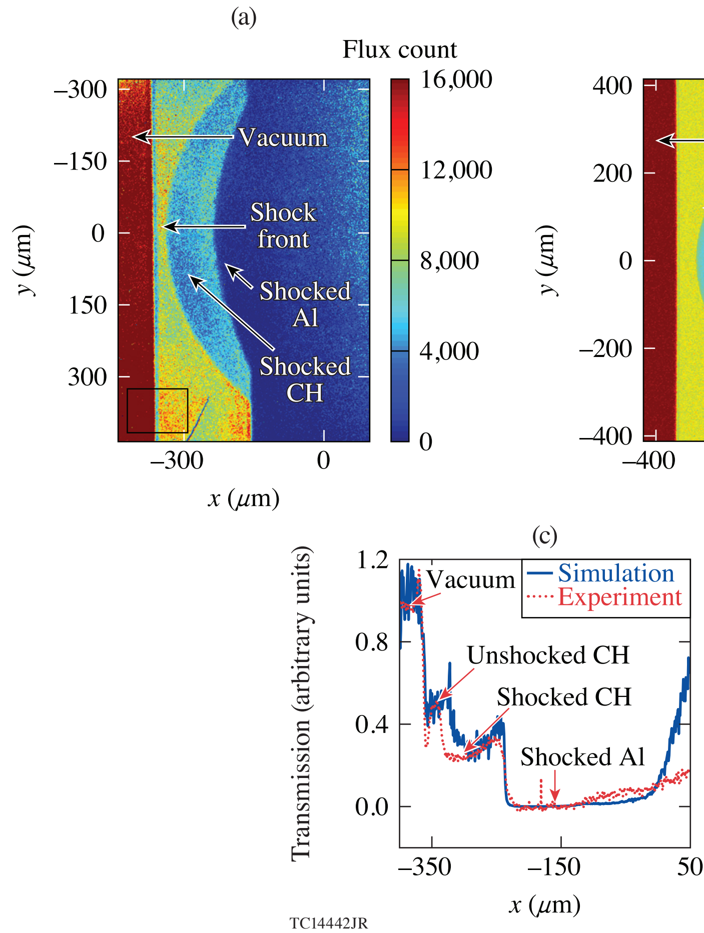

Figure 1
(a) Image obtained from an x-ray framing camera on OMEGA showing the bowing effect of the shock wave in plastic with the main features labeled. (b) Simulated radiograph for the same OMEGA experiment shows the shock profile in a plastic ablator. The x-ray flux is representative of the degree of transmission of the x rays through the different areas: vacuum (in red), unshocked plastic (in yellow), shocked plastic (in cyan), and shocked aluminum (in blue). (c) The transmission curves along the center of the beam axis obtained from the simulated radiograph and the experimental image showed good agreement between them for plastic and aluminum. For reference, the transmission in the vacuum region is set to 1 since there is no attenuation.

An experimental design to image multiple shock waves with REXR was proposed for the laser pulse in Fig. 2(a). Figure 2(b) shows the shock positions early in time and during main drive pulse that can be inferred from REXR when experimental diagnostics such as VISAR fail to locate the shock positions. REXR can be applied to design multiple-picket pulses with a better understanding of the shock locations. This will be beneficial to obtain the required adiabats for ICF implosions.

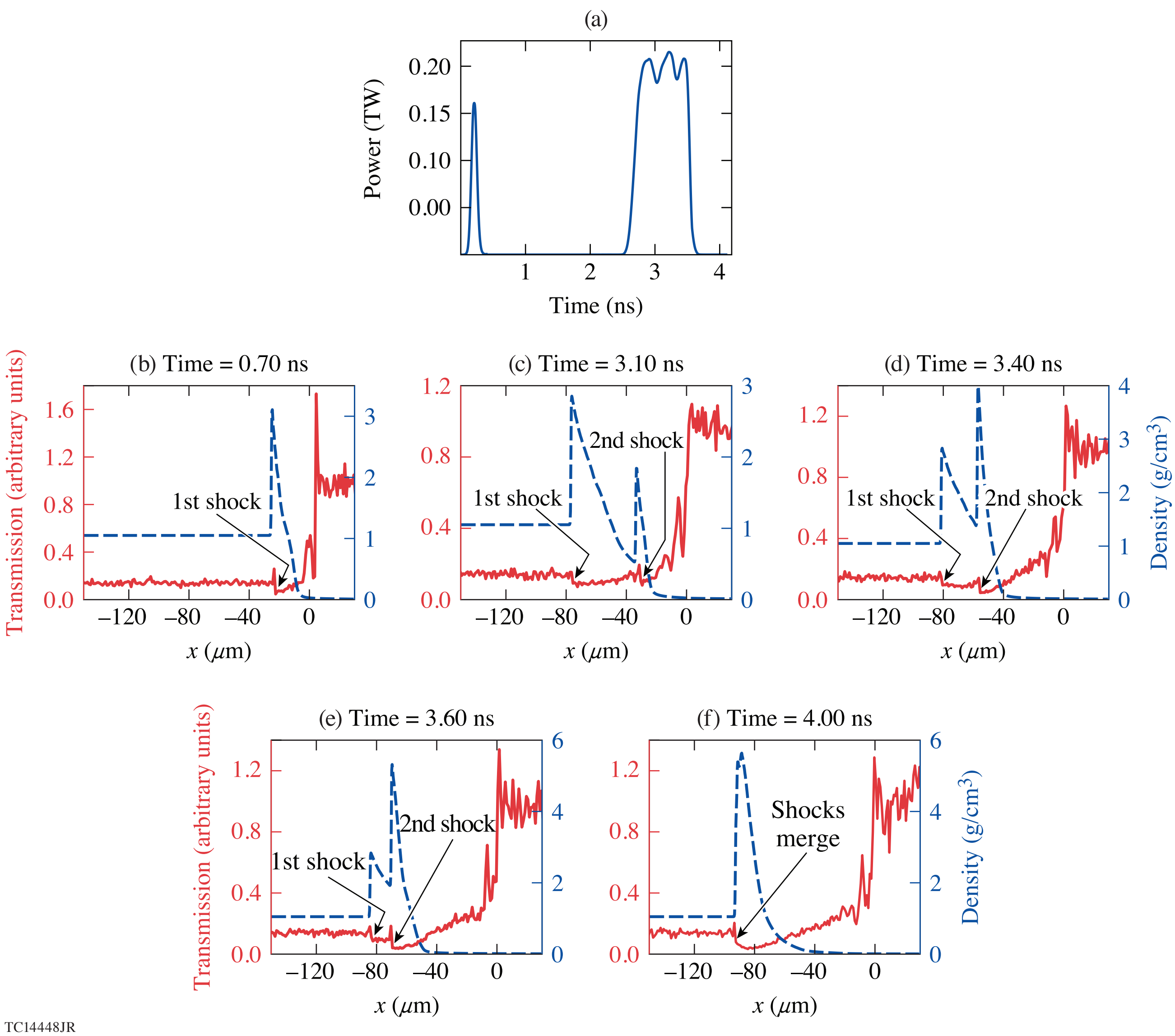

Figure 2
(a) A single-picket pulse with a main drive pulse of 190-J energy that launches two shock waves whose positions were inferred. [(b)–(f)] The transmission (red) and density profiles (blue) across the center of the beam axis obtained for the pulse shape in (a). The transmission has been scaled so that the intensity in the vacuum region is 1. The spikes followed by the dip (local minimum) in the transmission curve correspond to the shock fronts as labeled. The density profile also spikes at those points to illustrate this fact.

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3. T. R. Boehly *et al*., Phys. Plasmas **13**, 056303 (2006).