High Energy Density Physics 23 (2017) 90–94

Contents lists available at ScienceDirect

High Energy Density Physics

journal homepage: www.elsevier.com/locate/hedp

Demonstration of repeatability in a high-energy-density planar shear mixing layer experiment

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ARTICLE INFO

Article History:
Received 4 October 2016
Revised 3 March 2017
Accepted 11 March 2017
Available online 11 March 2017

Keywords:
High-energy-density plasmas
Instabilities

ABSTRACT

On laser-driven platforms the assumption of experiment repeatability is particularly important due to a typically low data acquisition rate that doesn't often allow for data redundancy. If the platform is repeatable, then measurements of the repeatable dynamics from multiple experiments can be treated as measurements of the same system. In high-energy-density hydrodynamic instability experiments the interface growth is assumed to be one of the repeatable aspects of the system. In this paper we demonstrate the repeatability of the instability growth in the counter-propagating shear experiment at the OMEGA laser facility, where the instability growth is characterized by the tracer layer thickness or mix-width evolution. In our previous experiment campaigns we have assumed the instability growth was repeatable enough to identify trends, but in this work we explicitly show that the mix-width measurements for nominally identical experiments are repeatable within the measurement error bars.

1. Introduction

A key underlying assumption to all laser-driven high-energy-density (HED) experiments is that the important dynamics of the system are repeatable over the course of multiple experiments as long as the defining metrics of the platform remain constant [1–4]. Experiment repeatability allows one to map the entire evolution of a system, even when diagnostics are only capable of capturing portions of a single experiment due to limitations like small-temporal or spatial windows compared to the experiment scales. If the platform is repeatable, then measurements of the repeatable dynamics from multiple experiments can be treated as measurements of the same system. While this basic technique is true in many types of experiments in many fields, on laser-driven platforms it is particularly important due to a typically low data acquisition rate that doesn't often allow for data redundancy.

In HED hydrodynamic instability and turbulence experiments interface growth is assumed to be one of the repeatable aspects of the system, so this class of experiments is often diagnosed with some form of imaging of the instability interface which effectively makes a movie of the system using frames from several different experiments [5–9]. The LANL counter-propagating (CP) shear experiments are part of this class of HED instability experiments [10,11]. These experiments examine Kelvin–Helmholtz (KH) shear instability growth as seeded by variety of different boundary initial conditions [12,13]. In general we define the experiment 'platform' as the overarching experiment setup, including laser drive and target geometry. Since the purpose of these experiments is to study the instability under a variety of initial conditions, and the instability growth has been shown to vary significantly between different initial conditions, it is useful to define the set of experiments for each individual set of initial conditions as a single 'campaign'. Every individual experiment, or 'shot', in a campaign corresponds to a single physical target which is destroyed in the process of the experiment. With our current data acquisition rate for experiments at the OMEGA laser-facility, and even with the increased data acquisition rate for the associated NIF experiments, we require multiple shots per campaign to measure the instability evolution. So the underlying assumption for our platform is that the instability growth is repeatable within a campaign and we should be able to treat the images of our time sequence obtained by separate shots as realizations of the same underlying target with minimal considerations of shot-to-shot variation. In this manuscript we demonstrate repeatability at the shot-level within a campaign by repeating image timings, where we define repeatability as measurement agreement within the diagnostic and data analysis error of the platform.

2. Experiment platform

In this manuscript we will focus on results from the OMEGA counter-propagating shear platform. This platform uses a physics package located inside of a ~1.5 mm long, 0.5 mm inner diameter Be cylindrical shock tube [14]. The physics package (Fig. 1a) consists

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http://dx.doi.org/10.1016/j.hedp.2017.03.007
1574-1818/

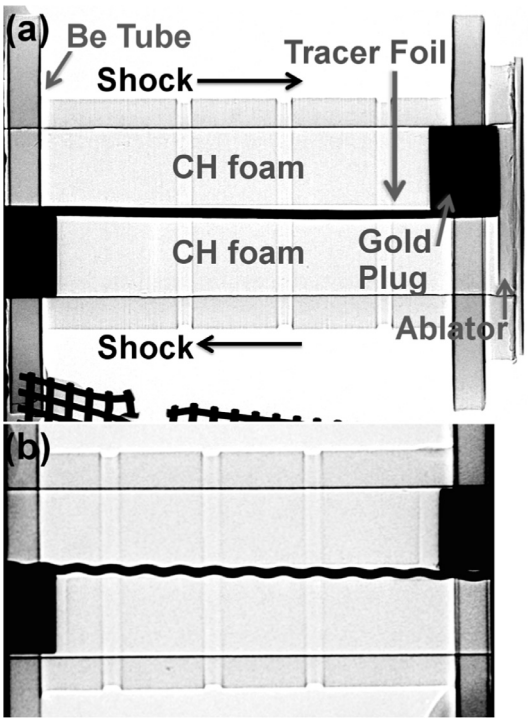

Fig. 1. (a) Pre-shot radiograph of a representative smooth/flat foil target with labeled components.The target consists of a cylindrical Be tube around two hemi-cylindrical foams separated by a metal 20 μm thick Al tracer layer. The radiograph shows the ablator cap on the right side, which is directly irradiated to launch shocks into the system. Gold plugs at the ends of the tube block the shocks on that side of the tracer foil to create the counter-propagating shock geometry. (b) Pre-shot radiograph of a representative sinusoidal foil target with a 20 μm thick Al foil with $\lambda = 100$ μm.

of two hemi-cylindrical low-density (60 mg/cm^3) CH foams around a thin solid metal plate which serves as a tracer layer. At opposite ends of the foams are two solid-gold 0.2 mm thick hemi-cylindrical plugs. At both ends of the Be tube are 0.075 mm Rexolite (polystyrene) ablator caps. Lasers directly irradiate the ablators to launch 110 μm/ns shocks into the physics package, which are partially blocked by the gold plugs and collimated by the metal plate. This geometry results in two nominally identical counter-propagating shocks above and below the metal plate. When the shocks cross in the center of the system it creates a region of pressure-balanced shear flow. RAGE simulations estimate post-shock flow speeds of 70 μm/ns, ~ 2 Mbar pressures and ≈ 40 eV temperatures in the foams. The Reynolds number of the system has previously been estimated to be Re~ 10^6–10^7 [12]. We only change the tracer layer characteristics to vary the initial conditions that seed the KH evolution. Each different set of tracer layer characteristics, such as tracer layer material [12,13] or surface profile [15,16], is considered it own campaign.

In this paper we demonstrate the repeatability of the instability growth, as represented by the tracer layer thickness or mix-width evolution, for several different initial condition campaigns. We show shot-to-shot mix-width repeatability within measurement error at one shot time from our sinusoidal foil campaign with a 20 μm thick Al tracer and an initial sinusoidal perturbation (Fig. 1b) of wavelength $\lambda = 100$ μm (width of a single-peak, not the full 2π wavelength) coined into the foil [14]. We also show mix-width agreement within error bars for a larger experiment time window by comparing results from our campaign with smooth 20 μm thick Al foils (Fig. 1a) with results from a campaign with $\lambda = 200$ μm foils. The smooth Al foil results have previously been presented in [11] and [12]. The results from the smooth and $\lambda = 200$ μm campaigns are considered to be equivalent enough here to make assumptions about repeatability because variation in the instability growth, as represented by the mix-width, due to the fact that the difference in initial conditions is below the diagnostic and analysis resolution of the experiments.

3. Experiment results

The most direct way to demonstrate repeatability within a campaign is to compare results from multiple identical shots. In the current CP shear platform the only deliberate variation between campaigns is the design of the tracer foil and the diagnostic setup. Thus two shots using the same tracer foil, camera and detector, and x-ray backlighter (BL) material can be considered identical. Previous experiments [12] already demonstrated that otherwise identical shots do not yield repeatable instability mix-widths with the current data analysis techniques for significant variation in the detector sensitivity.

To compare the instability growth across shots we focus on the experiment time window of 10 ns $\leq t \leq$ 14 ns, after the passage of transients behind the shock front and after the experiment has entered the linear KH phase. Figure 2a,b shows the radiographs from a set of nominally identical shots for the campaign using $\lambda = 100$ μm sinusoidal foils and measured at 10 ns after the initial drive using scandium BLs onto an x-ray framing camera with a CCD detector. These two shots were taken on two different shot days, where shot 77604 was from Shear 15B in June 2015 and shot 80966 was from Shear 16B in April 2016. The drive for these two shots was the same to within < 1% for both the total energy and energy balance between the two sets of drive beams. Shot 77604 had a total drive energy of 7714 J, where the two sets of drive beams had energies of 3850 J and 3863 J. Shot 80966 had a total drive energy of 7646 J, the sets of drive beams had energies of 3813 J and 3834 J. The sinusoidal foil profiles for the two shots had the same wavelength and similar surface roughness, but a significant difference in the sine wave amplitudes due to batch-to-batch variation in the repeatability of the coining method used to imprint the waves on the foils. The foil used in shot 80966 had an rms surface roughness of 0.52 μm and an amplitude of 1.67–1.91 μm, as determined using a sinusoidal fit to surface scans of both sides of the foil. A representative foil from the target batch containing the target for shot 77604 showed only a slightly larger rms surface roughness, 0.72 μm, but a greater than factor of two larger amplitude of 4.01–4.21 μm.

We focus our analysis near the center of the shock tube (as shown by the delineated areas in Fig. 2a,b), where the experiment in shear flow dominated since the shear instability growth is only measurable we assume to be repeatable. Near the ends of the shock tube where the platform is more dominated by transient shock interactions, for example with the end of the foil and corner of the gold plug which cause the large s-shaped wisp structures, there is always structure shot-to-shot variation. This variation is expected since the transients are not assumed to be repeatable. These radiographs do show variation in the experiment center as well between the shots, where periodic structure is more evident on shot 77604. The difference in structure present is most likely due to variation in on-shot BL intensity since shot 77604 has a BL signal 2–3 times higher, ~2000–3000 counts, than shot 80966, ~1000 counts, in the region of interest.

Mixing half-widths and error bars for the $\lambda = 100$ μm foils were determined using the fitting metrics in [12], but were additionally averaged over an ≈ 100 μm window about the center of the tube (Fig. 2a,b)). Specifically, the values are averaged over the results of $\lambda/(w/2) \approx 20$ overlapping sub-windows of the image where the window width is $w = 10$ μm. Each sub window is the same sub-window used in previous work to determined a single averaged line-out. The individual line-outs for each sub-window are shown in Fig. 2c,d as