Hydrodynamic growth experiments with the 3-D, “native-roughness” modulations on NIF

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Abstract. Hydrodynamic instability growth experiments with three-dimensional (3-D) surface-roughness modulations were performed on plastic (CH) shell spherical implosions at the National Ignition Facility (NIF). The initial capsule outer-surface roughness was similar to the standard specifications (“native roughness”) used in a majority of implosions on NIF. At a convergence ratio of ~3, the measured tent modulations were close to those predicted by 3-D simulations (within ~15-20%), while measured 3-D, broadband modulations were ~3-4 times larger than those simulated based on the growth of the known imposed initial surface modulations. One of the hypotheses to explain the results is based on the increased instability amplitudes due to modulations of the oxygen content in the bulk of the capsule. These new experiments results have prompted looking for ways to reduce UV light exposure during target fabrication.

1. Introduction
Hydrodynamic instabilities, including Rayleigh-Taylor, Richtmyer-Meshkov, and Kelvin-Helmholtz instabilities, and mix play a central role in the implosion performance degradation. Any drive asymmetries and surface imperfections are amplified by the hydrodynamic instabilities during implosion resulting in a distorted shell with reduced hot-spot temperature, volume, and pressure [1]. In addition, small-scale turbulence seeded by these instabilities can mix ablator material into the DT hot spot [1].

Fig. 1. Experimental configuration Au hohlraum, plastic (CH) capsule, Au cone, and an iron backlighter.
The presence of mixed ablator material was correlated with reduced experimental yields and temperatures in high-compression layered DT implosions [2] in experiments during National Ignition Campaign (NIC). Several experimental platforms have been developed to measure and understand various aspects of the instability growth on NIF. Recent experiments with the Hydrodynamic Growth Radiography (HGR) platform were used to study instability growth using large-amplitude, two-dimensional (2-D) pre-imposed modulations [3].

These experiments showed that the measured instability growth of sinusoidal outer surface ripples were modeled well with 2-D simulations [3]. This article describes experiments with the 3-D, “native-roughness” modulations. They were measured at ignition relevant conditions on NIF and compared with 3-D simulations. In addition to the 3-D surface-roughness growth, these measurements included imaging of the modulations caused by a support membrane (the “tent”) used to hold capsules in a hohlraum, and pre-imposed divots. The experimental configuration is described in Sec. 2; while the modulation growth data are discussed in Sec. 3. The results are summarised in Sec. 4.

2. Experimental configuration
The experimental configuration used in the experiments is shown in Fig. 1. It is similar to the HGR platform used in earlier experiments [3] to measure instability growth with 2-D modulations during acceleration phase. The configuration includes a Au hohlraum, a plastic (CH) capsule, a Au cone, and an iron backlighter. The experiments were conducted with laser drives and conditions similar to those used in high-compression layered DT implosions [4]. They were designed to test the acceleration phase hydrodynamic growth predictions used to model these DT layered implosions that achieved fuel areal densities of ~1.2 g/cm², peak fuel velocities of ~320-330 km/s, and peak radiation temperatures of ~300 eV [4].

The nominal 209-µm thick plastic capsule with nominal 1120-µm outer radius had the same Si-doped layers as used in the previous DT layered implosions [4]. These capsules used an extra 20-µm thick CH layer to replace the 69-µm thick DT ice layer, thereby
maintaining approximately the same shell mass as in the layered DT implosions. The
capsule had two divots that were imprinted on the surface by laser ablation, to be spatial
fiducials for the convergence measurements. The divots were both ~40-μm wide, with
peak-to-valley amplitudes of ~260 nm and ~280 nm.

Fig. 4. Measured Fourier amplitudes of optical-depth modulations in the central, 360-μm square region (thick solid curve), compared to the simulated optical-depth modulations (thin solid curve).

The target also used two different support membranes (“tents”), with 110-nm and 45-nm thickness, located at the lower and upper parts of the target, respectively. The modulation growth was measured with through-foil x-ray radiography [5] using ~6.7-keV x-rays generated by the iron backlighter, which was located 12 mm from the target center [5]. X-ray images of the growing capsule modulations were formed using 20-μm diameter pinholes located 80 mm from the capsule. The images were captured using a framing camera [5] with a magnification of ~8 for the imaging system.

3. Ablation-front Rayleigh-Taylor instability experiments

Figure 2 shows measured capsule optical-depth (OD) x-ray image on a framing camera. It represents an average of 30 independent intensity images captured during a ~240-ps temporal range. The dark color in Fig. 2 represents areas of stronger backlighter x-ray absorption (or spikes), while the light color represents areas of weaker backlighter x-ray absorption (or bubbles). One can see the locations of both 45-nm and 110-nm tents, two divots, and non-systematic 3-D modulations in this image. In addition, the “eye” feature is also prominent in the central part of this OD image. Such a feature was not measured in outer-surface capsule characterization, indicating it could have been present in the bulk of the shell, or created during target assembly subsequent to characterization, as will be discussed later. Figure 3 shows a comparison of the measured tent data with the simulations. In the experiment, the peak-to-valley of the 110-nm tent modulation of ~0.4 OD was larger than that of the 45-nm tent by a factor of 1.5. Such large tent modulations would be expected to significantly degrade the performance of the layered DT implosions. In the simulation, the predicted modulations were in fair agreement with the measured ones, as shown in Fig. 3(b). The widths of the modulations were similar in experiment and simulations, however the shapes of the modulations were slightly different. The spikes on sides towards capsule center are more evident in simulation than data, indicating the difference in the modulation shapes. On average, the simulated tent amplitudes were ~20% lower than the measured amplitudes [5].
The modulation growth of the randomly seeded 3-D modulations was quantified by analyzing the central 360-μm square parts of the measured radiographs, away from the tent and divot modulations. This is quantitatively demonstrated in Fig. 4 by comparing the optical-depth Fourier spectra of the measured and predicted modulations. The measured modulations do not resemble the simulated modulations, indicating that they do not originate from the outer-surface modulations, but come from some other seeds, possibly from modulations in the bulk of the capsule [5]. These results are consistent with the hypothesis that spatially non-uniform oxygen contamination in the bulk of the capsule could seed significant modulation growth [6]. Oxygen absorption is increased by exposure to UV or to visible light [6]. The targets used for layered DT implosions routinely experience UV and visible light during handling and assembly procedures, and modulations in exposure are very likely. Coherent features like the “eye” in Fig. 2 could very plausibly arise from differential exposure to light or UV. Experiments with reduced UV exposure were recently performed and the measured image is shown in Fig. 5. The lack of “eye” feature in Fig. 5 suggests that that reduced UV exposure can eliminate these oxygen-induced modulations.

![Image](image.png)

**Fig. 5.** Optical-depth image of the modulations in a shot with reduced UV exposure during target assembly. The round feature in the middle of the image was expected to grow from the feature measured on the capsule before the experiment. The “eye” feature was not present in this shot, suggesting the new assembly procedure was able to eliminate it.

4. Conclusions
Hydrodynamic instability growth of three-dimensional (3-D) surface-roughness modulations was studied in spherical implosions at the National Ignition Facility. The measured 3-D broadband modulations were ~3-4 times larger than those simulated based on the growth of the known imposed initial surface modulations. These modulations included a striking systematic feature, presumably originating from some part of the target fabrication process. The hypothesis to explain the results is the seeding of instability growth by modulations of the oxygen contamination in the bulk of the capsule.

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