Hydrodynamic instability measurements in DT-layered ICF capsules using the layered-HGR platform

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Abstract. The first measurements of hydrodynamic instability growth at the fuel-ablator interface in an ICF implosion are reported. Previous instability measurements on the National Ignition Facility have used plastic capsules to measure ablation front Rayleigh-Taylor growth with the Hydro-Growth Radiography (HGR) platform. These capsules substituted an additional thickness of plastic ablator material in place of the cryogenic layer of Deuterium-Tritium (DT) fuel. The present experiments are the first to include a DT ice layer, which enables measurements of the instability growth occurring at the fuel-ablator interface. Instability growth at the fuel-ablator interface is seeded differently in two independent NIF experiments. In the first case, a perturbation on the outside of the capsule feeds through and grows on the interface. Comparisons to an implosion without a fuel layer produce a measure of the fuel's modulation. In the second case, a modulation was directly machined on the inner ablator before the fuel layer was added. The measurement of growth in these two scenarios are compared to 2D rad-hydro modeling.

1. Introduction
Understanding and mitigating the hydrodynamic instability growth that occurs during the implosion of an inertial confinement fusion (ICF) capsule is important for improving performance in experiments on the National Ignition Facility (NIF). This has been the focus of an experimental campaign using face-on radiography to measure the in-flight growth of pre-imposed perturbations [1, 2]. Thus far, good agreement between simulations and the observed growth has been found at several mode numbers and using several pulse shapes. These hydro-growth radiography (HGR) measurements were made on gas-filled plastic capsules (called symmetry capsules or “symcaps”), where the thickness of the ablator is increased to compensate for the missing DT fuel mass. It is expected that ablation front growth is similar between a symcap and a capsule with a DT ice layer, but this has not been experimentally verified. Additionally, the fuel-ablator interface can be unstable and mix ablator material into the fuel. Recently the first experiments directly measuring instability growth in the presence of a DT ice layer have been conducted [3] and are reported here.
2. Experimental Setup

These experiments have perturbations on two separate surfaces. The first set of experiments uses perturbations on the outer surface of the ablator. This perturbation feeds through to the fuel-ablator interface and grows through the Rayleigh-Taylor and Richtmyer-Meshkov instabilities. The effect on the interface is identified by comparison to a separate experiment using a symcap with identical outer-surface perturbations. In the second experiment, a perturbation is machined directly on the inner ablator surface, between the DT ice and the CH plastic.

The setup for these experiments is shown in Fig. 1(a). The capsule is placed on an Au cone, centering it within the Au hohlraum. Of NIF’s 192 laser beams, 184 are directed into the hohlraum, with the remaining 8 laser beams pointed towards a scandium backlighter, creating 4.5 keV x-rays. The backlighter x-rays pass down the axis of the cone, through half the shell of the capsule as it is imploding, out a high-density carbon (HDC) window in the wall of the hohlraum, through a 12 µm wide slit, and finally are recorded by the gated x-ray detector (GXD). The GXD is timed to record images at four times as the capsule is imploding.

These targets are similar to the ignition-scale design[4] used during the National Ignition Campaign (NIC), but scaled down by 0.8× in order to be hydrodynamically similar yet operate at reduced laser energy (and reduced laser damage). The laser pulse has 0.9 MJ of energy and a peak power of 230 TW. The capsule for the DT layered experiment is 909 µm in radius with a 153 µm thick CH ablator and a DT ice layer that is 55 µm thick in the field of view. The ablator contains graded silicon dopant of up to 2.5% to block high-energy x-ray preheat. The symcap contains 10 µm of additional CH to account for the absent DT mass.

The target for the inner-surface perturbation experiment is shown in Fig. 1(c). The ice layering process was precisely controlled so that the ice would be a uniform 55 µm thickness over ±90° and have minimal grooves within the field of view. The perturbation at the interface can be seen in the radiograph. This perturbation was imposed through a new technique using laser ablation[5]. After the hole for the Au cone was cut into the capsule, a UV laser was used to remove individual spots to create a sinusoidal mode 60 pattern. This technique also left higher-mode features the size of the laser spot (mode ~500). Because of these higher mode
features and the small amplitude growth expected at the interface, only a single wavelength was included on this experiment to simplify the analysis. While high modes (∼1000) are of the most interest at this interface because they reflect the in-flight Atwood number, those small scales are challenging to measure. Mode 60 was chosen because it is expected to grow to a measurable size and can be compared to the outer-surface experiment.

The outer-surface perturbations for the comparison between the symcap and the layered capsule were made using a lathe technique, similar to past HGR experiments. Side-by-side perturbations of modes 60 and 90 and amplitude of 0.7 µm are used, chosen because modes near 60 are expected to grow the fastest. These perturbations are shown at the bottom of Fig. 2(a). The perturbation amplitudes for all experiments are chosen so that the radiograph has sufficient contrast (optical depth modulation of ∼0.1 during the measurement), requiring perturbations that are much larger than those that natively appear on NIF capsules.

3. Results
The results from outer-surface perturbation experiments are shown in Fig. 2(a). The images from the GXD were processed to show optical depth and the spatial dimension was converted to angle around the capsule by aligning individual perturbations. A similar amplitude is observed between the symcap (dashed) and layered capsule (solid) at the earliest time, but later in time the symcap appears to grow larger. This effect is reproduced in post-shot modeling and occurs when the ablation front growth feeds through to the interface. In the simulations, both capsules have the same ablation front perturbation amplitude and the same ρR (∫ρdr) modulation, but the low opacity of the DT fuel to the x-ray backlighter compared to the CH results in less observed optical-depth (∫κρdr) modulation.

The single mode amplitudes from these experiments are shown in Fig. 2(b) and compared with post-shot simulations using HYDRA[6]. Here the transfer function of the imaging system has been corrected for. Good agreement is found between the simulations and the data, with the simulation falling within the error bars of most data points. Both the experiments and the simulations show the optical depth modulation amplitude growing larger in the symcap than in the layered capsule. As mentioned previously, this is consistent with both the ablation front amplitude and the ρR amplitude being similar between the two capsules, but a lower optical
depth modulation due to feed-through of growth to the interface and the low DT opacity.

Results from the experiment with a perturbation at the interface are shown in Fig. 3(a). The 2.2 µm amplitude mode 60 perturbation is shown at the bottom of this figure. The phase of the perturbation was expected to invert from the initial condition, but this cannot be constrained given the uncertainty in angle between the initial condition and the in-flight radiographs. In the data, moderate amplitude growth can be observed between the earliest and latest time. There are also variations in the modulations further from the center of the target (the spike at θ=10-15° appears larger than in the center). This is an effect also observed in simulations and appears to be due to the curvature of the capsule - rays going at an angle (rather than radially, as with θ=0°) have a longer path length (and optical depth).

The sinusoidal amplitude from the center three waves are shown in Fig. 3(b). Two post-shot calculations are also shown in this figure. When only mode 60 is included in the calculation and higher modes are filtered out, the simulation shows good agreement with the earlier time data but over-predicts the late-time growth. The high-mode structure, resulting from the laser-ablation process used to create the perturbation, is included in the “multimode” calculation. The growth in this case saturates later in time, with high modes coupling to lower modes. This case shows good agreement with all of the experimental data. This suggests that high-mode features may be influencing current measurements. Future experiments will seek to directly measure the growth of these small wavelengths.

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