Simulations of symcap and layered NIF experiments with top/bottom laser asymmetry to impose P1 drive on capsules

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Abstract. Integrated hohlraum/capsule post-shot simulation of the first full-scale cryogenic layered-DT experiment with top/bottom laser asymmetries of 8% is discussed. The imposed P1 Legendre mode drive on the capsule results in downward velocity of 85 ± 15 km/s as measured by neutron time of flight (NTOF) diagnostics and x-ray imagers, which is in excellent agreement with the calculated velocity of 87 km/s. The measured DT yield is approximately 30% less than the average of two comparable shots using the same 4 shock HiFoot pulse shape without drive asymmetry. The calculated DT yield of 5.0e15 is very close to the measured value of 4.86e15 for the shot with drive asymmetry, which implies that P1 effects dominate yield reduction. The neutron activation diagnostics (NADs) give clear indication of higher areal density in the direction of the north pole in excellent agreement with calculations. Integrated post-shot simulation of an earlier symcap (capsule with appropriate ablator thicknesses to act as a surrogate for an ignition capsule) experiment with laser asymmetries show that calculated neutron-wighted velocity is a strong function of capsule shape.

1. Introduction

In approximately 50% of NIF layered shots the neutron time of flight (NTOF) diagnostics show that the capsule has a bulk velocity of 50 km/s or greater for reasons that are not clearly understood[1]. Capsule only simulations have shown that radiation drive asymmetries and associated bulk capsule motions can be a source of yield reduction[2]. In order to understand the effects of bulk capsule motion a number of experiments have been conducted with top/bottom laser asymmetries using various scale targets and different capsule types. In this paper we focus on the latest one (N150318), which is a full-scale cryogenic layered-DT experiment with top/bottom laser asymmetries of 8%. We also discussed results from post-shot simulations of an earlier (N130625) CH symcap (capsule with appropriate ablator thicknesses to act as a surrogate for an ignition capsule) experiment with similar laser asymmetries.

Our integrated hohlraum/capsule post-shot simulations determine the drive asymmetry from laser asymmetries and hohlraum dynamics. We use measured laser powers but backscatter data is only available on a subset of inner and outer beams in the bottom half of the NIF chamber. We
assume that the backscatter power scales with laser power to estimate the backscatter for other beams. Separate plasma conditions at the upper and lower hohlraum laser entrance holes (LEHs) are used to calculate the crossbeam energy transfer between the outer and inner beams[3]. We use the same crossbeam saturation model for upper and lower beams.

2. Results

The NIF laser drive for shot N150318 is 4% higher/lower than nominal for the upper/lower beams, which produces a nonuniform radiation drive on the capsule giving an initial drive $P_1/P_0$ Legendre mode ratio of approximately 4%. However, radiation of x-rays within the hohlraum smooths the nonuniformity so that the drive $P_1/P_0$ ratio is approximately 2% at time of peak drive. This is shown in Figure 1 along with time dependence of the drive. This imposed $P_1$ drive on the capsule results in downward velocity of $85 \pm 15$ km/s as measured by neutron time of flight (NTOF) diagnostics and x-ray imagers, which is in excellent agreement with the calculated neutron-weighted velocity of 87 km/s. The total laser energy was 1.78 MJ, a measured DSR (down scatter ratio, 10-12/13-15 MeV neutrons) of 2.6%, and a implosion velocity of $371 \pm 20$ km/s. The measured DT yield is approximately 30% less than the average of two comparable shots (N140520 and N150121) using the same 4 shock HiFoot pulse shape but no drive asymmetry. The calculated yield for shot N140520 is approximately 2 times larger than what was measured[4]. Such a difference is common when the simulation does not include detailed calculations of the capsule support tent and 3D effects. In contrast, for the shot being studied here with drive asymmetry the calculated DT yield of $5.0e15$ is very close to the measured value of $4.86e15$ implying $P_1$ effects dominate yield reduction.

The neutron activation diagnostics (NADs) give clear indication of higher areal density in the direction of the north pole as seen in the right image of Figure 2 where the angular dependent DT yields relative to the average yield are shown. In order to compare with the 2D simulation, we give the relative yield as a function of angle from south pole to north pole in the left image. The calculated curve is in excellent agreement with the data. The reduction of yield in the direction of the north pole is due to neutron scattering by a high density region at the upper portion of the capsule as seen in Figure 3. The density is given at the time of peak of the x-ray emission (16 ns). The center of capsule has been shifted downward by approximately 25 microns at this time.

The post-shot simulation for N150318 uses a crossbeam transfer model that results in an
Figure 2. Left image is the measured (dots) change in yield going from south to north pole from the neutron activation diagnostics (NADs) and the calculated angular dependence (curve). Error in data is slightly less than size of dots. Right image shows the data for all locations.

Figure 3. The calculated density at time of peak x-ray emission showing higher areal density in the direction of the north pole.

Figure 4. Left images are x-ray emission and primary neutrons and simulation results on right. The 17% contour shown on 3 images.

inner/outer laser-beam cone fraction that is slightly greater than 0.4 during the rise to peak power dropping to approximately 0.25 during peak as transfer is shutoff. The measured x-ray emission and primary neutron images and corresponding images generated from the simulation are given in Figure 4. The calculated images are only slightly more pancake than data. The post-shot simulation for N140520 that matches measured x-ray images uses a smaller saturation parameter that gives an inner/outer cone fraction of 0.3 during the rise and the same 0.25 during peak[3]. Using this amount of transfer for N150318 gives severely pancaked images that are not consistent with the data. Ideally the same saturation model for crossbeam transfer and laser-drive multipliers that give good agreement with data on x-ray emission shape and bang times on
the control shots are used for the corresponding shots with drive asymmetry. However, our post- shot simulations of an earlier syncap experiment (N130625) with top/bottom laser asymmetries showed that simulations with incorrect shapes can produce neutron-weighted that are an order of magnitude lower than measured[5]. Thus it can be necessary to adjust crossbeam parameters to match observed x-ray images, which is what is done for N150318. The same laser-drive multipliers that were used for N150520 are used for N150318.

The calculated ion temperature at time of peak x-ray emission is shown in Figure 5. The peak temperature at this time is less than 1/2 the peak value of 7 keV, which occurred approximately 200 ps earlier. The calculated DT neutron production per unit volume at 16 ns (log scale) is shown in Figure 6. The location of peak production is a function of density and Tion. The time of peak neutron production is approximately 50 ps later.

3. Summary
Results from an integrated hohlraum/capsule post-shot simulation of the first full-scale cryogenic layered-DT experiment with top/bottom laser asymmetries are in excellent agreement with the data. In particular, NADs give clear indication of higher areal density in the direction of the north pole in excellent agreement with calculations. In order to match x-ray emission and primary neutron images, a cross beam transfer model with more transfer during the rise to peak power is needed for a comparable shot without drive asymmetry. The agreement between calculated and measured yield implies that P1 effects dominate yield reduction.

4. Acknowledgements
Work was performed under the auspices of the U.S. Dept. of Energy by LLNL under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC. LLNL-JRNL-679579

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