

## A new symmetry model for hohlraum-driven capsule implosion experiments on the NIF

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**Abstract.** We have developed a new model for predicting the time-dependent radiation drive asymmetry in laser-heated hohlraums. The model consists of integrated Hydra capsule-hohlraum calculations coupled to a separate model for calculating the crossbeam energy transfer between the inner and outer cones of the National Ignition Facility (NIF) indirect drive configuration. The time-dependent crossbeam transfer model parameters were adjusted in order to best match the P2 component of the shape of the inflight shell inferred from backlit radiographs of the capsule taken when the shell was at a radius of 150-250  $\mu\text{m}$ . The adjusted model correctly predicts the observed inflight P2 and P4 components of the shape of the inflight shell, and also the P2 component of the shape of the hotspot inferred from x-ray self-emission images at the time of peak emission. It also correctly captures the scaling of the inflight P4 as the hohlraum length is varied. We then applied the newly benchmarked model to quantify the improved symmetry of the N130331 layered deuterium-tritium (DT) experiment in a re-optimized longer hohlraum.

### 1. Introduction

Minimizing low mode asymmetry in the radiation drive is required to efficiently implode ICF capsules at high convergence [1]. Low mode drive asymmetry of NIF implosions has primarily been diagnosed by measuring the shape of filtered x-ray emission images near the time of peak x-ray emission [2]. Other experimental techniques have provided information on the early-time symmetry, prior to the launch of the main laser pulse [3,4], but there has been no direct measurement of the shape of the compressed shell as it converges prior to stagnating and forming the hotspot. However, recently a technique was developed to obtain backlit pinhole images of imploding capsules in NIF [5]. With the addition of this capability, which is commonly referred to as the two-dimensional convergent ablation or “ConA-2D” technique, there is now data available during the full duration of the radiation drive that can be used to constrain our symmetry prediction models.

We calculate the symmetry of NIF implosions by modeling the integrated hohlraum-capsule system using the Hydra radiation hydrodynamics code [6]. Experimentally we control the lowest even mode Legendre asymmetry (P2) by varying the wavelength separation ( $\Delta\lambda$ ) between the inner and outer beam cones to control the amount of cross-beam energy transfer (CBET) that occurs near the laser entrance hole where the inner and outer cone laser beams intersect. CBET is modeled in a separate calculation [7] using plasma parameters extracted from a Hydra simulation with no laser backscatter removed. We have found that the CBET model can accurately predict the radiation symmetry during



the low power portion of the laser pulse as inferred from the experimental shock symmetry. However, the calculated CBET at high power during the peak of the laser pulse is generally larger than inferred from experiment and so is moderated by setting a threshold density perturbation value ( $\delta n/n$ ) for the CBET [7]. When the resonant process that drives CBET causes the local  $\delta n/n$  to exceed that threshold, no further transfer is allowed in that portion of the laser beam crossing volume. A second Hydra calculation is then done with the measured input laser power modified by the measured laser backscatter and calculated crossbeam energy transfer. The input drive is further modified in order to match shock timing, trajectory, and neutron bang time data from other experiments [8].

In this work we introduce a laser-power-dependent  $\delta n/n$  value for the CBET that is a best fit to all the available symmetry data. We find that with this adjustment the integrated calculations correctly predict the low mode (P2, P4) inflight and stagnation shape of NIF implosion experiments. We used this model together with experimental data to improve the drive symmetry. The re-optimization resulted in a longer hohlraum and a smaller  $\Delta\lambda$ .

## 2. Power-dependent saturation model that matches P2

A series of ConA-2D experiments were done to determine the scaling of inflight shape with various control parameters. The baseline experiment was done in a 5.75 mm diameter, 9.43 mm length hohlraum and used a 360 TW peak power variant of the NIF N120802 436 TW laser pulse. The  $\Delta\lambda$  settings were 6.6 Å separation between the 30° beams and the outer (44.5° and 50°) beams, and 8.1 Å separation between the 23° beams and the outer beams. To determine the dependency of shape on peak power, a second experiment was done at a lower peak power (250 TW). We were able to match the scaling with laser power of the inflight and stagnation P2 shape using a  $\delta n/n$  that depends on the laser power, as shown in Fig. 1.

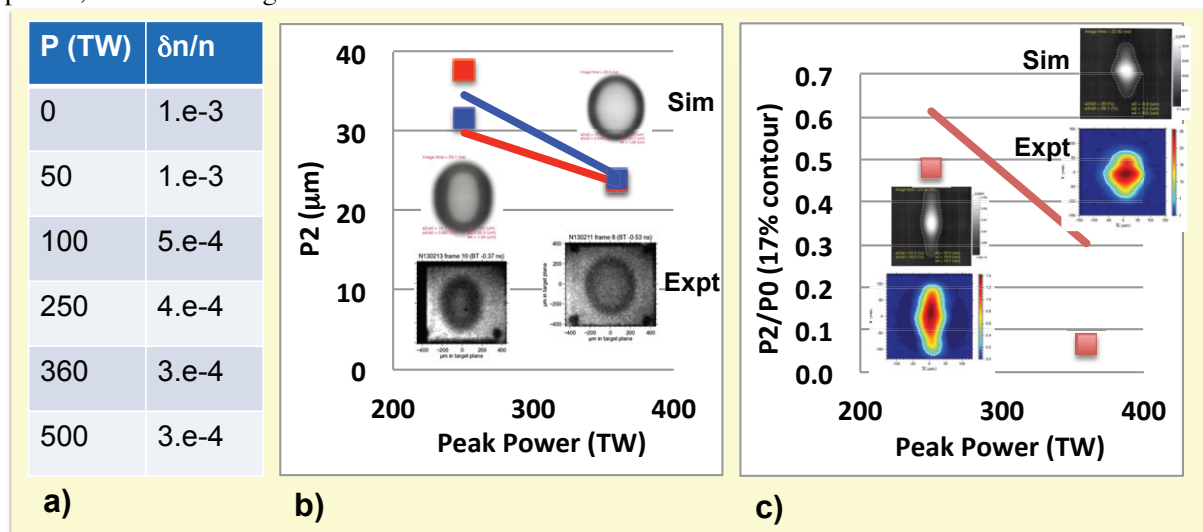


Figure 1 – a) CBET saturation vs. laser power, b) P2 distortion at 200  $\mu\text{m}$  vs. peak power (red is limb minimum, blue is max slope, squares are experimental data), c) self-emission P2/P0 vs. peak power (squares are experimental data).

## 3. Model predictions of P4 compared to experiment

Backlit images of the baseline case described above also indicated there was an easily detectable inflight positive P4 distortion of  $\sim 10 \mu\text{m}$  when the average shell radius was  $\sim 200 \mu\text{m}$ . Modeling indicated that a longer hohlraum would be required to minimize the inflight P4. To determine the scaling with length, a series of ConA-2D experiments were done with hohlraum length varied from 9.13 mm (300  $\mu\text{m}$  shorter than baseline) to 10.43 mm (1000  $\mu\text{m}$  longer than baseline). As the hohlraum length was varied, the outer beam pointing (where beams cross the hohlraum axis) was changed so that the outer cone position stayed fixed relative to the LEH. In contrast, the inner cone pointing was not changed, which meant that the distance in  $z$  between the inner and outer spots varied

with the hohlraum length. As a result of this pointing, for the longest hohlraums (10.13 and 10.43 mm) the LEH diameter was increased from 3.1 mm to 3.38 mm.

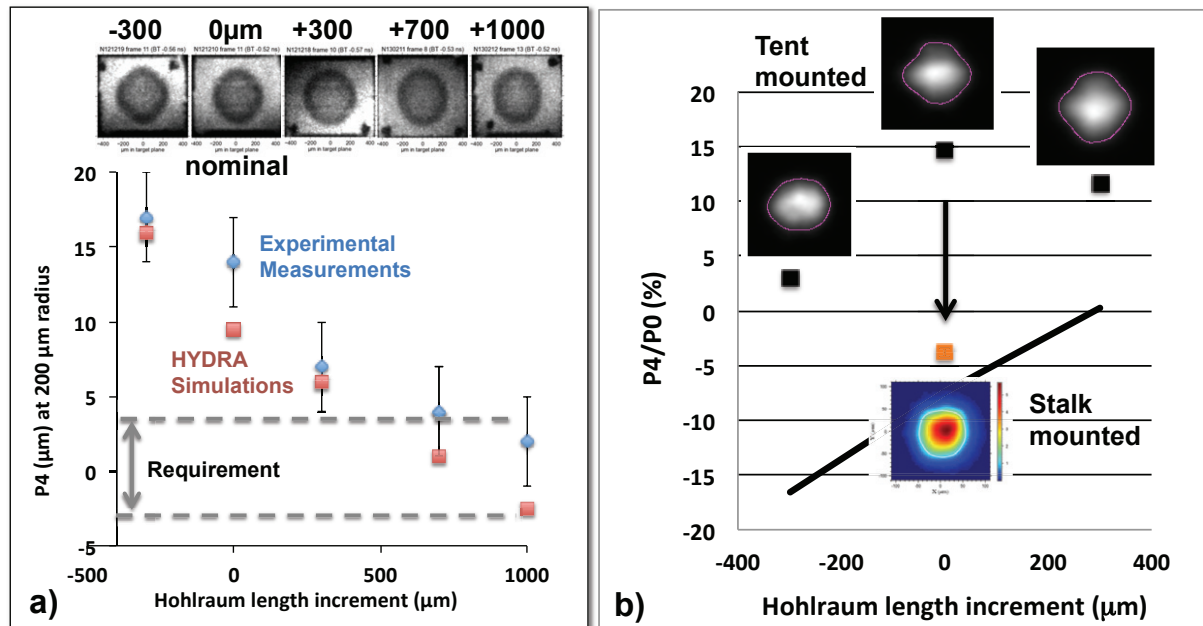


Figure 2 – a) P4 distortion of shell at 200 μm, b) P4/P0 of self-emission 17% contour at time of peak emission (line is simulation, squares are the data).

Figure 2a shows the P4 component in μm of the minimum transmission limb contour when the limb minimum average radius is 200 μm as a function of the hohlraum length. We see that as the hohlraum is lengthened, the magnitude of the P4 component is reduced and that the length scaling is well predicted by the integrated Hydra model. However, Figure 2b shows that the P4 component of the x-ray self-emission did not agree at all with the model for capsules that were mounted to the hohlraum in the usual way using a thin (~50 nm thick) tent. For example, the baseline 9.43 mm long hohlraum had a measured P4/P0 of +15%, whereas the expected value was -8%. The backlit images appeared to show a feature distorting the shell at an angle of ~45°, very close to where the support tent lifts off from the capsule. To test the theory of whether the tent imprint was causing the x-ray images to have an apparent positive P4, an experiment was done with the 9.43 mm hohlraum in which the capsule was held with a stalk instead of a tent. The result was the orange square in Figure 2b, which showed that the emission P4/P0 changed from +15% to -5%, which is much closer to the predicted -8%.

#### 4. Predicted shape improvement of the re-optimized 10.13 mm hohlraum

The hohlraum length scan experiments showed that the hohlraum length and  $\Delta\lambda$  that we were using for most of the 2012 ignition experiments was not optimal. The hohlraum was too short and had too much  $\Delta\lambda$ , resulting in measureable positive P2 and P4 inflight distortions of the compressed shell.

Using the newly benchmarked symmetry model as a guide, the hohlraum length was increased from 9.43 mm to 10.13 mm, and the color separation was changed from 6.6/8.1A to 4.5/6.0A. Because the hohlraum length had been changed, a shock timing experiment was done to retune the arrival times of the first three shocks. A subsequent ConA-2D experiment with this configuration (shot N130314) showed that the inflight shape had been changed as predicted by the bench-marked model and was very round in flight, so a cryogenically layered DT capsule was shot with the same configuration (shot N130331) to determine the effect of these improvements on overall performance (ion temperature, yield, etc.).

Since there was not a DT shot with the 9.43 mm hohlraum at the same peak laser power and energy to compare to, we used the new integrated symmetry model to quantify the improvement. To estimate

the performance of the 9.43 mm hohlraum, we used the measured laser pulse shape and capsule dimensions for the N121210 ConA-2D experiment, which used a gas-filled symmetry capsule, but replaced the inner 14.2  $\mu\text{m}$  of the ablator with an equivalent mass (68.8  $\mu\text{m}$ ) of frozen 50/50 DT. For the retuned 10.13 mm hohlraum we simply did a post-shot simulation of the actual DT shot (N130331).

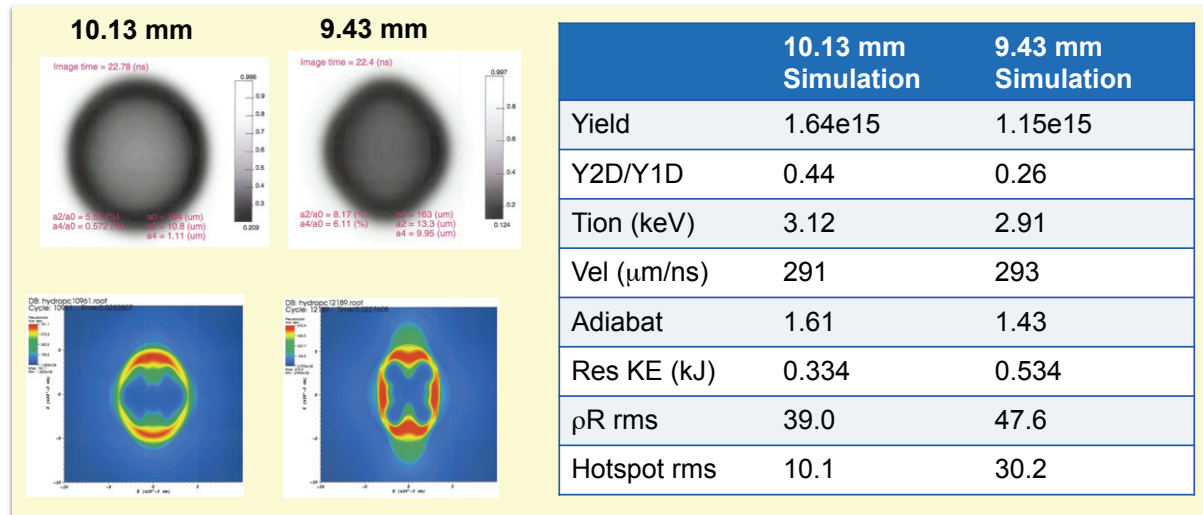


Figure 3 – Comparison of calculated performance of DT implosions in 10.13 mm and 9.43 mm long hohlraums

In Figure 3 we compare the calculated DT performance in the two hohlraums. On the left are simulated inflight radiographs and density slices at bang time for each hohlraum. The yield and ion temperature are higher for the re-optimized 10.13 mm hohlraum, even though the 1D performance is slightly worse (lower velocity, higher fuel adiabat). We also calculate the 1D yield by artificially symmetrizing the 2D calculation and then find the ratio of the 2D calculated yield to the 1D calculated yield, which is a measure of the portion of the yield degradation due to low mode drive asymmetry. This ratio is improved for the 10.13 mm hohlraum, although it could still be further improved. The 10.13 mm hohlraum also has less residual kinetic energy at the time of maximum compression, lower  $\rho\text{R}$  rms, and lower hotspot rms, all of which indicate a rounder, more efficient implosion. Note that the experimental yield of N130331 was  $3\text{e}14$  or 18% of calculated, indicating that low mode drive asymmetry was not the primary cause of yield degradation for this experiment.

## 5. Conclusions

We used data from backlight radiography of NIF implosions to develop a new power-dependent CBET saturation model. Using this model coupled with integrated Hydra calculations we can accurately predict the low mode P2 and P4 components of the inflight and stagnation shape of the implosion due radiation drive asymmetry. This model predicts the scaling of P4 distortion with hohlraum length. We used to model to show that the N130331 DT implosion in a 10.13 mm long hohlraum had improved symmetry compared to a comparable implosion in a 9.43 mm long hohlraum.

## References

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