

CONF-9606229--9

UCRL-JC-123315

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Ignition with the National Ignition Facility**

**S. V. Weber, S. G. Glendinning, D. H. Kalantar,
B. A. Remington, J. E. Rothenberg,
M. H. Key, and J. P. Knauer**

**This paper was prepared for submittal to the
24th European Conference on Laser Interaction with Matter
Madrid, Spain
June 3-7, 1996**

July 9, 1996

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LASER IMPRINT AND IMPLICATIONS FOR DIRECT DRIVE IGNITION WITH THE NATIONAL IGNITION FACILITY

S. V. WEBER, S. G. GLENDINNING, D. H. KALANTAR, B. A. REMINGTON,
J. E. ROTHENBERG

*Lawrence Livermore National Laboratory, Livermore,
CA 94550, USA*

M. H. KEY

*Rutherford Appleton Laboratory,
Chilton, Didcot, UK*

J. P. KNAUER

*Laboratory for Laser Energetics, University of Rochester,
Rochester, NY 14627, USA*

For direct drive ICF, nonuniformities in laser illumination can seed ripples at the ablation front in a process called imprint. Such nonuniformities will grow during the capsule implosion and can penetrate the capsule shell, impede ignition, or degrade burn. We have simulated imprint for a number of experiments on the Nova laser. Results are in generally good agreement with experimental data. We have also simulated imprint upon National Ignition Facility (NIF) direct drive ignition capsules. Imprint modulation amplitude comparable to the intrinsic surface finish of ~ 40 nm is predicted for a laser bandwidth of 0.5 THz. Ablation front modulations experience growth factors up to several thousand, carrying modulation well into the nonlinear regime. Saturation modeling predicts that the shell should remain intact at the time of peak velocity, but penetration at earlier times appears more marginal.

1 Introduction

In direct drive inertial fusion, spatial nonuniformities in the laser intensity create hydrodynamic perturbations in the imprint process. These perturbations grow during the implosions and can degrade performance. Beam smoothing schemes^{1,2} introduce spatial and temporal incoherence into the laser beam, giving a strongly modulated speckle pattern at any instant of time. In time average, the modulation smooths out to a large degree. Thermal transport between where the laser energy deposits and the ablation front gives additional smoothing. We have examined the imprint and growth in numerical simulations, and tested the modeling against experiments. Simulations can assess imprint upon ignition capsules such as those planned for the National Ignition Facility (NIF).

2 Numerical Method and Simulations of Experiments

Imprint has been simulated using the computer code, LASNEX. Simulations are two-dimensional with reflecting boundary conditions in the transverse direction, and include multigroup radiation diffusion, electron conduction by flux-limited diffusion with a flux limiter of $f_e = 0.1$, and ray trace laser deposition. The speckle pattern is introduced by adjusting the powers of the rays according to their aim point on the surface of the target.

After some time, the growth history of a perturbation created by laser imprint parallels that of a perturbation originated at the target surface. This fact has been confirmed in Nova imprint experiments³. Consequently, we define the "equivalent surface finish" which is the spatial amplitude spectrum which results in the same modulation growth history as some given imprint condition, during the parallel evolution. A related quantity is the "imprint efficiency" which is the ratio of the equivalent surface finish to the intensity modulation amplitude. As long as the hydrodynamic perturbations are linear ($a < 0.1\lambda$), the imprint amplitude should be proportional to the intensity modulation. This quantity tells how smooth the beam must be to obtain a desired level of target smoothness.

Experiments on the Nova laser have measured effects of imprint. Modulations arising in a planar foil accelerated by the laser were diagnosed by x-ray radiography. Imprint of modulations from random phase plates (RPP)¹ and smoothing by spectral dispersion (SSD)² for $0.53 \mu\text{m}$ light at 10^{14} W/cm^2 were examined³. The equivalent surface finish decreased from $1.24 \mu\text{m}$ for RPP illumination to $0.26 \mu\text{m}$ for SSD with 0.9 THz bandwidth. Imprint of $0.35 \mu\text{m}$ and $0.53 \mu\text{m}$ RPP illumination at $1 - 2 \times 10^{13} \text{ W/cm}^2$ was compared⁴. The $0.35 \mu\text{m}$ light generated higher imprint by a factor of ~ 1.65 . Simulations were in approximate agreement with these experiments. Imprint upon $3 \mu\text{m}$ -thick Si foils was probed with an XUV laser of 15.5 nm wavelength, for $0.35 \mu\text{m}$ light at $3 \times 10^{12} \text{ W/cm}^2$ ⁵. Simulations agreed with the imprinted modulation amplitude for RPP illumination, but predicted a factor of ~ 3 too little modulation for SSD with 0.33 THz bandwidth.

3 NIF Capsule Imprint

The dimensions and pulse shape of a NIF ignition capsule design⁶ are shown in Figure 1. The capsule is driven with a shaped pulse of 1.5 MJ of $0.35 \mu\text{m}$ light and gives a clean 1-D yield of up to 30 MJ. We have calculated imprint for this capsule a single spatial frequency at a time. We have evaluated imprint in planar geometry, as convergence effects are small during the imprint phase. An

uncorrelated intensity pattern was imposed every laser coherence time. Thus, the laser intensity was taken to be a cosine in space direction and white noise in time, with a coherence time of 2 ps, corresponding to the 0.5 THz NIF bandwidth.

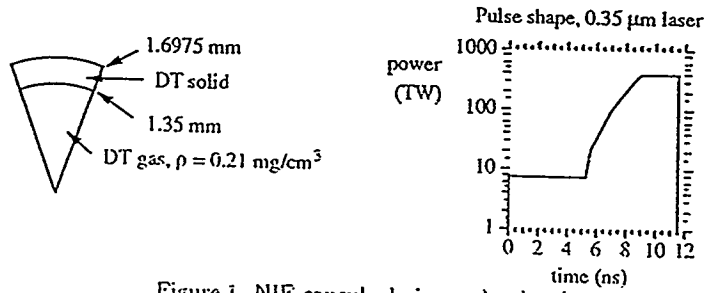


Figure 1. NIF capsule design and pulse shape

We evaluated the imprint efficiency at 2 ns, by which time we expect the imprint is mostly complete. We also used the 2 ns time-average of the white noise intensity modulation as the source amplitude to get the imprint efficiency. The resulting efficiency was about $30 \mu\text{m}$ for $l < 100$, falling off at higher l from thermal smoothing. Multiplying these imprint efficiencies by the intensity modulation spectrum, we get the equivalent surface finish mode spectrum shown in Figure 2. The total power under this spectrum corresponds to 36 nm rms, compared to 30 nm rms from the surface finish spectrum.

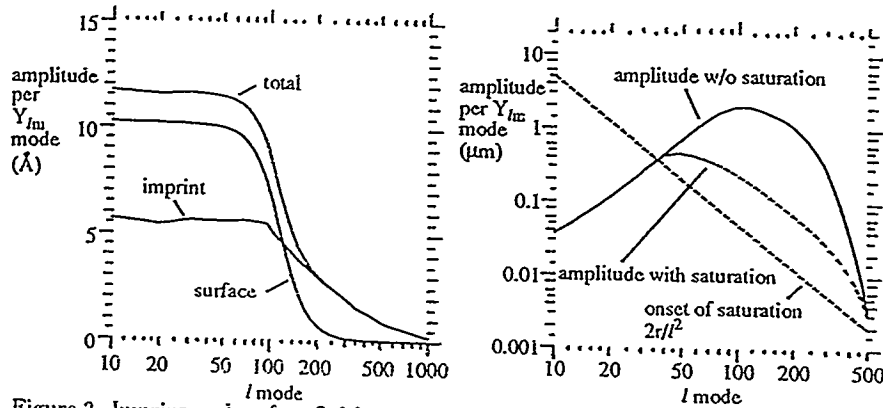


Figure 2. Imprint and surface finish spectra Figure 3. Modal spectrum at peak velocity

The modulation amplitude during the implosion was evaluated by multiplying the equivalent surface finish by a growth factor spectrum. The effective surface finish used was the quadrature sum of imprint and surface finish, shown by the top curve in Fig. 2. We used the expression for the growth

rate $\gamma(k) = \sqrt{\frac{ak}{1+kL}} - 3kv_a$, where the acceleration, $a = 8.5 \times 10^{15} \text{ cm/s}^2$, the wavenumber, $k = r/l = 0.1 \text{ cm/l}$, the density gradient scale length, $L = 0.5 \mu\text{m}$, and the ablation velocity, $v_a = 3.4 \mu\text{m/ns}$. The linear growth factor on the ablation front to the time of peak shell implosion velocity is $GF(k) = e^{\gamma\Delta t}$, where $\Delta t = 4.66 \text{ ns}$ is the acceleration time.

The resulting amplitude spectrum is shown in Figure 3. According to the saturation model of Haan⁸, modes enter into nonlinearity when the amplitude exceeds $2r/l$, shown as the dotted line for a radius of $250 \mu\text{m}$. The modes above $l=30$ are nonlinear, substantially so at the peak of the linear spectrum at $l \cong 100$. The dashed curve shows the mode amplitude corrected for saturation. The rms bubble amplitude at peak velocity is $12 \mu\text{m}$, well below the shell thickness of $110 \mu\text{m}$. 2-D multimode simulations are in progress to test the saturation model and check upon shell viability.

4 Conclusions

Lasnex simulations of imprint are in reasonable agreement with experimental data for several beam smoothing conditions relevant to the performance of ignition capsules. Simulations of imprint upon a specific ignition design indicate that bandwidth of 0.5 THz will be sufficient to yield imprint comparable in effect to an expected intrinsic surface finish of $30 - 40 \text{ nm rms}$. Modulations of this level at the ablation front evolve well into the nonlinear regime. Examination of shell viability to such modulations is still in progress.

Acknowledgments

Work performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

References

1. Y. Kato *et al.*, *Phys. Rev. Lett.* **53**, 1057 (1984).
2. S. Skupsky *et al.*, *J. Appl. Phys.* **66**, 3456 (1989).
3. S. G. Glendinning *et al.*, *Phys. Rev. E*, in press, 1996.
4. S. G. Glendinning *et al.*, 24th ECLIM, 1996.
5. D. H. Kalantar *et al.*, *Phys. Rev. Lett.* **76**, 3574 (1996).
6. C. P. Verdon, *Bull. Am. Phys. Soc.* **38**, 2010 (1993).
7. J. Lindl, *Phys. Plasmas* **2**, 3933 (1995).
8. S. W. Haan, *Phys. Rev. A* **39**, 5812 (1989).