Section 2
PROGRESS IN LASER FUSION

2.A Uniformity Requirements for Direct-Drive Laser Fusion

The present objectives of the Drive Uniformity Program at the University of Rochester are (a) to determine the radiation and drive uniformity requirements for directly driven targets, and (b) to achieve the required degree of uniformity with multiple beam irradiation of spherical targets using overlapping beams. This integrated program, which began almost two years ago, has made steady progress in meeting these objectives by the following means:

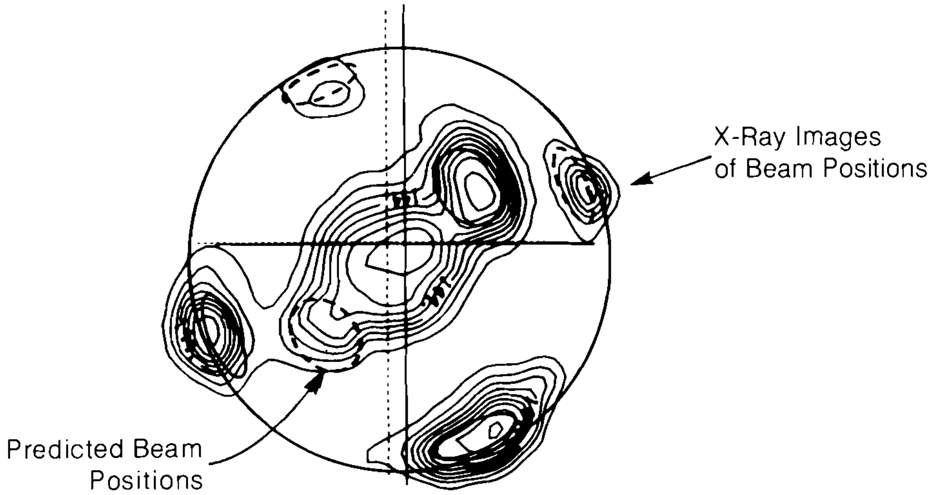
1) characterizing and optimizing the uniformity of irradiation on the 24-beam OMEGA laser system;
2) conducting experiments to determine the effects of specific, characterized drive uniformity on imploding targets; and
3) comparing the first direct measurements of compressed DT fuel conditions with 1-D and 2-D code calculations to indicate satisfactory low-order symmetry of target implosions.

In considering the necessary irradiation uniformity requirements for direct-drive, the following principal points can be made. For high-compression (1000X) targets a drive uniformity of $\pm 1\%$ is required. The most serious nonuniformities are those with large scalelengths. Large-scalelength nonuniformities in laser irradiation can be smoothed only at high intensities and with long laser wavelengths. Our studies show that it should be possible to attain the required degree of irradiation uniformity by using multiple beams ($n \geq 20$), while maintaining a beam balance (of the order of 5%) and a reasonable individual beam spatial uniformity ($\pm 20\%$).

In this section we will describe the characterization of uniformity on the OMEGA laser system, discuss some of the factors which influence overall irradiation uniformity, and mention some of the measures to be taken to improve it further. The analysis of uniformity is facilitated by decomposing the total irradiation distribution on the target into a set of spherical harmonics or modes. The lowest order modes are directly associated with large-scalelength nonuniformities, and these modes have commanded most of our attention to date.

Multibeam symmetric irradiation of targets places severe requirements on the output characteristics on the laser, especially with regard to beam aiming precision, beam-to-beam energy stability, and uniformity of beam profile. In order to achieve beam placement accuracy, OMEGA routinely places beams on target to within 10 μm of the nominal aim point. This is illustrated in Fig. 3, which shows a reduced x-ray image of a target irradiated specifically to measure aiming accuracy. Symmetric sets of 6-beams are focused onto the surface of a gold-coated sphere, and the spatial coordinates of the resulting x-ray images compared to their expected positions. On all occasions when this test has been made, the RMS pointing error has been no more than 11 μm, well within the margins which insure that beam placement is not a factor in reducing overall irradiation uniformity.

- Six-beam surface-focused pointing shots on gold-coated, 200-μm-diameter targets



Mean pointing error for 24 beams is 11 μm ± 6 μm.

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Fig. 3
Isointensity contour plot of the x-ray image from a gold-coated spherical target irradiated by six OMEGA beams focused at the target surface.

The balance in energy between individual beams is an important factor in determining overall uniformity, particularly the amplitude of the low-order modes that are most difficult to suppress once established in an implosion. A typical OMEGA beam calorimeter report shows typical individual beam output energies which deviate from the mean beam energy with a peak-to-peak variation of 20%, and an RMS fluctuation of approximately 5%. It is our intention to take measures in the future which will eventually lead to the reduction of this number to the 1 to 2% level. This should satisfy the requirements for uniformity in the low-order modes.

The characterization of the dependence of the uniformity on multiple overlap of individual beam profiles has been extensively studied at LLE. The procedure used to gain an approximate quantification of the energy deposition uniformity is outlined in Fig. 4. The distribution of energy and intensity in the target plane is recorded for each beam on a series of shots, generating a large quantity of data. The two-dimensional beam profiles are individually digitized and an azimuthal average of the intensity distribution obtained. From this data a representative beam profile is obtained, and then used in a pseudo-three-dimensional, spherical, beam superposition code, together with the individual beam energies. This code then computes the uniformity of spherical energy deposition utilizing specific absorption prescriptions for resonance and inverse bremsstrahlung absorption, and incorporates a ray-tracing prescription to account for beams at high angles of incidence to the target surface. The resulting energy deposition uniformity can then be portrayed either as great circle cuts of the spherical distribution, or more usefully by decomposition into simple spherical harmonic modes.

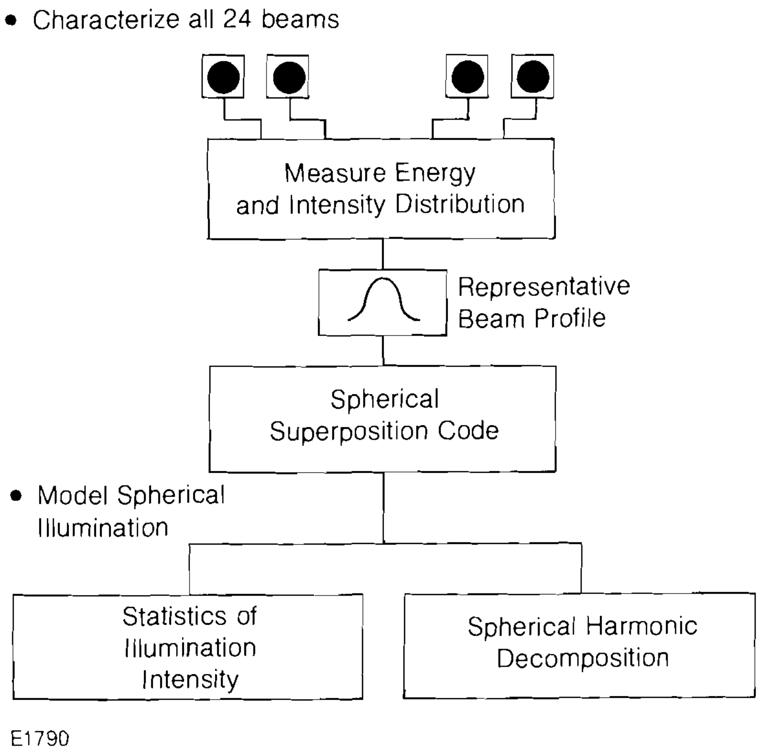

Fig. 4
Procedure used to characterize spherical illumination uniformity.

Such an assessment for a typical 24-beam, one-nanosecond target shot with beams focused 10 target radii beyond target center is shown in Fig. 5. The conical beam profile is provided as input into the beam superposition code, which gives a spherical isoenergy deposition distribution plot as shown on the right, and a distribution of amplitudes of the lower harmonic modes shown in the lower plot. It can be seen that apart from the $\ell = 8$ mode, the rms amplitude is typically less than 2%. Since the peak variation of the irradiation amplitude of these modes would be a factor of 3 or more, we have set a goal of improving uniformity by a factor of approximately 5 for future high-compression target experiments.

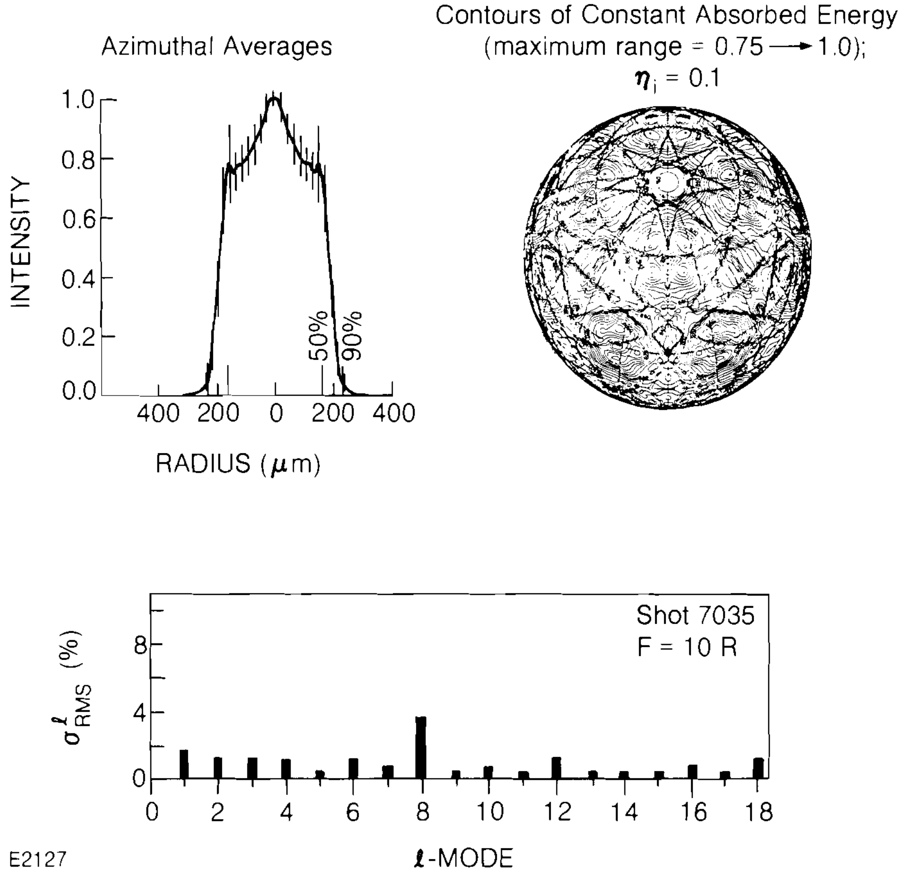

Fig. 5
Model of irradiation uniformity in the OMEGA system.
- *a) Azimuthally averaged intensity distribution obtained from equivalent plane photography*
- *b) Contours of constant absorbed energy obtained from a three-dimensional, numerical ray trace, assuming 24 identical beam profiles of the form shown in (a)*
- *c) Decomposition of the irradiance distribution into spherical harmonic modes*

We must next ask what factors control the intensity profiles of the individual beams and to what extent we can manipulate them to optimize uniformity. We have, through the use of the beam propagation code *MALAPROP*, been able to model the propagation of real beam profiles through the system with high accuracy. The uniformity and radial symmetry of the resulting output beam profile in the equivalent target plane is found to be dependent on (1) the radial and azimuthal gain profiles in all amplifier units, (2) the shape, symmetry, and stability of the input beam profile from the oscillator to the beam line, and (3) the precision of alignment of the individual beams through amplifiers, apertures, and spatial filters. Preservation of a uniform phase distribution through the entire amplifier chain, the transport optics, and focusing elements to the target is of particular interest to us since the output phase distribution strongly influences the relationship between the output beam distribution in the near field and that in the target plane.

Typical measurements of the radial phase aberration of the output beam—measured by shear-plate interferometry—for various pulse lengths are shown in Fig. 6. It can be seen that for nanosecond pulses, the temporal range in which we are most interested, the oval radial phase aberration is at most a few tenths of a wave. This radial phase distribution has been used together with measured, near-field intensity distributions to determine, with the use of the propagation code *BEAMPROP*, the expected intensity distribution in the equivalent target plane (Fig. 7). Comparison of the calculated and measured intensity distributions shows close agreement as demonstrated in Fig. 8.

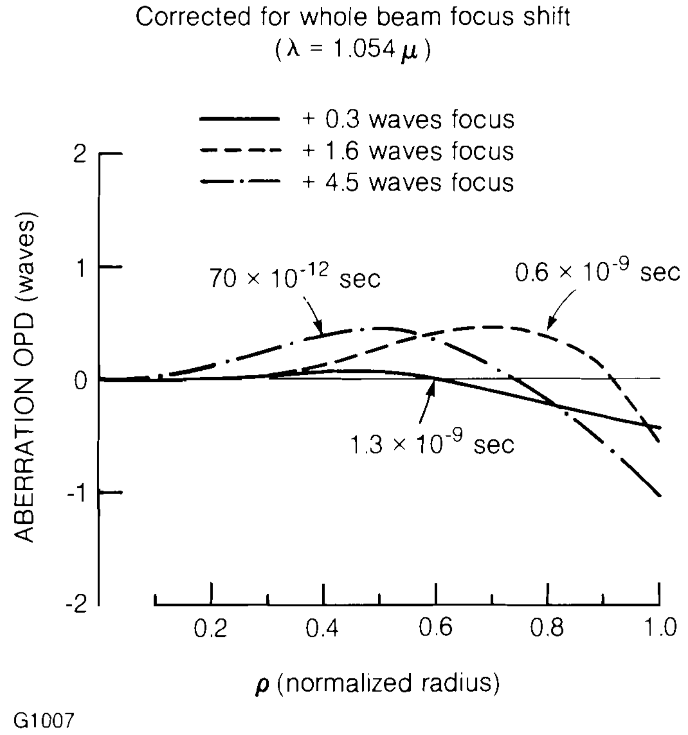

Fig. 6
Residual aberration of laser beam output for various pulse widths, with account for the whole beam focus shift (λ = 1.054 μm).

These studies represent a step forward in characterizing the beam-to-beam intensity distribution; nonetheless, further progress in improving the individual beam profile is both necessary and possible. That this is possible is demonstrated by recent data obtained from the single-beam GDL system. Figure 9 shows the current intensity distribution in the equivalent target plane for infrared light. As can be seen, the azimuthally averaged IR intensity distribution varies locally by no more than 10% and by no more than 15% across the whole beam distribution.

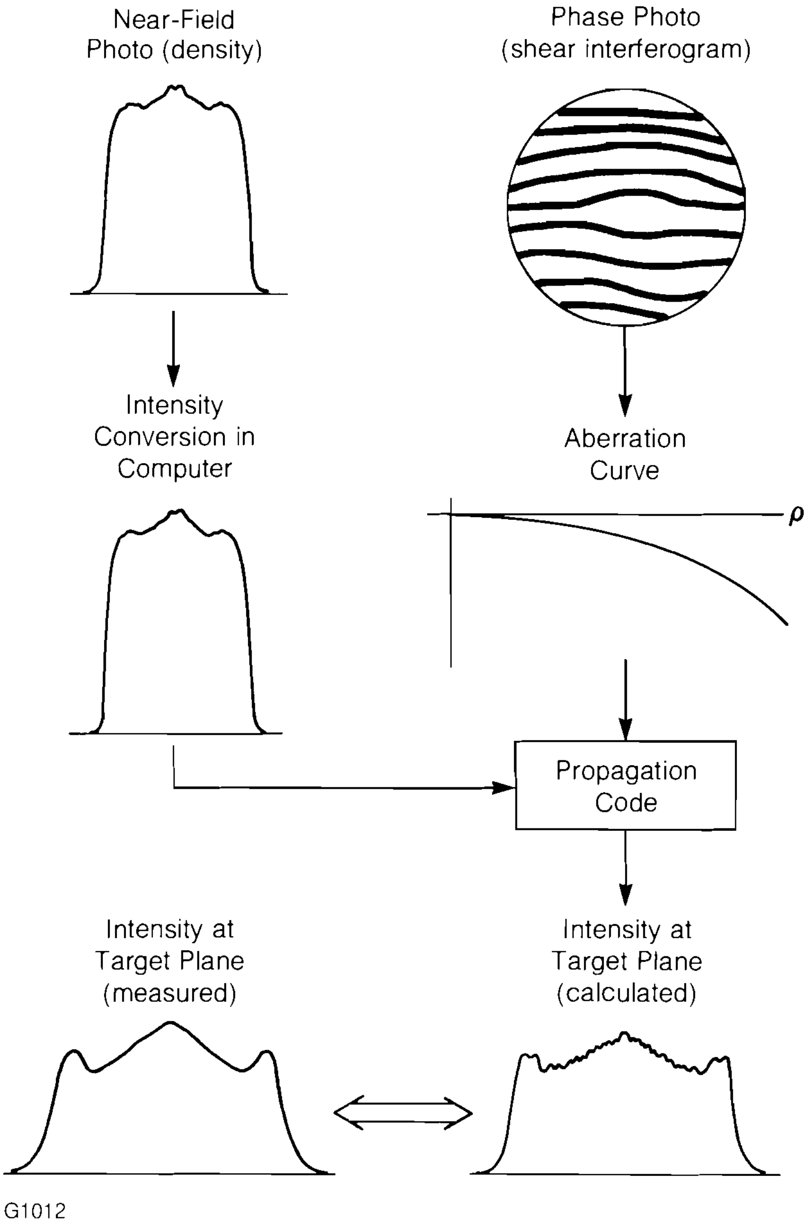

Fig. 7
Procedure used to normalize the beam propagation code.

Fig. 8
Comparison of single-beam, measured and calculated intensity distributions at the target plane for OMEGA shot number 6369.

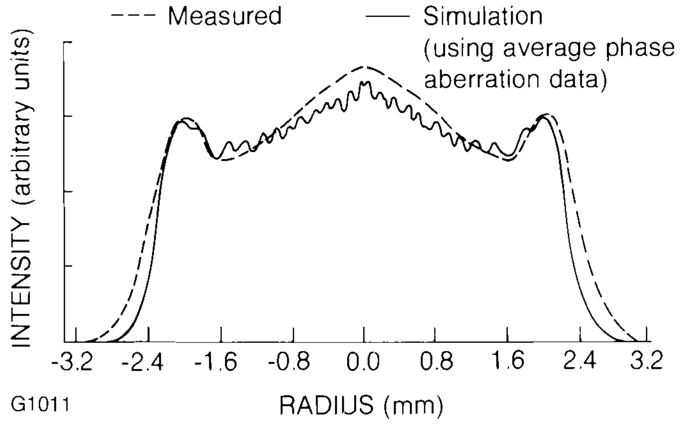

Fig. 9
Target plane intensity distribution obtained from the GDL laser system (λ = 1.054 µm).