Numerical Study of Large-Scale, Laser-Induced Nonuniformities in Cryogenic OMEGA Implosions

3-D ASTER simulations of shot 78378

$\rho$ (g/cm$^3$)

$T_i$ (keV)

4- to 8-keV x ray

Offset $t = 2.56$ ns

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57th Annual Meeting of the American Physical Society
Division of Plasma Physics
Savannah, GA
16–20 November 2015
Summary

Large-scale, laser-induced nonuniformities can explain performance degradation of cryogenic implosions on OMEGA

- The 3-D hydrodynamic code *ASTER* was developed to study direct-drive implosions
- Simulations consider the OMEGA laser’s configuration and include typical target offsets and measured beam imbalance, mispointing, and mistiming
- The effects of the stalk mount were mimicked by applying surrogate perturbations
- Simulations suggest that the implosions are mostly affected by target offset and beam imbalance
Collaborators


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Short-scale perturbations alone cannot explain the performance of cryogenic implosions on OMEGA

- Implosions with $\alpha \gtrsim 3.5$ and in-flight aspect ratio (IFAR) $\lesssim 22$ underperform
- Images of implosion cores evidence the evolution of low-$\ell$-mode structures

X-ray images in the 4- to 8-keV range (shown in shot 77064)*

100 $\times$ 100-µm image regions

- $T_i$ measurements suggest significant bulk motions in the hot spot**

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**T. J. Murphy, Phys. Plasmas 21, 072701 (2014).
The 3-D code ASTER studies the effects of large-scale nonuniformities in OMEGA implosions

- Based on the Eulerian piecewise-parabolic method (PPM)*
- Utilizes a two-temperature (ion and electron) fluid model of plasma, which can consist of multiple materials (DT, CH, etc.)
- Implemented on a 3-D orthogonal spherical grid (R, θ, φ)
- Parallelized using the domain-decomposition approach
- A nominal-resolution (700 × 60 × 120) implosion simulation takes less than 48 h
- Current physical options
  - tabulated Z and equation of states (EOS’s)
  - Spitzer thermal conduction (with optional flux limitation)
  - simplified 3-D laser-deposition model

ASTER uses a simplified 3-D laser deposition model

- The assumption of a spherical corona
- Adopts a ray-tracing routine with cross-beam energy transfer (CBET)*
  from the 1-D code LILAC**

Simulated effects:
- OMEGA beam overlap
- beam-energy imbalance
- beam mispointing
- beam mistiming
- target offset

OMEGA shot 78378 was simulated assuming measured 3-D laser-imposed perturbations

\[ \alpha = 4 \]
\[ \text{IFAR} = 22 \]

\[ E_L = 26 \text{ kJ} \]
\[ I_{\text{max}} \approx 10^{15} \text{ W/cm}^2 \]

- Nominal model:
  - Beam overlap
  - 10% \( \sigma_{\text{rms}} \) imbalance
  - 10-\( \mu \text{m} \) \( \sigma_{\text{rms}} \) mispointing
  - 5-ps \( \sigma_{\text{rms}} \) mistiming

- Typical target offset \( \sim \) 10 to 20 \( \mu \text{m} \)
Simulations of a nominal model with a 10-μm offset suggest that offset and beam imbalance have the largest effect.

- Larger perturbations are needed to explain OMEGA implosions (YOC ~ 30)

YOU = 0.51

YOU: yield over uniform
YOC: yield over clean
A nominal model with a 20-μm offset shows the typical performance of OMEGA α = 4 cryogenic implosions.

3-D ASTER simulations of shot 78378

YOU = 0.22

\( P_n = 47 \text{ Gbar} \) (versus 45±6 Gbar for shot 78378)

- Self-emission x-ray images loosely reproduce the hot-spot shape
- The cold shell must be imaged

\( D_{\text{eff}} = 46.2 \mu m \)

17% contour defines the hot spot size
Large-scale perturbations increase the variation of inferred $T_i$, which is in good agreement with measurements.

Nominal model with 20-μm offset

Normalized neutron spectra* with and without the effects of plasma bulk motion (BM)

The directions of measurements and inferred $T_i$

$\langle T_i \rangle_n = 2.73$ keV

Shot 78378
Inferred $T_i$: 3.6, 3.7, and 4.6 keV

Perturbations from a mount stalk and other sources interact, reducing the implosion performance

Equatorial density map at neutron peak ($t = 2.56$ ns)

Nominal model

Beam overlap and stalk

Perturbations in laser deposition mimic the effects of a stalk mount

\[ \text{YOU} = 0.51 \]

\[ \text{YOU} = 0.48 \]
Summary/Conclusions

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