High-Performance Cryogenic Designs for OMEGA and the NIF

Ignition hydroequivalent OMEGA design, $R_b/R_t = 0.75$ (R75)

ASTER simulation OMEGA R75

SDD NIF R75 design $E_L = 1.6$ MJ

58th Annual Meeting of the American Physical Society Division of Plasma Physics San Jose, CA 31 October–4 November 2016

V. N. Goncharov
University of Rochester
Laboratory for Laser Energetics
Summary

Reducing cross-beam energy transfer (CBET) losses improves stability properties of ignition spherical direct-drive (SDD) designs at the National Ignition Facility (NIF)

- Hot-spot energy in direct-drive (DD) implosions is a factor of 5 or more larger than that of indirect-drive (ID) implosions
  - the required hot-spot pressure in an igniting NIF-scale DD design must exceed 120 Gbar (350 Gbar in ID)

- Without CBET mitigation, SDD designs on the NIF have in-flight aspect ratios in excess of 30
  - CBET mitigation in hydroequivalent designs on OMEGA involves reducing beam size relative to the target size* to $R_b/R_t = 0.75$
  - high-yield and ignition SDD designs on the NIF require both beam-size reduction and wavelength detuning**

---

* I. V. Igumenshchev, Phys. Plasmas 17, 122708 (2010); I. V. Igumenshchev, CI3.00002, this conference (invited).
** J. A. Marozas et al., NO5.00009 and P. B. Radha et al., NO5.00005, this conference.
Collaborators


University of Rochester
Laboratory for Laser Energetics
The hot-spot pressure in an ignition design must exceed a threshold value.

Direct-drive designs are in a less-challenging hydrodynamic regime with CR \( \leq 22 \) and \( P_{hs} > 120 \) Gbar; indirect-drive–ignition targets require CR = 30 to 40 and \( P_{hs} > 350 \) Gbar.

- Pressure threshold for ignition
  \[ P_{th} \sim \frac{1}{\sqrt{E_{hs}}} \]

- For direct drive
  \[ P_{hs} \sim V_{imp}^{10/3} P_{a}^{1/3} / \alpha \sim P_{a} \text{ IFAR}^{5/3} \]

---

IFAR: in-flight aspect ratio
Coupling losses caused by CBET are larger on the NIF-scale targets because of longer density scale length.

\[ P_{hs} \sim P_a^{IFAR^{5/3}} \]

![Graph showing ablation pressure vs. laser intensity with and without CBET]
CBET losses make ignition target designs too unstable during acceleration

1-D LILAC simulations

Current stability threshold for OMEGA cryogenic implosions

Yield\(_{1-D}\) (×10\(^{16}\))

NIF SDD designs

\(V_{\text{imp}} = 3.8 \times 10^7\) cm/s

Full CBET, \(P_a = 90\) Mbar

\(\alpha = 4.1\)

\(P_{hs} = 72\) Gbar

CR = 18.5

\(\alpha = 2.9\)

\(P_{hs} = 90\) Gbar

CR = 19

\(\alpha = 1.4\)

\(P_{hs} = 130\) Gbar

CR = 21

Gain = 1

IFAR

CR: convergence ratio
CBET reduction* and improved laser coupling have been demonstrated on OMEGA by reducing $R_{\text{beam}}/R_{\text{target}}$

The performance of larger shells is limited by drive asymmetries. The near-term goal is to quantify and reduce laser power imbalance (part of the “100-Gbar” campaign).

** V. N. Goncharov et al., J. Phys. Conf. Ser. 717, 012008 (2016);
Combination of $R_b/R_t < 1$ and wavelength detuning leads to robust high-yield SDD designs on the NIF

R75 with wavelength separation ($\Delta \lambda = \pm 6$ Å)

Initial experiments on the NIF with $\Delta \lambda = \pm 2.3$ Å confirmed predicted CBET reduction.*

*J. A. Marozas et al., NO5.00009, this conference.
Combination of $R_b/R_t < 1$ and wavelength detuning leads to robust high-yield SDD designs on the NIF
The effect of improved laser coupling on target performance will be tested using an R75 design on OMEGA with improved power balance.

- The effect of CBET is smaller on OMEGA because of shorter scale lengths.
- Ignition hydroequivalent OMEGA design: $R_b/R_t = 0.75$, IFAR = 21.8, $\alpha = 3$
  $V_{imp} = 3.7 \times 10^7 \text{ cm/s}$

3-D ASTER* simulations at peak neutron production

Current OMEGA nonuniformities
$P_{hs} = 70 \text{ Gbar}$

“100 Gbar” illumination uniformity and offset
$P_{hs} = 100 \text{ Gbar}$

Reducing cross-beam energy transfer (CBET) losses improves stability properties of ignition spherical direct-drive (SDD) designs at the National Ignition Facility (NIF).

- Hot-spot energy in direct-drive (DD) implosions is a factor of 5 or more larger than that of indirect-drive (ID) implosions
  - the required hot-spot pressure in an igniting NIF-scale DD design must exceed 120 Gbar (350 Gbar in ID)

- Without CBET mitigation, SDD designs on the NIF have in-flight aspect ratios in excess of 30
  - CBET mitigation in hydroequivalent designs on OMEGA involves reducing beam size relative to the target size* to $R_b/R_t = 0.75$
  - high-yield and ignition SDD designs on the NIF require both beam-size reduction and wavelength detuning**

---

* I. V. Igumenshchev, Phys. Plasmas 17, 122708 (2010);
  I. V. Igumenshchev, CI3.00002, this conference (invited).
** J. A. Marozas et al., NO5.00009 and P. B. Radha et al., NO5.00005, this conference.