Analysis and Reconstruction of Highest-Performing OMEGA DT Layered Implosion Shot 90288

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61st Annual Meeting of the American Physical Society
Division of Plasma Physics
Fort Lauderdale, FL
21–25 October 2019
Experimental observables for shot 90288 were reconstructed using 2-D radiation-hydrodynamics simulations

- Shot 90288 produced Yield = $1.51 \times 10^{14}$ and $\rho R = 160$ (mg/cm$^2$), yet showed significantly lower yield than 1-D with YOC $\approx 0.4$

- Analysis of experimental data, suggests that degradation from a systematic low mode ($\ell = 2$) and a mid-mode ($\ell \geq 10$) is a viable hypothesis to explain lower performance

- The radiation-hydrodynamic code $DEC2D^*$ was used to reconstruct the experimental data using adhoc combinations of low and mid-modes

YOC: yield over clean
Collaborators


University of Rochester
Laboratory for Laser Energetics

A. Bose

Massachusetts Institute of Technology
Shot 90288 used a new pulse-shape design and achieved the highest performance to date on OMEGA

\[
\begin{align*}
\begin{array}{|c|c|}
\hline
\text{Yield} & 1.51 \times 10^{14} \\
\hline
\rho R & 160 \text{ mg/cm}^2 \\
\langle T_i \rangle_{n,\min} & 4.55 \text{ keV} \\
\langle P \rangle_n & 52 \text{ Gbar} \\
\chi_{\text{no } \alpha} (1.9 \text{ MJ}) & 0.74 \\
\hline
\end{array}
\end{align*}
\]

\( \chi_{\text{no } \alpha} \) = no-\( \alpha \) Lawson parameter for ignition
The performance of shot 90288 was significantly lower than predicted by 1-D code (*LILAC*).

When compared to performance as predicted by 1-D code *LILAC*

- Yield is 60% lower
- Inferred $\langle P \rangle_n$ is ~50% lower
- Convergence is 10% lower

This motivated an effort to find the dominant cause(s) of degradation for shot 90288.
Measured bang time, absorption, and trajectory are in general agreement with the 1-D simulation.

<table>
<thead>
<tr>
<th></th>
<th>LILAC</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption (%)</td>
<td>70</td>
<td>67</td>
</tr>
<tr>
<td>Bang time (ns)</td>
<td>2.090</td>
<td>2.109±005</td>
</tr>
</tbody>
</table>

It is unlikely that 1-D degradation is responsible for lower performance.
An SSD scan* was performed on a similar implosion (shot 90291) to infer the effect of imprinting at the highest available smoothing.

Data from the SSD suggest that the performance of implosions at this adiabat and IFAR is insensitive to imprinting at 100% SSD.

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**Table:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Shot 90288</th>
<th>Shot 90291</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD (μm)</td>
<td>960</td>
<td>980</td>
</tr>
<tr>
<td>(v_{imp}) (km/s)</td>
<td>467</td>
<td>455</td>
</tr>
<tr>
<td>(\alpha_{2/3})</td>
<td>5.2</td>
<td>4.5</td>
</tr>
<tr>
<td>IFAR(_{2/3})</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

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*J. P. Knauer et al., YO5.00004, this conference.

SSD: smoothing by spectral dispersion

OD: outer diameter

IFAR: in-flight aspect ratio

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Shot 90288 showed almost no $T_i$ asymmetry, suggesting mode 1 is not a dominant source of degradation.

Target offset, beam mispointing, ice roughness (sources for mode 1), etc. are unlikely sources of degradation.

YOC versus DT$_i$ for $\ell = 1$ only*

DT$_i = \frac{T_{\text{max}}}{T_{\text{min}}}$

*K. M. Woo, UI2.0002, this conference (invited).
Both framed and time-integrated x-ray self-emission images show a hot spot with ellipticity oriented in the general direction of the stalk (up–down).

- Separate experiments have been conducted to quantify in-flight low-mode asymmetry†
- These measurements evidence a systematic \( \ell = 2 \) aligned to the capsule mounting (stalk)
- Since cryogenic targets use similar mounting, we expect the results to hold true for the present analysis

The in-flight measurement of warm implosions also shows a residual \( \ell = 2 \) along the axis of the stalk consistent with the \( \ell = 2 \) asymmetry observed in x-ray images.

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X-ray self-emission images of the hot spot show a more peaked profile than a synthetic GMXI from a clean simulation at equal convergence.

Converging spikes from a mid-mode driven by OMEGA 60-beam port geometry is a likely cause for a more peaked profile.*

Framed image of Ge-doped cryogenic Implosions showing illumination nonuniformity

Image from a pointing shot showing the location of beams on a 4-mm-diam Au target

\[ \eta = \text{super-Gaussian exponent of the fit} \]

- Clean
- Experimental

\[ \eta = 3.4 \]

\[ \eta = 2.3 \]

The radiation-hydrodynamic code \textit{DEC2D} was used to match the experimental observables by varying the amplitudes of $\ell = 2$ and $\ell = 12^*$.  


\*\* PrismSPECT, Prism Computational Sciences, Inc., Madison, WI

Neutron yield, observed hot-spot profile \((R_0, \eta)\), neutron-averaged temperatures \(\langle T_i \rangle_n\), and areal density \(\langle \rho R \rangle_n\) were matched for the reconstruction

\[ \ell = 2 \text{ at } 8\% \bar{v}/v_{imp} \]
\[ \ell = 12 \text{ at } 20\% \bar{v}/v_{imp} \]

<table>
<thead>
<tr>
<th></th>
<th>Experiment</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>1.51 \times 10^{14}</td>
<td>1.47 \times 10^{14}</td>
</tr>
<tr>
<td>(\rho R) (mg/cm^2)</td>
<td>159.5</td>
<td>162</td>
</tr>
</tbody>
</table>

\[ \ell = 2 \text{ corrected yield } \rightarrow 2.27 \times 10^{14} \]
\[ \ell = 12 \text{ corrected yield } \rightarrow 2.02 \times 10^{14} \]
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Backup
Asymmetry in the laser illumination pattern is observed in Ge-doped* implosions

* D. Patel et al., JO7.0004, presented at the 59th Annual Meeting of the APS Division of Plasma Physics, Milwaukee, Wisconsin, 23–27 October 2017. TIM: ten-inch manipulator
Shot 90288 simulation

Time-integrated x-ray images

Experiment

Simulation
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<th>LILAC (1-D)</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield $\times 10^{14}$</td>
<td>1.51</td>
<td>3.8</td>
<td>0.4</td>
</tr>
<tr>
<td>$\rho R$ (mg/cm$^2$)</td>
<td>160</td>
<td>180</td>
<td>0.9</td>
</tr>
<tr>
<td>$\langle T_i \rangle_{n,\text{min}}$ (keV)</td>
<td>4.55</td>
<td>4.97</td>
<td>0.9</td>
</tr>
<tr>
<td>$\langle P \rangle_n$ (Gbar)</td>
<td>50</td>
<td>92</td>
<td>0.54</td>
</tr>
<tr>
<td>$R_0$ ($\mu$m)</td>
<td>27</td>
<td>24.5</td>
<td>0.9</td>
</tr>
</tbody>
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