Effects of Long- and Intermediate-Wavelength Asymmetries on Hot-Spot Energetics

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Summary

Low- and intermediate-mode nonuniformities exhibit different degradation mechanisms of inertial confinement fusion (ICF) implosion performance

• Low-mode ($\ell \sim 2$) asymmetries result in a drop of hot-spot pressure and the burn volume is larger, while intermediate-mode ($\ell \sim 10$) asymmetries result in a smaller volume

• Measurable observables on OMEGA are reproduced by using a combination of low and intermediate modes

• Extrapolation of the OMEGA implosion with the highest Lawson parameter to a 1.9-MJ symmetric direct drive leads to 125 kJ of fusion yield
Collaborators

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The effect of hydro instabilities is investigated by rewriting the yield-over-clean (YOC) in terms of the hot-spot properties

- Yield: \( Y = \int dt \int dV \frac{n^2 \langle \sigma v \rangle}{4} \sim P^2 \frac{\langle \sigma v \rangle}{T^2} V \tau \)

- Fusion reactivity in \( 2 < T < 7 \) keV: \( \langle \sigma v \rangle \sim T^{3.7} \)

- Burn volume: \( V = \int dt \int dV \frac{n^2 \langle \sigma v \rangle^{0.5}}{4} \approx V_{17}^{\text{ray}} \)

\[
YOC = \frac{Y}{Y_{1-D}} \approx \left( \frac{P}{P_{1-D}} \right)^2 \left( \frac{V}{V_{1-D}} \right) \left( \frac{T}{T_{1-D}} \right)^{1.7} \left( \frac{\tau}{\tau_{1-D}} \right)
\]
The radiation–hydrodynamic code *DEC2D* is used to simulate the deceleration phase of implosions.

- Hydrodynamic profiles at the end of the acceleration phase (from the 1-D code *LILAC**) are used as the starting point, followed by a simulation of the deceleration phase in multidimension.
- *Single- or multimode velocity perturbations are introduced to the inner surface of the shell.*

In-flight target

\[ R \sim 90 \mu m \]

\[ V_{imp} \sim 380 \text{ km/s} \]

\[ YOC \]

\[ \Delta V\% \text{ of } V_{imp} \]

\[ \ell = 2 \quad \text{and} \quad \ell = 10 \]

* K. M. Woo et al., GO5.00003, this conference;

Intermediate-$\ell$ modes exhibit degradation in burn volume, whereas low-$\ell$ modes show an increase.

**OMEGA target at time of peak neutron rate**

**Fuel shape**

- $YOC = 1.0$
- $YOC = 0.6$, $\ell = 2$
- $YOC = 0.6$, $\ell = 10$

**Hot-spot shape**

- $YOC = 1.0$
- $YOC = 0.6$, $\ell = 2$
- $YOC = 0.6$, $\ell = 10$

**Equation**

\[
YOC \approx \left( \frac{P}{P_{1-D}} \right)^2 \left( \frac{V}{V_{1-D}} \right) \left( \frac{T}{T_{1-D}} \right)^{1.7} \left( \frac{\tau}{\tau_{1-D}} \right)
\]
Yield degradation from low-\(\ell\) modes results from a significant reduction in pressure compared to the 1-D values.
Ion temperatures and burnwidths are little affected by nonuniformities

\[
\text{YOC} \approx \left( \frac{P}{P_{1-D}} \right)^2 \left( \frac{V}{V_{1-D}} \right) \left( \frac{T}{T_{1-D}} \right)^{1.7} \left( \frac{\tau}{\tau_{1-D}} \right)
\]
Measurable observables on OMEGA are reproduced by using a combination of low and intermediate modes

<table>
<thead>
<tr>
<th></th>
<th>Experiment</th>
<th>1-D simulation</th>
<th>2-D simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>$5.3 \times 10^{13} (\pm 10%)$</td>
<td>$1.7 \times 10^{14}$</td>
<td>$5.3 \times 10^{13}$</td>
</tr>
<tr>
<td>$P^*$ (Gbar)</td>
<td>56 ($\pm 7$)</td>
<td>97</td>
<td>57</td>
</tr>
<tr>
<td>$T_1$ (keV)</td>
<td>3.6 ($\pm 0.3$)</td>
<td>3.82</td>
<td>3.7</td>
</tr>
<tr>
<td>$R_{hs}$ ($\mu$m)</td>
<td>22 ($\pm 1$)</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>$\tau$ (ps)</td>
<td>66 ($\pm 10$)</td>
<td>61</td>
<td>54</td>
</tr>
<tr>
<td>$\rho R$ (g/cm²)</td>
<td>0.196 ($\pm 0.018$)</td>
<td>0.211</td>
<td>0.194</td>
</tr>
</tbody>
</table>

Combination of $\ell = 2$ with 5% $\Delta V$ and 2% $\Delta V$ for $\ell < 20$ with $22 < \ell^{-2} < 100$ spectrum $V_{imp} = 380 \, \mu$m/ns

TC12628

Extrapolating OMEGA results to hydro-equivalent targets driven by 1.9-MJ symmetric illumination leads to 125 kJ of fusion yield

**Shot 77068**

<table>
<thead>
<tr>
<th>OMEGA 26.18 kJ</th>
<th>1.9 MJ without $\alpha$ heating</th>
<th>1.9 MJ with $\alpha$ heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield</td>
<td>$5.3 \times 10^{13}$</td>
<td>$2.25 \times 10^{16}$</td>
</tr>
<tr>
<td>$P^*$ (Gbar)</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>$T_i$ (keV)</td>
<td>3.7</td>
<td>4.7</td>
</tr>
<tr>
<td>$R_{hs}$ ($\mu$m)</td>
<td>22</td>
<td>92.3</td>
</tr>
<tr>
<td>$\tau$ (ps)</td>
<td>54</td>
<td>215</td>
</tr>
<tr>
<td>$\rho R$ (g/cm$^2$)</td>
<td>0.194</td>
<td>0.83</td>
</tr>
</tbody>
</table>


**Scale up**

**$\alpha$ heating**

Y amplification = 2

**$\rho R$ (g/cm$^2$)**

**$\rho R$ (g/cm$^2$)**
Summary/Conclusions

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