Optimization of Direct-Drive Target Designs for the NIF

Gain = 43

Gain = 48

Power (TW)

Time (ns)

Distance (µm)

Density (g/cm³)

Adiabat/3

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A model has been developed to optimize NIF DD target designs

- A model has been developed to optimize target gain.
  
  - The model uses results of a stability postprocessor to calculate shell integrity during the acceleration phase and mode spectrum at shell stagnation.
  
  - Target gain is calculated by using the obtained mode spectrum and results of 1-D simulations with reduced implosion velocities.

- The model was applied to predict stability and gains for “all-DT” moderate-gain and high-gain foam target designs.

- The results of the model suggest that the maximum gain for the “all-DT” targets can be achieved for $\alpha = 3$ to $\alpha = 4$ designs.
The model consists of three main steps

<table>
<thead>
<tr>
<th>Step</th>
<th>Instability seeding</th>
<th>Acceleration, coasting, and deceleration phases</th>
<th>Target gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical phenomena</td>
<td>Imprinting, RMI, feedout</td>
<td>Ablative RTI, Bell-Plesset instability</td>
<td>Burn-wave propagation</td>
</tr>
<tr>
<td>Calculated by</td>
<td>Analytic theory, <em>ORCHID</em> simulations</td>
<td>Stability postprocessor</td>
<td>1-D simulations with reduced implosion velocity</td>
</tr>
</tbody>
</table>

*ORCHID* simulations
“All-DT” DD NIF targets driven on adiabat up to 7 were considered

Pressure \( p_{\text{kidder}} = \frac{p_0}{\left[1 - (t/\tau)^2\right]^{5/2}} \)

Power \( P_1 = \frac{P_0}{\left[1 - (t/\tau)^2\right]^4} \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Determined by</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_0 )</td>
<td>Shell adiabat</td>
</tr>
<tr>
<td>( P_{\text{max}} )</td>
<td>Damage threshold, shell stability</td>
</tr>
<tr>
<td>( t_0 )</td>
<td>Timing of compression wave and first shock</td>
</tr>
<tr>
<td>( t_1 )</td>
<td>Target gain</td>
</tr>
<tr>
<td>( t_{\text{end}} )</td>
<td>Laser energy</td>
</tr>
</tbody>
</table>
“All-DT” DD NIF targets driven on adiabat up to 7 were considered (continued)

<table>
<thead>
<tr>
<th>α</th>
<th>$\rho R_{\text{peak}}$ (g/cm$^2$)</th>
<th>$V_{\text{imp}}$ ($\times 10^7$ cm/s)</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.5</td>
<td>4.17</td>
<td>55</td>
</tr>
<tr>
<td>3</td>
<td>1.3</td>
<td>4.27</td>
<td>48</td>
</tr>
<tr>
<td>4</td>
<td>1.2</td>
<td>4.34</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>1.1</td>
<td>4.42</td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>4.42</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>0.9</td>
<td>4.45</td>
<td>9</td>
</tr>
</tbody>
</table>
A stability postprocessor\(^1\) was applied to study perturbation evolution of imploding targets during the acceleration, coasting, and deceleration phases.

\[ V_a \sim \alpha^{3/5} \]

\[ V_a = \alpha \left( \frac{\mu m}{ns} \right) \]

\[ GF_{\text{classical}} \sim e^{\sqrt{2\ell}} \arcsin \sqrt{1 - C_r^{-1}} \]

\[ \text{Abubble/thickness} (\%) \]

\[ \text{Acceleration (\mu m/ns}^2) \]

\[ \text{Convergence ratio} \ C_r = \frac{R_a(t)}{R_a(0)} \]

\(^1\text{V. Goncharov et al., Phys. Plasmas 7, 5118 (2000).}\)
Result of the model was compared against *ORCHID* simulations

- End of acceleration phase

Seeding: 3-$\mu$m inner-DT–ice roughness

![Graph showing mode number vs. $\sigma_{rms}$ (µm)](image)

- Ablation front
- Back surface
The postprocessor was used to calculate mode spectrum at stagnation

- \( V_a \) in decel phase is calculated by using theory of R. Betti\(^1\) et al.

\[
V_a \propto \frac{(T_{hs})^{5/2}}{R_{hs} \rho_{shell}}
\]

- Mode spectrum at the back surface of cold fuel at stagnation (1 THz SSD, 1 \( \mu \)m DT ice roughness, 800Å outer surface finish)

\[\alpha = 2\]

\[V_a \propto Ths^{5/2} Rhs \rho_{shell}\]

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TC5635
The mode spectrum at stagnation is related to the gain reduction

- According to Levedahl and Lindl\(^1\)

\[
\frac{V_{\text{mix}}}{V_0} = \left( \frac{r_0}{r_{\text{mix}}} \right)^{2/5} \quad r_{\text{mix}} = r_0 - \eta
\]

\[
\frac{V_{\text{mix}}}{V_0} = (1 - \xi)^{-2/5} \quad \xi = \eta/r_0
\]

- Perturbation is equivalent to a reduction in 1-D implosion velocity: \(^2\)

\[
\xi = 1 - \left( \frac{V_0 - \Delta V}{V_0} \right)^{5/2}
\]

\(^1\)W. Levedahl and J. Lindl, Nuc. Fusion 37, 165 (1997).
Gain is calculated by using the results of 1-D simulations with reduced $V_{\text{imp}}$

![Graph showing Gain, Marginal ignition, 1-THz SSD, 1 $\mu$m of DT ice, 80-nm outer finish]
Target designs with $3 < \alpha < 4$ have the highest 2-D gain.

- Target gain is calculated assuming 1-THz, 2-D SSD; 1-\(\mu\)m ice–DT gas roughness, and 800-Å outer surface finish.
- Imprint spectrum is assumed to be the same for different \(\alpha\)'s.
Change in EOS results in a small variation in target gain

\( \alpha = 3 \text{ design} \quad \text{SESAME (G = 48)} \quad \text{TF (G = 45)} \)

- Power (TW)
- Time (ns)
- \( V_a \) (mm/ns)
- Gain
- \( C_r \)
- \( \xi \) (%)
The ratio $\xi/\xi_c$ of $\alpha = 5$ and $\alpha = 6$ can be reduced by increasing the in-flight aspect ratio.

<table>
<thead>
<tr>
<th>$\alpha = 5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFAR</td>
</tr>
<tr>
<td>$A_{\text{bubble}}/Th$ (%)</td>
</tr>
<tr>
<td>$\xi/\xi_c$</td>
</tr>
<tr>
<td>1-D gain</td>
</tr>
<tr>
<td>2-D gain</td>
</tr>
</tbody>
</table>
Three high-gain “wetted foam” designs have been considered

**Design 1:**
- \( G = 124 \)
- \( V_{\text{imp}} = 3 \times 10^7 \text{ cm/s} \)
- \( \rho R_m = 1.7 \text{ g/cm}^2 \)

**Design 2:**
- \( G = 81 \)
- \( V_{\text{imp}} = 3.9 \times 10^7 \text{ cm/s} \)
- \( \rho R_m = 1.4 \text{ g/cm}^2 \)
Target stability and gain are calculated by using a developed model

<table>
<thead>
<tr>
<th>Design</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{\text{bubble}}/\text{Th}$ (%)</td>
<td>22</td>
<td>52</td>
</tr>
<tr>
<td>$\xi/\xi_{\text{c}}$ (%)</td>
<td>200</td>
<td>72</td>
</tr>
<tr>
<td>1-D gain</td>
<td>124</td>
<td>81</td>
</tr>
<tr>
<td>2-D gain</td>
<td>0</td>
<td>55</td>
</tr>
</tbody>
</table>

Assumptions:  
(1) imprint is the same for “all-DT” designs  
(2) perfect power balance  
(3) 1-μm DT-ice roughness and 80-nm outer surface finish
Summary/Conclusion

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