Single-Beam Smoothing Requirements for Wetted-Foam, Direct-Drive-Ignition Target Designs

Including imprint, power balance, surface, and ice roughness

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2-D simulations of direct-drive target designs indicate ignition requires 2-D SSD single-beam smoothing

- A low-IFAR wetted-foam ignition design is used to minimize the effects of single-beam nonuniformity.

- This 1-MJ design was found to require 2-D SSD for ignition.

- Simulations show a 1.5-MJ design also needs 2-D SSD when single modulators are used in each direction.

- Multiple frequency modulators can be used to significantly increase the 1-D SSD single-beam smoothing rate.
Collaborators

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Conventional ICF requires an intermediate in-flight aspect ratio

- If the in-flight aspect ratio, $\text{IFAR} = \frac{R_0}{\Delta R}$, is too high, ignition is prevented by hydrodynamic instabilities.

- If the IFAR is too low, the low-implosion velocity results in too low a hot-spot temperature.

- The minimum energy for ignition scales as $E \sim (\text{IFAR})^{-3^*}$

A low-IFAR wetted-foam design was developed for its comparative insensitivity to single-beam nonuniformity.

2-D SSD single-beam smoothing is required for ignition for the 1-MJ wetted-foam design*

- Integrated simulations include imprint, power imbalance, foam-surface nonuniformity (370-nm rms), and 0.75-μm initial ice roughness.

A new, low-IFAR, wetted-foam design has been developed to study SSD requirements at 1.5 MJ

- This design was simulated with power imbalance, surface and ice roughness, and imprint

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<table>
<thead>
<tr>
<th></th>
<th>All-DT pt. design</th>
<th>1.5-MJ foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V$ ($\mu$m/ns)</td>
<td>450</td>
<td>409</td>
</tr>
<tr>
<td>1-D Gain</td>
<td>45</td>
<td>44</td>
</tr>
<tr>
<td>IFAR</td>
<td>60</td>
<td>33</td>
</tr>
<tr>
<td>$A/\Delta R$ (%)</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>$\rho R$ (g/cm²)</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Margin (%)</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

A downhill simplex method was used to automatically optimize the 1.5-MJ, low-IFAR design

- The design was optimized in 1-D using a postprocessor to gauge stability.
- The 7-D parameter space includes target radius, layer thicknesses, and pulse shape.
- Starting from an all-DT design, the areal density was raised, IFAR lowered, and stability improved.
2-D SSD smoothing is also required for ignition for the 1.5-MJ wetted-foam design.
2-D SSD smoothing is also required for ignition for the 1.5-MJ wetted-foam design

Deceleration phase

1-D 1-THz SSD

2-D 1-THz SSD
The 1.5-MJ wetted-foam target ignites with 2-D SSD but not with 1-D SSD

Near peak compression

End of acceleration
Multiple frequency modulators can be used to increase the 1-D SSD single-beam smoothing rate

- The smoothing rate is increased by increasing the number of color cycles.
- The resulting resonance regions are filled with multiple frequency modulators\(^1\).
- The 1.5-MJ design, simulated with 1-D multiple-frequency SSD, showed dramatically improved performance.

Integrated simulations at the end of the acceleration phase.

See Marozas, JO3.00013, next.

Summary/Conclusions

2-D simulations of direct-drive target designs indicate ignition requires 2-D SSD single-beam smoothing

- A low-IFAR wetted-foam ignition design is used to minimize the effects of single-beam nonuniformity.

- This 1-MJ design was found to require 2-D SSD for ignition.

- Simulations show a 1.5-MJ design also needs 2-D SSD when single modulators are used in each direction.

- Multiple frequency modulators can be used to significantly increase the 1-D SSD single-beam smoothing rate.
The shell stability can be increased by lowering the implosion velocity and raising the in-flight shell thickness.

- The most-dangerous Rayleigh–Taylor modes feed through to the inner surface and have wavelengths comparable to the shell thickness, with wave numbers $k \sim \Delta R^{-1}$.

- The linear growth of these modes depends on the in-flight aspect ratio, IFAR:

  $\text{Number of e foldings} = \gamma t \sim \sqrt{kgt^2} \sim \sqrt{\frac{R_0}{\Delta R}} \equiv \sqrt{\text{IFAR}}$

- The in-flight aspect ratio depends mainly on the implosion velocity and average adiabat:*

  $$\text{IFAR} \sim \frac{V^2}{\langle \alpha \rangle^{3/5}},$$

  where $\alpha = P/P_{\text{Fermi}}$ is the adiabat.

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