Shock Fast Ignition of Thermonuclear Fuel with High Areal Density

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• High density/areal-density fuel can be assembled through low-velocity, low-adiabat implosions.

• 1-D simulations show that such a fuel assembly can be ignited by a spherically convergent shock.

• Two designs are presented with 100-kJ and 500-kJ fuel assemblies ignited by a 60-kJ and 200-kJ shock yielding 1-D gains of ~60 and ~120 respectively.

• 2-D simulations are being performed to evaluate the target robustness to inner surface roughness and laser imprinting.

Summary

Shock ignition offers interesting prospects for high gains at a low direct-driver energy.
Low implosion velocity leads to small RT growth and high gain; however, slow targets are difficult to ignite with standard central ignition.

- Low velocity = high-gain $G$

$$G \approx \frac{73.4}{I_{15}^{0.25}} \left( \frac{3 \times 10^7}{V_i \text{ (cm/s)}} \right)^{1.25} \left( \frac{\theta}{0.2} \right)$$

$$\theta = \frac{1}{1 + 7/\rho r}$$

- Low velocity = low RT growth. $Ne$ = number of RT e-foldings

$$Ne (kd = 1) \approx \frac{V_i}{3 \times 10^7} \left[ \frac{6.7}{I_{15}^{2/15}} \alpha_{if}^{0.3} \left( \frac{\lambda_L}{0.35} \right)^{2/15} - \frac{0.5}{I_{15}^{1/3}} \left( \frac{0.35}{\lambda_L} \right)^{2/3} \right]$$

- Low velocity = large energy for ignition

$E_{\text{ign}}$ is the energy required for ignition

$$E_{\text{ign}} \sim \alpha_{if}^{1.8} V_i^{-6} P^{-0.8}$$

R. Betti, GO1.07
A 100-kJ, RX-shaped pulse can assemble fuel with $\rho R = 1.6 \text{ g/cm}^2$ through a slow ($V_i = 2.5 \times 10^7 \text{ cm/s}$), low-adiabat implosion ($\alpha = 0.7$)

<table>
<thead>
<tr>
<th>Energy (kJ)</th>
<th>In-flight aspect ratio IFAR</th>
<th>Max. areal density (g/cm$^2$)</th>
<th>Implosion velocity (cm/s)</th>
<th>Gain (not ignited)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>29</td>
<td>1.6</td>
<td>$2.5 \times 10^7$</td>
<td>1.7%</td>
</tr>
</tbody>
</table>
The slow implosion velocity leads to small Rayleigh–Taylor growth during the laser flattop.

- Results from RT postprocessor based on Haan–Goncharov models and OMEGA laser nonuniformities with 1-THz SSD.
A spherically convergent shock driven by a 60-kJ spike in the laser intensity can ignite the hot spot of the 100-kJ fuel assembly.

\[
\text{Energy gain} = 68 \\
(1-D \text{ LILAC simulation})
\]
The laser-driven shock collides with the return shock, generating a high-pressure reflected shock propagating to the hot spot.

The ignitor pulse drives an incoming shock that collides with the return shock inside the shell.

A high-pressure shock resulting from the collision continues to propagate to the central hot spot, leading to ignition.
The high-pressure shock heats the hot spot above the ignition threshold.
Ignition is sensitive to the ignitor-shock launch time

- 60-kJ shock-ignitor pulse
- 20-kJ shock-ignitor pulse

- 100 ps
- 250 ps

1-D gain vs. Ignitor-shock launch time (ps)
The ignitor and return shocks must be synchronized to collide in the region of peak density.
A 500-kJ. NIF-size fuel assembly is ignited by a 200-kJ ignitor shock to produce a gain of 116
Preliminary work on the effect of ice-surface roughness shows encouraging results with respect to design robustness.

**Single mode** \( \ell = 20, \ a(0) = 2 \ \mu m \n YOC = 1 \)

**Multimode** \( \ell = 2 \text{ to } 24, \ \sigma_{\text{rms}} = 2 \ \mu m \n YOC = 0.82 \)
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Two designs are presented with 100-kJ and 500-kJ fuel assemblies ignited by a 60-kJ and 200-kJ shock yielding 1-D gains of \( \sim 60 \) and \( \sim 120 \) respectively.

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