Adiabat Shaping in Direct-Drive ICF Implosions Using the Intensity Picket

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Summary

Perturbation growth can be significantly reduced by adiabat shaping

• A technique is proposed to reduce the perturbation growth without compromising the target yield.

• Shaping the adiabat of the main fuel and ablator reduces both seeding and the growth of the Rayleigh–Taylor instability.

• The adiabat is shaped using an intensity picket that launches a decaying shock into the shell. The shock places the outer portion of the shell (ablator) on the higher adiabat, keeping the inner part (main fuel) on the lower adiabat.

• The stabilizing effect of the adiabat shaping is confirmed both numerically and experimentally.
Shell stability and compressibility depend on the adiabat

- Minimum energy required for ignition: \( E_{\text{min}} \sim \alpha^{1.88} \)
- Rayleigh–Taylor instability growth \( \gamma = \alpha_{RT}(kg)^{1/2} - \beta_{RT}kV_a \)

\[ \alpha = \frac{P}{P_{\text{Fermi}}} \]
\[ V_a \sim \alpha^{3/5} \]

\(^1\)M. Herrmann et al., Phys. Plasmas 8, 2296 (2001).
Adiabat shaping is done using an intensity picket.

Calculations show valid for $\gamma > 1.2$.

\[
\frac{p_s}{p_0} \approx \frac{\alpha_s}{\alpha_0} \approx \left( \frac{t - t_0}{t_{rw} - t_0} \right)^{2\gamma - 1}
\]
Numerical simulations confirm the shock-decaying rate

The 300-μm-DT foil is driven by 500-ps, 100-TW square pulse.

$$\frac{p_s}{p_0} \approx \frac{\alpha_s}{\alpha_0} \approx \left( \frac{t-t_0}{t_{rw}-t_0} \right)^{-0.64}, \quad \gamma = \frac{5}{3}$$
The adiabat at the ablation front depends on the picket intensity and picket width.

For $\gamma = 5/3$:

$$\alpha = \alpha_0 \left[ 1.5 \left( \frac{m}{m_0} - 1 \right) + 1 \right]^{0.94}$$

$$\alpha_0 = \alpha_b \left[ 1.5 \left( \frac{m_{sh}}{m_0} - 1 \right) + 1 \right]^{0.94}$$

$m_0 = \rho_0 U_{sh} (t_0 + t_{rw})$

Optimum adiabat shaping requires narrow (<100-ps) high-intensity pickets.
Stabilizing effects of the adiabat shaping were numerically tested on the “all-DT,” $\alpha = 3$ OMEGA target design.

Two pulse shapes were considered:

- **EL = 25 kJ**
- **DT ice 85 $\mu$m**

Two pulse shapes were considered.
The intensity picket reduces both the growth rate and laser imprint

- Imprint simulation using 2-D lagrangian code ORCHID

1% laser-intensity modulations; no SSD

For DT foils: $\gamma = 0.94 \sqrt{k_g} - 2.6 \, kV_a$

$R. \ Betti \ et \ al., \ Phys. \ Plasmas \ 5, \ 1446 \ (1998)$. 
Greater shell stability is predicted for high-performance OMEGA cryogenic target designs with an intensity picket.

\[ \rho R (\text{mg/cm}^2) \quad 330 \quad 305 \]

\[ Y (\times 10^{14}) \quad 6.5 \quad 6 \]

\[ A_{\text{bubble/Th}} (\%) \quad >100 \quad 55 \]

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Multimode ORCHID simulations demonstrate greater the stability of the shaped-adiabat design

Imprint simulations: $\ell = 2–200$, DPP + PS, 1-THz SSD

Shell is significantly less distorted in the picket design.
Mode decomposition shows the effect of the picket on the imprint amplitudes and growth rates.

Beginning of acceleration
(imprint amplitudes)

Acceleration phase
($\Delta R_a = 70 \, \mu m$)
The stabilizing effect of the adiabat shaping was studied experimentally using D$_2$-filled plastic shells.

33-$\mu$m-CH shells filled with 3 atm and 15 atm D$_2$ gas

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<th>$Y_{\text{exp}} / Y_{1-D}$ (%)</th>
<th>4</th>
<th>18</th>
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<tbody>
<tr>
<td>No picket LILAC</td>
<td>3</td>
<td>15</td>
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