Improved Performance of Direct-Drive ICF Target Designs with Adiabat Shaping Using an Intensity Picket

V. N. Goncharov
University of Rochester
Laboratory for Laser Energetics

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Adiabat shaping produced by an intensity picket significantly improves target stability

Summary

• 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 theoretically and experimentally.
Outline

• Importance of the shell adiabat for the target yield and shell stability
• Adiabat shaping using an intensity picket
• Improved-performance direct-drive target designs for NIF and OMEGA
• Reduction of the laser imprint and RT growth rates due to the picket
• Additional instabilities created by adiabat shaping
• Main results of adiabat-shaping experiments
Shell stability and compressibility depend on the adiabat

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

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

Adiabat shaping is done using an intensity picket

- \( t = 0 \) Picket creates a strong shock
- \( t = t_p \) Rarefaction wave (RW) is launched at \( t = t_p \).
- \( t = t_{rw} \) RW meets the shock
- \( t > t_{rw} \) Shock strength decreases in time

Calculations show

\[
\frac{p_s}{p_0} \approx \frac{\alpha_s}{\alpha_f} \approx \left( \frac{t - t_p}{t_{rw} - t_p} \right) \frac{\sqrt{2\gamma(\gamma-1)}}{2\gamma-1}
\]

valid for \( \gamma > 1.2 \).
Numerical simulations confirm the shock decaying rate

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

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

For $\gamma = 5/3$:
\[
\alpha = \alpha_f \left[ 1.5 \left( \frac{m}{m^*} - 1 \right) + 1 \right]^{-0.94}
\]
\[
\alpha_f = \alpha_b \left[ 1.5 \left( \frac{m_{sh}}{m^*} - 1 \right) + 1 \right]^{+0.94}
\]
\[
m^* \sim \rho_0 U_{sh} t_p
\]

Picket optimization gives $t_p (ns) \approx 10^{-3} \Delta_0 (\mu m) / \sqrt{\alpha_b}$

Pressure$_{picket}$ (Mbar) $\approx 16 \alpha_b$

$t_p \sim 50$ ps for OMEGA; $t_p \sim 200$ ps for NIF

pressure $\sim 50$–$60$ Mbar; $\alpha_b = 3$
A shaped-adiabat ignition target has been designed for the NIF facility

- CH 17 µm
- DT ice 290 µm
- 1660 µm

- FWHM = 200 ps
- $P_{\text{picket}} = 350$ TW
- $\rho R = 1.45$ g/cm²
- Gain = 55
Greater shell stability is predicted for high-performance OMEGA cryogenic target designs with an intensity picket.

![Diagram of target design with CH 5 μm and DT ice 65 μm layers, 430 μm total thickness.]

<table>
<thead>
<tr>
<th></th>
<th>CH 5 μm</th>
<th>DT ice 65 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH 5 μm</td>
<td>430 μm</td>
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<table>
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<tr>
<th>Picket</th>
<th>CH 5 μm</th>
<th>DT ice 65 μm</th>
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<tbody>
<tr>
<td></td>
<td>330</td>
<td>305</td>
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<tbody>
<tr>
<td>Y (× 10^{14})</td>
<td>6.5</td>
<td>6</td>
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| A_{bubble}/Th (%)^{1} | >100   | 55          |

Stabilizing effects of the adiabat shaping were numerically tested on the “all-DT,” $\alpha = 3$ OMEGA target design.

Two pulse shapes were considered.
The intensity picket reduces both the growth rate and laser imprint\textsuperscript{1}

- Imprint simulation using 2-D Lagrangian code ORCHID

1% laser-intensity modulations; no SSD

For DT foils\textsuperscript{2} $\gamma = 0.94\sqrt{kg} - 2.6$ k\textsubscript{Va}

\textsuperscript{1}T. J. B. Collins, S. Skupsky, Phys. Plasmas 9, 275 (2002).
Mode $\ell = 300$ is totally stabilized in the picket design

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**Theoretical prediction**

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**ORCHID simulation ($\ell = 300$)**

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Multimode *ORCHID* simulations demonstrate better stability of the shaped-adiabat design

Imprint simulations: \( \ell = 2–200 \), DPP + PS, 1-THz SSD; OMEGA design

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**
($\Delta R_a = 70 \ \mu m$)

![Graph showing amplitude vs. mode number for 'No picket' and 'Picket' conditions in the beginning of acceleration and acceleration phase.](image)
The stabilizing effect of the adiabat shaping was studied experimentally using D$_2$-filled plastic shells$^1$

$\alpha = 2$, 33-\mu m-CH shells filled with 3 atm and 15 atm D$_2$ gas

$Y_{exp} / Y_{1-D}$ (%) | 4  | 18 | 3  | 15

$^1$For details see talk FO2.012 by J. Knauer
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