Finite Atwood Number Effects on Deceleration-Phase Instability in Room-Temperature Direct-Drive Implosions

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Classically unstable material interface

OMEGA direct-drive room-temperature target

DT vapor

0.1 μm Al

27.0 μm CH

430 μm

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Observed $T_i$ variation decreases with increasing Atwood number in room-temperature implosions

- Room-temperature implosions have a finite Atwood number at the fuel–pusher interface that creates short-scale Rayleigh–Taylor (RT) growth during the deceleration phase.
- Simulations indicate residual kinetic energy in the core contributes to ion-temperature variation*;**
- Increasing the Atwood number (by changing the D:T ratio) results in increased short-scale growth and reduced bulk-fluid motion.
- Low Atwood number room-temperature targets, with reduced short-scale RT growth, have large $\Delta T_i$ similar to cryogenic targets.

** T. J. Murphy, Phys. Plasmas 21, 072701 (2014).
Collaborators


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Significant variations in DT ion temperature are observed in cryogenic implosions on OMEGA

- Ion temperature is observed from multiple lines of sight on OMEGA \( \rightarrow \Delta T_i \)
- Significant variation is caused by long-wavelength nonuniformities* – no classically unstable material interface in cryogenic targets

Room-temperature D–T and D–D implosions show much smaller \( \Delta T_i \).**

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One hypothesis is that deceleration-phase short-scale RT growth in room-temperature implosions reduces $\Delta T_i$

Classical Rayleigh–Taylor growth rate

$$\gamma = \sqrt{A_T kg}$$

$$A_T = \frac{\rho_{\text{pusher}}/\rho_{\text{fuel}} - 1}{\rho_{\text{pusher}}/\rho_{\text{fuel}} + 1}$$

$$\frac{\rho_{\text{pusher}}}{\rho_{\text{fuel}}} = \frac{m_{\text{pusher}}^{\text{i}}}{m_{\text{fuel}}^{\text{i}}} \frac{1 + Z_{\text{fuel}}}{1 + Z_{\text{pusher}}}$$
Higher Atwood numbers result in larger single-mode growth rates

**DRACO single-mode ($\ell = 40$) simulation**

“Peak-to-valley”

- Gas
- Shell

**DRACO multimode ($\ell = 4, 20, 200$) simulation**

1-D interface

**Mass density (g/cm$^3$)**

- 40
- 30
- 20

**Graph:**

- 10:90, $\ell = 40$
- 30:70, $\ell = 40$
- 50:50, $\ell = 40$
- 30:70, $\ell = 80$
- 50:50, $\ell = 80$

**Return shock interaction**

**Distance ($\mu$m)**

0 20 40 60 80

**Time (ns)**

2.0 2.1 2.2 2.3 2.4 2.5 2.6

Experiments to systematically change the Atwood number at the fuel–pusher interface were conducted on OMEGA

- Systematically vary D:T ratio for the same target and pulse shape
  - 860-μm-diam, 27-μm-thick CH, 10-atm DT fill

<table>
<thead>
<tr>
<th>D (%)</th>
<th>T (%)</th>
<th>Atwood number*</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>50</td>
<td>0.05 Unstable</td>
</tr>
<tr>
<td>25</td>
<td>75</td>
<td>0.00 Neutral</td>
</tr>
<tr>
<td>10</td>
<td>90</td>
<td>−0.03 Stable</td>
</tr>
</tbody>
</table>

*Atwood number at the start of the deceleration phase
Target performance improves relative to predictions with increasing Atwood number

- Contrary to intuition, yield-over-clean improves with increasing Atwood number (more short-scale growth)
Increased yield correlates with higher ion temperatures

\[ \frac{Y_{10:90}}{Y_{50:50}} \sim \left( \frac{T_{i_{10:90}}^{avg}}{T_{i_{50:50}}^{avg}} \right)^{4.5} \rightarrow \left( \frac{2.45}{2.7} \right)^{4.5} = 0.65 \]
Higher inferred $T_i$ is a result of short-scale RT growth preventing the fuel from penetrating into the cold bubbles

**Low Atwood number**
- Low-mode asymmetries only
- Larger $\Delta T_i$ along different lines of sight
- Fuel flows into cold bubbles because of bulk-fluid motion

**High Atwood number**
- Smaller hot spot, but more “1-D” → improved yield-over-clean
- Short-scale growth prevents fuel from flowing into cold bubbles

Larger $\Delta T_i$, similar to cryogenic implosions

“1-D” hot spot

Short-scale mix region

Less $\Delta T_i$
Larger ion-temperature variation is observed for lower Atwood numbers similar to cryogenic implosions

- Simulations indicate that higher bulk flows lead to higher $\Delta T_i$
Summary/Conclusions

Short-scale Rayleigh–Taylor growth reduces the effects of bulk fluid motion in room-temperature implosions

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- Simulations indicate residual kinetic energy in the core contributes to ion-temperature variation*,**
- Increasing the Atwood number (by changing the D:T ratio) results in increased short-scale growth and reduced bulk-fluid motion.
- Low Atwood number room temperature targets, with reduced short-scale RT growth, have large \( \Delta T_i \) similar to cryogenic targets.

Future multimode simulations are the next step to demonstrate short-scale growth effects on ion-temperature variation.

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