Hydrodynamic Scaling of the Deceleration-Phase Rayleigh–Taylor Instability

\[ FSC \left( n_m \right) t \left( mg/cm^3 \right) \]

\[ \rho \]

\[ YOC_{NIF} = 55\% \]
\[ YOC_\Omega = 68\% \]

Time of peak neutron rate

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Summary

The deceleration-phase Rayleigh–Taylor (RT) instability does not scale hydro-equivalently

- The nonscalability of the thermal transport in the hot-spot affects the deceleration-phase RT instability growth
- National Ignition Facility (NIF)-scale targets have lower mass ablation, resulting in higher RT growth factors and lower yield-over-clean (YOC)
- Simulations show that the YOC reduction with increasing target size caused by this effect is modest (~20% at implosion velocities of 430 km/s)
Collaborators

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OMEGA implosions are scaled hydro-equivalently to estimate performance on direct-drive symmetric NIF.

Hydrodynamic equivalence*

Same $V_i$, $\alpha$, $I_L$

Hydrodynamic scaling

$R \sim \Delta \sim E_L^{1/3}$, $\text{Time} \sim E_L^{1/3}$

$\text{YOC} = \left( \frac{\text{Yield}_{3-D}}{\text{Yield}_{1-D}} \right)$

The generalized Lawson criterion scales as $\text{YOC}_{\text{no }}^{0.4}$

$\chi_{3-D} \sim E^{0.37} \text{YOC}_{\text{no }}^{0.4}$

The deceleration-phase RT instability does not scale hydro-equivalently

• Ablation velocity scales with the target size as
  \[ V_a \sim \frac{k_0 T^{5/2}}{\rho_{sh} R} \sim 1/\sqrt{R} \]

• Larger targets have shorter density scale lengths because of lower ablation
  \[ N_{eRT} = \alpha \sqrt{\frac{k \langle g \rangle t^2}{1 + k \langle L_m \rangle} - \beta \langle V_a \rangle t} \]

\[ N_{RT \text{NIF}} > N_{RT \Omega} \]

\*R. Betti et al., Phys. Plasmas 9, 5 (2002);
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Simulations are performed using a 2-D deceleration-phase hydrocode*,**

- The code imports 1-D LILAC† profiles at the end of the acceleration phase and simulates the deceleration phase in 2-D
- Features of the code
  - second order Eulerian, with moving grid
  - faster but with less physics than DRACO‡

Studies of the effects of thermal conduction are presented; radiation and alpha diffusion are not included.

<table>
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<tr>
<th>$V_i$ (km/s)</th>
<th>~430</th>
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The ablation velocities and relative density-gradient scale lengths on OMEGA are greater than on the NIF.

\[ S \equiv \left( \frac{R_{\text{NIF}}}{R_{\Omega}} \right) \sim 4 \]
Thermal transport in the hot spot makes the deceleration phase nonscalable

- Density at hydro-equivalent times showing $\ell = 60$ growth

Classical deceleration-phase RT is exactly hydro-equivalent; thermal transport in the hot spot is nonscalable.
The deceleration-phase linear growth factors on the NIF are greater than on OMEGA for scaled initial perturbations.

\[ S \equiv \left( \frac{R_{NIF}}{R_\Omega} \right) \]

**Time evolution of deceleration RT growth factor for mode** \( \ell = 60 \)

- **NIF**
- **\( \Omega \)**

**Deceleration RT growth factors**

- **NIF**
- **\( \Omega \)**

**Growth factor**

- \( 50 \)
- \( 20 \)
- \( 10 \)
- \( 5 \)
- \( 2 \)
- \( 1 \)

**Time of peak neutron rate**

- \(-0.4\)
- \(-0.3\)
- \(-0.2\)
- \(-0.1\)
- \(0.0\)

**t\(_{NIF}\) or S \times t\(_\Omega\) (ns)**

**Mode number (\( \ell \))**

- \(10\)
- \(30\)
- \(50\)
Multimode simulations show that differences in the deceleration phase of hydro-equivalent implosions have a modest effect of the YOC ratio.

- Hydro-equivalent ignition condition on OMEGA*

\[ \chi_\Omega \approx 0.2 \left( \frac{\text{YOC}_\Omega}{\text{YOC}_\text{NIF}} \right)^{0.4} \]

\[ \Delta V/V_{\text{imp}} \% = 0.015 \]

10 < \ell < 60 with \ell^{-2} spectrum

\[ \text{Considering this effect only, YOC}_\Omega > \text{YOC}_\text{NIF} \]

*The effect of laser imprinting on the scaling of the \( YOC_{\text{NIF}, \alpha} \) is considered in R. Nora, GI3.00002, this conference (invited).
Multimode simulations show that differences in the deceleration phase of hydro-equivalent implosions have a modest effect of the YOC ratio.

- Hydro-equivalent ignition condition on OMEGA*

\[ \chi_\Omega \approx 0.2 \left( \frac{\text{YOC}_\Omega}{\text{YOC}_{\text{NIF}}} \right)^{0.4} \approx 0.21 \]

\[ \Delta V/V_{\text{imp}} \% = 0.015 \]

\[ 10 < \ell < 60 \text{ with } \ell^{-2} \text{ spectrum} \]

Considering this effect only, \( \text{YOC}_\Omega > \text{YOC}_{\text{NIF}} \)

*The effect of laser imprinting on the scaling of the \( \text{YOC}_{\text{NIF}} \) is considered in R. Nora, GI3.00002, this conference (invited).
The difference in deceleration RT growth factors are less important at lower implosion velocities*

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- The effect of mass ablation on the deceleration phase Rayleigh–Taylor scales with the implosion velocity

\[
\frac{kV_a}{\sqrt{kg}} \sim V_{imp}
\]

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