Three-Dimensional Simulations of the Deceleration Phase of Inertial Fusion Implosions Using *DEC3D*

\[ T_e = 1\text{-keV contour surface at stagnation} \]

\[ \ell = 8, m = 0 \]

\[ \ell = 8, m = 4 \]

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Summary

The radiation-hydrocode \textit{DEC3D} was developed to study the deceleration-phase Rayleigh–Taylor instability

- The 3-D code uses a second-order Riemann solver on a moving mesh and is fully parallelized by domain decomposition
- The yield degradation in 3-D versus 2-D single-mode simulations is compared and a reduction by about 10\% in neutron yield is observed in 3-D single-mode simulations
Collaborators


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**DEC3D** is a fully parallelized 3-D radiation hydrocode used to study the deceleration phase of implosions.

Mesh
- Shrinking Cartesian mesh
- Parallelized by domain decomposition

Hydrodynamics
- HLLC (Harten-Lax-van Leer-contact) second-order approximate Riemann solver

Thermal
- Red–black SOR (successive over relaxation) iteration for implicit thermal diffusion

Radiation
- Multigroup radiation transport*
- Tabular opacities

Alpha
- One-group alpha transport**

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Velocity perturbation is applied at the beginning of the deceleration phase to study the Rayleigh–Taylor (RT) instability

Initial velocity perturbations

\[ U_{3-D} = U_{1-D} + \Delta U_{m}^{\ell} (\theta, \varphi) \] ... single mode

\[ U_{3-D} = U_{1-D} + \sum_{\ell, m} \Delta U_{\ell m}^{\ell} (\theta + \theta_{\ell}, \varphi + \varphi_{m}) \] ... multimode

\[ DEC3D \leftrightarrow \text{hydro + thermal + radiation + alpha} \]

Deceleration phase

Stagnation

Initial data \((t = 10.7 \text{ ns}) = \rho, v, P, T_e\)

National Ignition Facility (NIF)-size target

\[ \rho_{\text{LILAC}} \text{ at } 10.7 \text{ ns} \]

\[ \rho \text{ (g/cm}^3) \]

\[ x \text{ (\mu m)} \]
The Rayleigh–Taylor instability during the deceleration phase is modeled by **DEC3D**.
Hydrodynamics, thermal conduction, and radiation transport have been validated against 1-D LILAC.
Single-mode Rayleigh–Taylor perturbation growth rates are compared to benchmark 3-D with 2-D simulations

- Simulated linear growth rates are consistent with theories* for converging targets in the deceleration phase

Nonlinear Rayleigh-Taylor growth leads to a thinner shell wall in 3-D than 2-D

2-D $\rho$  
$\ell = 8, m = 0$

3-D $\rho$  
$\ell = 8, m = 4$

Areal-density profile

$\Delta \rho R^{3-D}$ versus $\Delta \rho R^{2-D}$

- $\Delta \rho R^{3-D} \ell = 8, m = 4$
- $\Delta \rho R^{2-D} \ell = 8, m = 0$

Density (g/cm$^3$)
- 350
- 250
- 150
- 50

Density profile for Bubble and Spike

Starting point ($t = 10.7$ ns)

Stagnation point ($t = 11.7$ ns)
An ~10% reduction in neutron yield is observed in 3-D versus 2-D single-mode simulations

- Two types of 3-D initial perturbations are investigated to eliminate the possibility of design-dependence on the yield degradation

Orthogonal sinusoidal modes

\[ U_{3-D} = U_{1-D} + \Delta U [P_{2-D}(\ell \theta) + \sin m \varphi] \]

Spherical harmonic eigenmodes

\[ U_{3-D} = U_{1-D} + \Delta U Y^m_{\ell} (\theta, \varphi) \]

YOC\textsuperscript{3-D} versus YOC\textsuperscript{2-D}

- 2-D \( \ell = 8, m = 0 \)
- 3-D \( \ell = 8, m = 4 \)

\( \delta v/v_0 \) (%)

11.7 ns

-10% \( \triangledown \)
An ~15% reduction in neutron yield is observed in 3-D versus 2-D multimode simulations.

![Graph showing YOC\textsuperscript{3-D} versus YOC\textsuperscript{2-D} in multimode simulations.](image)

- $T_e = 1$ keV
- Density (g/cm$^3$): 350, 250, 150, 50

11.7 ns
Summary/Conclusions

The radiation-hydrocode \textit{DEC3D} was developed to study the deceleration-phase Rayleigh–Taylor instability

- The 3-D code uses a second-order Riemann solver on a moving mesh and is fully parallelized by domain decomposition.
- The yield degradation in 3-D versus 2-D single-mode simulations is compared and a reduction by about 10\% in neutron yield is observed in 3-D single-mode simulations.
DEC3D is a fully parallelized 3-D radiation hydrocode to study the implosions of the deceleration phase