LA-UR-13-26434

Approved for public release; distribution is unlimited.

Title: Development of ICF Mix Code

Author(s): Melvin, Jeremy A.
Miller, Sean
Vold, Erik L

Intended for: 2012 Computational Physics Student Summer Workshop Presentation

Issued: 2013-08-14

Disclaimer:

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Development of ICF Mix Code

Jeremy A. Melvin¹ Sean T. Miller²
Mentor: Dr. Erik Vold

¹Department of Applied Mathematics, Stony Brook State University of New York

²Department of Aeronautics and Astronautics, University of Washington

2012 Computational Physics Student Summer Workshop

Outline

1 Introduction

- Inertial Confinement Fusion
- Project Objectives

2 Code Development

- Lagrange Phase
- Remap Phase
- Remesh Phase

3 Results

- Shock Tube
- Blast Wave
- RM-Instability
- ICF

4 Conclusion

- Proposed Future Work
- Acknowledgements
- References
- Close

Introduction

What is ICF?

- Inertial Confinement Fusion (ICF) is a simple form of nuclear fusion
- Begin with a pellet of fusable material and rapidly heat and compress it to the point of fusion
 - Pellet of deuterium-deuterium (DD) or deuterium-tritium (DT)
 - Compression usually accomplished through laser ablation or using particle beams

Introduction

ICF Description

Ablation Implosion Concept

Omega Laser Direct Drive at
LLE (Rochester)

Laser Direct Drive at NIF
(National Ignition Facility)

Introduction

Applications

- An experimental regime to study high energy density fluid and plasma (HEDF&P) physics
- Validation for numerical simulations in this regime
- Study the behavior of matter under the conditions found in nuclear weapons
- Perhaps one day provide a clean fusion energy source

Introduction

ICF Issues (from NIF)

- Shape
 - Drive asymmetry
- Mix
 - RT (Rayleigh-Taylor)
 - RM (Richtmyer-Meshkov)
- Turbulence?
 - Drive asymmetry w/ convergence
- Plasma transport?

Introduction

ICF Experiment vs. Simulation

- Left: Youngs and Williams [7] turbulent mixing simulation of a simplified ICF
- Right: X-ray emission of an ICF experiment

Introduction

Project Objectives

- Develop an ICF mix code capable of handling:
 - Convergent geometries: Cylindrical and Spherical
 - Richtmyer-Meshkov and Rayleigh-Taylor instabilities
 - Plasma mixing through plasma diffusion and transport

Introduction

Project Approach

- Numerical algorithm: Lagrange + remesh/remap (ALE)
- Explored Lagrange + remap methods as described in:
 - Pember and Anderson's Staggered Grid Lagrangian with remap [3]
 - David Youngs' TURMOIL3D Lagrange with remap [6]
- Perform verification of the implemented hydro algorithm
 - Sod Shock Tube
 - Sedov
 - Interacting Blast Wave code comparison to [3]

Outline

1 Introduction

- Inertial Confinement Fusion
- Project Objectives

2 Code Development

- Lagrange Phase
- Remap Phase
- Remesh Phase

3 Results

- Shock Tube
- Blast Wave
- RM-Instability
- ICF

4 Conclusion

- Proposed Future Work
- Acknowledgements
- References
- Close

Implode Code

Governing Equations

We solve the Euler equations with an ideal gas EOS and a mass species concentration equation

$$\frac{D\rho}{Dt} = -\rho \nabla \cdot \vec{u} + S_\rho$$

$$\frac{D\psi}{Dt} = S_\psi$$

$$\rho \frac{D\vec{u}}{Dt} = -\nabla p + \vec{S}_u$$

$$p = (\gamma - 1)\rho e$$

$$\rho \frac{De}{Dt} = -p \nabla \cdot \vec{u} + S_e$$

$$\gamma = \frac{\psi \rho c_{v0} \gamma_0 + (1 - \psi) \rho c_{v1} \gamma_1}{\psi \rho c_{v0} + (1 - \psi) \rho c_{v1}}$$

Implode Code

ALE Method

- Mixture of both a Lagrange phase and an optional remesh/remap phase
- Minimize fluxed quantities to obtain maximal benefit from the Lagrange phase
- Prevent tangling by remeshing to a uniform grid

Implode Code

Code Structure Basics

- Built for unstructured meshes
- Able to utilize different geometric systems for symmetries
 - Cartesian
 - Cylindrical
 - Spherical

Implode Code

Lagrange Phase

- Staggered grid with velocities on the vertices
- Predictor-corrector time integrator
- Utilize artificial viscosity to handle dissipation

Implode Code

Lagrange Phase: Artificial Viscosity

- Monotonic Artificial Viscosity [1]:

$$q_m = \rho dv \left(\frac{1}{4}(\gamma + 1) dv (1 - \phi_v^2) + \frac{1}{2} c_s (1 - \phi_v) \right)$$

- Kuropatenko Viscosity [5]:

$$q_k = \rho dv (1 - \phi_v) \left(\frac{1}{4}(\gamma + 1) dv + \sqrt{\left(\frac{1}{4}(\gamma + 1) dv \right)^2 + c_s^2} \right)$$

Implode Code

Lagrange Phase: Artificial Viscosity

Left: Sod Shock Tube problem comparing artificial viscosities.
Right: Area of interest.

Implode Code

Lagrange Phase: Acceleration

$$\vec{a}_c = \frac{\sum_{i=0}^3 (p_i - p_{i+1} + q_i - q_{i+1}) A_i \hat{n}_i}{\sum_{i=0}^3 \rho_i V_i}$$

2D

1D

Implode Code

Lagrange Phase: Mesh Tangling

Implode Code

Remap Phase

- Monotonically conservative advection remap algorithm
- Flux state variables from Lagrangian grid to correct location in the remap grid
- Maintain conservation of required quantities
- Enforce conservation of energy

$$e^{remap} = e^{remap} + (ke^{remap} - kecalc^{remap})$$

Implode Code

Remap Phase

Implode Code

Remesh Phase

- Full ALE: Remesh phase is setup to handle a remesh to any arbitrary grid
- With symmetric shocks we remesh to the radial average coordinate and equally spaced angular coordinates
- Has effect of only remapping when tangling can occur (ALE)

Outline

1 Introduction

- Inertial Confinement Fusion
- Project Objectives

2 Code Development

- Lagrange Phase
- Remap Phase
- Remesh Phase

3 Results

- Shock Tube
- Blast Wave
- RM-Instability
- ICF

4 Conclusion

- Proposed Future Work
- Acknowledgements
- References
- Close

Results

Shock Tube

- Verification via comparison to a 1D Sod-like shock tube problem [8]
- Initial Conditions: $\gamma = 1.4$, $\rho_{left} = .1$, $\rho_{right} = 1$, $x_0 = 0$, $x_1 = 1$

Results

Shock Tube: 1D Lagrange

Results

Shock Tube: 1D Remap

Results

Interacting Blast Wave

- Comparison to a 1D interacting blast wave presented in Pember and Anderson [3]
- Initial Conditions:
 $\gamma = 1.4, \rho = 1, e_l = 2500, e_m = 0.0025, e_r = 250$
 $x_l = 0.1 \ x_r = 0.9$

Results

Shock Tube: 1D Lagrange

Results

Shock Tube: 1D Remap

Results

Richtmyer-Meshkov

- Initial perturbed density interface
- Pass shock through interface
- Bubbles (light into heavy) and spikes (heavy into light) appear

Results

RM Simulation Examples

Time = 0.14 Richtmyer-Meshkov ICs

Results

RM Simulation Examples

Time = 1.31 Richtmyer-Meshkov Bubble

Pseudocolor
Var: density

Max: 1.424
Min: 0.1311

Results

RM Simulation Examples

Time = 1.57 Richtmyer-Meshkov Reshock

Pseudocolor
Var: density

Max: 3.498

Min: 0.1234

Results

ICF

- Two fluid hydro setup mimicking ICF initial conditions [2]
- Internal species of deuterium-deuterium (DD)
- External species of polyethylene (CH_2)
- 20 [TW] Laser pulse over 1 [ns] with 20% absorption: 4 [kJ]

Results

ICF Results

Left: 1D Spherical ICF from implode code

Right: 1D Spherical ICF Lagrangian HELIOS code [4]

Outline

1 Introduction

- Inertial Confinement Fusion
- Project Objectives

2 Code Development

- Lagrange Phase
- Remap Phase
- Remesh Phase

3 Results

- Shock Tube
- Blast Wave
- RM-Instability
- ICF

4 Conclusion

- Proposed Future Work
- Acknowledgements
- References
- Close

Summary of Work

- Built a base multidimensional ALE ICF mix hydro code
- Performed verification of hydro code
- Successfully handle RM instability
- Mimic ICF like initial conditions for hydro simulations

Recommended Future Work

- Parallelize/Multithreading
- Revisit:
 - Adaptive dt calculation
 - Artificial viscosity in 2D/3D
 - Staggered grid vs cell centered hydro
 - Energy conservation
 - Remesh algorithm
- Plasma physics models
- Diffusion/Plasma transport
- Spherical symmetry in 2D

Acknowledgments

- Mentor: Dr. Erik Vold
- Workshop Coordinator: Dr. Scott Runnels
- Los Alamos National Lab
- University of New Mexico - Los Alamos

References I

[1] M. J. Shashkov E. J. Caramana and P. P. Whalen.
Formulations of artificial viscosity for multi-dimensional shock wave
computations.
Journal of Computational Physics, 144:70–97, 1998.

[2] Denis Keefe.
Inertial confinement fusion.
Annu Rev. Nucl. Part. Sci., 32:391–441, 1982.

[3] R. B. Pember and R. W. Anderson.
A comparison of staggered-mesh lagrange plus remap and cell centered direct
eulerian godunov schemes for eulerian shock hydrodynamics.
NECDC, 2000.

[4] Erik Vold and Leslie Welser-Sherrill.
Momentum transport and associated scale lengths in an icf plasma.
Presented at: 2012 HED Plasma and Fluids, 2011.

[5] Mark L. Wilkins.
Use of artificial viscosity in multidimensional fluid dynamic calculations.
Journal of Computational Physics, 36:281–303, 1980.

References II

[6] David L. Youngs.

The lagrangian remap method.

Implicit Large Eddy Simulation - Computing Turbulent Fluid dynamics, pages 147–153, 2007.

[7] David L. Youngs and Robin J. Williams.

Turbulent mixing in spherical implosions.

Int. J. Numer. Meth. Fluids, 56:1597-1603, 2008.

[8] Gary A. Sod.

A Survey of Several Finite Difference Methods for Systems of Nonlinear Hyperbolic Conservation Laws.

J. Comput. Phys, 27:1-31, 1978.

End

Thank you!

Questions?