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V&V Tier I Verification: The Sedov Test Problem (ALE codes)

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V&V Tier I Verification: The Sedov Test Problem (ALE codes)

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A-Division Code Group

Lawrence Livermore National Laboratory

NECDC

October 4-8, 2004

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University of California

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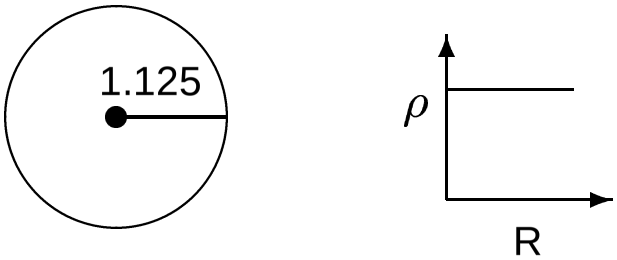
Test Problem Inventory

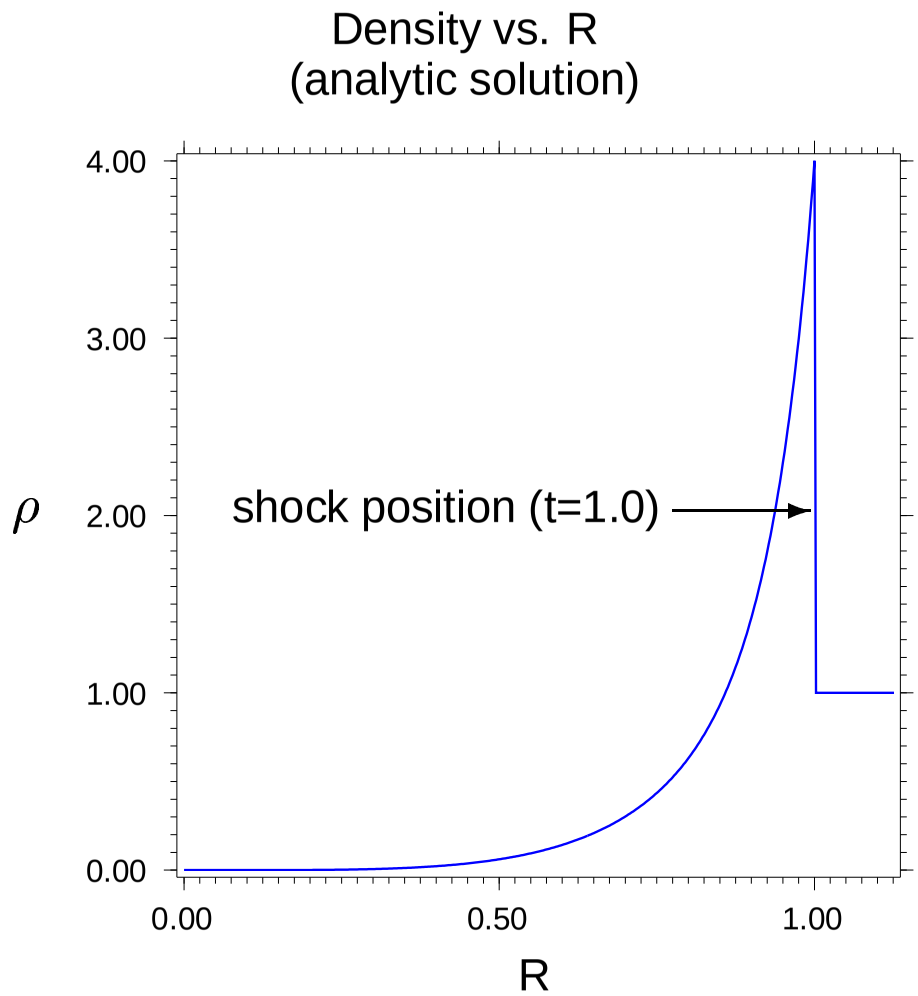
- Advection Tests
  - Smooth pulse advection
  - Square pulse advection
- Hydrodynamics Tests
  - Coggeshall [Example 1] (adibatic compression)
  - Sod/LeBlanc Shock Tubes (weak/strong shock propagation)(NA)
    - Rarefaction Test Problem
  - Noh (adiabatic/strong shock compression)
  - **Sedov Blast Wave (spherical expansion)**
  - Guderley (converging shock)
- Radiation Tests
  - Standard Marshak Propagation Test
  - Non-Equilibrium Marshak Problem (Su and Olsen)
- Radiation-Hydrodynamics Tests
  - Coggeshall 8 (adiabatic expansion with heat conduction)
  - Reinicke (blast wave with heat conduction)

The Sedov Test Problem (Standard Configuration)

- Sedov, L.I., *Appl. Math. Meth.* **9** (1945)
- A $\gamma = \frac{5}{3}$ gas sphere with unit density is initialized with 0.49359 energy units deposited at the center point

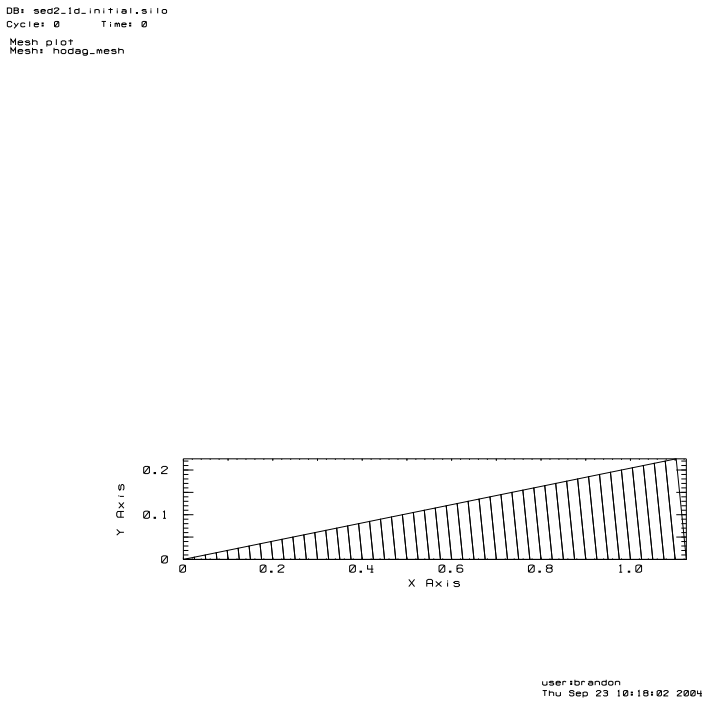


- Shock expansion and position is checked

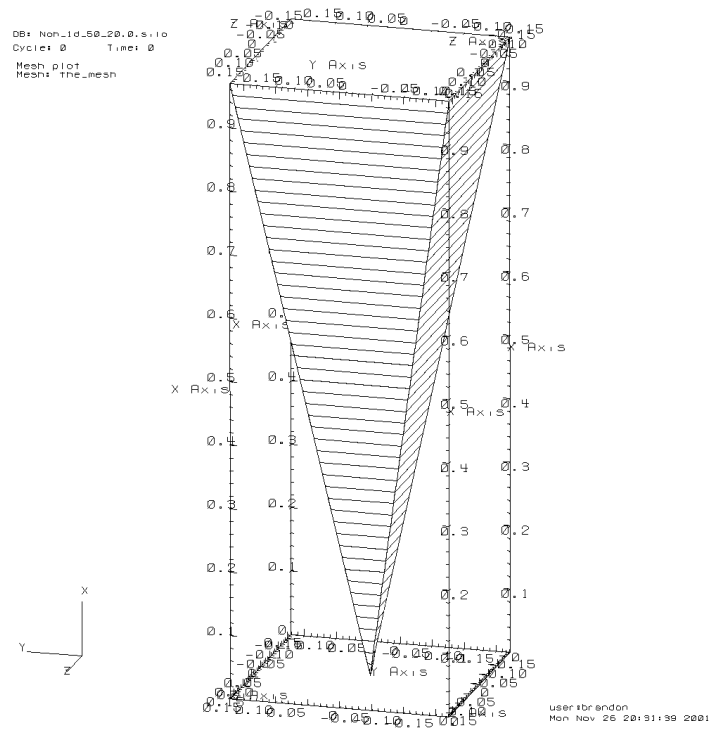


1-D Problem, 2-D or 3-D Implementation

2-D Wedge Mesh
(cylindrical)

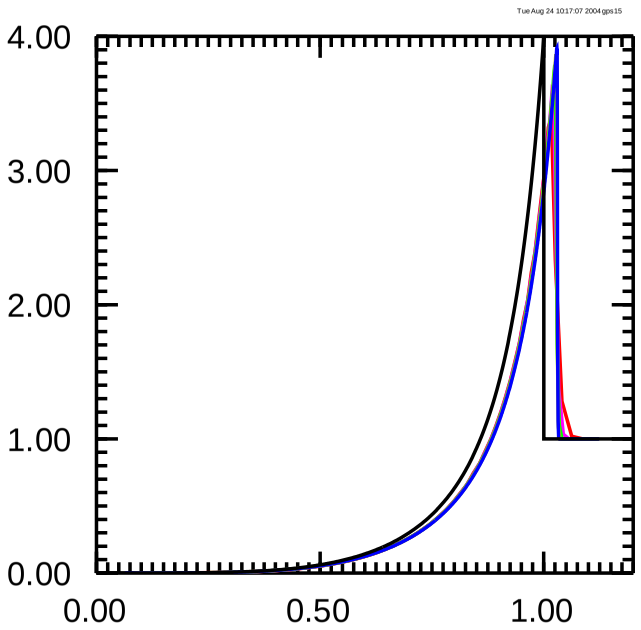


3-D Spike Mesh
(spherical)



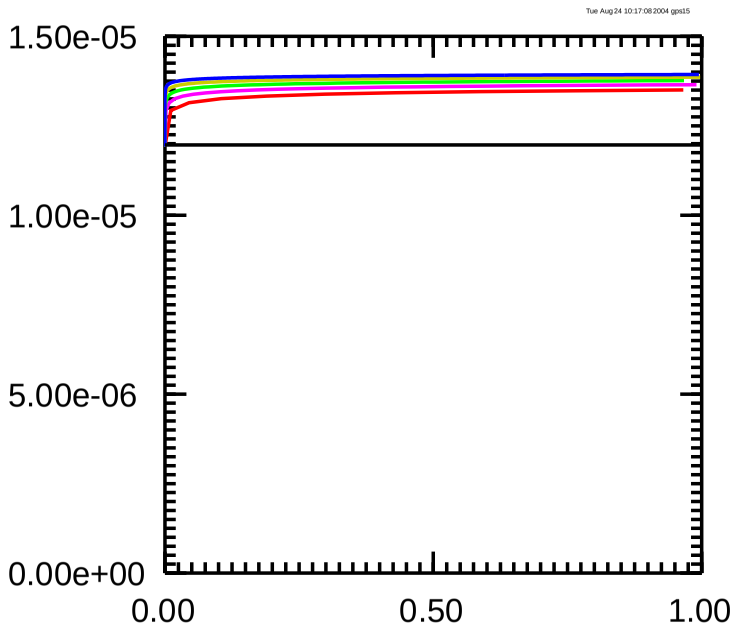
KULL: 1-D Sedov Problems [SPIKE mesh]

Density vs. R
(45 - 720 zones)



A KULL: Sedov density at t=1.0 (45 zones)
B KULL: Sedov density at t=1.0 (90 zones)
C KULL: Sedov density at t=1.0 (180 zones)
D KULL: Sedov density at t=1.0 (360 zones)
E KULL: Sedov density at t=1.0 (720 zones)
F Solution (density)

Total Energy vs. time
(45 - 720 zones)

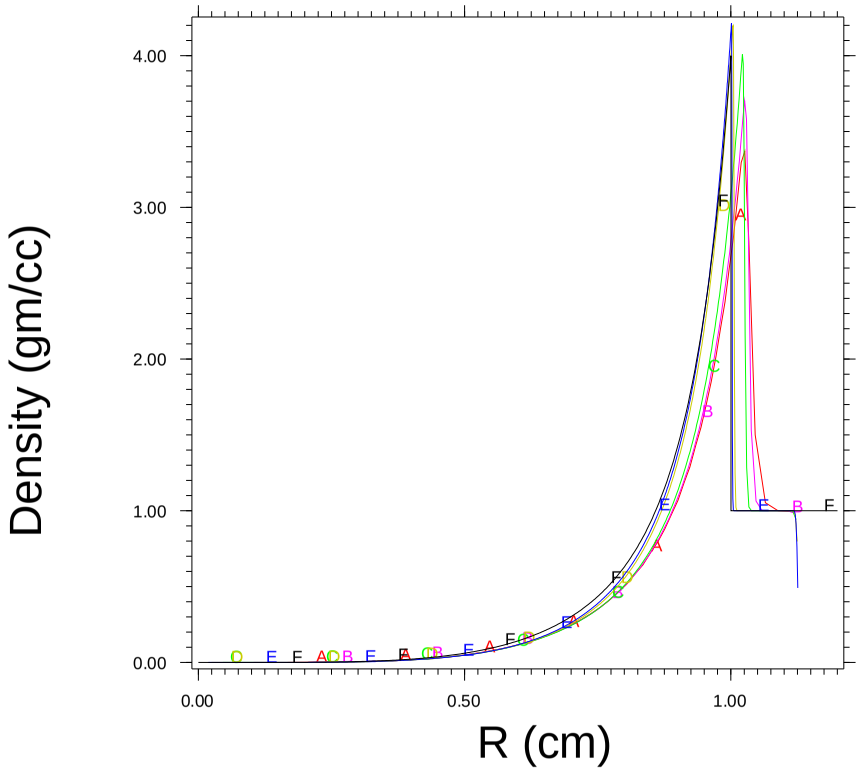


A KULL:Sedov Total Energy vs. time (45 zones)
B KULL:Sedov Total Energy vs. time (90 zones)
C KULL:Sedov Total Energy vs. time (180 zones)
D KULL:Sedov Total Energy vs. time (360 zones)
E KULL:Sedov Total Energy vs. time (720 zones)
F initial energy

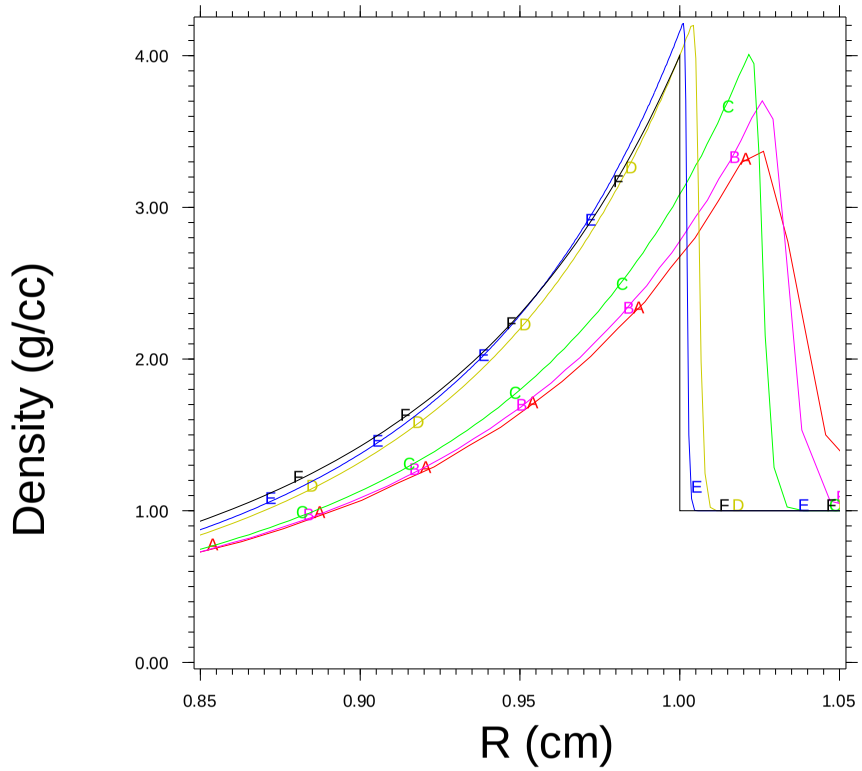
Note: Compare KULL's 20% energy growth to 30+% growth for CALE

KULL: Adding newALE to Sedov Problems I [1-D]

Density vs. R [t=1.0]
(45 - 720 zones)



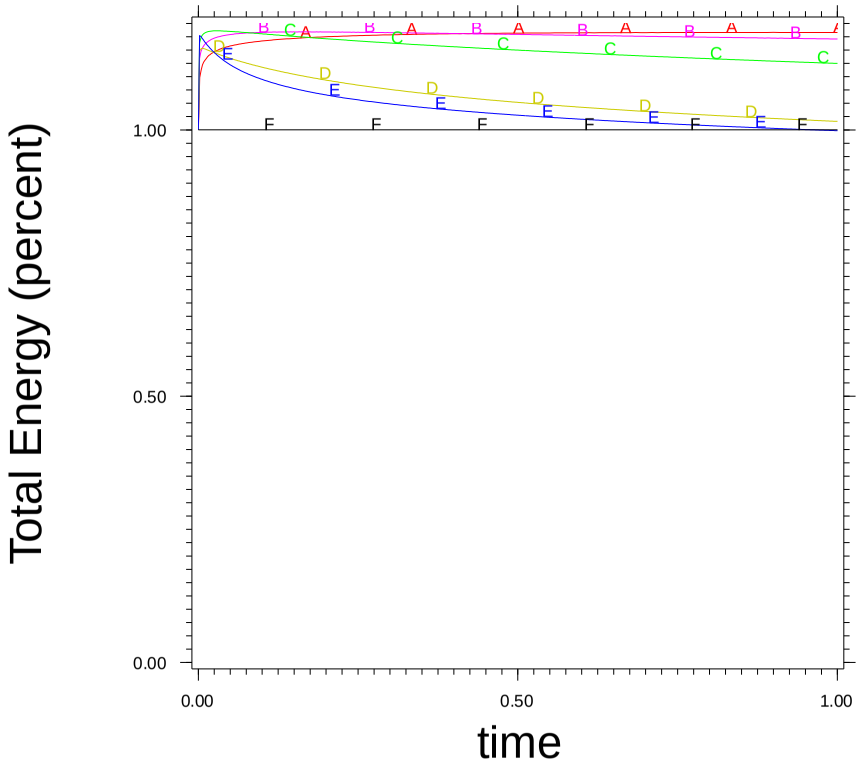
Density vs. R
(zoomed to show shock)



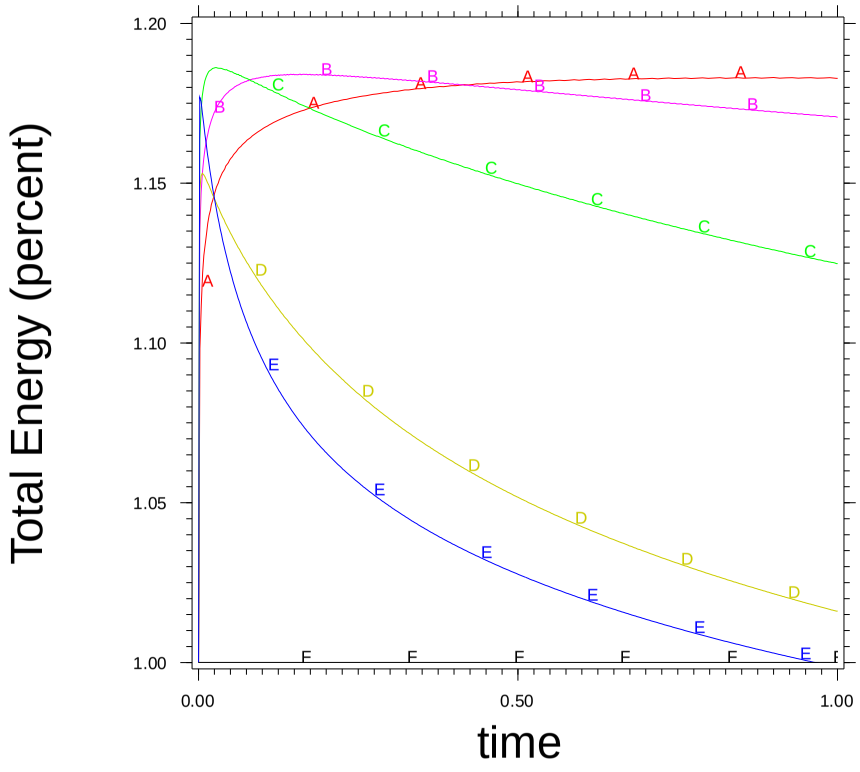
Note: Adding ALE “improves” this result

KULL: Adding newALE to Sedov Problems II [1-D]

Total Energy vs. time
(45 - 720 zones)



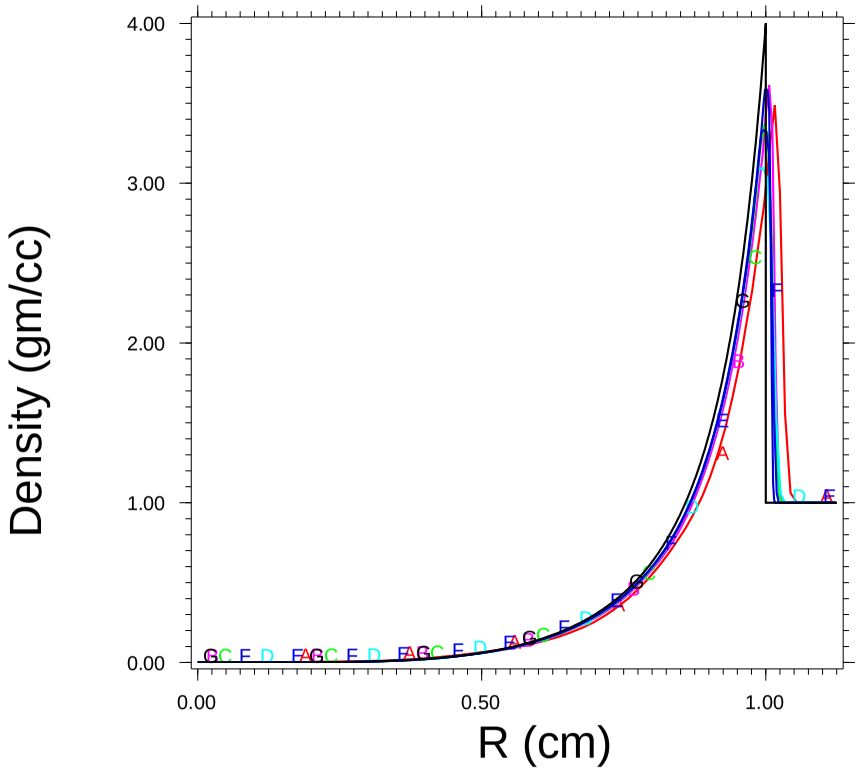
Total Energy vs. time
(zoomed to show behavior)



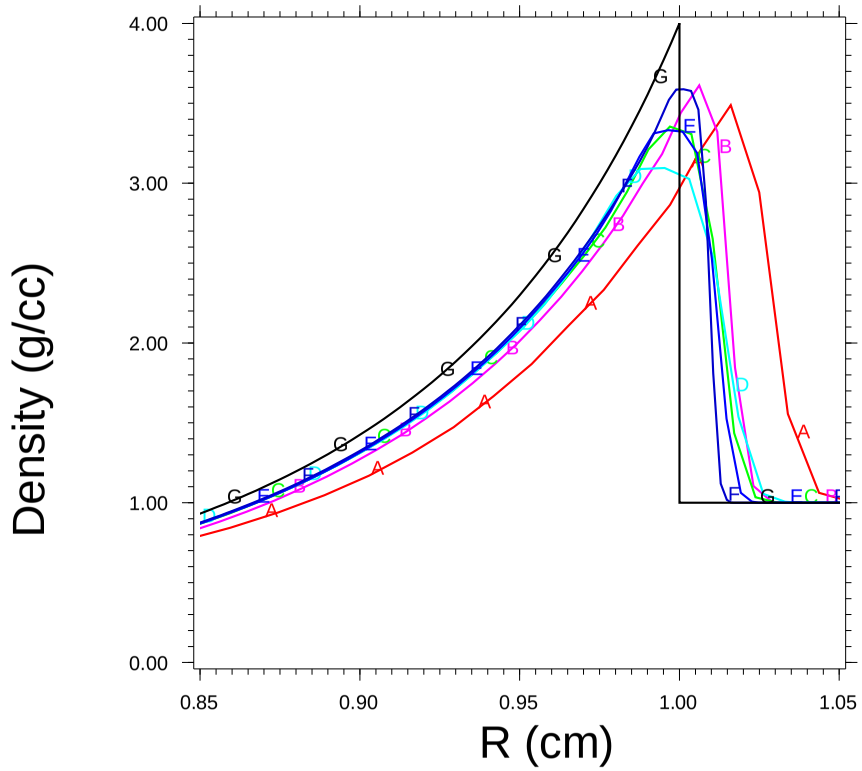
Note: Adding ALE reduces the growth in total energy

CALE: Adding ALE to Sedov Problems I [1-D wedge mesh]

Density vs. R [t=1.0]
(45 - 1440 zones)



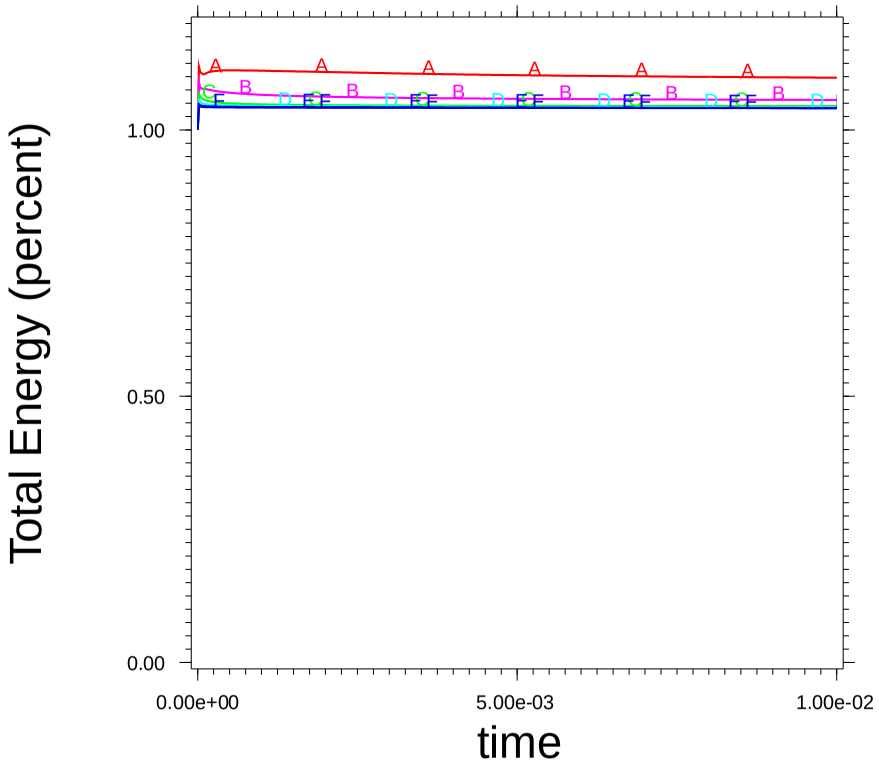
Density vs. R
(zoomed to show shock)



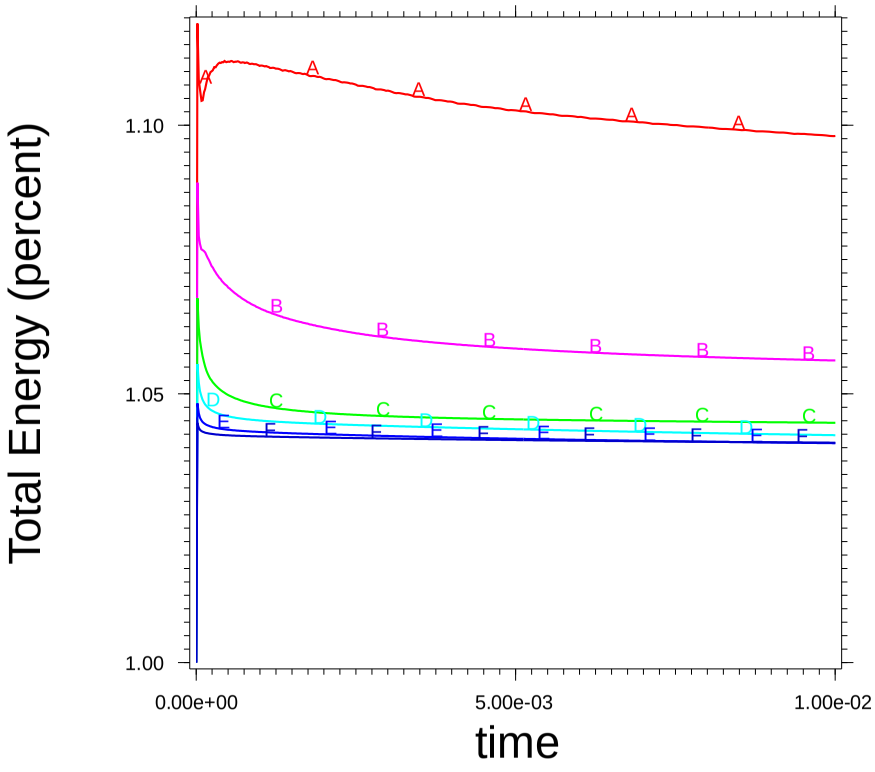
Note: Adding ALE “improves” this result

CALE: Adding ALE to Sedov Problems II [1-D wedge mesh]

Total Energy vs. time
(45 - 1440 zones)



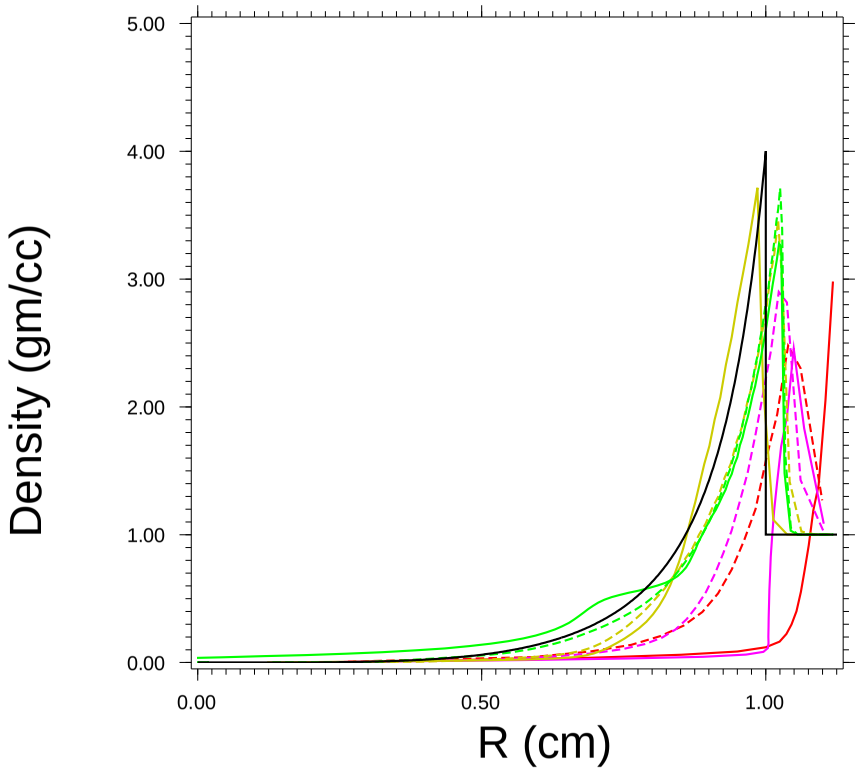
Total Energy vs. time
(zoomed to show behavior)



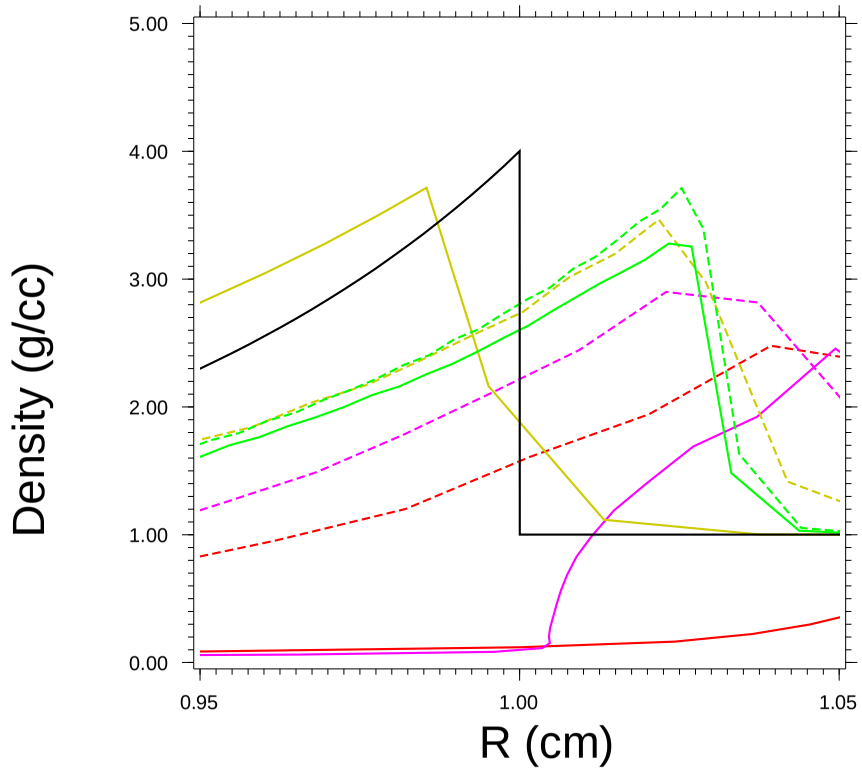
Note: Adding ALE reduces the growth in total energy

CALE: Lagrange Sedov Problems I [2-D square mesh]

Density vs. R [t=1.0]
(16 - 90 zones)



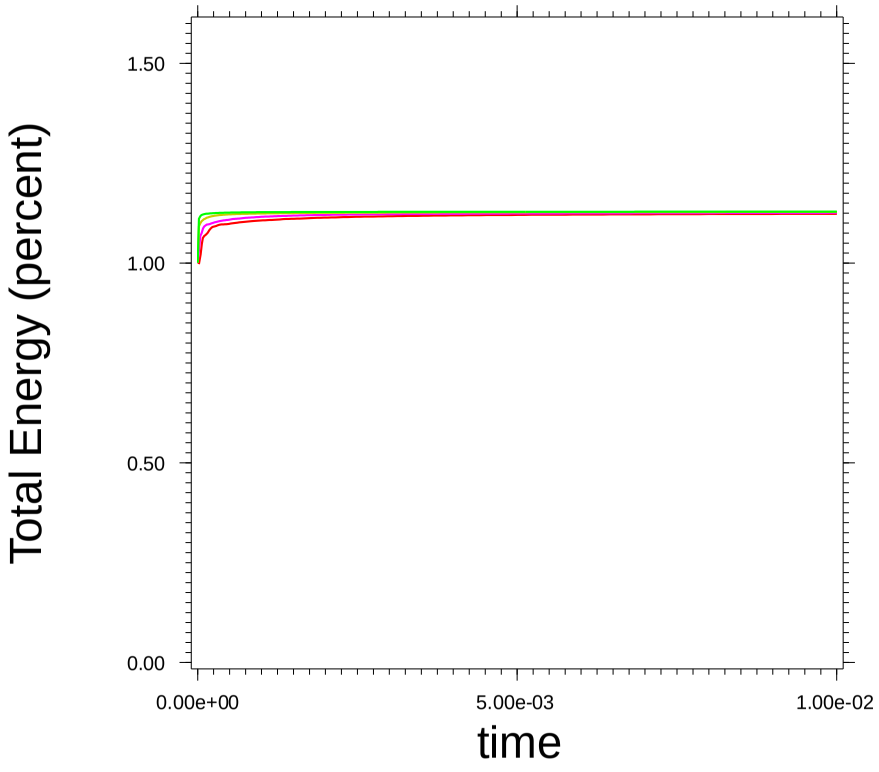
Density vs. R
(zoomed to show shock)



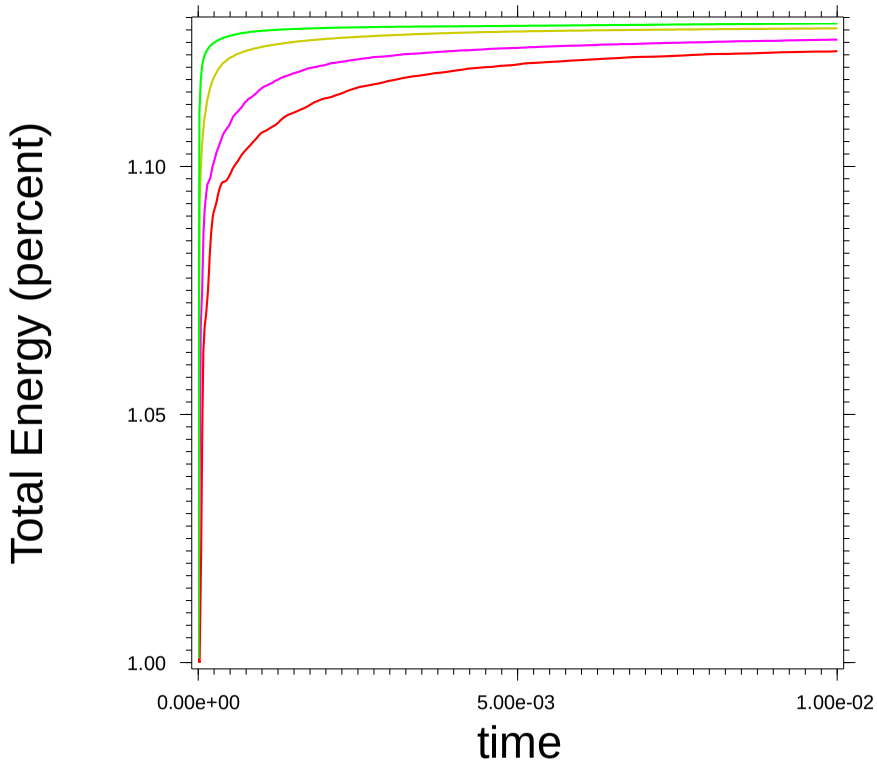
Note: Dashed lines correspond to slices along the waist

CALE: Lagrange Sedov Problems II [2-D square mesh]

Total Energy vs. time
(14 - 90 zones)



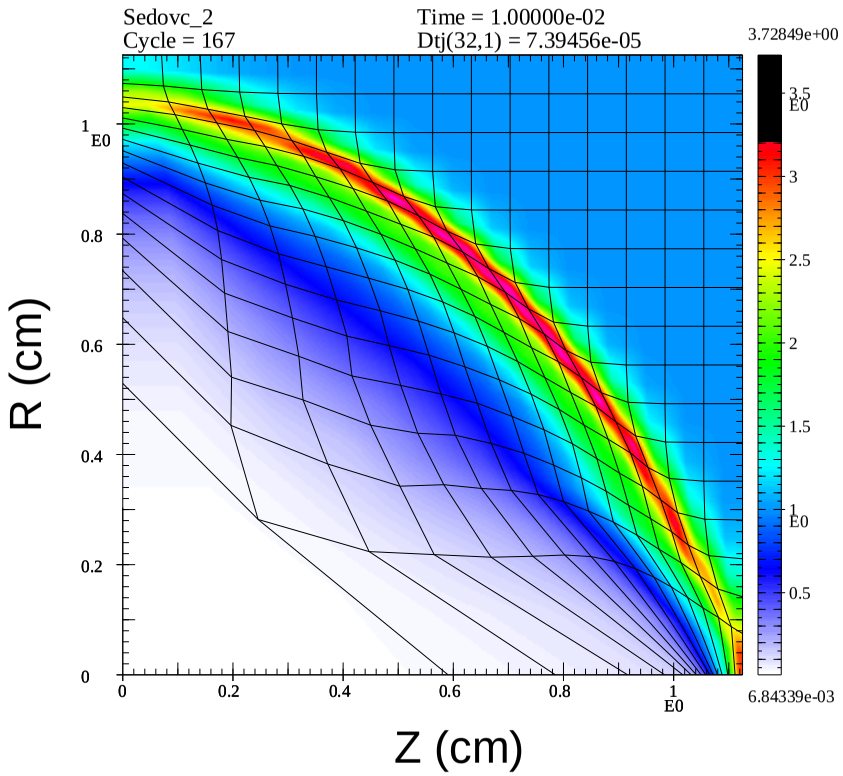
Total Energy vs. time
(zoomed to show behavior)



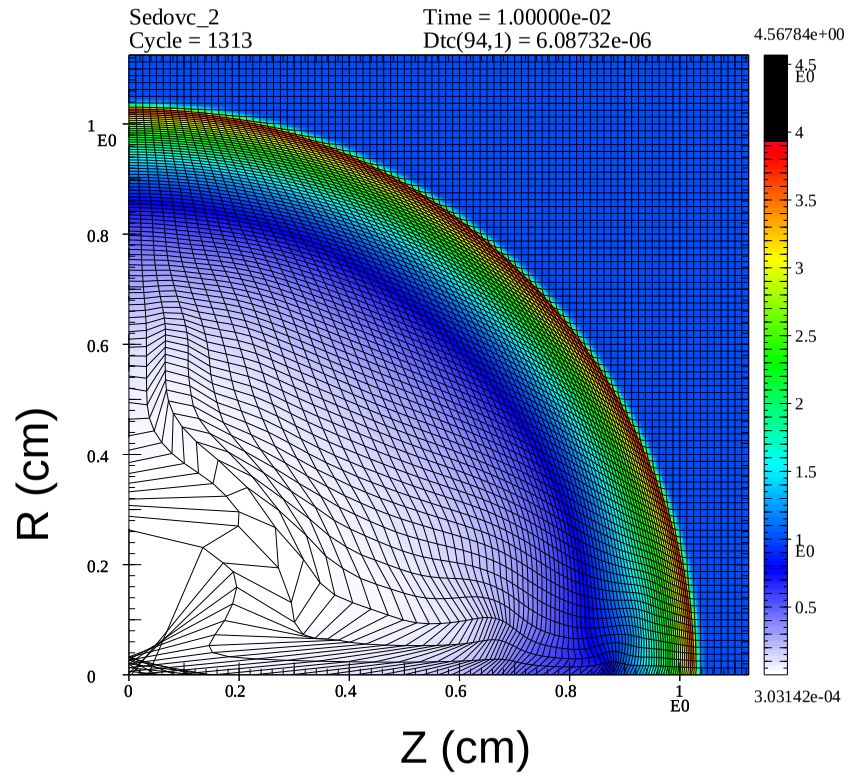
Note: Adding ALE reduces the growth in total energy

CALE: Lagrange Sedov Problems III [2-D square mesh]

Density vs. R [t=1.0]
(32 * 16 zones)



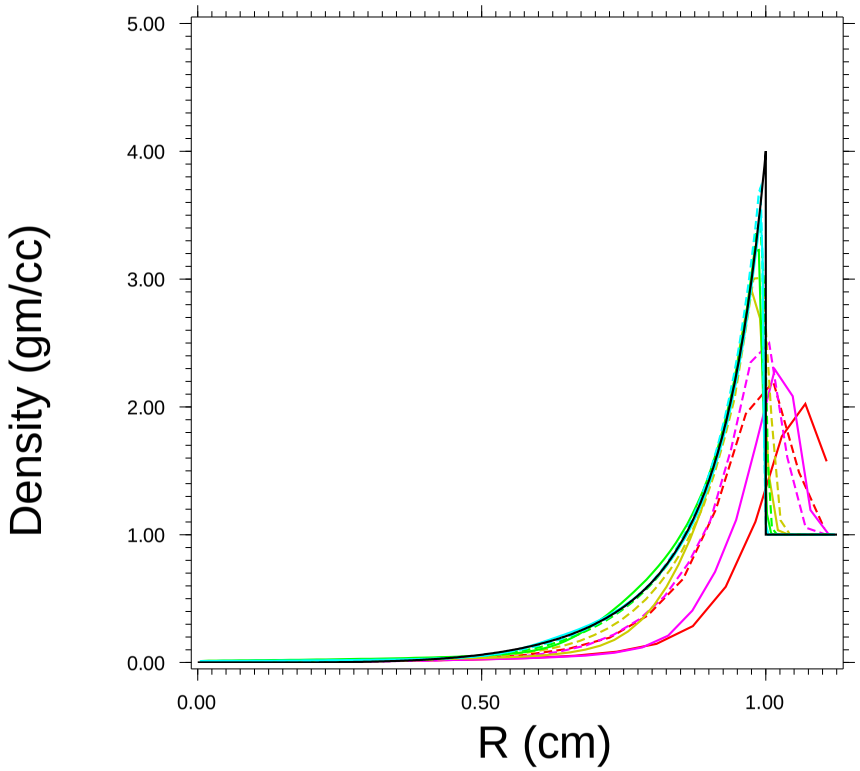
Density vs. R
(180 * 90 zones)



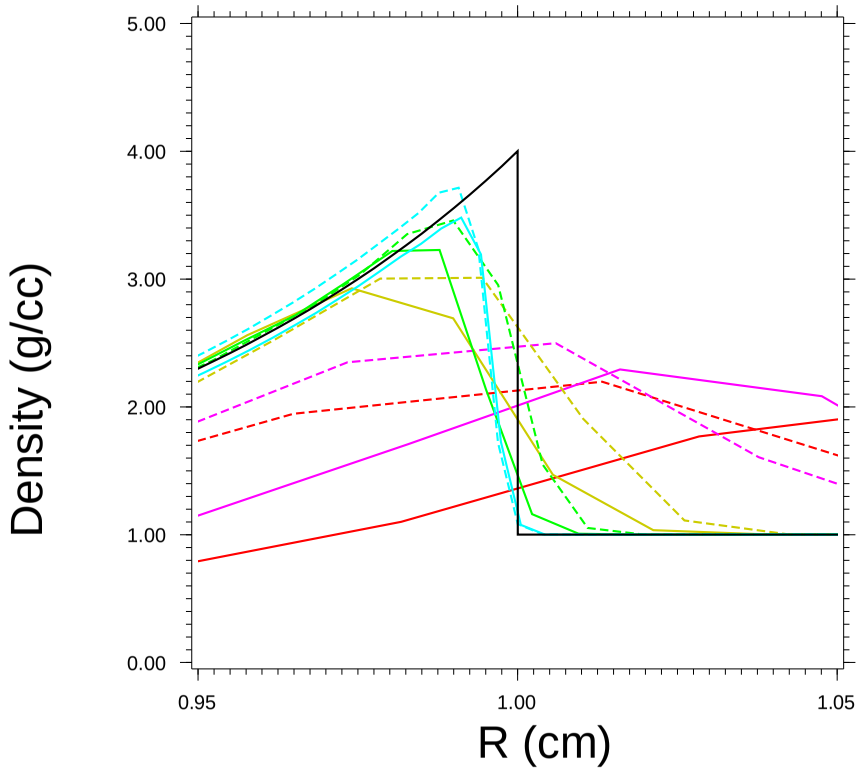
Note: ALE options allow larger problems to complete

CALE: Adding ALE to Sedov Problems I [2-D square mesh]

Density vs. R [t=1.0]
(16 - 90 zones)



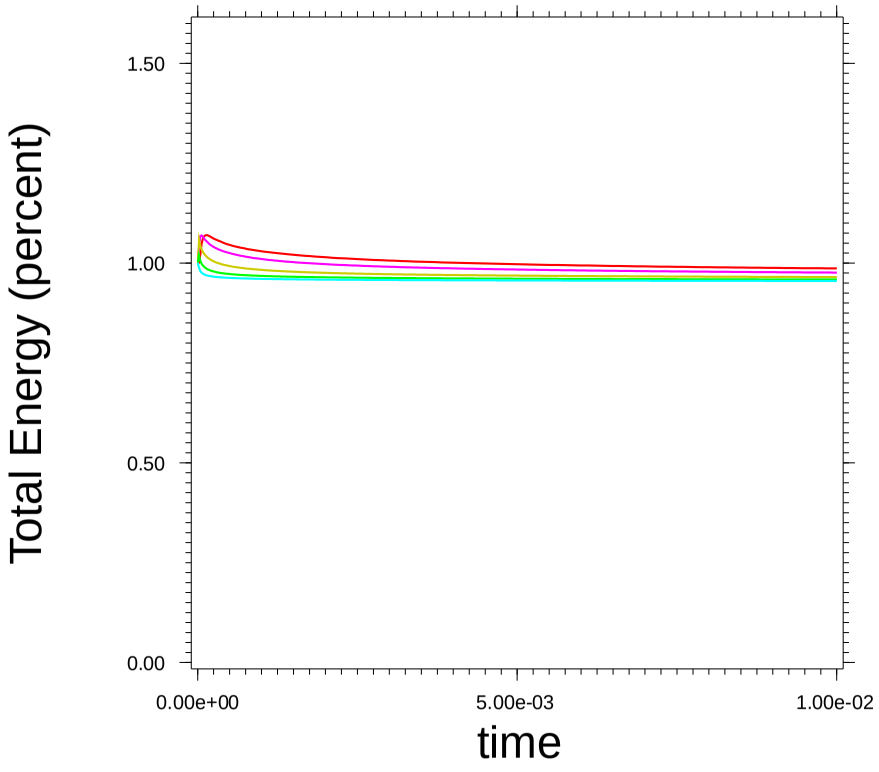
Density vs. R
(zoomed to show shock)



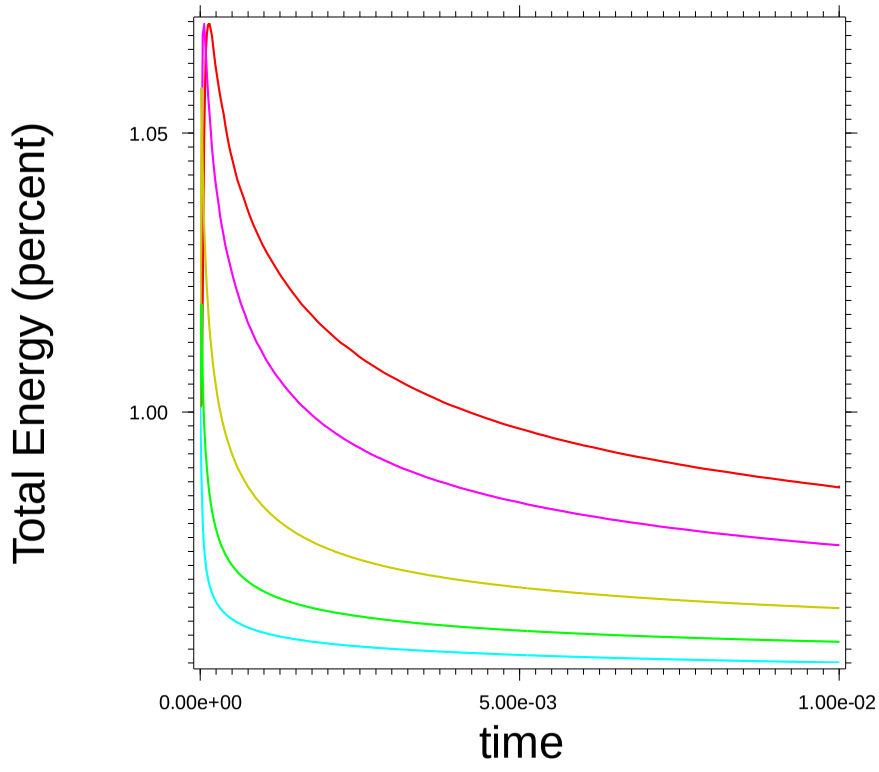
Note: Density curves along the waist are dashed

CALE: Adding ALE to Sedov Problems II [2-D square mesh]

Total Energy vs. time
(14 - 90 zones)



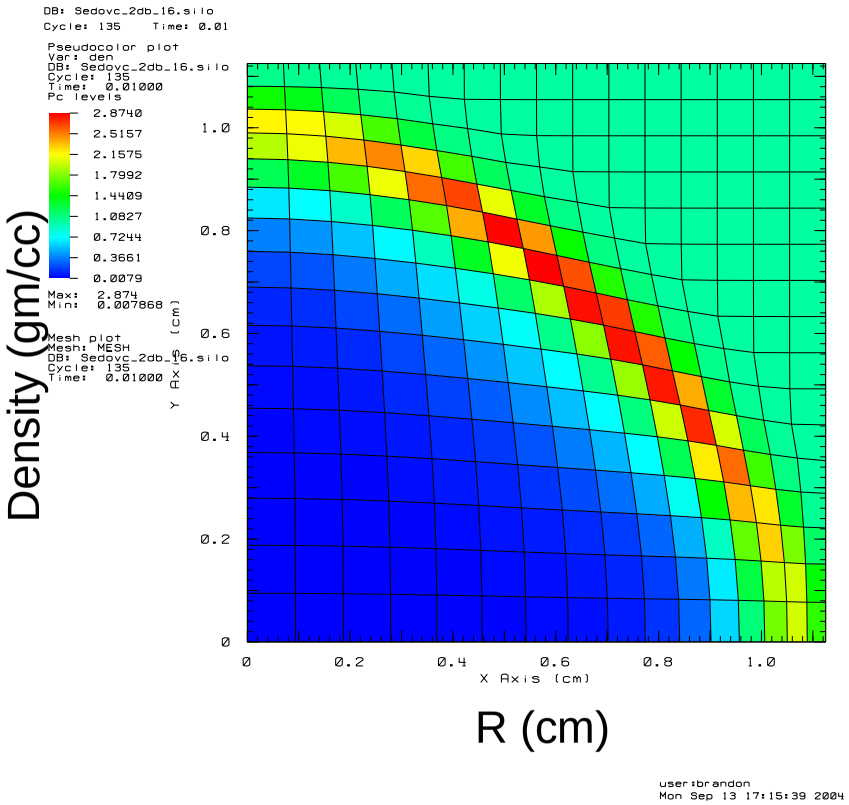
Total Energy vs. time
(zoomed to show behavior)



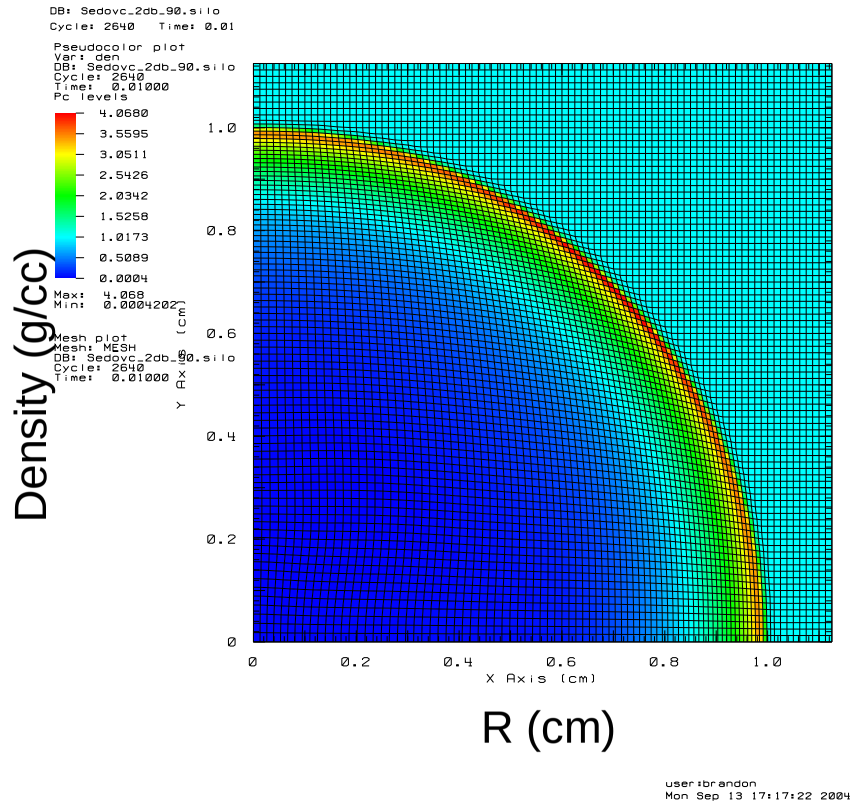
Note: Adding ALE lowers the total energy in the problem (below the initial value)

CALE: Adding ALE to Sedov Problems III [2-D square mesh]

Density vs. R [t=1.0]
(32 * 16 zones)



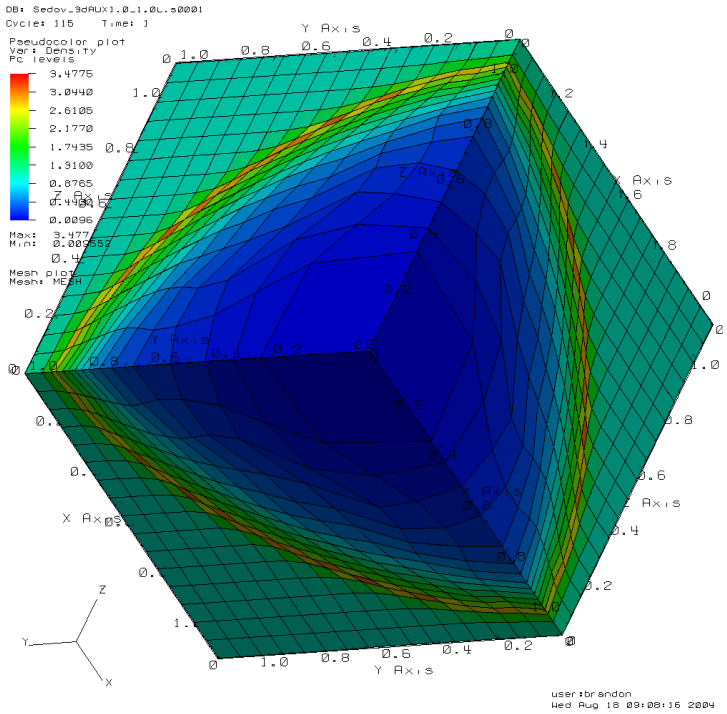
Density vs. R
(180 * 90 zones)



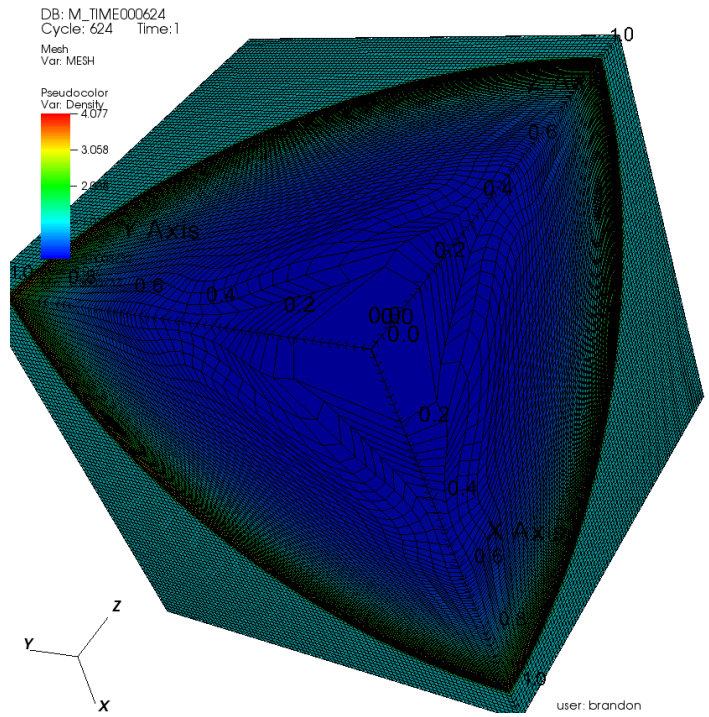
Note: Requires an additional ALE option to handle zones near the origin

KULL: Lagrange Sedov Problems I [3-D octant]

Density/mesh [t=1.0]
(16^3 zones)

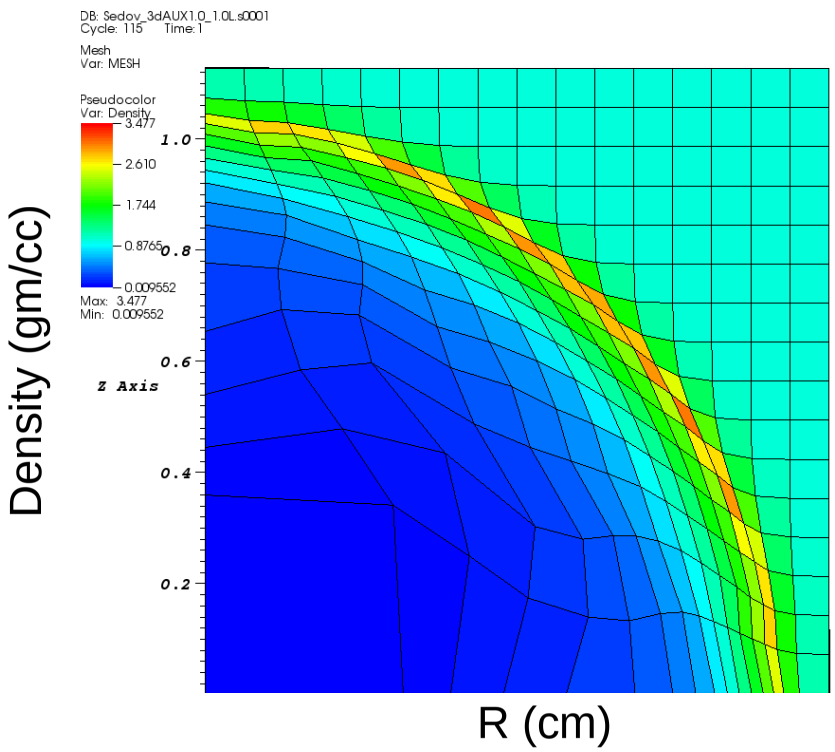


Density/mesh [t=1.0]
(90^3 zones)

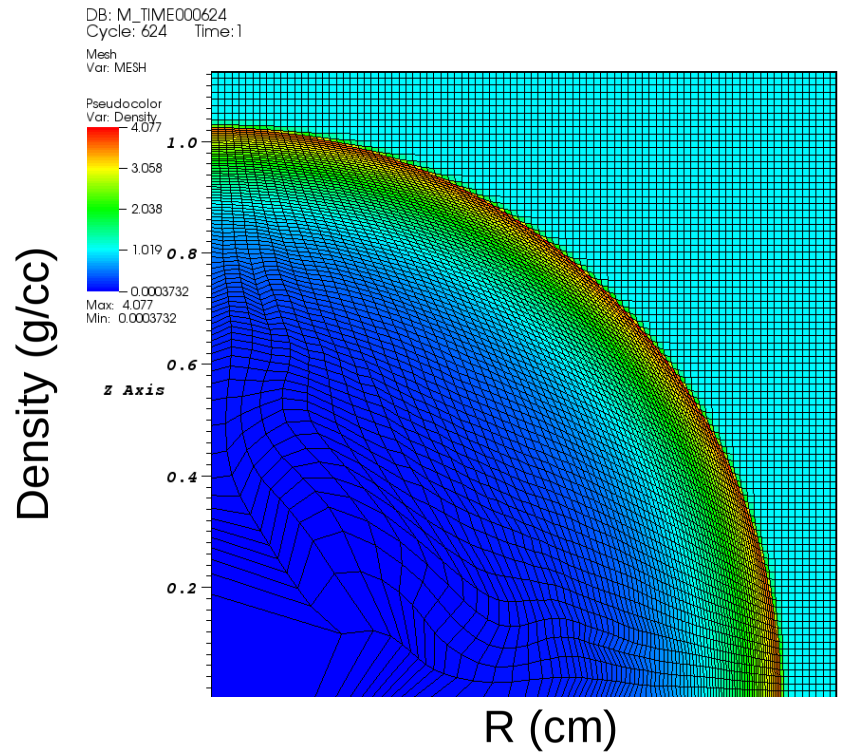


KULL: Lagrange Sedov Problems II [3-D octant]

Density vs. R [t=1.0]
(16^3 zones)

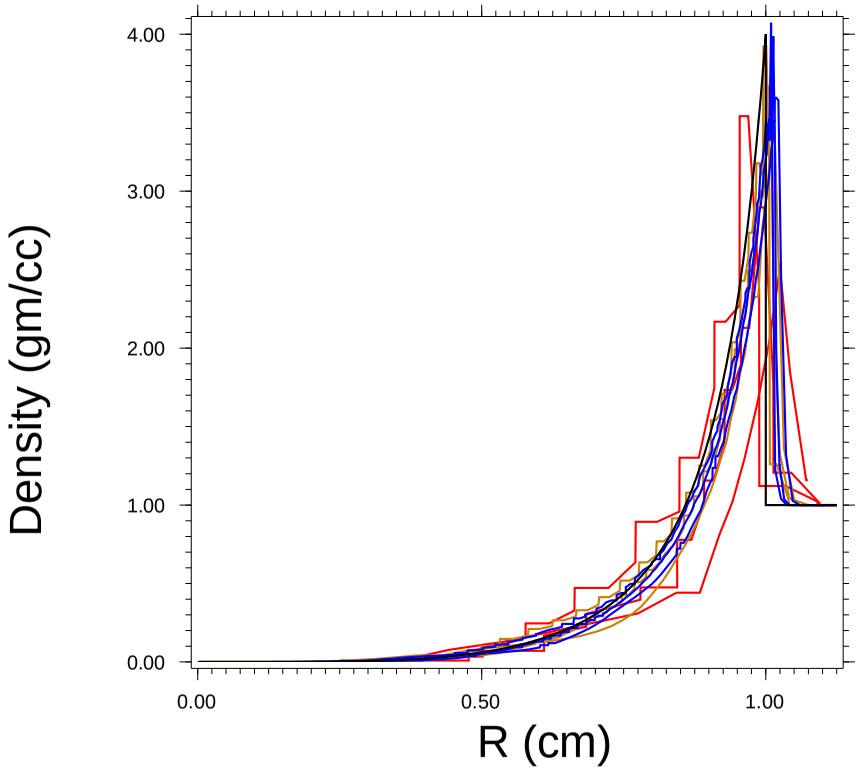


Density vs. R [t=1.0]
(90^3 zones)

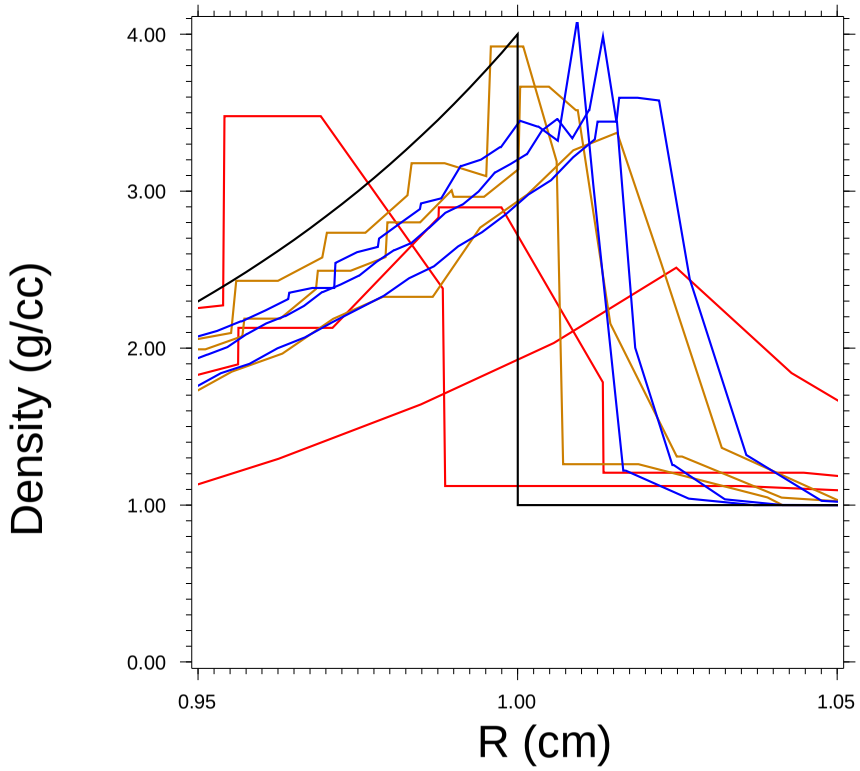


KULL: Lagrange Sedov Problems III [3-D octant]

Density vs. R [t=1.0]
(16^3 - 90^3 zones)

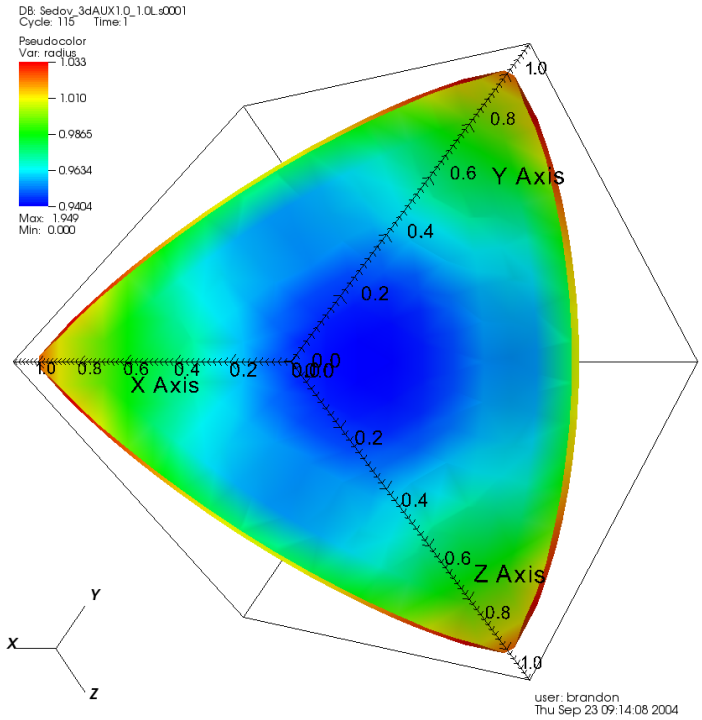


Density vs. R
(zoomed to show shock)

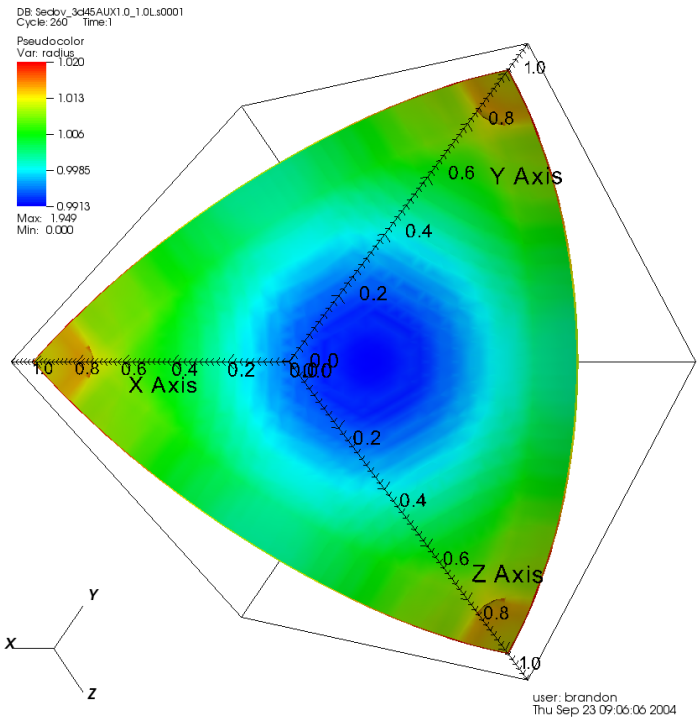


KULL: Symmetry Properties for the Octant Calculations

R (inside shock front) [t=1.0]
(16^3 zones)

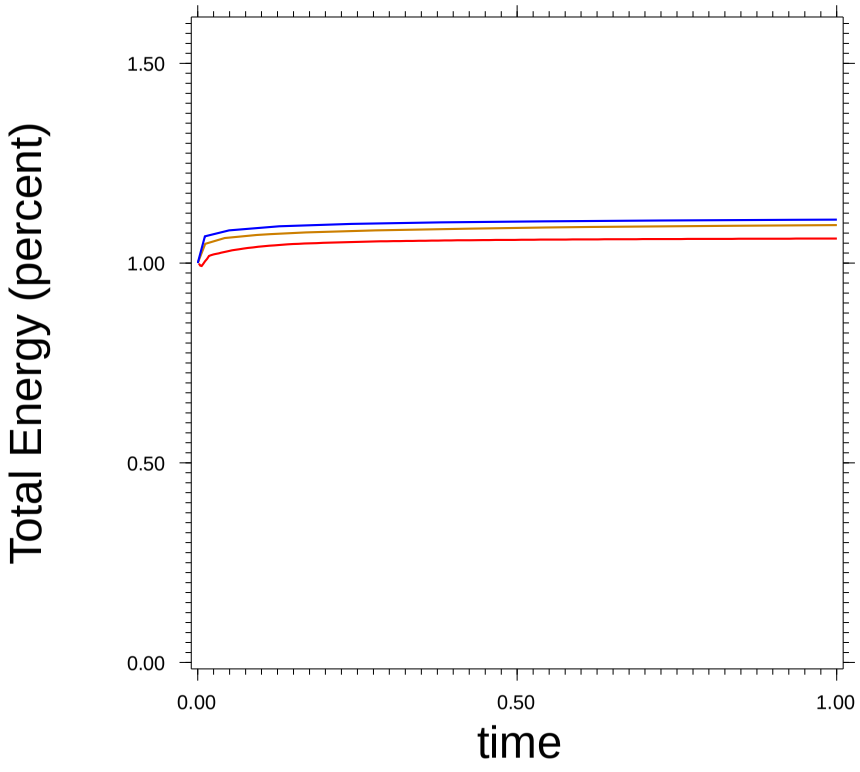


R (inside shock front) [t=1.0]
(45^3 zones)

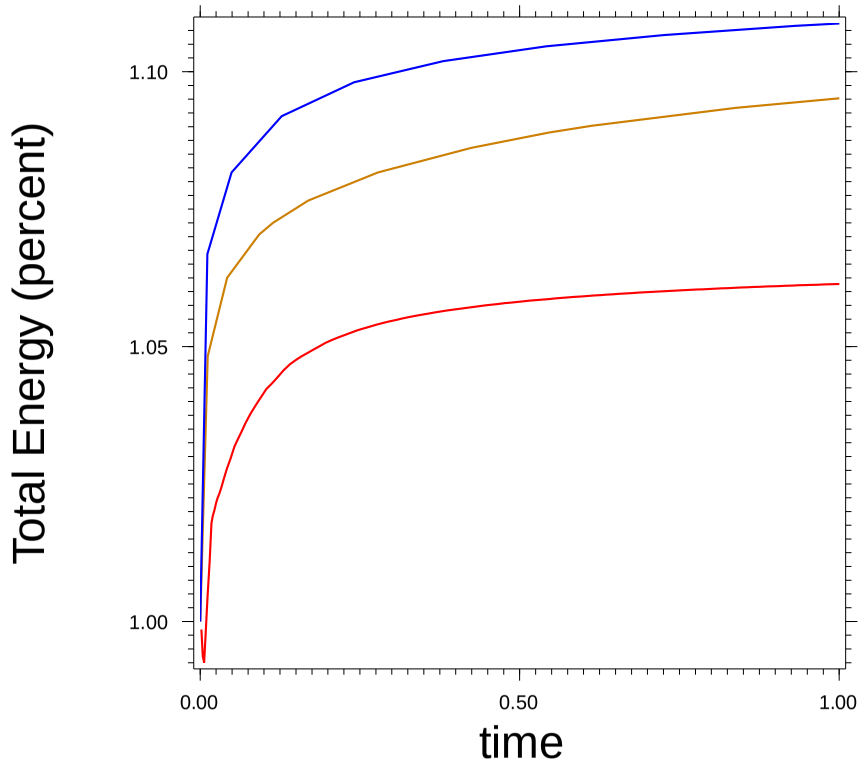


KULL: Lagrange Sedov Problems IV [3-D octant]

Total Energy vs. time
(16^3 - 90^3 zones)



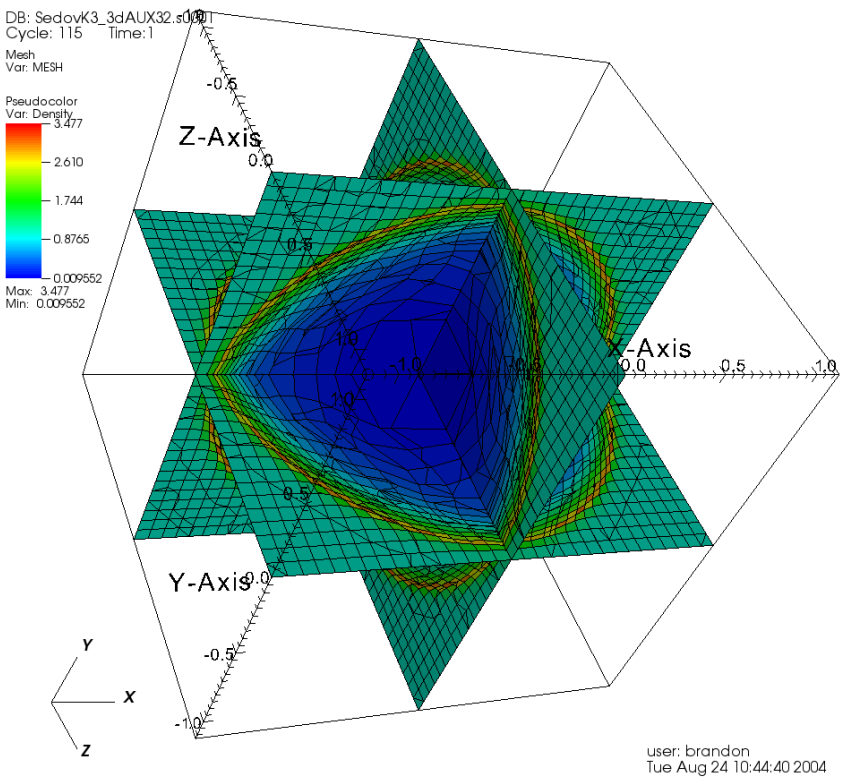
Total Energy vs. time
(zoomed to show behavior)



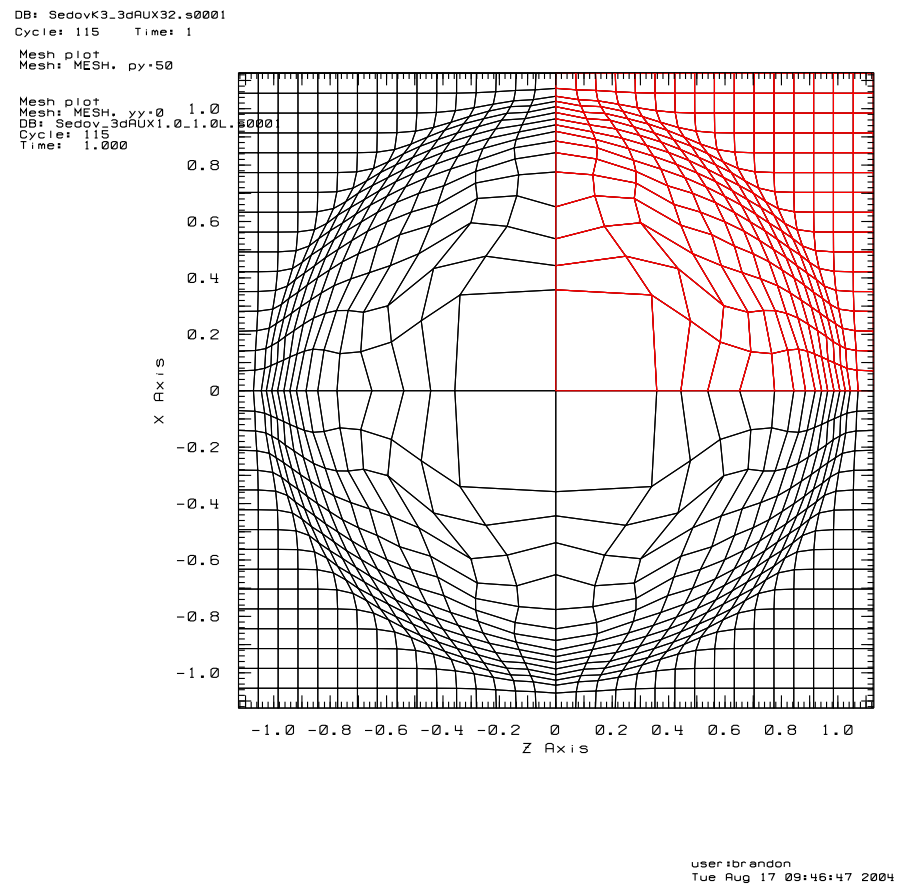
Note: Adding ALE reduces the growth in total energy

KULL: Maintains Symmetry in 4π Calculations

Full space Calculation
(32^3 zones, orthogonal slices)



Full space vs. octant
(32^3 & 16^3 zones, orthogonal slices)



Note: The KULL octant and full space mesh boundaries overlay (octant bc's OK)

Conclusions

- 1-D Analytic test problems provide useful information for every geometry option supported by the host code
- Adding ALE to simple test problems provides a way to quantify the effects of the relaxation/remap process
- The mesh resolution survey provides much more information than is available from results at any specific resolution
- More work is required in order to obtain multi-dimensional results that can be used to compare codes
- Establishing bounds for acceptable performance involves comparison of peers
- Obtaining and analyzing test problem results for all options and geometries for 2-D and 3-D ALE codes is computationally challenging