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Wire Initiation Using 1D And 2D ALEGRA Simulations

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Abstract

ALEGRA (**A**rbitrary **L**agrangian **E**ulerian **G**eneral **R**esearch **A**pplication), a multidimensional dynamic material response simulation program, is used to model a variety of phenomena including the environments found in Sandia's Z-Machine and Saturn accelerator. The predictive capability of ALEGRA can only be ascertained through extensive verification and validation of the code. Verification shows that the **r**adiation **m**agneto**h**ydro**d**ynamics (**RMHD**) equations are implemented correctly and validation shows that the RMHD model is sufficient to describe the phenomena. We are using ALEGRA to model a set of z-pinch experiments from wire initiation to radiation power pulse in a self-consistent way.

Modeling a z-pinch begins with a 1D-wire initiation simulation. From the 1D simulation, radial profiles of density, temperature, and velocity are extracted. The start time for the 2D simulation is calculated by taking the radius of the expanding wire to be ¼ times the gap between wires. These profiles of the wire are then insert onto a 2D periodic mesh with 1 to 3 wires out of the total wire array. Both the 1D and 2D simulations are driven using a current profile taken from Saturn. The goal is to show that these 2D simulations capture the radiation energy and power output trend shown by Sanford. At a later time it is our hope to show that a 3D version allows for a more quantitative comparison with the experimental data.

– Sanford, T.W.L. et al, (2001). Laser and Particle Beams 19, p. 541-556.

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Outline

- Goal
- Physical bases for experiment
- What is ALEGRA
- General simulation setup
- 1D wire simulations
  - Lagrangian Simulations
  - Eulerian Simulations
- 2D wire simulations
- Conclusions

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Goal

- The objective is to verify ALEGRA's ability to capture radiation energy and power output trends as wire numbers go from 10 to 200 as shown by Sanford.
  - Sanford, T.W.L. et al, (2001). Laser and Particle Beams 19, p. 541-556.

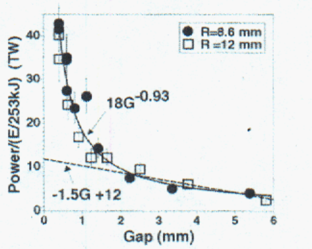
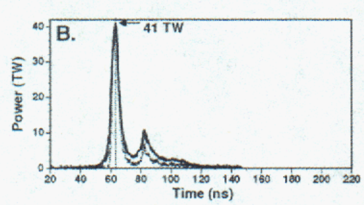
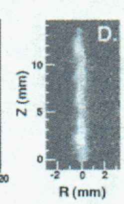


Fig. 2. Total radiated power normalized by the total radiated energy (scaled such that the normalized power agrees with that measured at the smallest gap) versus initial interwire gap.





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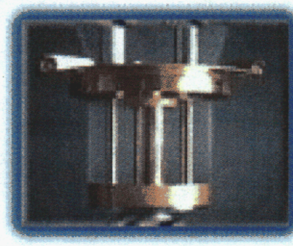
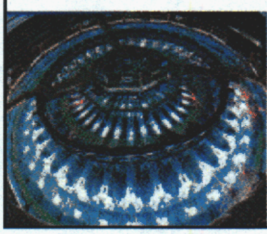
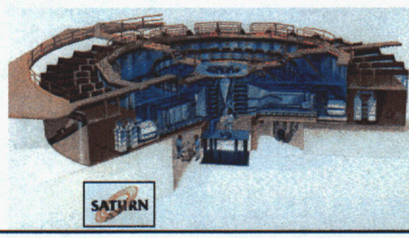
Saturn and ALEGRA



- **Saturn**
  - Total power of 36 TW
  - 36 Marx generators
  - 10 MA of current for z-pinches
- **ALEGRA**
  - A multidimensional dynamic material response simulation program
  - A multi physics hydrodynamic code





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General Simulation Setup

- **Physics used for simulations**
  - Radiation magnetohydrodyanamics with conduction
  - 1 group radiation diffusion
  - 1 temperature
- **Aluminum wires**
  - Lee-more-Desjarlais conductivity
  - Los Alamos sesame equation of state
  - XSN opacities
- **The wire array mass is kept constant while varying number of wires per array.**
- **The simulations are driven with a current profile taken from Saturn.**

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1D Wire Simulations

- Meshes
  - Eulerian
    - Resolution dependency
      - Uniform wire meshes 150 - 400 cells under the wire, graded void region.
  - Lagrangian
    - Resolution dependency
      - Graded meshes 25-200 cells
      - Uniform meshes 25-400 cells

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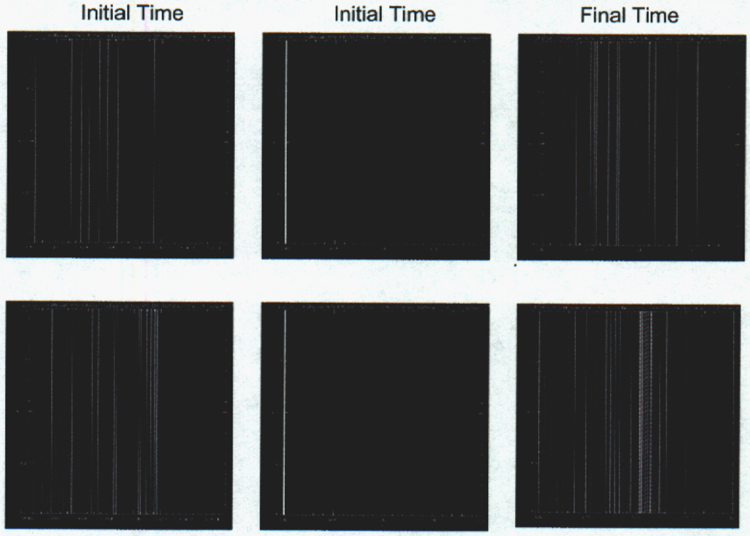
1D 40 Wire Lagrangian Mesh

Initial Time | Initial Time | Final Time



Uniform Mesh 50 Cells

Graded Mesh 50 Cells

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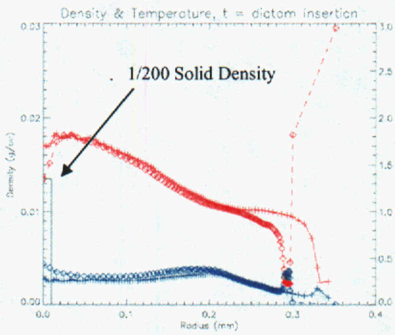
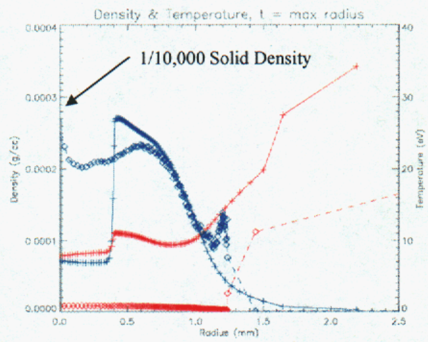
Density and Temperature





Dashed lines with diamonds = graded mesh
Solid lines with plus signs = uniform mesh

Blue = Density profiles
Red = Temperature profiles

The plots are from a 40 wire array with 100 cells. The graded and uniform meshes are compared to one another. When radial profiles for the diatom insertions are taken, both the graded and uniform meshes have similar density and temperature profiles. The vertical green line is the initial wire radius.

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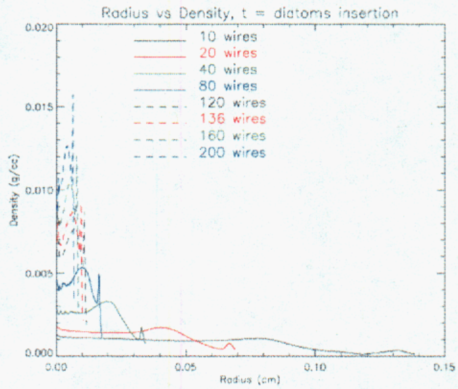
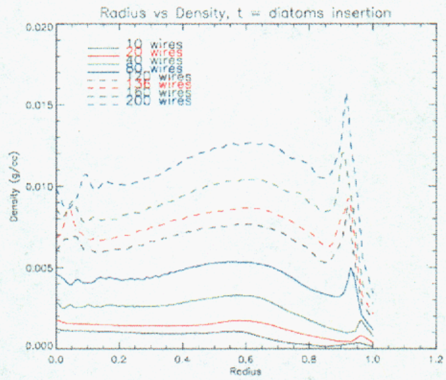
Density Profile for All Wires





The left plot is a radial profile of the density for the 2D wire. The right plot uses a normalized radius to show the density profile.
The the normalized curves show a that all the wires have similar profile characteristics.

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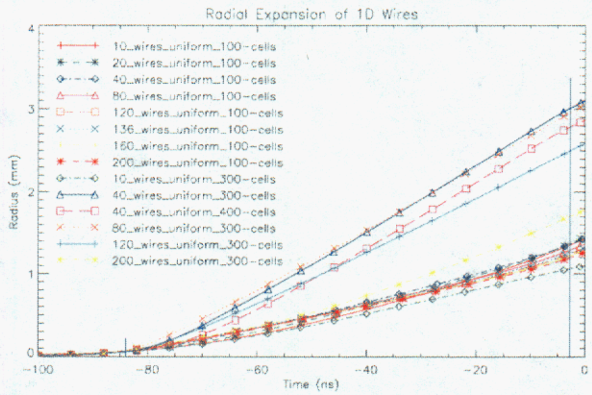
Wire Expansion vs. Time, 100% Mass



The Vertical lines indicate the time at which the 1D profiles are taken for the 2D simulation. The intersection of the vertical line and the matching expanding wire radius is ¼ times wire gap radius used for the diatom insertion.

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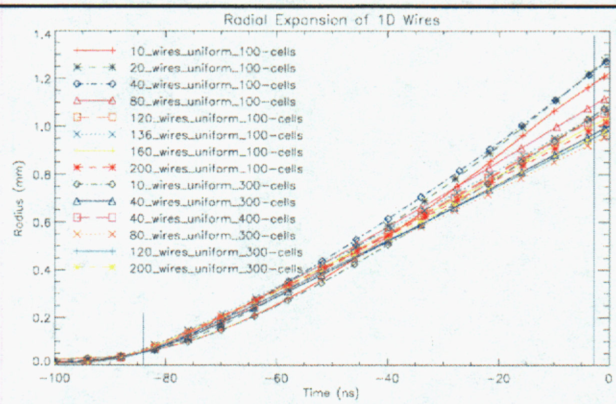
Wire Expansion vs. Time, 95% Mass



The Vertical lines indicate the time at which the 1D profiles are taken for the 2D simulation. The intersection of the vertical line and the matching expanding wire radius is ¼ times wire gap radius used for the diatom insertion.

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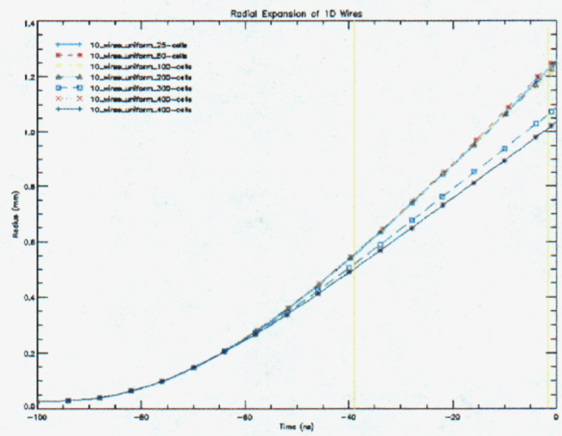
Resolution Scan Of Lag 10 Wires



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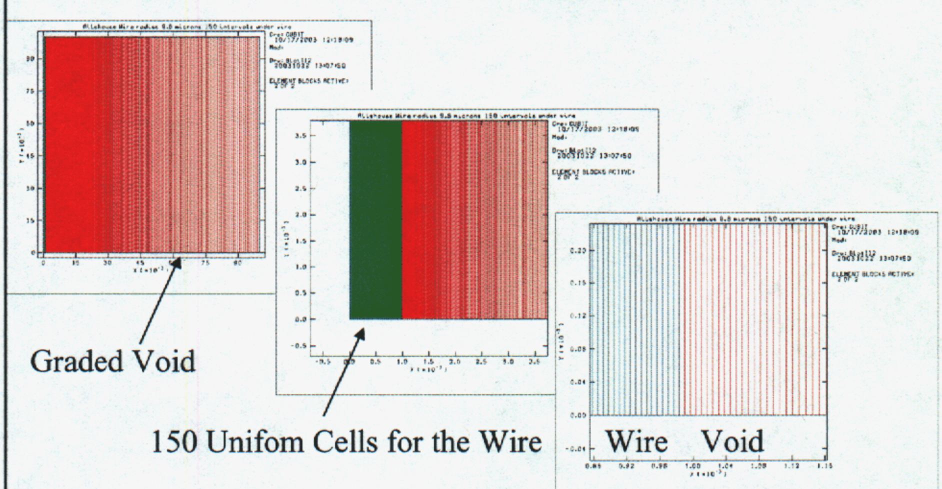
1D 40 Wire Eulerian Mesh



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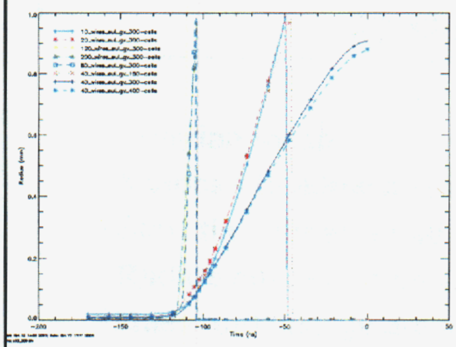
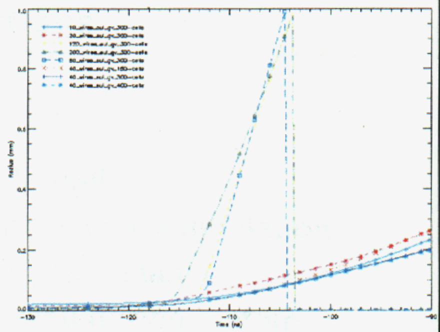
Wire Expansion vs. Time, 100% Mass, EUL





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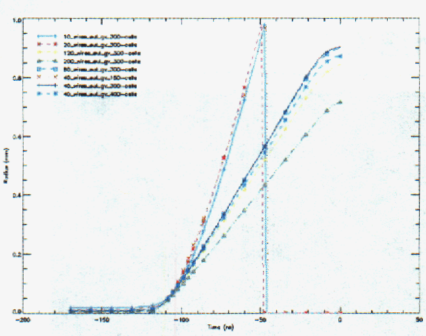
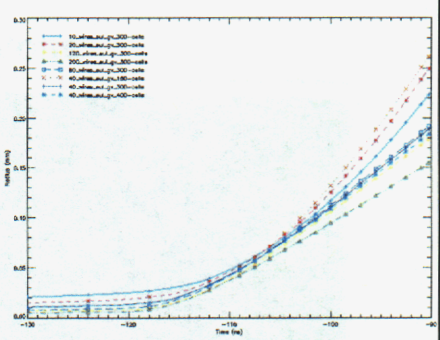
Wire Expansion vs. Time, 95% Mass, EUL





The Vertical lines indicate the time at which the 1D profiles are taken for the 2D simulation. The intersection of the vertical line and the matching expanding wire radius is ¼ times wire gap radius used for the diatom insertion.

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2D Simulations

- Eulerian mesh
- 5 blocks to allow a smooth transition
- Start time determined by radius of 1D simulation
- Radius chosen to be 1/4 the gap distance
- Mass and energy are conserved during diatom insertion
  - Density – Mass conservation
  - Temperature – Internal energy conservation
  - Radial velocity – Kinetic energy conservation
  - Total array current

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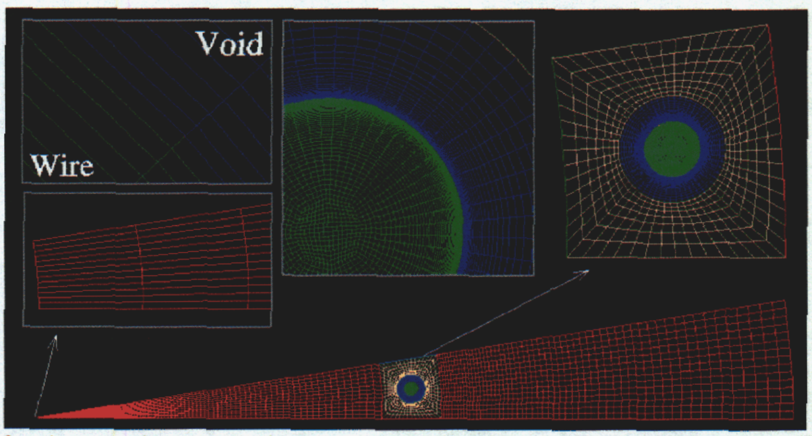
2D Simulations



40 wire mesh, green circle mesh is the expanded wire, the rest of the mesh is void. 2548 elements for the wire with a total of 6804 elements in the mesh

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Conclusions

- 1D lagrangian simulations exhibit the same density and temperature profiles for uniform and graded meshes at the time of diatom insertion go the 2D mesh.
- 2D current driven problems are producing radiation power pulses in the terawatt range and energy outputs in the kilo-joule range, which is expected from Saturn.
- The next step is to use a voltage and circuit model to drive the 2D simulations, allowing the current to be consistent with the mesh resistance and inductance. The voltage driven simulations can be used to compare radiation power as the wire number varies.

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