Full System Simulations of the Experiments

Fall 2011 Review

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We initialize CRASH with laser energy deposition

Ongoing work to build our own laser package has paid off – now can run with CRASH laser package or H2D as the preprocessor

- Used in the early stage (first 1.1 ns) of the simulations
- More on the CRASH laser package in Ben Torralva’s talk tomorrow afternoon
- H2D was used in many of the runs shown today
We are using the CRASH Laser Package in runs

- Laser energy transport via 2-D ray-tracing based on geometric optics
- Laser energy absorption via inverse bremsstrahlung
- Efficient parallel AMR implementation using block adaptive tree library (BATL)
- Verification tests based on laser ray turning point and energy deposition in simple analytic density distributions
We have verified the CRASH Laser Package

- Test based on ray propagation through a linear density profile
- Analytic solution for turning point and energy absorption based on ray incidence angle, distance to critical density location, and the collision frequency

![Graph showing log(laser energy density deposition) vs. X with color bar and turning point error vs. Grid resolution with 2nd order slope indicated.]
CRASH Radhydro Code: Hydro and Electron Physics

\[
\frac{\partial}{\partial t} \begin{cases} 
\rho \\ \rho \mathbf{u} \\ \mathcal{E} + \frac{1}{2} \rho \mathbf{u} \cdot \mathbf{u} \end{cases} + \nabla \cdot \begin{cases} 
\rho \mathbf{u} \\ \rho \mathbf{uu} + \mathbf{pI} \\ \mathbf{u} \left( \frac{1}{2} \rho \mathbf{u} \cdot \mathbf{u} + \mathcal{E} + \mathcal{P} \right) \end{cases} = \mathbf{S}
\]

\[S = \begin{cases} 
\nabla \cdot C_e \nabla T_e - S_{re} + S_L \\
-S_{rm} \\
-p_e \nabla \cdot \mathbf{u} + \nabla \cdot C_e \nabla T_e + \frac{\rho k_B (T_i - T_e)}{M_p A \tau_{ei}} - (S_{re} - S_{rm} \cdot \mathbf{u}) + S_L
\end{cases}\]

- Laser energy deposition
- Radiation/electron momentum exchange
- Electron heat conduction
- Compression work
- Collisional exchange
- Radiation/electron energy exchange

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CRASH Radhydro Code: Multigroup diffusion

- Radiation transport equation reduces to a system of equations for spectral energy density of groups.
- Diffusion is flux-limited
- For the $g^{th}$ group:

$$\frac{\partial E_g}{\partial t} + \nabla \cdot (E_g \mathbf{u}) - p_g \nabla \cdot \mathbf{u} - \frac{\nabla \cdot \mathbf{u}}{\Delta (\log \varepsilon)} \Delta (p_g) = \text{diffusion} + \text{emission} - \text{absorption}$$

$$\text{diffusion} = \nabla \cdot (D_g \nabla E_g) \quad \text{emission-absorption} = c\chi_{abs_g}(B_g - E_g)$$

$$\Delta(\cdot) = (\cdot)_{g+\frac{1}{2}} - (\cdot)_{g-\frac{1}{2}}$$

(advection, compression work, photon energy shift)
Overview of Solver Approach

- Self-similar block-based adaptive grid
- Finite-volume scheme, approximate Riemann solver for flux function, limited linear interpolation
- Level-set equations used to evolve material interfaces; each cell treated as single-material cell
- Mixed Implicit/Explicit update
  - Hydro and electron equations
    - Advection, compression and pressure force force updated explicitly
    - Exchange terms and electron heat conduction treated implicitly
  - Radtran
    - Advection of radiation energy, compression work and photon shift are evaluated explicitly
    - Diffusion and emission-absorption are evaluated implicitly
  - Implicit scheme is a preconditioned Newton-Krylov-Schwarz scheme
CRASH Postprocessor

- Synthetic radiographs generated by integrating absorption coefficients along lines of sight
- Poisson noise is added to simulate finite photon count
- Smoothing is done at scale associated with finite aperture in experiment
- Tests included in verification suite – grid-convergence studies on problems with analytical solutions
We have improved the fidelity and efficiency of the code this year

- Laser package implemented and tested
  - Dramatically increases our throughput of runs
  - All-CRASH runs give greater freedom in measuring sensitivity of outputs to pre-processor inputs
  - Allows cross-code comparison with H2D pre-processor

- Multigrid-based preconditioning implemented
  - Uses HYPRE algebraic multigrid library
  - Alternative to block-ILU preconditioning
  - Has potential to scale to greater number of processors than block-ILU
  - Payoff in AMR runs is not as great as that of fixed-grid runs

- HDF5 I/O support implemented and tested
  - Gives us access to VISIT visualization

- Non-LTE modeling under development

- Robustness of CRASH heavily tested in UQ Runsets 5 and 6, varying numerical parameters
We extensively test our code

- New program units implemented with **unit tests**
  - Nightly execution of many unit tests for CRASH and its parent code
- New features implemented with **verification tests**
  - Daily verification & **full system tests** are run on a 16-core Mac.
  - Tests cover all aspects of the new feature, including restart, using grid convergence studies and model-model comparison.
- Compatibility & reproducibility checked with **functionality test suite**
  - Nightly runs. 9 different platforms/compilers on 1 to 4 cores: tests portability
- **Parallel Scaling Tests**
  - Weekly scaling test on 128 and 256 cores of hera.
  - Reveals software and hardware issues, and confirms that results are independent of the number of cores.
Test result reporting is automated

38 verification tests: pass if converge at the correct rate
17 full system tests: pass if results have not changed includes restart

Nightly SWMF Tests

Latest CRASHTEST, previous CRASHTEST, CRASHTEST archive, and weekly CRASH SCALING tests.
Latest CCHMTEST and previous CCHMTEST

See explanations for the tests, the tables and the scores.

Log file of creating the SWMF manuals, BATSRUS manuals, PWOM manual, and CRASH manuals.

Source code changed: diff -r SWMF SWMF _yesterday

Summary of test differences between SWMF TEST_RESULTS/2011/10/16 and SWMF TEST_RESULTS/2011/10/15

Test results and scores for 7pm 10/16
ALL: 90.1%, CCHM: 92.7%, CWMM: 78.8%, CRASH: 100.0%

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<th>test / machine</th>
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<th>grid results</th>
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Nightly unit and functionality tests:
96 SWMF tests
65 BATSRUS tests
4 unique to CRASH including restart
CRASH Weak Scaling on BG/L, hydro

![Graph showing weak scaling performance](graph.png)
CRASH Strong Scaling on Hera and Pleiades, Full system
PDT Weak Scaling

![Graph showing parallel efficiency vs. cores](image)

Parallel Efficiency

Cores

1 4 16 64 256 1024 4096 16384

- Weak Scaling
Biermann battery

- Magnetic field generation by non-aligned electron density and pressure gradient
- Source term verification in rz-geometry with waves for density and pressure
We can now simulate the Year-5 Experiment

Present year-5 experiment

600 x 1200 μm elliptical tube

Side Views

Rear Views

This research was supported by the DOE NNSA/ASC under the Predictive Science Academic Alliance Program by grant number DEFC52-08NA28616.
CRASH simulation of Y5 experiment
CRASH simulation of Y5 experiment
Full system with CRASH laser package
Concluding Remarks

- We implemented a laser package
  - Substantially more automated than Hyades
  - Shock morphology more consistent with observations
  - Decreases uncertainty and enhances our UQ capability

- We continue to follow good practices on code development and verification

- We have simulated our year-five experiment with full physics at 1.6 µm resolution