The Physics of Radiative Shock Waves

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This research investigates the structure of radiative shock waves and the ability of our simulation codes to accurately predict such waves. A radiative shock is a wave in which both hydrodynamic and radiation transport physics play a significant role in the shock's propagation and structure. The addition of thermal radiation broadens the temperature profile of a hydrodynamic shock, in much the same manner as thermal conduction. At very high temperatures, when the material and radiation energies are comparable in magnitude, radiation plays an additional role in determining the shock jump relations.

One goal of this research is to generate semianalytic radiative shock solutions with sufficient accuracy that they may be used to quantify errors in simulation codes. There are very few existing test problems with such nonlinear, coupled physics. The radiative shock problems will also help answer whether temporally unsplit numerical algorithms are significantly more accurate than operator-split algorithms and to help develop better mesh refinement criteria.

The detail that the semianalytic solution provides has also led to the discovery of temperature profiles that have a more intricate structure than has previously been documented [3].

Thus far, we have developed solutions for the Euler equations of gas dynamics, coupled with two different gray radiation models:

- Equilibrium Diffusion: The radiation and material temperatures are assumed to be the same. For this simple model, the radiation adds nonlinear thermal conduction and effectively modifies the equation of state.

- Nonequilibrium Diffusion: The radiation and material temperatures may be different, and the radiation energy is assumed to propagate via a Fick's law. When the opacity is large, this model reduces to the equilibrium diffusion model.

Figure 1 compares our solutions [3] with results from the RAGE code [1]. RAGE solves a discretization of the nonequilibrium diffusion model. The RAGE results compare well with the semianalytic solution. Such results give us confidence that RAGE can accurately compute highly nonlinear, coupled ratiation-hydrodynamics.

Figure 2 shows the errors in the shock location as a function of mesh resolution, for two different simulation codes. For this problem, the opacity is large enough that equilibrium diffusion holds, regardless of the radiation model. Each code uses a different radiation model, yet in this large-opacity limit, both predict the equilibrium diffusion answer with reasonable accuracy. The results also show that there is some benefit in using a second-order time integration scheme. See Ref. [2] for more discussion.

Future work will include additional physics, more advanced radiation models, and using these solutions to verify simulation codes and improve their algorithms.

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[1] M. Gittings, et al., "The RAGE Radiation-Hydrodynamics Code," Los Alamos National Laboratory report LA-UR-06-0027 (2006).
[2] R.B. Lowrie and R.M. Rauenzahn, "Radiative Shock Solutions in the Equilibrium Diffusion Limit," Los Alamos National Laboratory report LA-UR-06-8283 (2006); to appear in *Shock Waves*.
[3] R.B. Lowrie and J.D. Edwards, "Shock Wave Solutions for Radiation Hydrodynamics," Proceedings of the American Nuclear Society M&C+SNA Meeting, Monterey, 2007.

Funding Acknowledgements
NNSA's Advanced Simulation and Computing (ASC), Computational Physics and Mathematics Program.

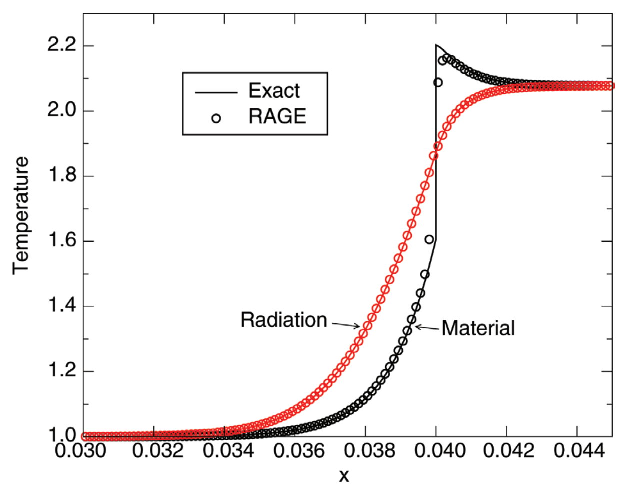

Fig. 1.
Shock temperature profile for a Mach 2 shock, nonequilibrium diffusion. The shock is propagating right to left. RAGE values are shown at each mesh cell-center. Note that there is an embedded hydrodynamic shock at x = 0.04.

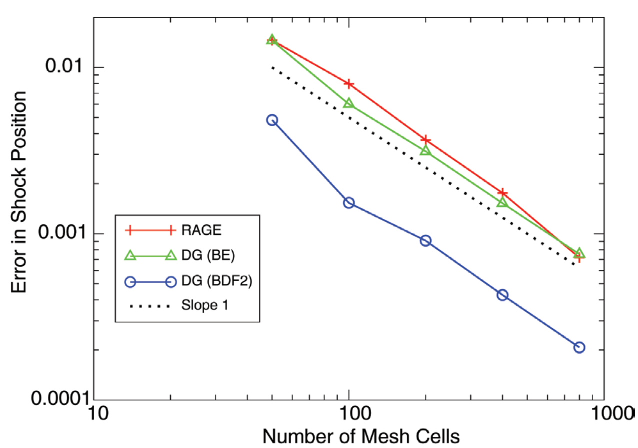

Fig. 2.
Errors in computing the shock position as a function of mesh size, Mach 10 shock, in the equilibrium diffusion limit. RAGE and DG(BE) use a first-order time integration method, while DG(BDF2) uses a second-order method. All the methods are second-order in space.