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research note

Applied Physics Division

X-6:Transport Methods Group

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Subject: Momentum Deposition in IMC Codes

Executive Summary

We discuss the analog tallying of momentum deposition from radiation to material in an Implicit Monte Carlo (IMC) code. We also make note of a small oddity in the way that an IMC code deposited momentum in the past. Finally, we present results from the Milagro IMC code and compare them with analytic solutions.

1. Introduction

In an operator-split, radiation-hydrodynamics calculation, the hydro code package requires the radiation energy deposition and the radiation momentum deposition from the radiative transfer code package. Without momentum deposition, a radiative transfer code is limited to "radiation-only" calculations. Until now, Milagro [1], an Implicit Monte Carlo (IMC) code package, was limited to radiation-only calculations. With its next release, Milagro will contain an analog momentum deposition tally. The momentum deposition capability resides in the general IMC classes, so any of our IMC code packages will have the capability.

We discuss the analog momentum deposition tally and one instance of how it was implemented in the past. We conclude by comparing Milagro results to analytic solutions of the momentum deposition for a few test problems.

2. Analog Momentum Deposition Estimator

From Mihalas and Mihalas [2], the momentum of a photon with energy $h\nu$ and traveling in direction $\mathbf{\Omega}$ is $(h\nu/c)\mathbf{\Omega}$, where h is the Planck constant, ν is the frequency of the photon, and c is the speed of light. The net radiative momentum transport across a differential surface, $d\mathbf{S}$, is $(1/c)\mathbf{F}\cdot d\mathbf{S}$, where the radiation flux, $\mathbf{F} = \int\int \mathbf{\Omega} I \, d\nu \, d\Omega$, is the first angular moment of the specific intensity, I. The net momentum *deposition*, then, from the radiation to the material is $\sigma\mathbf{F}/c$, where σ is the macroscopic cross section [3].

In a Monte Carlo simulation of radiative transfer, momentum deposition is scored whenever a particle interacts with the material in such a way that momentum is exchanged. The accumulated quantity is the energy-weight, ew, of a particle multiplied by its direction, $\mathbf{\Omega}$. Table 1 lists the events and corresponding quantities accumulated. The specific momentum deposition is obtained

TABLE 1: Analog scoring of momentum deposition from radiation to material, where ew is the particle's energy-weight and Ω is a particular direction cosine.

Event	score
volume emission (time-explicit portion)	$-ew \cdot \Omega$
time-rate absorption	$\Delta ew \cdot \Omega = (ew_{old} - ew_{new}) \cdot \Omega$
effective scatter	$ew \cdot (\Omega_{old} - \Omega_{new})$
kill due to low ew	$ew \cdot \Omega$

by dividing through by c, Δt, and V_c, the volume of the cell,

$$\boldsymbol{p}_{dep} = \frac{1}{c\Delta t\, V_c} \sum_{events} ew_c \cdot \boldsymbol{\Omega} \quad . \tag{1}$$

By "specific" momentum deposition, we mean that the momentum deposition is expressed per unit time and per unit volume.

When a particle contributes to an *analog* estimator, it undergoes a specified event *before* it contributes to the estimator. Conversely, when a particle contributes to an *implicit* estimator, it contributes according to the probability of the event regardless of whether it actually undergoes the event or not. The estimator we use for momentum deposition is mostly an analog estimator. This analog estimator of momentum deposition does have one implicit component, namely the accumulation due to time-rate absorption. In the current Milagro IMC code package, the particles always deposit energy continuously over their paths. (We have used the term "implicit" here to describe a certain type of Monte Carlo estimator. In Fleck and Cummings' Implicit Monte Carlo, or IMC, method, it refers to time-implicitness.)

3. **Algorithms of Old**

We take this opportunity to mention that these algorithms have been implemented in the past in vectorized codes [4]. One disconcerting aspect of that momentum deposition tally was that the contribution from the volume emission had the same sign as the absorption-type scores. We suspect that the negative sign was missing because a positive direction cosine is statistically equivalent to a negative direction cosine when the emission direction is isotropic. With many particles, then, the same expected value is achieved.

Assuming our suspicions are true, we cannot think of any reason to rely on this statistical equivalence. We can however think of many reasons not to employ such opaque coding. For one, the momentum deposition is not correct for an individual particle. Also, there is no appreciable time savings (often a reason for such statistical tricks). Finally, the trickery can extend beyond its intended scope, possibly with deleterious effects. To wit, an angular biasing scheme was implemented for the volume emission. This biasing scheme uses the same coding for momentum deposition, which will, at the very least, tax the calculation with larger statistical deviations.

4. **Results and Discussion**

We ran Milagro, with its new capability for accumulating momentum deposition, on three test problems,

1. Steady-State, Infinite Medium Test Problem
2. Marshak-1D Test Problem
3. Marshak-2B Test Problem

and compared the results to analytic solutions. The steady-state, infinite medium problem should have no net momentum deposition. The analytic solutions for the Marshak Test Problem came from Mark Gray's Analytical Test Suite[1]. The Analytical Test Suite is a powerful, easy-to-use, GUI-driven python script that allows the user to view (statically or animated) all sorts of quantities from analytic benchmarks, such as Marshak Waves. Users are able to dump the analytic data for their own use.

Figure 1 shows the $x-$, $y-$, and $z-$directions of the momentum deposition for the steady-state, infinite medium problems. The expected value for each component of the momentum deposition is

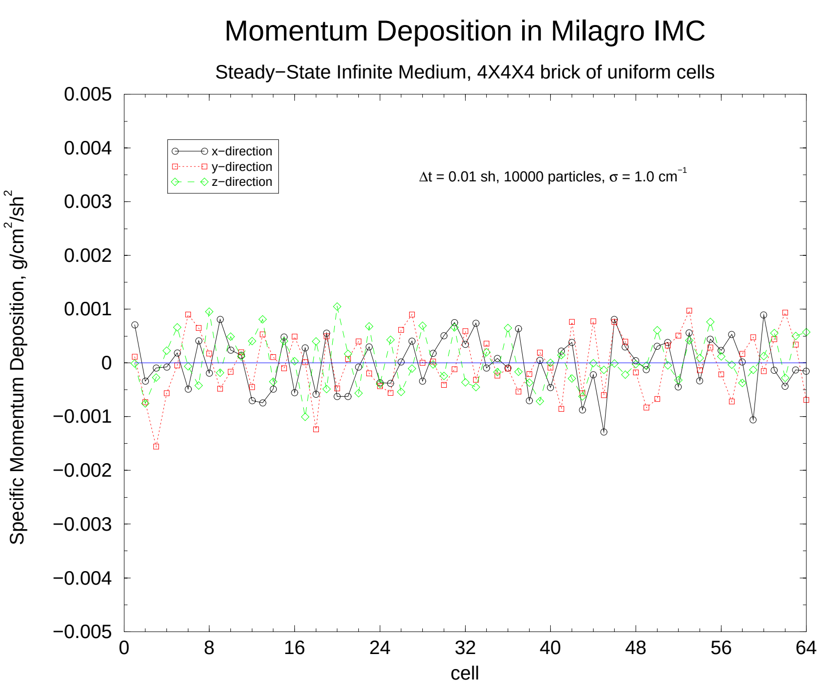

FIG. 1: Momentum deposition in a steady-state, infinite medium problem.

identically zero. Indeed, the results oscillate about zero.

[1]The Analytical Test Suite is an X–6 application used to verify radiation transport packages.

Figure 2 shows the momentum deposition into the slab for the Marshak-1D test problem. This problem has a delta function source at time zero and zero depth into the slab. The Milagro results

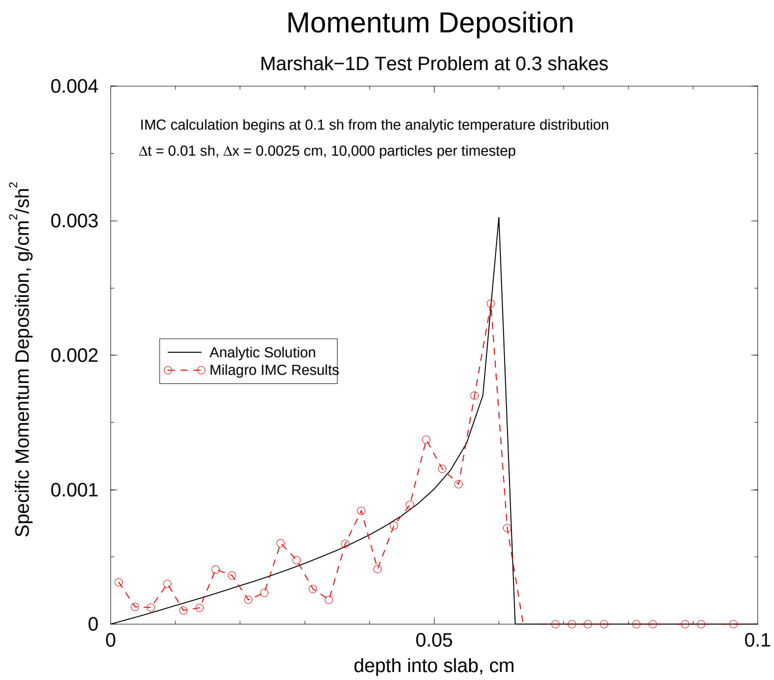

FIG. 2: Momentum deposition in the Marshak-1D test problem.

tend to admit the analytic solution, albeit with some noise. The temperature profiles, which we have presented in previous Milagro release notes [5–7], are much smoother because the relatively small heat capacity damps out the comparable noise in the stochastic energy deposition. The momentum deposition peak at the wavefront is hard to resolve because of discretized space and the fact that our cold temperatures are not actually zero as in the analytic solution. Since the opacity varies as $1.0/T^3$, our opacity is not infinite in front of the wave.

Figure 3 shows the momentum deposition into the slab for the Marshak-2B test problem. This Marshak Wave has a continuous, blackbody surface source impinging on a cold slab. The first Milagro attempt at this problem used 10,000 particles and a cell width of 0.005 cm, and it produced fairly large statistical variations. In the second attempt, we crudely attacked the problem by increasing the number of particles by an order of magnitude and doubling the size of the cells. Both attempts produced what appear to be correct results. However, the loud-and-clear message from this test problem is that transport methods are not necessarily well suited for problems with such severe diffusion qualities. The opacity in this problem never drops below 100 cm^{-1} (the mean-free-path never goes above 0.01 cm). The momentum deposition tallies in this problem are the sums of lots of large numbers, both positive and negative, and thus, they have large variances. A diffusion method of solution could be better suited to at least parts of this problem.

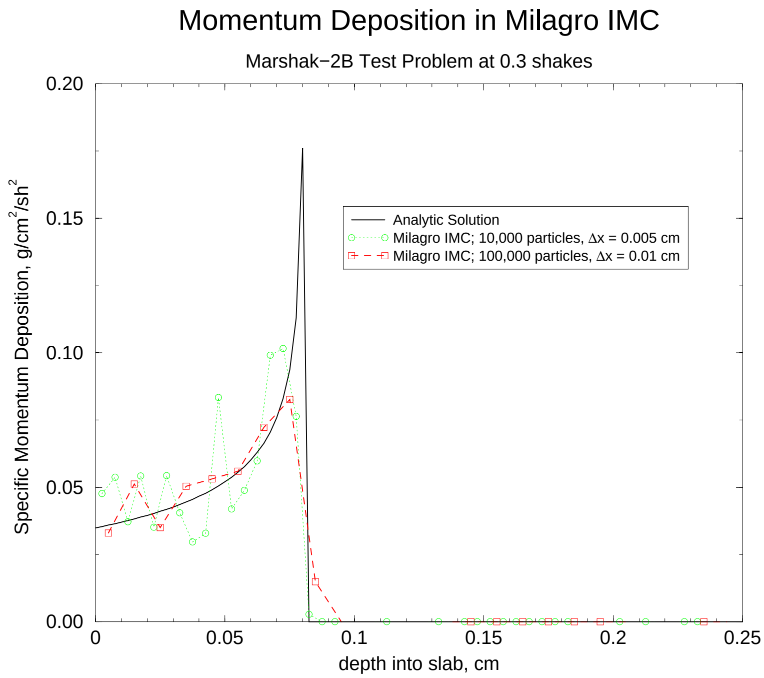

FIG. 3: Momentum deposition in the Marshak-2B test problem.

5. Conclusion

We have implemented a momentum deposition capability into Milagro, our Implicit Monte Carlo radiative transfer code package. The results tend to be noisy, but compare well to analytic solutions for three problems: a steady-state, infinite medium problem; a Marshak-1D Wave; and a Marshak-2B Wave. The momentum deposition estimator is mostly analog in nature, possibly accounting for some of the large statistical variations that we observed. We plan to add an implicit estimator for momentum deposition in the future. We also briefly described how one existing momentum deposition algorithm employed a statistically valid, but disconcerting coding trick.

References

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