New Developments in Ejecta Modeling in the FLAG Code

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Summary: A model of ejecta formation, transport and interactions is being developed as a PIC-type model in the Lagrangian-ALE hydrocode FLAG. Computed production rates, particle properties and dynamics (particle drag) are as expected, and code predictions are being validated against experiments.

We present the ongoing development and implementation of a mass ejection package, or "ejecta model," in the FLAG hydrocode. Following shock propagation into a material and reflection at its free surface, conditions may be sufficient to induce phase changes, damage, or fragmentation at the surface [1-2], and to eject a cloud of solid particles or liquid droplets—ejecta—from the surface.

Modeling such phenomena in a continuum hydrodynamics code challenges the assumptions underlying the numerical approximations made in the hydrodynamics. The representative scales for the particulate matter are often much smaller than the representative scales for the bulk material producing the ejecta. However, this scale separation allows for statistical descriptions of ejecta that are compatible with continuum mechanics.

Earlier work [3] documents early stages of the ejecta modeling effort in the FLAG [4-6] hydrocode. FLAG computes continuum mechanics solutions for fluid and solid materials in a Lagrangian or Arbitrary-Eulerian-Lagrangian (ALE) framework. To model ejecta in FLAG, a hybrid particle-continuum representation was defined that allows for coupling with continuum materials on large (bulk) scales; this is similar to well-known PIC methods [7]. Numerical models were developed and implemented for particle production (sourcing) as well as for solving the particle equations of motion. The numerics were shown to conserve mass, momentum and energy, and preliminary results were given for modeling drag and volume effects.

The ejecta source model includes components that evaluate criteria (thresholds) for ejecta production, calculate production rates, and generate computational particles with initial sizes and velocities sampled from user-specified statistical distributions. Each computational particle represents one or some (possibly large) number of physical particles with approximately equal sizes, trajectories and thermodynamic states. The donor surface experiences recoil forces when mass is ejected, and the code ensures conservation of mass, momentum and energy.

The ejecta production threshold is based on the acceleration of the donor surface, but is modified as a function of surface conditions such as damage or melt state.

Although the ejecta production rate is typically specified by the user, we have recently implemented a new production rate model developed by Chitanvis [8].

The space into which the ejecta move may be occupied by a "background" fluid, with which the particles interact dynamically and thermodynamically. To model thermodynamic interactions (pressure and temperature relaxation), an "ejecta phase" is created as an alternate description of *the same matter* that is represented by the ejecta particles, and that fluid phase is treated as a component of a continuum mixture with the background fluid.

On the other hand, dynamic interactions (drag forces) with the background fluid are treated in the particle description, with a Reynolds-number-dependent drag force that depends on particle size and velocity relative to the fluid. We have verified that this model matches analytic solutions to a test problem proposed by Cloutman [9].

The FLAG ejecta model is being compared with experimental determinations of mass ejection rates and velocities [10], and early results are encouraging.

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Acknowledgments

We acknowledge computational support and analysis by Jeremy Margulies, discussions with Shirish Chitanvis, and experimental data and images and explanatory information from William T. Buttler and Russell T. Olson.

Los Alamos National Laboratory is operated by the Los Alamos National Security, LLC, for the National Nuclear Security Administration of the U.S. Department of Energy under Contract DE-AC52-06NA25396.