

Preserving Shape and Spin in Asteroid Reaccumulation Simulations with SSDEM. K. J. Walsh¹, R.-L. Balou², D. D. Durda¹, D. C. Richardson², P. Michel³, and M. Jutzi⁴, ¹Southwest Research Institute, 1050 Walnut St. Suite 300, Boulder, CO 80302 USA, kwalsh@boulder.swri.edu, ²University of Maryland, College Park, MD 20742, ³Observatoire de la Côte d’Azur, Lagrange/CNRS, Nice, France 06304, ⁴University of Bern, Center for Space and Habitability, Physics Institute, Sidlerstrasse 5, 3012 Bern, Switzerland.

Introduction: Large asteroids that experience a catastrophic impact may produce a huge number of fragments that, owing to their self-gravity, may reaccumulate into a family of smaller asteroids. Modeling of this reaccumulation process can match many properties of observed asteroid families [1,2,3], and also produce orbiting debris found as satellites around large asteroids [4,5]. An important insight from these studies is the finding that all but the largest asteroids are likely reaccumulated fragments from catastrophic collisions [1,2].

However, shape and spin has not typically been retained in this modeling. By including shape and spin in the reaccumulation outcomes, this work is positioned to use the combined constraints of impact-generated asteroid families and the largest remnants’ shapes and spins to constrain the surface forces that govern the reaccumulation processes.

***N*-body code capabilities:**

Numerical simulations of asteroid collisions typically require two stages. First, a hydrodynamics code (SPH) is required to model the shock and fracture of a target asteroid. Second, a gravitational *N*-body code is used to model the gravitational reaccumulation of the fragments. We use `pkdgrav` for the reaccumulation stage. Over the years new capabilities have been added to the code that permit different choices for handling this stage. The classic approach treats collisions as perfect-merging events, where colliding pairs of particles are replaced with a sphere of the combined masses [1,2,3]. With this approach there is an option for particles to bounce with dissipation if they have encounter speeds over a threshold value; in this case the collisions are treated as idealized point-contact events, using the so-called Hard-Sphere Discrete Element Method (HSDEM). A later capability for HSDEM simulations permits particles to form bonded aggregates at certain relative speeds (or to break the bonds at higher speeds) [5,6].

The most recent advance with `pkdgrav` is a Soft-Sphere Discrete Element Method (SSDEM) implementation [7] in which particles are permitted to overlap slightly as a proxy for surface deformation, and collisions are finite-duration events mediated by damped spring/dashpot restoring and dissipative forces. With SSDEM it is possible to include much more realistic surface forces (static, sliding, rolling, and twisting fric-

tion) and non-ideal shape effects, but much smaller timesteps are needed for SSDEM compared to HSDEM.

SPH to *N*-body:

Some adjustments must also be made to the transfer procedure from Hydrodynamics collision outcomes to initial conditions for *N*-body particle code. Since all particles must be kept in the simulation, they must be converted from SPH formats to physically reasonable particles—meaning masses and radii that relate to asteroid-relevant density values. Due to the nature of SPH simulations, and the need to rapidly transfer to a *N*-body gravity code (in those cases where no gravity is modeled in the SPH), there can be significant particle overlaps when scaled to an asteroidal density. Thus, the solution utilized here is to use “perfect merging” for a single timesteps, until all overlaps exceeding 1% of particle radii have been removed by simply combining these severely overlapping particles. This puts the system in a state with reasonable density values and with overlaps small enough to be handled by all versions of the *N*-body code.

Next, the system is still quite hot—there are a large number of particles with very high speeds. This poses a problem for some versions of the code where allowed overlaps, combined with high speeds, stress the timestepping requirements. Meanwhile the bonded aggregate version of the code will not bond these high-speed particles until they have damped significant energy. Therefore a short period of time is simulated in the *N*-body code with the classical hard-sphere collision handling (HSDEM), where collisions are predicted and resolved ahead of time, and while the surface forces are implemented in a simple way, the energy damping during collisions is perfectly adequate to allow the high-speed clumps to collide and dissipate energy. This is the same version of the code as perfect merging, so we are simply stepping from a very short simulations with perfect merging, into one with strictly dissipative bouncing.

Finally, a system with no major overlaps, and that has cooled off after a brief spell of collisions, can be run with either of two versions of the code.

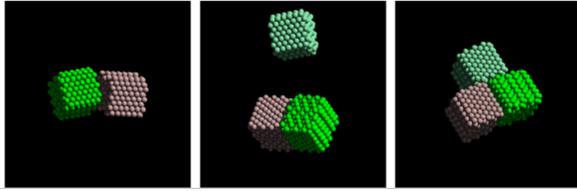


Figure 1. Bonded aggregate code where three colliding rigid cubes are made up of identical spheres and experience torques via mutual gravity and dissipative collisions. From [6].

Modeling Large Asteroids Families, Shape & Spin:

Owing to the numerous parameters governing the reaccumulation gravity code, we seek a good case study to constrain the properties of the actual asteroids being studied. The test case used here is the asteroid (87) Sylvia that has an elongated shape with a 5.18-h rotation period [9], two satellites [9], and an asteroid family associated with it [3]. Thus, the test constraints are the size-frequency distribution (SFD) of the Sylvia family [3], the shape/elongation and rotation rate of a simulation outcome compared to that measured for Sylvia, and enough mass in orbiting debris to account for its two satellites.

Here, we first examine reaccumulation simulation outcomes using the bonded aggregate code. Merging limits and fragmentation limits are varied, as is the coefficient of normal restitution. The reaccumulation is tested for a few cases—one is the SPH collision simulation taken from Durda et al. (2007) [3] that was considered to be a good match for the size frequency distribution of the Sylvia family (Basalt_4_60_1.8). The other test cases come from a new suite of SPH impacts into porous targets [10].

The first-order test results are shown in Figure 2, where a full perfect-merging case is compared to the known family SFD, along with SFDs produced from bonded-aggregate tests with two different merging limits of 0.5 and 0.8 (where merge limits are measured in units of mutual escape speed between two particles; all particles are the same mass and radius in this case). The SFDs are reasonable, but not perfect matches for this singular set of collision parameters, suggesting a need for an expanded search of possible collision circumstances for this test case.

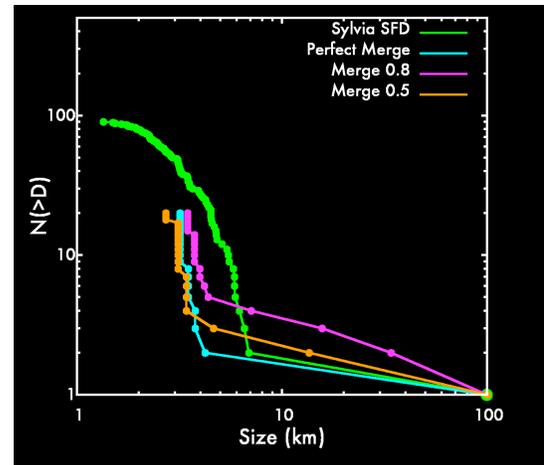


Figure 2. The size-frequency distribution (SFD) of the Sylvia family (green) compared to simulations with perfect merging (cyan) and aggregate bonding at two different values of the merge limit (magenta and orange for 0.8 and 0.5, respectively).

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