Preserving Shape and Spin in Asteroid Reaccumulation Simulations. K. J. Walsh[1], D. D. Durda[1], D. C. Richardson[2], P. Michel[3], and M. Jutzi[4], [1]Southwest Research Institute, 1050 Walnut St. Suite 300, Boulder, CO 80302 USA, kwalsh@boulder.swri.edu, [2]University of Maryland, College Park, MD 20742, [3]Observatoire de la Cote d'Azur, Lagrange/CNRS, Nice, France 06304, [4]University of Bern, Center for Space and Habitablity, Physics Institute, Sidlerstrasse 5, 3012 Bern, Switzerland.

Introduction: When large asteroids experience a catastrophic impact they can produce a huge number of resulting fragments that, with the help of their self-gravity, can re-accumulate into a family of smaller asteroids. Previous research has found that the re-accumulation following collisions can match many properties of orbit- and spectra-linked asteroid families [1,2,3]. These events have also been found to produce orbiting debris explaining some of the satellites found around large asteroids [4,5]. One of the most important insights from these studies is the expectation that all but the largest asteroids are likely re-accumulated fragments from a previous catastrophic collision [1,2].

Numerical simulations of asteroid collisions typically work in two stages. First, a hydrodynamics code is used to simulate the shock and fracture of the target asteroid. Second, a gravitational *N*-body code is used to simulate the gravitational re-accumulation of the fragments. Here we explore the upgraded capabilities for the second stage, the *N*-body calculations, that no longer simply merges colliding particles into spherical particles. Rather, we can now track particles as they "stick" or "bond" together, preserving shapes as they re-accumulate following the collision.

Shape Aggregation Code Upgrade: Due to code and computing-power limitations most previous *N*-body simulations of the re-accumulation have utilized a "perfect merging" N-body technique to determine the outcome of particle-particle interactions. This simply merged two colliding particles, conserving their mass and momentum. While this was very successful in matching the bulk properties of the size-frequency-distribution of asteroid families and properties of some binary asteroids, significant information is lost in this process – shape and rotation. The *N*-body code `pkdgrav` has been upgraded to retain this information [6]

Preserving shape and spin information of the fragments requires that all 100,000 individual particles remain intact following the end of the SPH collision simulation and throughout the *N*-body calculation. This allows each accumulated remnant to take whatever shape and spin the accumulation process creates, rather than having everything bunched into a perfect single sphere. However, when using ~100,000 particles the computation cost is extremely high without some mechanism to reduce gravitational or collision-search computational costs. Thus the upgrade to `pkdgrav`, hereafter dubbed the "bonded-aggregate" code, saves computation by modeling any "aggregates" as single rigid bodies, saving on collision computations between each particle in each bonded aggregate. As particles in the simulation enter into the collision resolution routine, if they are colliding below a "merging limit" they can be frozen together, and then treated as bonded aggregates. Each bonded aggregate is then treated as a single rigid body in all collision routines from that point forward – with their response to collisions integrated using Euler's equations for rigid body motion. Simple tests of these rigid-body interactions confirm that they bounce and evolve to a lower resting energy state. However, the bonded-aggregate upgrade allows for an additional measure of realism by allowing each aggregate the ability to break.

Particles can be liberated from an aggregate if they feel an instantaneous force above a certain fragmentation limit. Thus the aggregates can be broken and particles re-distributed. This makes up for some of the basic limitations of modeling re-accumulation with a code using spherical particles – that there is no source of "stickiness", either cohesion or interlocking of irregular shaped particles. The merging and fragmentation limits allow for particles to re-accumulate into realistic shapes and break back out of the shapes after undergoing energetic collisions.

Calibration Simulations: There are a few additional simulation parameters to understand when utilizing the shape-aggregation features with `pkdgrav`. First, the merging and fragmentation parameters, which are characterized as fractions of the two interacting particles' relative escape speeds. Impacts with relative velocities below the merging speed result in a merger for particles. Similarly, the fragmentation limit is used to determine when individual particles are freed from an aggregate during an impact (this is always a greater velocity than the merging limit). Finally the tensile and shear strength of individual aggregates is a parameter in each simulation that determines when rotational or tidal stress on a bonded aggregate is enough to break it entirely.

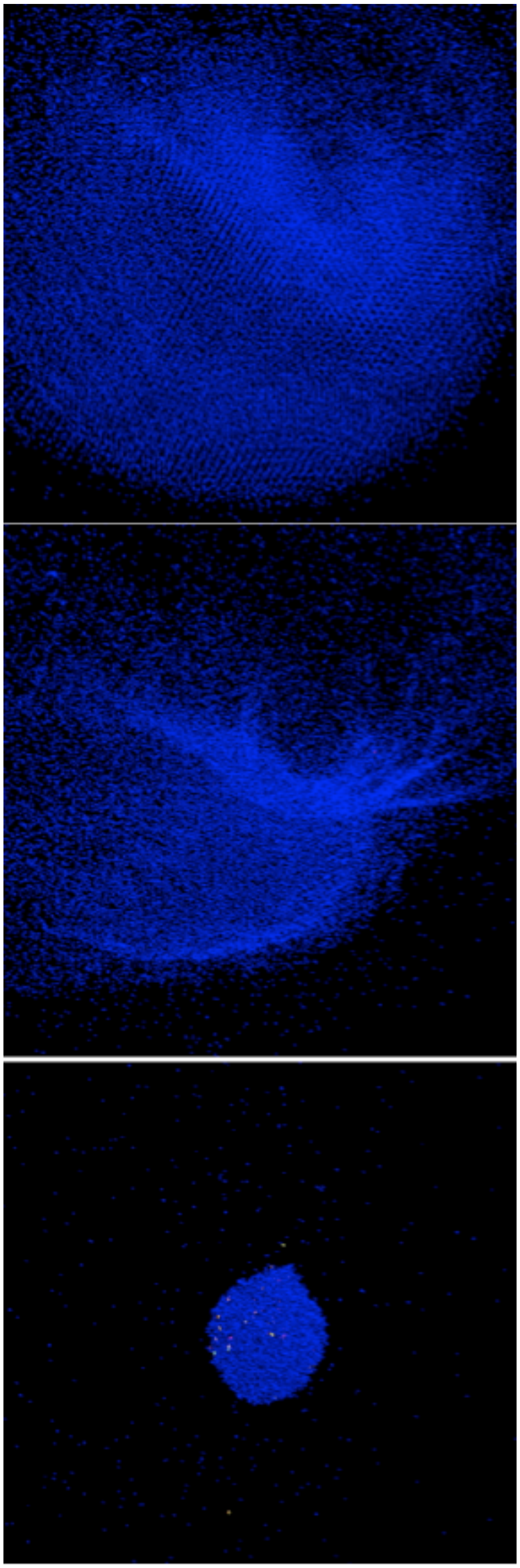

Figure 1: The three panels show (top) immediately following the SPH handoff to `pkdgrav` (middle) the initial dispersal of the fragments, and (bottom) the final reaccumulated body that is covered in single liberated particles (blue) around a heavily bonded core. This simulation used merging limit of 0.5 mutual escape speed and coefficient of restitution of 0.5. This simulation used 25,000 particles.

The test case used in this study is the asteroid (87) Sylvia that has a resolved elongated shape with a rapid 5.18 rotation period [7], two satellites [7], and a dynamical family. The target constraints are the size frequency distribution of the Sylvia family [3], the elongation and rotation rate of its largest remnant compared to the actual body, and enough mass in orbiting debris to account for its two satellites.

Here, we examine reaccumulation simulation outcomes using the bonded aggregate code. We vary the merging limits from 0.01-0.5, and fragmentation limits from 0.5-2.0. The coefficient of normal restitution is only varied minimally, using values 0.5-0.8. The reaccummulation is tested for the same SPH collision simulation, taken from Durda et al. (2007) [3] that was previously considered to be a match for the size frequency distribution of the Sylvia family (Basalt_4_60_1.8). A suite of SPH collisions simulations is currently being prepared utilizing a porous target body, and some of this study will utilize these simulations as they may represent more ideal representations of high-porosity and low-density asteroids [8].

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