FORMATION OF BINARY ASTEROIDS BY SPIN FISSION.
K. A. Holsapple, Dept. of Aeronautics and Astronautics, University of Washington 352400, Seattle, WA 98195.

Introduction: Increasingly it is known that a significant proportion of the asteroid population consists of binary bodies. Different mechanisms have been proposed for their formation, including spin fission, and re-accumulations after tidal or impact disruptions. The possibility and nature of spin fissions is considered here.

Analysis: Spin fission might occur when a body has its spin increased in some way to a value where the internal stresses are larger than some failure criterion in a significant portion of the body. An analysis of the internal stresses is required to determine those spin limits, and to determine where and how the body would deform. Then finally, a final state with a separation of the two parts to give a configuration that is a distinct binary (as compared to a contact binary) requires sufficient energy for the orbit mechanics of a bound pair. An analysis of spin fission into binaries then has these three distinct parts.

Spin Limits: The spin limits for a uniform ellipsoidal solid body spinning about its shortest axis have been found. Holsapple [1] presented such results for purely granular bodies using a Mohr-Coulomb failure criterion with zero cohesion, and the results for solid bodies with cohesive strength was presented in Holsapple [2]. A typical results for a cohesionless granular body such as a rubble-pile is as shown below. This result is independent of the body size. It is seen that the maximum spin depends on the body shape and on the material’s angle of friction. (A fluid body has a zero angle of friction.).

A cross-plot of the maximum allowable spin versus the body diameter for the aspect ratio of 0.7 is as follows:

![](image1)

where the body of data for the asteroids and the large TNO’s is included here. It is seen that for the large bodies, the strength is irrelevant, and the gravity forces determine the spin limits. But, for bodies with a diameter less than about 10 km a cohesive strength can allow significantly greater spins. This is a classical separation into gravity and strength regimes.

Failure Deformations: For all large bodies, and rubble-pile bodies of any size the cohesion can be ignored. The failure spins are then given by the previous first figure. Then what is the nature of the deformation when a spin limit is exceeded? Holsapple [1] showed that the failure is simultaneous throughout the body. And during that global deformation the body’s angular momentum is conserved. That requires a change in aspect ratio and spin that is in a particular direction on the spin limit plot. Specifically, at a typical point on the failure curve for a particular angle of friction, the blue arrow in the next plot shows that direction. The deformation is a global elongation which decreases the spin to a value that is within the failure curve for that angle of friction. That is, the deformation leads to new but stable configuration, it is not a global disruption. These bodies (all large, and all with negligible cohesion such as rubble-piles) would seem to be unlikely to experience spin disruptions.
So next consider a body where the cohesive strength must be accounted for, those bodies with a diameter less than 10 km or so. Then the stresses at the failure spins do not lead to failure simultaneously throughout the body. Instead, the failure generally occurs first at the body center; then as the spin increases, a failed region spreads to the surface of the body, until it is entirely across some cross section. A stress analysis of this case produces that failed distribution at the final maximum spin shown in the next figure. (It is from Holsapple [3]. The light blue region is at a failed state. Only one segment of the ellipsoidal body is shown.)

Here it is seen that the body has the propensity to break into two parts, and those two parts are both of significant size. These are candidates for binary formation.

Energy Considerations: Finally, what would happen to the two pieces indicated by the former failure analysis? They must have enough kinetic energy to overcome the mutual binding energy if they are to separate. However, if they have too much, they will simply fly apart to become two distinct bodies. That limits the spins at disruption to form binaries to distinct limits.

I have determined those energy states using a numerical method to get the mutual gravitational potentials of such separated bodies. The final plot below shows a shaded region of those spins as a function of the body aspect ratio where a separated but bound binary is a plausible final state from the energy considerations. Superposed over that region are the curves of the actual spin limits for different values of a scaled cohesive strength. So, for a binary outcome, the body must have some cohesive strength, but not too much. A spin fission of a very strong body will just produce two distinct bodies, and a spin fission of a fairly weak body will not be able to separate into two distinct pieces, but will remain in contact. For the binary outcomes, a greatly elongated body would have to have a very small strength, while a roughly spherical body would require more cohesion.

Summary: The analysis of spin limits for solid bodies and the probable results of exceeding those limits suggests that spin fission will not create binary bodies unless the original body is less than about 10 km in diameter. And it will not occur for rubble-pile bodies of any size. For these cases the nature of the deformation when spin limits are exceeded tends to be a uniform elongation creating a smaller spin and a new stable state.

However, when the cohesive strength is significant, then the body will tend to split into two pieces, and of not disparate size. Then, if the spin is not too fast (not too strong) the bodies can remain relatively close, creating a binary outcome. But if the strength is too large, the two pieces will just fly apart and escape each other’s mutual influences. Thus, small bodies with significant strength will not form binaries by this spin fission mechanism.

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REFERENCES: