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Field Exam in Space System Engineering (SS)

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Space debris is becoming an increasingly serious problem for satellites in Earth's orbit. This was exemplified in February 2009 by the collision of an active Iridium-33 satellite (600 kg) that was launched in 1997 into roughly a 100-minute orbit with an inactive Russian Cosmos-2251 satellite (1000 kg) that was launched in 1993. The collision occurred at an orbital altitude of 790 km over Siberia and generated over 500 pieces of new space debris that are now being tracked by the U.S. space surveillance network.

1. Assuming that the two satellites were both in perfectly circular orbits, estimate the maximum amount of energy that might have been involved in this collision. Calculate the energy relative to a stationary object on Earth's surface.

2. Estimate more closely the amount of kinetic energy involved in the collision based on the fact that U.S. authorities have reported a relative impact velocity of 11.7 km/s at a relative angle of 102.2 degrees. For simplicity assume that the collision was perfectly inelastic and that linear momentum was therefore conserved.

3. Discuss how close to the worst-case scenario this satellite collision was on a scale from 0 to 10 and if anything could have been done to avert the event in the first place.

4. Consider Table 1 of the attached paper by Wiedemann et al. Please rationalize for up to what debris size (e.g. 10^{-6} m) it may make sense to shield a spacecraft. Calculate approximately the kinetic energy for such a particle and plot it in Fig.3. What would be the failure probability of the satellite according to this model? Does this make sense to you?

5. Considering both space debris size and relative impact velocity what are the high level options for satellite failure mitigation to such collisions? What are the important systems engineering tradeoffs between these options? Do any of these options have policy implications and if so, what are they?

Wiedemann C., Oswald M., Stabroth S., Alwes D., Vörsmann D., "Cost and benefit of satellite shielding", *Acta Astronautica*, Volume 63, Issues 1-4, July-August 2008, Pages 136-145