Modeling Collision Effects

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Introduction

An "inventory" published in 1986 by the North American Aerospace Defense Command (NORAD) and NASA's Goddard Space Flight Center identified 6194 radar-trackable objects, that is, of baseball size and larger, in space. In addition, NASA experts estimated the presence of 30000 marble-to baseball-sized objects, trillions of tiny paint flakes, and tens to hundreds of trillions of dust-sized particles of aluminum oxide. When objects, even the very small ones, travel at hypervelocity (defined to be in excess of 3 kilometers per second), the effects of a collision can be devastating. For example, an orbiting particle 0.3 millimeter in diameter, just slightly larger than a grain of salt, can puncture a spacesuit with a hole large enough to force an astronaut to return quickly to the spacecraft or risk depressurization.

An object in motion possesses kinetic energy, from the Greek word kinetos, meaning moving. Physicists have determined that the kinetic energy (KE) of a body of mass M traveling with a velocity v is given by the relationship $KE = \frac{1}{2}mv^2$.

Kinetic energy is measure in units that may not be immediately familiar, so we attempt to minimize confusion by using metric units consistently in the following activity. In this system, if mass is measured in kilograms (km) and velocity is measured in meters per second (m/s), energy will be measured in units called joules (j) where $1j = \frac{kg \cdot m^2}{s^2}$.

1. To get a better sense of what one joule of energy means, calculate the kinetic energy means, calculate the kinetic energy of a 3500-pound truck traveling at 60 miles per hour.

2. Compare that result with the kinetic energy of a 350-pound satellite orbiting at 17,500 miles per hour and with the energy of a 1-gram paint chip orbiting at the same speed. Remember that 1 miles = 1.61 kilometers, 1 kilometer = 0.62 mile, 1 pound = 0.45 kilogram, and 1 kilogram = 2.20 pounds.

3. What might be the kinetic energy of a hard-hit baseball or a well-served tennis ball?

High Velocity

NASA studies the effects of high-velocity collisions in its Hypervelocity Impact Test Facility (HITF) at the Johnson Space Center in Houston. The HITF contains three light-gas "guns." These guns accelerate particles that range in diameter from 100 microns (0.1 mm) to 10 millimeters velocities in the range of 2km/s to 7 km/s, the high-speed particles are fired into samples of various materials in different configurations to study the effects of the impacts. Each gun fires particles of different masses: gun A, 0.0015 milligram to 5.8 milligrams; gun B, 0.091 milligram to 46 milligrams; and gun C, 46 milligrams to 1.45 grams.

The highest velocities achieved in the laboratory, about 7 km/s, correspond to speeds of nearly 16,000 miles per hour; nevertheless, NASA estimates that only about 25 percent of the orbital-debris impacts occur at speeds of 8 km/s or less. Thus, it is necessary to rely on mathematical modeling to scale the experimental results observed in the laboratory to higher velocities.

1. Using a computer spreadsheet or the table function of your graphing calculator, create a model that allows you to calculate the kinetic energies of various objects, from microscopic particles moving at orbital or near-orbital speeds to familiar objects moving at realistic Earth-bound speeds.

2. What effect does mass have on the kinetic energy of a moving body? For example, if two objects, one with ten times the mass of the other, travel at the same speed, how do their kinetic energies compare?

3. What effect does velocity have on the kinetic energy of a moving body? For example, if two objects of equal mass are moving, one with ten times the velocity of the other, how do their kinetic energies compare?

4. Which factor, mass of velocity, makes the greater contribution to the total amount of kinetic energy? Why?

5. NASA scientists have stated that trackable objects pose a relatively small hazard to spacecraft but that the vast number of smaller breakup-debris particles present a hazard disproportionate to their size. Why do you suppose that they would say that?