National Aeronautics and Space Administration

Educational Product	
Educators & Students	Grades 5–12

EB-2001-12-014-JPL

Educational Brief

CASSINI SCIENCE INVESTIGATION

When the Sky Is Falling

Objective

Impact cratering has shaped planetary surfaces and life on Earth. Students will explore the cratering process and understand the relationship between the projectile, the energy it delivers, and the landform it creates.

Time Required: 1–2 hours

Saturn System Analogy: Cratered satellite surfaces

Keywords: Asteroid, Collision, Crater, Impact, Kinetic Energy, Mass, Meteorite, Meteoroid, Volume

The Barringer Meteor Crater in Arizona.

MATERIALS

- Baking pan or cardboard box at least 7 centimeters deep, to make a portable sandbox (the depth is necessary to avoid bouncing the projectiles off the bottom)
- Projectiles: BBs, marbles, and bearing balls (various sizes)
- Sand (to fill the pan)
- Optional: flour, cocoa, or colored sand to provide a thin layer on top of the sand that will better show the effects of the impact; colored sand is available from craft stores
- Ruler or tape measure
- 3 meters of string (may need to be longer depending on your laboratory situation); heavy washer (tied to end of string to make a plumb bob)
- Piece of cardboard (to smooth sand surface)
- Magnet (to help retrieve bearing balls that get buried)
- Optional: one serving of cooked oatmeal and spoon (for experiment extension)

Discussion

Craters are found on nearly every solid body in the solar system. The exceptions are Jupiter's moon Io, which continually resurfaces itself with lava flows that cover any craters formed there, and perhaps Titan (a moon of Saturn), whose surface we haven't yet seen in detail. Tiny craters are found on Moon rocks, they have been seen on asteroids, and they are found on the largest solid planet in the solar system, Earth.

The process of crater formation on planets involves the transformation of the energy of motion of a projectile (a meteoroid or small asteroid) into heat. This heat, in turn, causes an explosion that creates the crater. Crater diameters typically range from 10 to 20 times greater than the size of the projectile. Large projectiles, on the order of 1 to 15 kilometers in size, can be very destructive. The devastation resulting from the impact, earthquakes, tsunamis, and atmospheric effects can cover state-size territories or even larger and can lead to mass extinctions, such as that of the dinosaurs 65 million years ago.

Cosmic velocities exceeding 11 kilometers per second cannot be reproduced in the school laboratory. Still, cratering by excavation rather than explosion will demonstrate the principles involved.

Procedure

In the simplest experiment, projectiles are dropped one at a time from a fixed height into the sandbox. The diameter of the excavated crater is measured and the data are recorded for further analysis. With a little more effort, additional data can be acquired that will significantly add to the scientific investigation.

Gravity provides a constant, repeatable impact velocity for the different-sized projectiles. For all the projectiles recommended for experimentation here, air resistance should be neglected. The projectiles can be dropped from desk height, some shelf or ladder, and if available, from the upper stories of a building. Use the plumb bob to center the sandbox directly under the projectile release point. Smooth the sand before each drop. After impact, gently remove the projectile so as not to damage the crater. Measure the diameter of the crater. (These measurements are more challenging than might first be thought. Deciding where the crater rim peaks is not always easy and individuals will make different choices. Expect experimental variability in these measurements.) Repeat the smooth-drop-measure-record process for each projectile at each of several different heights.

Before the drop tests are made, students should prepare a table of characteristics for the projectiles. Each projectile should be weighed and its diameter measured, and the volume and density of each projectile should be computed. The kinetic energy at impact can be calculated from $KE = 1/2(mv^2)$, where m is the measured ("weighed") mass and v is the velocity just before impact. The velocity can be computed from $v = (2gL)^{1/2}$ where g is the gravitational acceleration 9.8 m/s^2 and L is the drop distance.

Once these parameters and crater sizes are known, have students compare various parameters with crater diameter. While diameter and volume will show little relationship to crater size, mass and kinetic energy will show a strong relationship.

Extensions

An impact has more effects than the excavation of a crater. The initial contact with the surface generates a far-ranging spray of material that can cover an area much larger than the sandbox. This is one good reason to do this activity outdoors.

As the projectile impacts, the excavation process not only sprays surface material out, but subsurface material may be thrown short distances or overturned to help create the crater rim. These effects can be studied in more detail by using two or more layers of colored sand/flour/cocoa (so that the layers are distinctive). New layers will have to be added after each smoothing if additional drop tests are conducted.

This analogy to impact cratering in the solar system suffers from a serious deficiency: the projectiles remain whole after impact, something that is uncommon except for small meteoroids striking Earth. Most large cosmic projectiles explode on impact with the surface. To observe this effect in these classroom scale experiments, drop individual spoonfuls of cooked oatmeal from various heights. The oatmeal has enough tensile strength to hold together as it falls (large water droplets will break up and gelatin holds together on impact) but will "shatter" on impact with the sandbox, splattering oatmeal and sand over a fairly wide area. Use food coloring in the oatmeal to help distinguish it from sand after the impact. Note that experiments with oatmeal are messy enough that they should be conducted outdoors.

Real-world craters often have central peaks caused by the rebound of subsurface material at the end of the collision process. Do classroom craters develop central peaks? Why or why not?

Numerous challenges to the students can be made for measuring the drop distance. While a tape measure is the obvious solution and measuring the length of the plumb line is easy, other physics can be used. For example, a precision barometer can be used as an altimeter.

The height can be measured by timing the duration of the fall: $s = 1/2(gt^2)$. A stopwatch is a necessity, and experimental error due to reaction time will be notable and variable among students.

A stopwatch can also be used to measure the period of a pendulum extending from the drop point to the top of the sand (move the sandbox out of the way so the pendulum can swing freely). The length L = drop height can be determined by timing the period of the pendulum, $T = \pi(L/g)^{1/2}$. Experimental error will creep in with the timing; compare the period measured for a single swing back and forth with the period determined by measuring the duration of 5 and 10 swings and computing the average period.

Compare the potential energy of the projectiles, $PE = mgL$, with the projectiles' kinetic energy.

Sporting goods stores sell special baseballs that use time of flight to determine the speed of a pitch. These can be used to measure the average speed of your projectiles (make sure someone catches the baseball, rather than letting it hit the sandbox hard).

What is the effect of air resistance on the speed of the projectiles? How does it vary with size?

Do projectiles with different shapes generate different crater shapes?

Use a slingshot to create craters with angles of impact different from 90 degrees (or tilt the sandbox at various angles to the maximum angle of repose (at which a landslide starts). Do the craters have different shapes? Why or why not?

Several vendors offer accelerometers and speed-measuring sonar systems that acquire data and plot it under computer control. Such systems can be adapted for quantitative measurements of the projectiles in this activity. Computerized data acquisition is common in many laboratories.

Have the students watch the movies *Deep Impact* and *Armageddon*. Are the asteroids and comets in the films realistic? (This might take a bit of background research.) Are the effects of the impactors portrayed realistically? Consider whether small projectiles "burn" all the way to Earth's surface and if they are moving so fast that a nearby observer, as presented by the movies, would be able to follow their motion as they came down. Are the effects of the large impact realistic? Are there other effects that might occur?

Education Standards

A visit to the URL http://www.mcrel.org yielded the following standards and included benchmarks that may be applicable to this activity.

Science Standards

3. Understands essential ideas about the composition and structure of the universe and Earth's place in it.

LEVEL 3 (GRADES 6–8)

Knows characteristics and movement patterns of the nine planets in our solar system (e.g., planets differ in size, composition, and surface features; planets move around the Sun in elliptical orbits; some planets have moons, rings of particles, and other satellites orbiting them).

10. Understands forces and motion.

LEVEL 1 (GRADES K–2)

Knows that the position of an object can be described by locating it relative to another object or the background.

LEVEL 2 (GRADES 3–5)

Knows that an object's motion can be described by tracing and measuring its position over time.

12. Understands the nature of scientific inquiry.

LEVEL 1 (GRADES K–2)

Knows that learning can come from careful observations and simple experiments.

Mathematics Standards

3. Uses basic and advanced procedures while performing the processes of computation.

LEVEL 2 (GRADES 3–5)

Adds, subtracts, multiplies, and divides whole numbers and decimals.

Solves real-world problems involving number operations (e.g., computations with dollars and cents).

LEVEL 3 (GRADES 6–8)

Adds, subtracts, multiplies, and divides whole numbers, fractions, decimals, integers, and rational numbers.

6. Understands and applies basic and advanced concepts of statistics and data analysis.

LEVEL 1 (GRADES K–2)

Understands that observations about objects or events can be organized and displayed in simple graphs.

LEVEL 2 (GRADES 3–5)

Understands that data represent specific pieces of information about real-world objects or activities.

Organizes and displays data in simple bar graphs, pie charts, and line graphs.

Reads and interprets simple bar graphs, pie charts, and line graphs.

LEVEL 3 (GRADES 6–8)

Reads and interprets data in charts, tables, plots (e.g., stem-and-leaf, box-and-whiskers, scatter), and graphs (e.g., bar, circle, line).

Organizes and displays data using tables, graphs (e.g., line, circle, bar), frequency distributions, and plots (e.g., stem-and-leaf, box-and-whiskers, scatter).

LEVEL 4 (GRADES 9–12)

Selects and uses the best method of representing and describing a set of data (e.g., scatter plot, line graph, two-way table).

9. Understands the general nature and uses of mathematics.

LEVEL 2 (GRADES 3–5)

Understands that numbers and the operations performed on them can be used to describe things in the real world and predict what might occur.

Understands that mathematical ideas and concepts can be represented concretely, graphically, and symbolically.

LEVEL 3 (GRADES 6–8)

Understands that mathematicians often represent real things using abstract ideas like numbers or lines; they then work with these abstractions to learn about the things they represent.

Teachers — Please take a moment to evaluate this product at
http://ehb2.gsfc.nasa.gov/edcats/educational_brief.
Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.

Student Worksheet — When the Sky Is Falling

Procedure

- Provide a description of the type of sand surface into which the projectiles will be dropped.
- Prior to drop tests, write down:

  Drop distance (L) that will be used ____________________
- For each projectile that will be used, measure:

  Mass

  Diameter
- Then, for each projectile, calculate:

  Volume

  Density

  Velocity

  Kinetic energy
- Record the data in a table, including these parameters:

  Projectile description

  Mass (g)

  Diameter (cm)

  Volume (cm^3)

  Density (g/cm^3)

  Velocity (cm/sec)

  Kinetic energy ($g\text{-}cm^2/sec^2$)
- After the drop test, record the drop height and the diameter of the crater formed by the projectile.
- Required equations:

  Density = mass/volume

  Kinetic energy (KE) = $1/2(m*v^2)$

  Velocity, $v = (2*g*L)^{1/2}$, where g = acceleration due to gravity = 9.8 m/s^2

  Volume = $4/3(pi*r^3)$, where pi = 3.14159

  R = radius = 1/2(diameter)
- Plot four graphs, of crater diameter versus

  1. Projectile mass
  2. Projectile volume
  3. Projectile diameter
  4. Projectile kinetic energy

Which parameter(s) show the strongest relationship to crater size? What mathematical relationships are exhibited?