Shriek Science: Simple Physics Powers Extreme Roller Coasters

Human endurance and economics limit just how hair-raising these rides can get

- By Jennifer Hackett on October 14, 2015

Credit: Dusso Janladde/Wikimedia Commons

The fastest, tallest and longest dive coaster, on which amusement park thrill seekers can experience free fall, is set to open next summer at Cedar Point in Sandusky, Ohio. Valravn is designed to take riders 20 stories up to a 66-meter peak from which they plummet at a 90-degree angle and feel weightless. That first drop generates sufficient energy to propel the coaster car throughout the rest of the ride.

By cranking the roller coaster's cars up to the top of a hill, the cars store a large amount of gravitational potential energy. This type of energy is dependent on the mass of an object (the coaster cars and the riders) and its vertical displacement (how far the cars are from the ground). As the cars crest the hill and begin to speed down, this potential, or positional, energy is converted into kinetic, or motive, energy. According to Kevin Hickerson, a physicist at the California Institute of Technology, "All the energy a roller coaster gets comes from the initial point it's cranked up to, and from there it just gains more and more kinetic energy."

The height of this first drop also determines the speed of the coaster cars. The longer the drop, the more the cars accelerate due to the force of gravity.

The advent of steel-frame roller coasters in 1959 made taller structures possible. The new frames were sturdier, lighter and easier to build as the tracks could be manufactured remotely then delivered to the intended amusement or theme park for final assembly.

Steel roller coasters require less dense support beams than wooden ones do because the steel track itself helps support the structure. Additionally, steel coasters lose less energy to friction. Rather than rattle along the tracks like wooden ones do, the wheels on steel coasters are surrounded by the track itself, making for a smoother, faster ride. Hypothetically, without friction and other resistance a roller coaster car could cruise along indefinitely, provided it never climbed as high as the initial hill. The car's energy would perpetually be converted from potential to kinetic and back again as the car glided along the track, according to the law of conservation of energy.

Whereas height remains one of the best ways to attain intense speeds, a coaster car can also be shot from its starting point via electromagnetic propulsion, a catapult or a mechanism that utilizes hydraulic or pneumatic power. Cars on these launched coasters have the potential to go from zero to nearly 130 kilometers per hour in about two seconds.

Even though theme parks tout the top speeds of their newest attractions, engineers have yet to truly push these joyrides to their potential extremes. "In terms of the physics of going fast, that's something that roller coasters haven't really peaked at," Hickerson says. "Trains and airplanes go way faster."

Although coasters can definitely go faster, they're limited by the acceleration those higher speeds would require. Roller coasters reach their peak speeds in a matter of seconds. The achieved acceleration is what causes *g*-forces, which allows riders, like astronauts in space, to feel as an increased or decreased sense of their mass. These *g*-

forces can be dangerous but they are also well understood by physicists, so roller coasters are built according to strict standards that keep them well within safe levels.

"The *g*-forces [that] pull blood out of your brain and into your legs are the ones typically experienced on roller coasters," says Leland Stone, a scientist with NASA's Human Systems Integration Division focused on how extreme *g*-forces impact the human body.

Coasters avoid this direction by controlling riders' orientation in space. If seated upright, or at least always dangling their feet toward the ground, the forces are always directed toward the feet. "Riding a roller coaster upside down in the seat would not be a safe thing," Stone says.

Engineers rely on this information to build rides that provide all the thrill of danger yet avoid genuine life-threatening risks. Riders on some of the most extreme coasters can experience up to 6.5 *g-forces*, which is more than astronauts experience on liftoff and more than NASCAR drivers feel while tearing around the track. The trick for coaster riders is duration. Those 6.5 *g*-forces typically last for a second at most whereas astronauts might endure four for a period of minutes.

Parks continually aim to offer up newer, record-breaking rides, but neither engineering nor human tolerance determine all the limits. Economics also comes into play. Larger, more intense rides require space, special materials and long-term maintenance, all of which come with a hefty price tag.

For true adventurers, however, there are more and more routes to that same rush. Caltech's Hickerson, for example, is ambivalent toward roller coasters. He would "rather ride a rocket."

ANSWER ALL QUESTIONS ON LOOSELEAF. PLEASE WRITE IN FULL SENTENCES AND RESTATE THE QUESTIONS IN YOUR ANSWER.

1) Please read the following statement: "its vertical displacement (how far the cars are from the ground)." Which energy does this describe?
A) kinetic energy
B) thermal energy
C) gravitational potential energy
D) mechanical energy

2) According to the law of conservation of energy, the roller coaster would:
A) keep moving without friction
B) stop because of inertia
C) jump off the tracks due to an unbalanced force
D) fly because of air resistance

3) Referring to paragraph 6, which rollercoaster can be described as so?
A) Great Bear at Hershey Park
B) Expedition Everest at Animal Kingdom
C) Kingda Ka at Six Flags
D) Wildcat at Hershey Park

4) Why do you feel like you are flying on a rollercoaster or as if your stomach dropped?
A) Physicists use g-forces cause increased acceleration that will change your mass.
B) It will harm your body.
C) The gravitational potential energy is too high.

5) What conclusion can be made from reading this article?
A) Rollercoasters have many different scientific features involved that contribute to its thrill. However, scientists have not reached its limits quite yet.
B) Rollercoasters are fun because you can twist.
C) Rollercoasters can change your view: exciting, scary, and adventurous.

6) What is the tone of this article?
A) informative
B) humorous
C) disinterested
D) angry

Please write a few sentences (3-5) for each question.
7) Using the picture to your right, describe happens to each energy (GPE and KE) at points A-D?

8) Why is the first drop the tallest?