Roller Coaster Physics

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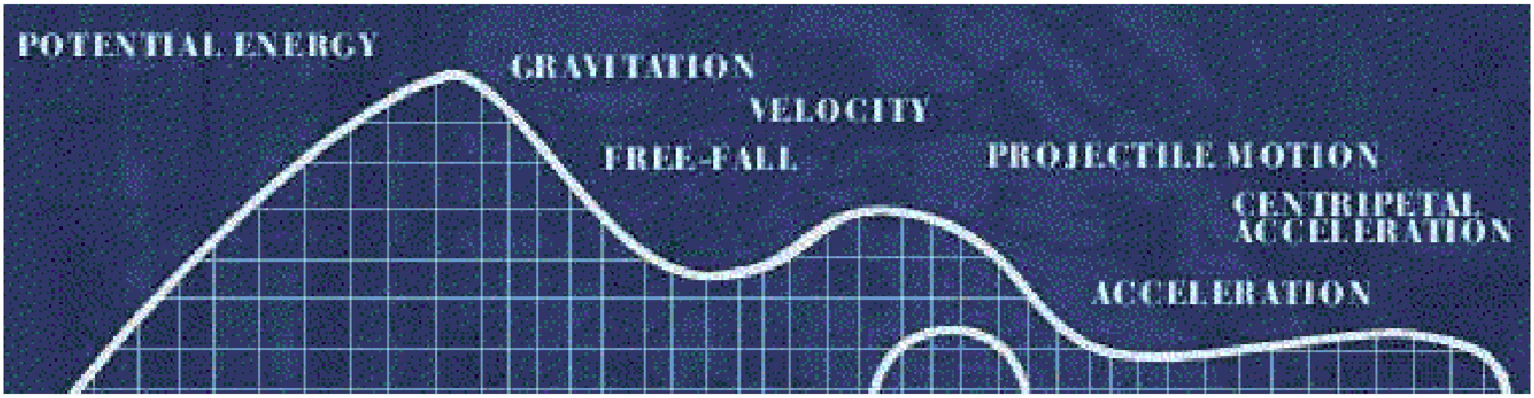


Above are the types of forces that affect the coaster as it follows the track. Below are the explanations of each one.

Potential Energy: Often referd to as stored energy that depends upon the relative position of various parts of a system. A train of cars on a gravity-powered roller coaster has more potential energy raised above the ground at the top of a hill than it has after falling to the earth along the hill's inclined track.
At This Point in the Ride: At the top of the lift hill, the potential energy of the gravity-powered coaster is at its greatest, because the coaster is at its highest elevation.

Gravitation: Gravity is the traditional source of power for roller coasters, accelerating the cars through all the twists and turns of the ride, from the lift hill through to the brake run.
At This Point In The Ride: Gravitation, which powers the coaster throughout the entire ride, detaches the car from the lift mechanism and forces it off its highest elevation along the inclined track of the first hill.

Free Fall: Newton's laws of motion show that a body in free-fall follows an orbit such that the sum of the gravitational and inertial forces equals zero. This explains why a rider in a roller coaster following a parabolic path may experience the condition of weightlessness. Because of the motion of the coaster, the effect of gravity is canceled by the equal and opposite force of inertia.
At This Point In The Ride: The car speeds down the inclined track of the first hill under the force of gravitation and the riders experience downward centripetal acceleration and the sensation of being lifted out of their seats.

Velocity: Quantity that designates how fast and in what direction a point is moving.
At This Point in the Ride: The track curves back upward and the speed drops as the roller coaster climbs the second hill.

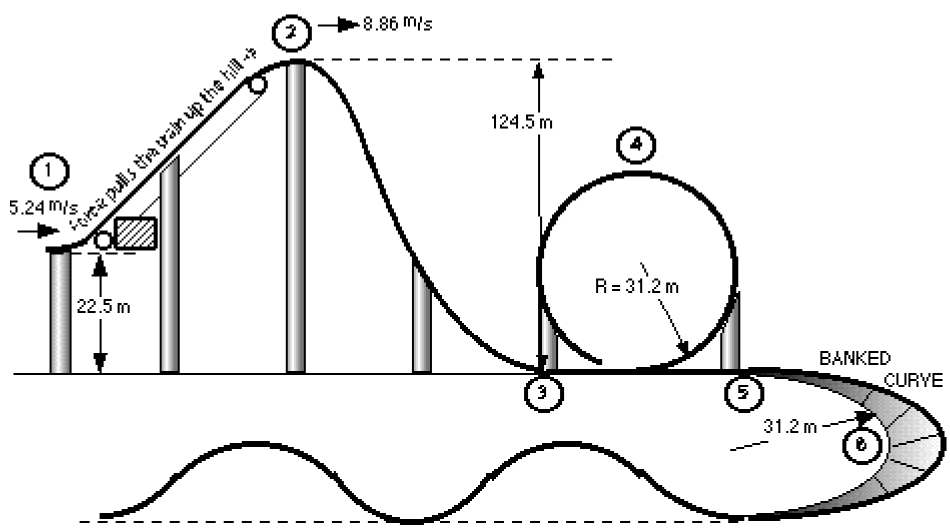
Projectile Motion: Form of the motion of a body launched by an initial velocity along a trajectory determined entirely by gravitational acceleration and air resistance. Neglecting

air resistance and rotational effects, a projectile thrown outward into the air follows the path of a parabola.
At This Point in the Ride: The riders experience the sensation of weightlessness as they follow the parabolic path of projectile motion from the point of elevation.

Acceleration: Time rate at which a velocity is changing.
At This Point In The Ride: At the bottom of the second hill, the coaster, in theory, reaches an instant of zero acceleration, at the point where its speed is greatest, relative to anywhere else on that hill.

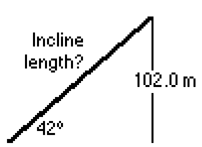
Centripetal Acceleration: The acceleration is directed radially toward the center of the circle and has a magnitude equal to the square of the body's speed along the curve divided by the distance from the center of the circle to the moving body.
At This Point In The Ride: The coaster enters a banked curve, and as the track is curved and as the car is in a state of acceleration, it becomes subject to centripetal force, which may give the riders the sensation of being pushed sideways.

Now that all the aspects that affect the ride have been explained the example that I chose to analyze is:



Weight of the train: 4000kg
Angle of incline: 42 degrees

Incline length = 102/(sin 42)
Incline length = 152.4 m



$ET_{(OUT\ OF\ STATION)+Work} = ET_{(TOP\ OF\ 1^{st}\ HILL)}$
EK + EP +W = EK +EP
$(^1/2)mv^2 + mgh + Fd = (^1/2)mv^2 + mgh$
$(^1/2)4000(5.24)^2 + 4000(9.8)(22.5) + F(152.4) = (^1/2)4000(8.26)^2 + 4000(9.8)(124.5)$
54915.2 + 882000 + F(152.4) = 136455.2 + 4880400
F(152.4) = 4079940
F = 26771.26 N ... is the pulling force along the incline.

The acceleration of the train is found from
$(v_f)^2 = (v_o)^2 + 2ad$
$(8.26)^2 = (5.24)^2 + 2(a)d$
$a = 0.134\ ^m/s^2$

$v_f = v_o + at$
8.26 = 5.24 + 0.134(t)
t = 22.537 sec ...is the time to climb the incline.

$ET_{(LOCATION\ \#2)} = ET_{(LOCATION\ \#3)}$
EK + EP = EK +EP
$(^1/2)mv^2 + mgh = (^1/2)mv^2 + mgh$
$(^1/2)4000(8.26)^2 + 4000(9.8)(124.5) = (^1/2)4000(v)^2 + 4000(9.8)(0)$
$136455.2 + 4880400 = 2000(v)^2$
$2508.428 = (v)^2$
v = 50.084
$v = 50.1\ ^m/s$ ... At the bottom of the first hill

The velocity as the rider enters the loop and as the rider leaves the loop is the same as the velocity at the bottom of the first hill. This is because all three locations are at the same height.
The height of the loop is simply double the radius. h = 2(31.2) = 62.4 m

As the rider enters and leaves the loop
v = 50.084 m/s
r = 31.2 m
$a_c = 8.2$

As the rider passes the top of the loop
$v = 35.852\ ^m/s$
r = 31.2 m
$a_c = 4.2$

The banked curve can be calculated using:
Tan(q)=v2/rg
=0.164
q = 9.3° .... That's almost a flat turn.

A lot of safety factors must also be included in the design of roller coasters. That is not because the coaster might not be able to handle it, it might be the riders who can’t. There are limits to how many g forces and loops a human body can withstand in one coaster.