ASEN 2003 LAB 1: ROLLER COASTER DESIGN

- Assigned: Tuesday, January 14, 2020
- Group Report Due: Tuesday, January 28, 2020 11:59PM

OBJECTIVES

- Use your knowledge of particle dynamics to design and analyze the performance of a new roller coaster.
- Gain design experience using an example in particle dynamics.
- Practice using FBD's and energy methods to set up and solve problems in dynamics.
- Document your design and analysis in a professional technical report.

PROBLEM STATEMENT

Roller coasters are one of the main attractions for amusement and theme parks and vary considerably in their design. Trains on the coaster are brought to the top of a hill by some kind of lifting mechanism and from then on they coast for the remainder of the ride. Although things like friction, air resistance, mass distribution in the cars, etc. complicate things, we will do a first-cut design of a roller coaster by ignoring all that and treating the train as a point mass moving on a frictionless rail through space.

The primary tasks for this design project are to:

1) analyze the dynamics of typical coaster track elements (hills, valleys, turns, loops, twists);
2) design specific track elements meeting the project requirements;
3) assemble a track design;
4) analyze overall track performance; and
5) document the design and analysis in a group lab report.

The features that make a roller coaster ride exciting are novelty, speed, and G's experienced, so your task is to optimize the experience in terms of these parameters. We will quantify novelty in terms of the number of different elements incorporated in the design. Maximum speed is limited by the initial height of the coaster, and you can adjust the speed entering and leaving each element of the track by selecting its height. G's experienced must be defined carefully. The number of G's the particle experiences is equal to the normal force (**N**) exerted by the track on it, divided by the particle weight (mg). The normal force will also be a function of m, so the mass of the car should not affect the final "G" calculation. Note that the normal force is a vector quantity so we can express the number of G's felt in each of three directions relative to the train car (up, forward, left for example). The human body is more sensitive to G's in some directions than others, so we will set the design requirements to make the ride comfortable (well, at least not deadly) for the riders.

ASSUMPTIONS

1. Assume that the roller coaster train and people inside may be treated as a particle or point mass.
2. The track is frictionless (except for any braking sections).
3. The train is initially brought to the top of a 125 m (h_0) hill where it has zero velocity. The speed at any point on the track can be found based on the height compared to the initial height. $v(h) = \sqrt{2g(h_0 - h)}$.
4. The train must remain above ground (i.e. the height must always be greater than or equal to zero).

5. The train is locked to the track so that the force exerted on the train by the track can act in any direction orthogonal to the track (i.e. you can be held in your seat by the lap bar and pushed right or left by the side of the seat).
6. A track element will refer to one of the following:

   circular or parabolic hill

   circular or parabolic valley

   loop

   helix

   Note that neither the horizontal banked turn nor the braking section are considered a "track element". (Let me know if you think of other possibilities.)

DESIGN REQUIREMENTS

1. The total linear distance of the track must be less than 1250 m with the train coming to rest (using a braking mechanism) at a final height of 0 m.
2. The coaster must include at least three different types of track elements with transitions between them.
3. All transitions must be smooth.
4. The coaster must include at least one section that produces zero g throughout the ENTIRE element (not just at one point).
5. The coaster track must contain at least one banked turn at a constant or changing altitude (i.e. the track cannot remain in a single plane.)
6. The G's experienced by the passengers must be within the following ranges defined in a coordinate system fixed to the train:
   - forward (back of seat pushing on rider) < 5 G
   - back (seat restraint pushing back the rider) < 4 G
   - up (i.e. pushing up through the rider's seat) < 6 G
   - down (i.e. pushing down on the rider through the lap bar) < 1 G
   - lateral (pushing to the left or right on the rider) < 3 G

NOTES

1. To compute the "Gs" acting on a passenger in a certain direction, take the total force exerted on the passenger in that direction and divide by "m g", where g is the gravitational acceleration (9.81 m/s^2). Examples:
   a. The upward G's experienced by someone standing on the floor is the normal force of the floor on their feet ($N = mg$) divided by their weight (mg), and equals $N / m\,g = 1\ G$.
   b. The backwards G's experienced by a passenger in a train car that is decelerating at a rate 20 m/s^2 equals the force acting on them in that direction, $F = m * 20$, divided by their weight, $m\,g$, and equals 20/g ~ 2 Gs.
2. The acceleration of a passenger in a train going through a circular curve of radius R equals V^2 / R and is pointed towards the center of the circle. Thus the force of the track pushing on the passenger due to this motion equals "$m\,V^2 / R$" and points towards the center of the circle. The force of gravity must be added to this. Thus, the total upwards force acting on a passenger travelling through a circle of radius R at the

bottom of the circle will equal $N = m (g + V^2/R)$, and the total Gs will be $1 + V^2/(Rg)$. While at the top of the circle and upside down, however, the total force acting on the passenger will be $N = m (- g + V^2/R)$ and the total Gs will be $-1 + V^2/(Rg)$.

3. The force of a track acting on a passenger in a train going down a constant slope with angle θ and no friction will equal $m\, g \cos(\theta)$ and act normal to the track. The net force acting on the passenger tangent to the slope will equal zero, as the gravitational acceleration in this direction is exactly balanced by the acceleration of the train.