ASEN 2003 LAB 1: Roller Coaster Design

- Assigned: Tuesday, January 11, 2022
- Due: Thursday, January 27, 2022 at 8:59PM

1 Objectives

- Use your knowledge of particle dynamics to analyze the performance of a roller coaster.
- Gain experience using an example in particle dynamics.
- Practice using FBDs and energy methods to set up and solve problems in dynamics.
- Improve MATLAB skills to aide in analysis.

2 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 analysis 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,
2. assemble a track design,
3. analyze performance.

The features that make a roller coaster ride exciting are novelty, speed, and Gs experienced. Maximum speed is limited by the initial height of the coaster. Gs experienced must be defined carefully. The number of Gs 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 Gs felt in each of three directions relative to the particle (up, forward, left). The human body is more sensitive to Gs 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.

3 Assumptions

1. Assume 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 particle will 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).

4 Track 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).
2. The coaster must include a loop, parabola, banked turn, and a braking section with transitions between them.
3. All transitions must be smooth.
4. The coaster must include at least one section that produces zero Gs throughout the ENTIRE element (not just at one point).
5. The coaster track must contain at least one banked turn at a constant 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

5 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 Gs 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 $N/mg = 1$ G.

   b. The backwards Gs 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, mg, and equals $20/g \approx 2Gs$.

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 "mV^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 $mgcos(\theta)$ 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.

6 Brief Report Contents

FBDs and Governing Equations (should have accompanying diagrams, can be handwritten)

- For each track element (loop, parabola, banked turn, braking section) and transition region provide a brief qualitative description, a clear mathematical description, and a sketch.
- Show FBD and acceleration diagrams for critical points and/or a diagram for all points along the element. These diagrams can be side by side, but must be distinct, i.e. do not put them together.
- Give expressions for the Gs experienced by the particle throughout the element. Clearly mention if Gs in a direction are zero.
- Clearly define coordinate frame.

Performance Analysis

- Plot the up/down, forward/backward, and lateral G loads as a function of path length along the track for the individual track elements. Path length is not the same as position.
- The plots should be the same ones that are generated by MATLAB grader upon successfully completing the assessment.

Member contributions

- List the contributions of each team member.
- One to two sentences for each person.

Acknowledgements - Describe assistance or contributions provided by classmates or others (not including group members who authored the report).

Report Grading

5	Title Page (Group Members)
35	Derivations: Diagrams, governing equations, and description for each element. (7 pt each)
35	Performance: Gs experienced vs. path length for each element (7 pt each)
15	Full coaster: Gs experienced vs. path length for full coaster
5	Member contributions, Acknowledgements
5	Style and Clarity - organization, grammar, spelling, clarity of diagrams and figures)
100	