ASEN 2803 Dynamics & Controls Lab

Spring 2025

Lab 1: Pilot Simulator

Assigned Monday, January 13, 2025

Due Friday, February 14, 2025, at 11:59pm

OBJECTIVES

1. Use your knowledge of particle dynamics to analyze the performance of a pilot simulator.
2. Gain experience using an example in particle dynamics.
3. Practice using FBDs and energy methods to set up and solve problems in dynamics.
4. Improve MATLAB skills to aid in analysis.

PROBLEM STATEMENT

Your team has been tasked with the preliminary design for a re-configurable roller coaster that will be used for pilot training. The background "motivation" of this project is to use Virtual Reality (VR) goggles synced to the roller coaster track sections to achieve a low-cost simulator of basic flight maneuvers*.

Trains on the roller coaster are brought to the top of a hill by some kind of lifting mechanism. From that point, the train coasts for the remainder of the ride. Although effects such as friction, air resistance, mass distribution in the cars, etc. can complicate things, we will perform a first-cut analysis of the roller coaster by ignoring the above effects 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. design specific track elements meeting project requirements,
3. assemble a track design,
4. analyze overall track performance, and
5. document the design and analysis in a group lab report.

Some important considerations:

1. The features that make roller coaster sections suitable as a pilot simulator are track element shapes, speed, and Gs experienced. This assignment will focus on the shapes of: loop, zero-G parabola, banked turn, and braking section.
2. The maximum speed is limited by the initial height of the coaster.

3. 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.
4. Note that the normal force is a vector quantity, thus 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 for the training pilots.
5. You will analyze each section independently as if each section is located at the bottom of the initial hill, and then only place the sections in three-dimensional space in the order of your choosing.

*Note: Due to budget and time constraints, the VR aspects of this project are beyond the scope of this course and are not included in this assignment.

ASSUMPTIONS

1. Assume the roller coaster train and pilot 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 will remain above ground (ie. 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 (ie. you can be held in your seat by the lap bar and pushed right or left by the side of the seat).

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) at a final height of 0 m.
2. The simulator must include at least three different types of track elements (a loop, parabola, and banked turn) and a braking section with transitions between them. All transitions must be smooth.
3. The track must include a zero G parabola that produces zero Gs throughout the ENTIRE element (not just at one point).
4. The track must contain at least one banked turn at a constant or changing altitude (ie. the track cannot remain in a single plane).
5. The Gs experienced by the pilot must be within the following ranges defined in a coordinate system fixed to the train:
    a. forward (back of seat pushing on rider) < 5 G
    b. back (seat restraint pushing back the rider) < 4 G
    c. up (pushing up through the rider's seat) < 6 G

d. down (pushing down on the rider through the lap bar) < 1 G
e. lateral (pushing to the left or right on the rider) < 3 G

NOTES

1. To compute the "Gs" acting on the pilot in a certain direction, take the total force exerted on the passenger in that direction and divide by mg, 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 of $20\, m/s^2$ equals the force acting on them in that direction, $F = m \times 20$, divided by their weight, mg, and equals $20/g \approx 2$ G.

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 $1 + V^2/(Rg)$.

   However, while at the top of the circle and upside down, 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 $mg\cos\theta$ 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.

REPORT CONTENTS

The report is intended to be a brief assessment with minimal descriptive writing. See the Lab 1 Introduction slides for more information.

Reports should be written using the AIAA paper format. Word and LaTeX templates may be found at the following website: https://www.aiaa.org/publications/Meeting-Papers/Meeting-Paper-Author.

The report should follow the structure outlined below:

1. **Abstract**
   a. This should be a brief summary of your work, and should cover the ***motivation***, ***problem statement***, ***approach***, ***results***, and ***conclusion***.
   b. The abstract should be less than 200 words.
2. **Derivations: Free-Body Diagrams and Governing Equations**
   a. For ***each track element*** (loop, parabola, banked turn, braking section) and ***transition region***, provide a brief ***qualitative description***, a ***sketch***, the ***FBD and acceleration diagram***, and a clear ***mathematical description*** (ie. equations of motion and final G equations).
   b. 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 (ie. do not put them together).
   c. Provide expressions for the Gs experienced by the particle throughout the element. Clearly mention if Gs in a direction are zero.
   d. Clearly define the coordinate frames.
3. **Performance Analysis**
   a. For ***each track element*** (loop, parabola, banked turn, braking section) and for the ***full coaster***, include plots of the ***up/down***, ***forward/backward***, and ***lateral Gs*** as a function of ***path length*** along the track. Note that path length is not the same as position.

      Reminder: Path length is <u>*not*</u> the same as position.
   b. You may wish to explore the "subplot" command in MATLAB to create 3 plots in one figure.
   c. For all plots: Clearly label your plots with the plot title, axis labels with units, and G limits.
   d. For the full coaster plots: Indicate which section represents which track element.
   e. Include a short explanation (two to three sentences) for each figure.
4. **Conclusions and Recommendations**
   a. This should be a brief summary of your design, and should ***describe your design***, ***what was learned/deduced*** from the work, the ***limitations*** of your model (think about the assumptions/idealizations used), and ***recommendations*** to improve the model in the context of future work.

b. The conclusion is not a verbatim re-statement of your abstract.

5. **Member Contributions**

   List the contributions of each team member (one to two sentences for each person).

6. **Acknowledgements**

   Acknowledge any resources or help you might have received from sources outside your team.

7. **Style and Clarity**

   Points are awarded for style and clarity (ie. Assigning pages to your submission in Gradescope, submission organization, grammar, spelling, clarity of diagrams & figures, etc.).

REPORT GRADING

1. **Group Submission**

10	Abstract
25	Derivations: FBDs, governing equations, and description for each element.
25	Performance Analysis (each element)
15	Performance Analysis (full coaster)
10	Conclusions and Recommendations
5	Member Contributions and Acknowledgements
10	Style and Clarity

100 points total

2. **Individual Submission**

10	Self-Assessment and Peer Evaluations

10 points total