# Roller Coaster Mania

**Description:**

In this activity, you will work in groups to design a roller coaster. A physical model of the design will be constructed. The motion of a roller coaster car will be described using the language of physics. Furthermore, this motion will be analyzed mathematically in order to determine the speeds, accelerations, normal forces, and the number of Gs experienced at strategic locations along the track. Finally, your design and accompanying analysis will be presented to the class.

**Procedure:**

1. **Brainstorming**:

   Brainstorm some roller coaster designs with your group. Concentrate on how vertical drops, loops, turns (90° and 180°) can be combined in order to provide a thrilling ride. Sketch your design ideas on sheets of *scratch* paper. Your design **MUST** be a *gravity-powered* design that includes a first drop, at least two clothoid loops, at least two hills, and at least one 180° turn. You may include other features in your design; but the mathematics associated with those features will not be investigated.

2. **Deciding on Design Parameters:**

   Select a roller coaster design from among your sketched ideas. Create a layout of the design on a large sheet of paper. Begin to make <u>tentative</u> decisions about the height and incline angle of vertical drops (between 50 m and 80 m), the height and steepness of small hills, the radius and maximum height of vertical loops, the radius and banking angle of the 180° turns; the height (h) of each section of track, and the length of straight sections of tracks. Label all these design features on the diagram. A vertical drop, loop, curve, hill, and straightaway are all considered separate sections.

3. **Labeling Strategic Locations:**

   Starting at the top of the first drop, begin labeling each strategic location with a letter. The top of the first drop would be location **A**; the bottom of the first drop would be location **B**; etc. Strategic locations are defined as follows:

   First drop: top and bottom locations

   Loops: top and bottom (when entering exiting) locations

   Hills: top and bottom (when entering and exiting) locations

   180° Turn (horizontal): beginning and end locations

   Braking Section: beginning and end locations

   Conceptual descriptions and mathematical analyses will eventually be conducted for each of theses strategic locations. Thus, it would be sensible to letter the locations in the order of the alphabet so that the rider moves from **A** to **B** to **C** to

… . If you use all 26 letters of the alphabet, then you can begin to use double letters like **AA**, **BB**, **CC**, etc.

4. **Conducting an Energy Analysis:**

   Assume a mass for your rider. Use energy conservation principles to determine the speeds at various locations along the track. Label and organize all calculations for future reference. Calculate the PE, KE, height (h), and speed (v) at all strategic locations along the track. Tabulate the results of your calculations on the provided pages.

5. **Conducting a Force Analysis:**

   Utilize free-body diagrams and Newton's second law to determine the normal force and accelerations which riders experience on each section of track (specifically at the top and the bottom of loops, at the top and bottom of hills, along vertical drops, on banked turns, and in the braking section). If necessary, revise the original design parameters (heights, radius, angles, etc.) to ensure the safety of your passengers. Label and organize all calculations for future reference. Label the acceleration (a), net force ($F_{net}$), and normal force ($F_{norm}$) for each section of track. If necessary, make revisions to your original design parameters in order to insure safety while maintaining a thrilling ride. A safe ride is defined as follows:

   | | |
   |---|---|
   | Loop Tops: | Greater than 0.2 Gs; less than 3.0 Gs; 3.0 Gs to 7.0 Gs is brutal. |
   | Loop Bottoms: | Less than 5.0 Gs; between 5.0 Gs and 7.0 Gs is brutal. |
   | Hill Tops: | Negative Gs (safety bar pushing down) should not exceed 0.8. |
   | Hill Bottoms: | Less than 5.0 Gs; between 5.0 Gs and 7.0 Gs is brutal. |
   | Banked Turns: | Less than 3Gs. |
   | Braking Section: | Less than 2Gs. |

6. **Verbal Description of Rider Experience:**

   Using the language of physics, describe the motion of the car along each section of track. State whether the motion can be described as constant velocity or accelerated motion and explain how you know. State whether the occupants would feel less than normal weight, normal weight, or greater than normal weight and explain why. Describe the motion as being either fast or slow and either speeding up or slowing down.

7. **Construction of a Physical Model to Scale**

   Use a physical material (foam pipe insulation, thick metal wire, etc.), construct a physical model of your roller coaster design that shows the arrangement of loops, hills and turns. Select a scale like 1 cm = 2 meters, and construct the model to scale. Use small strips of paper or a note card to label all the strategic locations. Indicate the acceleration and number of Gs for each of these locations.

8. **Preparing Your Presentation:**

   Prepare your complete written and oral presentations. Your written presentation must be word-processed and constructed using the computer (including diagrams). Calculations can be hand-drafted on separate pages and made reference to from within the report. The presentation should be a multimedia presentation utilizing a variety of media (e.g., posters, computer graphics, transparencies, physical model, presentation software).

**Due Dates**

The following due dates have been set in order to guide you in the completion of your project.

| | |
|---|---|
| Track Design (1st draft) - steps 1 and 2 | ________________ |
| Energy Analysis (1st Draft) - steps 3 and4 | ________________ |
| Force Analysis (1st Draft) - step 5 | ________________ |
| Verbal Description (1st Draft) - step 6 | ________________ |
| Physical Model - step 7 | ________________ |
| Design, Analysis, and Description (final draft) | ________________ |
| Presentation - step 8 | ________________ |

**Assessment**

Your project will be assessed using the accompanying rubric. The following five outcomes will be assessed: Teamwork and Collaboration, Verbal Description, Mathematical Analysis, Communication, and Technology Usage.

**Things You Should Know About Roller Coasters**

**Vertical Drops:**

Roller coasters almost always begin with an initial vertical drop. A motor hauls the cars to the top of a high hill and from that point on gravity is doing all the work. Typical vertical drops might range in height from 50 - 80 meters. The height of the first drop determines the rider speed at all locations and subsequently the rider experience at all locations. The angle at which the car drops is another variable that affects the rider experience. Typical angles range from 30° to 80°.

**Loops:**

Roller coaster loops are never circular loops. Instead, they are clothoid loops - a loop in which the radius is continuously changing. The radius is typically large for the bottom sections of the loop and small near the top sections of the track. This is done to prevent high G-forces as riders enter the bottom of the loop at high speeds; and with a smaller radius at the top of the loop (where the car is traveling slower), the riders are less likely to fall out of the car. Designers generally attempt to design loops that have a radius of curvature at the top that is about 1/3$^{rd}$ the height of the loop and radius of curvature at the bottom that is about 2/3$^{rd}$ the height of the loop.

**Turns:**

Roller coaster turns can be regarded as part of a horizontal circle and their degree of curvature is sometimes described by listing a radius value. The radius value represents the radius of the circle about which the roller coaster car moves. A small radius value is generally typical of a sharp turn and a large radius value is typical of a mild turn. The sharpness of the turn effects the acceleration and the forces experienced by the riders. Such turns are often banked at an angle to the horizontal in order to direct more of the normal force towards the center of the turn as well as to ensure the safety of the riders.

**Hills:**

Roller coasters often have a small series of hills that makes the rider feel as though her stomach is suspended in the air or falling through the seat. These hills are curved sections of track that can be regarded as part of a vertical circle and the degree of curvature of the circle is described by listing a radius value. The sharpness of the ascension and the drop effect the acceleration and the forces experienced by the riders. A small radius value is indicative of a sharp rise and fall. A larger radius value is more typical of a mild rise and fall.