**Roller Coaster Project**

**Objective**

Working in groups of 3 students or less, you will design and construct a scale model of a roller coaster ride. Imagine that your engineering team is going to present your coaster to a theme park for possible construction. Your ride must have some theme that will grab the attention of the riders because that is what draws in buisness. More importantly you will be engineering the design of your coaster so it is actually survivable, while at the same time providing a thrilling experience. This means it can not have g-forces which would inflict injury or possibly death upon the riders but it must at the same time meet minimum g-forces to create the “thrill factor”. The details of this project are explained below.

**Materials**

The following list of materials are suggestions of what you might use to construct your scale model.

* **Bendable Wire**: You will need about 6 feet of wire for the project. You must be able to easily bend this wire into the shape of your rollercoaster and the wire must maintain its shape well. The single piece of wire represents the track of your coaster. Pipe cleaners and solid copper electrical wire work well for this.
* **Track Supports**: Anything, that will help keep your track in shape and hold it to the correct height. Balsa wood or pipe cleaners work great because they are inexpensive, easy to cut to length and prevent the track from changing shape.
* **Platform**: What you will use as the base of your coaster. The base must be rigid so that you can carry the coaster around. Styroboard, foamcore board or cardboard work well for this. Make sure it is something that you can easily attach your coaster supports to.
* **Decoration**: At the very least you must include the name of your roller coaster along with your group member names as part of your coaster display. The addition of other decorations that help to “sell” your roller coaster to the theme park (teacher) will earn you extra credit. These decorations should allign with the theme of your rollercoaster. Be creative, the better the decorations match the theme of your coaster the more points you will earn.

Most importantly you should think cheap. Wire, popsicle sticks, and styrofoam shouldn’t cost that much. Don’t spend tons of money decorating your model. Look for items you already have at home.

**Criteria**

1. The model of your coaster must be to scale. This is explained below.
2. Design the coaster to include *at least* the following elements (key points), you can choose any order to put them in and add other elements as well if you wish:
3. A first hill. This will be the tallest hill which will provide all of the potential energy for the ride. You will calculate the g-force on the rider at the top and bottom of this hill. This will necessarily need to be your first element. The g-force at the top of the hill must fall between 0.5g’s and 1g. The g-force at the bottom of the hill must fall between 3g’s and 5 g’s.
4. A second hill. This hill will be shorter than the first hill. You will calculate the g-force at the top of this hill. The g-force must fall between –0.5 g’s and 1 g.
5. A vertical loop. You will calculate the g-force going into or out of the loop (at the bottom) and at the top of the loop. Your g-force must be between 2 g’s and 5 g’s at the bottom of the loop. The g-force must be between 0g’s and 2 g’s at the top of the loop.
6. A horizontal corkscrew, *horizontal loop 360°* minimum turn. You will calculate the g-force about midway through the turn. The g-force at this location must be between 2g’s and 4 g’s.
7. The design of the coaster must be a complete loop. This means that your ride must end back at the loading platform which is located just before the first hill.
8. The normal force (FN) must be between -0.5 and 5 g’s at all times. You will calculate the g force on the rider at each of the key points above and must stay within the maximum and minimum values for g-force at each key point as explained in #2 above.
9. The speed of the coaster must never be in excess of 45 m/s (100 mph).
10. Use an average mass for each passenger on your ride of 80 kg.

## **Example Coaster**

Corkscrew

540O turn

Loop

First Hill

Second Hill

Start

180O Turn

## This is a simple example of the minimum elements that your coaster must include. The order in which the elements occur does not matter. Feel free to add more to your ride to make it more interesting.

**What you will turn in**

1. Your mounted scale model of the track with labels indicating each key point listed above.
2. Written work to include (typed or neatly printed)
3. Title page with the name of the coaster, student name(s), and period(s)
4. One-paragraph advertisement for your coaster. Think of this as what a park brochure would use to advertise the new ride.
5. Preliminary 2-dimensional sketch of coaster drawn to scale with all reference points labeled. This sketch must include the following information labeled at each key point: height, radius and length along ride.
6. A printout of the spreadsheet showing data from model (mass, heights, curve radii (used in calculations) and calculations (PE, KE, v, Fnet, Fseat, g force).
7. One sample calculation (equation, substitution, answer) showing each step in the process of determining the g’s at the top of the second hill.
8. An electronic copy of your spreadsheet on disket or sent via e-mail to [ajohnson@susd.org](mailto:ajohnson@susd.org).

**Be sure to**

1. Include units with all measurements and answers
2. Label everything clearly
3. Complete all aspects of the project to earn full credit

## **Step 1: Create a scale drawing of your coaster**

## I will provide you with a long piece of printer paper so that you can create a simple line drawing to define the shape and height of your rollercoaster track. The scale of this model must be determined and written on the drawing in the top left corner. The drawing should begin with the first hill and must include each of the key elements which are required as part of your roller coaster. Remember, the first hill must be the tallest element on your roller coaster to provide the energy necessary to make it through the remaining components. Adjust your scale as necessary to make sure your speed does not exceed 45 m/s when you reach the bottom of the hill. It is important to remember that the size of the curves and hills on this drawing will be the guide to your calculations and scale model. For each of the key points on the ride you must measure and write on the scale drawing the height above the ground, the radius of the track’s curve and the length along the ride that you are.

## The length along the ride will be used to determine how much energy has been lost along the ride and so how much energy is left to provide height and speed to your coaster. Your coaster will “begin” at the top of the first hill (after the motor lifts the coaster to the top) and will “end” at your last key point or later. During this time, your coaster will lose 50% of the energy it began the ride with due to friction. You will need to calculate how much energy remains in order to successfully calculate the speed and g-force of the ride at each key point.

## Keep in mind, that as you get farther along the ride you will have less energy to work with. This means that later sections of the ride will need to have lower heights and/or tighter turn radii in order to create necessary speeds.

## **Step 2: Determine actual height and radius**

In order to complete the spreadsheet and determine wether or not your roller coaster is survivable, you will need to know the height, radius of curvature and length along the ride for each of the key points. This information should be measured and written on the drawing at each point along with the coverted distance (in meters).

*example Height = 12cm : 50meters*

*Radius = 4cm : 20meters*

## **Step 3: Complete the calculations for your roller coaster**

In order to simplify the process of completing the calculations, you will be using microsoft excel (separate instructions provided) to create a spreadsheet for your measurements and equations. Your calcualtions for G-force will depend on the **actual** height and radius of the track at each key point along your coaster. The height will determine the energy (velocity) that the riders have at each one of those points. In turn the velocity and radius will determine the centripetal force acting on the rider. Even though we will be using microsoft excel to complete most of our calculations you will need to complete the calculations for g’s at the top of the second hill to demonstrate the work. The sections that follow provide a review of calculating energy and force.

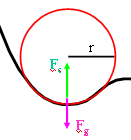
Energy

* Estimate a mass of the train with passengers. (80kg/passenger 250kg/cart)
* Determine the energy of the rollercoaster at the beginning of the first hill.
* Determine the total energy of the coaster at each of the key points.
* Determine the PE and KE at each key points of the ride.
* Use the KE to determine the velocity of the car at each key point

Forces

The force that causes the rider to follow the curve of the track is the centripetal force. The centripetal force is the net of all forces acting on the rider. To simplify this situation we will consider the normal force and the force of gravity as they act on the rider.(Fc = FN + Fg) We will not include any wind resistance, friction or other forces that may toss the rider side to side. Track friction, which slows the ride, has already been taken into account in the calculation of the car’s velocity.

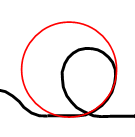
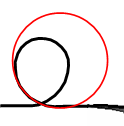
From knowing the velocity of the car and the mass of the rider we will be able to determine Fc as well as Fg. We will be solving for FN, which represents the force of the rider. Rearange the above equation to solve for FN.(FN = Fc – Fg) Use the diagrams and explanations below to determine wether Fc or Fg should be positive or negative.

Bottom of a hill

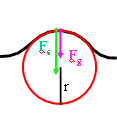
At the bottom of a hill the track is curved upward, this places the center of curvature above the track. Since the passenger is upright the following are true.

* Radius of curvature is positive
* Fc acts upward (positive)
* Fg acts downward (negative)

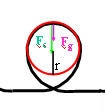
Entering/Exiting a loop

While entering or exiting a vertical loop the track is curved upward just as it is at the bottom of a hill. The rider is also still upright so the direction and sign of the forces remains the same as above. Although you may have slight variation in the curvature of your scale model you can assume that the forces for entering and exiting your vertical loop are the same.

Top of a hill

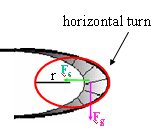
At the top of a hill the track is curved downward, this places the center of curvature below the track. Since the passenger is upright the following are true.

* Radius of curvature is negative
* Fc acts downward (negative)
* Fg acts downward (negative)

 Top of a loopAt the top of a loop the rider is upside down, this changes things. Their perspective is now reversed. Although the track is curved downward, according to the reversed perspective of the rider, the center of curvature is now above the track making it positive. The force of gravity also appears to be positive.

* Radius of curvature is positive
* Fc acts “upward” (positive)
* Fg acts “upward” (positive)

Horizontal Turn / Corkscrew

While in any horizontal turn the center of curvature is now to the side of the track instead of above or below. This means that the centripetal force acts perpendicular to the force of gravity. In this situation we can ignore the force of gravity. Make sure to enter a value of zero for Fg in your spreadsheet.

* Radius of curvature is positive
* Fc acts sideways (positive)
* Fg is not used (zero)

**Data Table**

Separate instructions have been included for you to create a data table using Microsoft Excel. This data table will include given values (mass of rider), measured values (height and radius) as well as calculated values (total energy, potential energy, kinetic energy, velocity, radius, centripetal force, gravitational force, normal force, and finally g’s). You must include a calculation of the g’s that the rider will experience at each key point along your ride. If you include additional turns, loops, hills, or corkscrews you must include more calculations in your spreadsheet to demonstrate the g’s throughout the entire ride. This will not be difficult as the spreadsheet will do the work for you.

**Step 4: Adjust your scale model**

Once you determine your g-forces at each point along the ride you may find that your coaster does not fit within the g-force ranges required for each key point. If this happens you will need to adjust your coaster dimensions to fix any problem areas. If a ride hits too many g-forces consider raising the height of the track at that point or making the radius of curvature larger. If the a ride hits too few g-forces you will need to do the opposite. Once you make the changes to your drawing, you will need to remeasure the height, radii and length along the ride for each key point and plug it the corrected values into your spreadsheet. Since your spreadsheet will be completed at this point you will be able to see immediately if the changes you made bring your roller coaster into specifications or if further changes are needed. Continue to adjust your drawing and measurements until you get the coaster to fit into the g-force requirements.

**Step 5: Build your scale model**

Once you know your roller coaster is survivable (between -0.5 and 5 g’s) you can begin to build your scale model. The heights and radii of this model must be based on the values that are used in your excel spreadsheet and shown in your scale drawing. Once you know the height and radius of the model you can begin to shape your track and create track supports. Remember that your model rollercoaster must form a complete loop (see example diagram). Part of your grade on the project will be based on how well your scale model represents the calculations which you have made. It is important to have the correct height and curvature to your track, especially at the key points. If you have sudden bends in your track rather than curves you might miss a few points. Be sure to use enough track supports to prevent the height and shape of your coaster from changing. Remember to include the name of your coaster as well as the names of all your group members. Decorate your coaster to represent the theme.

Final Checklist

The following items must be turned for this project. If you neglect to complete any portion of the project you will receive a reduced grade. Please make sure the following items are put together in a folder when you turn in your project.

* Scale Drawing (in folder)
  + Include measured and actual heights and radii
* Example Calculation (in folder)
  + Provide one handwritten copy of the calculations for g’s at the top of the second hill.
  + Demonstrate each step in the process of completing this calculation including each equation, the given and unknown values, and the solution.
* One copy of your final excel spreadsheet (in folder)
  + The values on this spreadsheet must match your example calculation and your scale model.
* Your Scale Model
  + The measurements of this model must represent the heights and radii shown on the excel spreadsheet.
  + All key points must be labeled with their name *(top of second hill)* and amount of g’s.
* Advertisement
  + One paragraph that would be used as a radio or TV advertisement.
* Cover Sheet
  + Include the name of your coaster and the names of all group members.
* Electronic copy of your spreadsheet
  + This must be provided either by turning in a diskette with the information saved on it or by e-mailing it directly to [ajohnson@susd.org](mailto:ajohnson@susd.org).

**Roller Coaster Project Grade Sheet**

Title Page \_\_\_\_\_\_\_\_/10

Name of coaster

Student Names

Period #’s

Name of spreadsheet file

Advertisement \_\_\_\_\_\_\_\_/10

Printed Spreadsheet \_\_\_\_\_\_\_\_/50

2-d sketch \_\_\_\_\_\_\_\_/30

6 key points

radii

length along coaster

height

Sample Calculations \_\_\_\_\_\_\_\_/40

Percent Energy Lost

Total Energy Lost

Potential Energy

Kinetic Energy

Velocity

Centripetal Force

Seat Force

G-force

Mounted Scale Model \_\_\_\_\_\_\_\_/50

Electronic copy of spreadsheet \_\_\_\_\_\_\_\_/10

### TOTAL \_\_\_\_\_\_\_\_/200

**Roller Coaster Project – Excel Spreadsheet Directions**

Complete the following steps and you will create an excel spreadsheet to help with the calculations necessary for this project. Since we are providing you with the format for this spreadsheet it is important that you follow the directions exactly so each group will have a similar finished product. Although we have provided you with the equations that you will be using be sure that you and your group understand why we have each equation in the format that it appears and how it is being applied.

* Open Microsoft Excel and it will display a blank workbook. Each workbook is made up of worksheets.
* Each worksheet consists of an array of cells organized in rows and columns. At the top of each column there is a letter that corresponds to all the cells in that column. To the left of each row there is a number that corresponds to all the cells in that row. Each individual cell has a name, which consists of its column letter followed by its row number. In these directions we will refer to specific cells by their names and will prompt you to enter the proper labels, values, and equations to complete the spreadsheet.
* **Important step! Save the file onto the desktop now! Name it whatever you wish. SAVE often! You do not want to have to redo this work. It would be a good idea to save the file to a backup location as well (like a school fusion account).**
* Enter the text as shown in the picture below. These row and column labels will help you keep track of what each piece of data represents. The order that you enter the 6 data points from the ride should be in the order that these features occur in your roller coaster.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E | F | G | H | I | J | K | L | M |
| 1 | Mass of the coaster (kg) |  |  |  |  |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | Length of the coaster (m) |  |  |  |  |  |  |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 5 | Mass of rider (kg) |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 | Weight of rider (N) |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 8 | Location on the ride | Height (m) | Length along ride (m) | % energy lost | total energy lost (J) | PE (J) | KE (J) | v (m/s) | r (m) | Fc (N) | Fg (N) | Fs (N) | g’s |
| 9 | Top of first hill |  |  |  |  |  |  |  |  |  |  |  |  |
| 10 | Bottom of first hill |  |  |  |  |  |  |  |  |  |  |  |  |
| 11 | Top of second hill |  |  |  |  |  |  |  |  |  |  |  |  |
| 12 | Bottom of vertical loop |  |  |  |  |  |  |  |  |  |  |  |  |
| 13 | Top of vertical loop |  |  |  |  |  |  |  |  |  |  |  |  |
| 14 | End of horizontal curve |  |  |  |  |  |  |  |  |  |  |  |  |

* You will need to adjust some of the column widths so the text will fit as shown. One way to adjust the column width is to place your cursor on the right side of the column label, click and hold and drag the column wider or narrower. For example, if you want to make column C wider, place your cursor on the line between the column labels for columns C and D. The cursor will change shape when you are in the right spot, click and hold and drag the column as wide as you wish.
* It will help you in entering data if you can scroll across the columns and keep your row labels on the screen. To prevent cells from moving you can freeze some of the panes. Place your cursor over cell B9 and click once to select. To freeze panes, select “freeze panes” in the “View” tab. It is important that the correct cell remains selected when you do this. As you scroll to the right the row labels should remain on the screen and if you scroll down the column labels should remain on the screen.

**Entering data and equations**

* In cell B1 you will need to enter an approximate mass of your roller coaster in kilograms. This mass should include the cars of the roller coaster and the riders when it is full. Make a reasonable approximation for this mass.
* In cell B3 you will need to enter the total length of your coaster along the track. This length is used for calculating the energy lost along the ride. Your coaster will begin to lose energy at the top of the first hill and will lose 50% of its energy when it reaches your final feature (your 6th star). Don’t forget to scale this number so that it is entered in meters on your spreadsheet.
* In cell B5 you will need to enter the mass of a single rider on your coaster. Again, make a reasonable estimate for this value. In the end it will not matter what mass you choose as each rider will experience the same g-force.
* In cell B6 we want the weight of the rider in Newtons. While this value is easy to calculate yourself, this is the perfect opportunity to practice entering equations into the Excel program. The weight of a rider is equal to the rider’s mass (in kg) times 9.81 so we want to tell the Excel program to perform this operation. All equations must begin with an = sign. Enter into cell B6 **=B5\*9.81**. Any time you enter an equation, you must hit enter to finish the equation. This equation will tell the program to take the value entered into B5 (which is the mass of the rider) and multiply it by 9.81. Exactly what we want!
* Height - In cells B9 through B14 you will need to enter the height of your roller coaster **in meters** at each specified location along the ride.
* Length along ride - In cells C9 through C14 you will need to enter the length along the ride that each of the specified locations occur. Remember to also scale this length to meters.
* % Energy loss – By the end of the ride, your coaster will have lost 50% of its initial energy. We want to determine what percent of energy your ride has lost at each specified location. We will assume the ride loses its energy uniformly throughout the ride. To do this, enter into cell D9 the equation **=(C9/$B$3)\*0.50.** Now we want to “fill” this equation down through cell D14. To do this, highlight all the cells from D9 through D14. On the Home tab select Fill and then Down. Notice that the program has calculated the percent energy lost (in decimal form) for each position along the ride. Click on cell D12 and look at the text box at the top of the page, the equation in this cell should say =(C12/$B$3)\*0.50. The program automatically knew to use the C12 for this calculation and that is the beauty of spreadsheets. The dollar signs surrounding the B in B3 tell the program to “lock” this cell or not change it as you fill down.
* Potential Energy – For a moment we are going to skip column E. First let’s enter the Potential Energy into column F. Recall PEg = mgh. The PEg that the ride has at any given moment depends on the height of the coaster at that point, which is given in column B. So enter into cell F9 the equation **=$B$1\*9.81\*B9.** Then fill that equation down through cell B14.
* Total energy – Now, let’s back up and fill in column E. As the cars are pulled up the first hill, the electrical energy of the motors changes into potential energy. The total energy that is available depends on the potential energy of the coaster at the top of the first hill. Enter the following equation in cell E9 **=$F$9,** this will copy the value from the initial potential energy in cell F9 over to this cell. In the perfect world, this roller coaster would always have this much total energy, but unfortunately, due to friction it will lose energy along the ride. To account for this enter the following equation into cell E10, **=$E$9-($E$9\*D10)**. Fill this equation down through cell E14.
* Kinetic Energy – As the rider tops the first hill they have obtained their maximum potential energy. As they begin to move down the hill they lose potential energy and gain kinetic energy. The calculation for kinetic energy will just be the difference between total energy and potential energy. Enter the following equation in cell G9, **=E9-F9**. Fill this equation down through cell G14.

* Velocity – From the kinetic energy of the coaster we can determine the velocity at which it will be moving. Solve the following kinetic energy equation (KE = ½mv2) for velocity and you end up with v =. In cell H9 you will enter the following equation **=sqrt(2\*G9/$B$1).** Fill this equation down through cell H14.
* Radius – To calculate the centripetal force at given spots along the ride, we will need to know the radius of curvature of your ride. Enter into column I the radii that you measured at the specified locations. Don’t forget that this radius must be converted according to your scale so it represents the actual radius that the track will have in meters. (note: the radius is negative at the top of both hills and positive everywhere else).
* Centripetal Force – The equation for centripetal force is Fc = mv2/r. We are trying to determine the force on a single rider at this point so m is the mass of the rider. In cell J9 enter **=$B$5\*H9^2/I9** this equation will guide excel to calculate the centripetal force at each point along the ride. Fill this equation down through cell J14.
* Force of Gravity – The force of gravity is the weight of the rider. You’ve already calculated this in cell B6. However, during the horizontal curve, the weight of the rider does not contribute to Fs so it should be entered as zero. Enter by hand the appropriate values for the weight of the rider at each point. (note: the weight of the rider is + at the top of the loop since the rider is upside down, zero for the horizontal turn and negative everywhere else.)
* Seat Force (Fs) – The seat force is the force that the seat pushes up on the rider with, this is also known as the normal force. Centripetal force is the net force on the rider so Fc = Fg + Fs.  Solving for seat force you get Fs = Fc – Fg. So enter into cell L9 the equation **=J9-K9** and fill this equation down through L14.
* To calculate g-forces you must divide the force that the riders feel by the weight of the rider. Enter the following equation in cell M9 **=L9/$B$6.** This will calculate the g-forces on the rider. Fill this equation down through cell M14.

You’re done with the programming part! If you haven’t done so recently, save your spreadsheet at this point. Take a serious look at your g-forces, did they all lie between the parameters set at the beginning of this assignment? If not, you have some changes to make to your coaster. Remember the hints I gave you before about making the coaster more passenger friendly. Make needed changes to the spreadsheet until your coaster fits the parameters. This is where the spreadsheet will come in really handy. You can make quick changes to hill heights and radii and all your calculations will be done for you. After you have made the changes you need, you will have to adjust your 2d drawing so that it fits your new coaster design. If you make a new drawing, please make sure to show all your new measurements. Most changes you will make will likely affect the length along the ride that each of your key points lie. Make sure to remeasure these and enter those new measurements on your spreadsheet. Finally, bend your wire coaster into a 3d model. All the measurements on the 2d and 3d model must be a scale of the measurements on the spreadsheet.

Reminder of what needs turned in:

1. Your mounted scale model with reference points labeled.
2. Written work to include (typed or neatly printed)
3. Title page with the name of the coaster, student names and periods.
4. One-paragraph advertisement for your coaster
5. A two dimensional sketch of your coaster with all reference points labeled and all measurements given.
6. A printed spreadsheet or table showing data from model (mass, heights, curve radii used in calculations) and calculations (PE, KE, v, Fnet, Fseat, g force).
7. One sample calculation (equation, substitution, answer) for each unique calculation done for the top of the second hill.
8. E-mail Mrs. Johnson your saved spreadsheet file. Be sure to indicate in the e-mail the names of all of your group members. Send the e-mail to [ajohnson@susd.org](mailto:ajohnson@susd.org) .