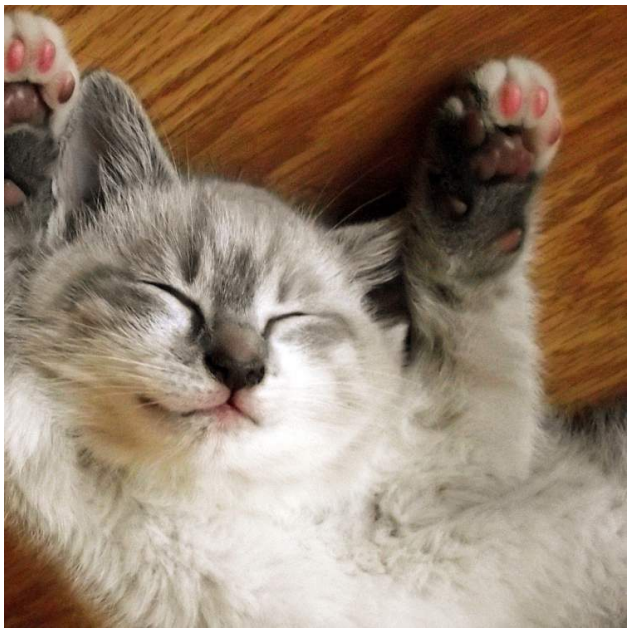
El Segundo High School

AP Calculus and AP Physics

Rollercoaster Design Document



Qing Ying **Li**, *Project Manager*
Victoria **Chu**, *Systems Engineer*
Henry **Smith**, *Technical Engineer*
Luke **St. Regis**, *Mechanical Engineer*

Contents

1 Abstract

We need to build a roller coaster with at least two loops, one spiral, one sine/ cosine function, and two other functions and two interlocking parts on a base of at least 500mx500mx300m. It must be eco-friendly, incorporate STEM, trigger a 10J device, and meet the standards of the IAAPA. It is intended to attract more people to visit the fabulous Coco Islands. With reference to one of the biggest roller coasters in the world. The tallest wooden roller coaster

is 183 feet. The longest wooden roller coaster is 7400 feet. These roller coasters have banked angles, wooden supports, and sturdy tracks. These will all be implemented into the roller coaster as it is also a very big roller coaster. This roller coaster will help enrich the cultural, biological, physical, and mathematical knowledge of the world as people flock to the Cocos Island to ride the roller coaster. To approach this problem we will first analyze the functions and pieces required of the roller coaster. Then, we will use the calculations from the analysis to figure out in what order and placement we should put the pieces and functions to optimize the usage of the area of the base while still maintaining a physically sound roller coaster. We will then build a model of this roller coaster out of straws, wooden sticks, and a wooden base and test it with a marble. This will be used to demonstrate the idea to possible donors. The results of this project are to be determined and will be added to the abstract as it gets done. In the future we hope to build more monstrously large roller all over the world to increase tourism.

2 Team Overview

2.1 Bios

Icy Li, Project & Business Manager

Icy Li, a sophomore girl who studies in El Segundo High School. She came from China and started learning in the high school a year ago. Right now, she is taking AP Calculus class. She works hard and tries to get ideal grade in all her classes. Besides, she plays the piano and has accompanied several times for choir during the formal concerts. She has performed in a couple of recitals as well. Her favorite hobby is reading. And she wants to achieve double majors on business and music in university. She is also taking AP World History class. Next year, she will take LMU courses, AP Physics, and AP Statistics. She had also learned physics for two years while she was studying in Shanghai No. 3 Girls' Middle School in China. In a word, she is ready for this job and will try her best on the project.

Victoria Chu, Lead Systems Engineer

Victoria Chu is a 16 year old junior who has taken all basic high school math classes up to AP Calculus. She is confident in her math skills. She received an A on the calculus final. She is taking AP Physics this year, but her confidence in this subject area is particularly questionable. She is also taking AP

Spanish. She has taken AP Biology last year. Other APs she has taken include: AP US History, AP World, and AP Computer Science. She has taken one engineering pathway course (POE). She is involved with other activities such as CyberPatriot, Zero Robotics, PicoCTF, NCWIT, and more. She has held one job in the past as a HSSRP unpaid research scholar in which she worked alongside graduate students at UCLA to create a mobile application that collects data on mobile phones and users for energy optimization among other reasons. She has recently received a paid internship after interviewing with Northrop Grumman. Victoria works hard and has managed to spread herself across 5 AP classes. She will try her best on this project. She chose to be systems engineer because re skill set is more rounded than particularly specialized in an area.

Henry Smith, Lead Technical Expert

Henry Smith is a 17 year old junior Who has studied every year of math in High School up through AP Calculus. He is highly invested in his skill as a mathematician and enjoys practicing his ability to solve theoretical and practical problems. Along with Calculus, he is taking AP Physics this year and is moderately confident in his ability to apply calculus principles to his understanding of Physics. Along with Calculus and Physics, Henry has taken AP Computer Science and the PLTW engineering track up through Aerospace which he is taking now. He is a member of a CyberPatriots team with Luke St. Regis and Victoria Chu and has participated in at least five separate Computer Science CTF Competitions in his spare time. He asked to be the Technical Expert because he prefers the work of design and problem solving over the physical act of building (although he will participate in construction of the model as necessary). He will do his best to support his team.

Luke St. Regis, Lead Mechanical Engineer

Luke St. Regis is a 16 year old junior who has taken every math class from Algebra 1 through AP Calculus. He is confident in his skills in calculus, and comfortable applying them to real world problems. He is in AP Physics and has a solid understanding of the basics of kinematics and how to apply calculus to them (and move away from an equation sheet). Through the PLTW engineering pathway Luke has gained experience with the design and construction of a number of projects, such as a coilgun. He has also reanalyzed some of these projects with a more advanced understanding of the physics behind them. Luke also received a summer internship with Boeing in the field

of Aerospace engineering. He wanted the role of mechanical engineer because he enjoys combining the design aspects with the physical construction of a project.

3 Research

3.1 Real World Roller Coasters

Roller coasters are a popular form of entertainment. The tallest wooden roller coaster is the T Express in Everland of South Korea. It is 183 feet tall and 5,384 feet long in track length. It reaches a speed of 65 miles per hour The longest wooden roller coaster is the Beast on Kings Island in Ohio. It is 7400 feet long in track length and 110 feet tall. It reaches a speed of 64.78 miles per hour. These roller coasters have banked angles, wooden supports, and sturdy tracks.

The beast and the T express (Figure 1) are good models of safe large wooden roller coasters in the real world.

3.1.1 Properties of a Roller Coaster

Wooden Roller coasters typically consist of a boarding station, a lift, an initial drop, and a braking system at the end. Usually roller coasters have a lift hill (Figure 2) where the car of the roller coaster is lifted up a hill by the chain. At the top of the roller coaster the chain releases the cart, which then continues through the rest of the roller coaster. At the end of the roller coaster circuit there is a brake. The most common form of brake is a brake run.

3.1.2 Physics of a roller coaster

Many people go to amusement parks all over the world to experience the thrill roller coasters provide. This thrill comes from the physics of the design of the roller coaster.

Roller Coasters typically rely on gravitational potential energy between the point of release at the top of the lift hill and the brake run at the end of the ride. As the roller coaster cart moves through the course of the ride, this energy is converted to kinetic energy and lost to friction and air resistance in the form of heat or sound. Since the initial drop only sets a limit on the amount of energy available to power the roller coaster through the rest of the circuit, the roller coaster must follow these energy constraints. This idea is demonstrated in Figure 4.

Additionally, some parts of the roller coasters require different speed requirements for the coaster cars to not fly off the track or fall in the middle of a loop. For instance, there is a minimum speed requirement required for the coaster car to remain in contact with the track at the top of the loop. There is also a maximum speed for the sine wave function such that the car does not fly off the top of the hills. The spiral does not necessarily have to have a maximum or minimum speed depending on the banked angles, which can help make the x component of the normal force hold the coaster car in.

Finally, the roller coaster cars go through certain types of accelerations throughout the ride. Longitudinal and lateral acceleration affect the cars throughout the course of the roller coasters. When a person goes through a loop or down a drop, the change in acceleration, often expressed as Gs, affects the normal force the person feels from the rollercoaster cart pushing back on them (Figure 5).

3.1.3 Safety Precautions

The average human can withstand 5Gs parallel to their spine and in the upward direction and -3G parallel and downwards without losing consciousness, though some roller coasters exceed this for short periods. The human body is more resistant to Gs perpendicular to the spine; for short periods of time untrained humans can withstand up to 20Gs forwards. For instance, g forces can be felt on a banked curve as shown in figure 6.

3.1.4 The biological aspect

As the rider prepares to drop off a hill, the excitement comes from the epinephrine and norepinephrine of the adrenal medulla on your kidneys.Through a negative feedback loop the persons brain regulates the body systems and causes the flight or fight response that creates the thrill of the ride.

3.1.5 Calculus of a Roller Coaster

In general calculus can be applied to real world situations through physics. Many of the formulas derived in physics come from calculus. Additionally the first derivative of displacement is velocity and the second derivative of the displacement is acceleration and finally the third derivative of displacement is jerk. The jerk helps provide thrill, but can also be dangerous. Thus, calculus helps us analyze these vectors to ensure a safe and physically possible ride.

Roller coasters have certain points at which the thrill of the ride is greatest, such as the maximum, the minimum (Figure 7), and the inflection points

of the roller coaster. Thus, we can use calculus to find these points using the first and second derivative tests.

3.2 Isla de Coco

Cocos island (Figure 8), a nature reserve, is 550 km from the Costa Rica. It is 8 km by 3 km roughly and has a diverse terrestrial and marine ecosystem. As of now, only rangers are allowed on the island for laboratorial research. Although sometimes tourists are allowed to go there with invitation from one of the rangers. Often people go there to scuba dive and explore the rich marine life.

3.2.1 Climate

The average temperature of Cocos island is 79.9F (Figure 9). It is usually rainy and cloudy. Average rainfall is 276 inches. The oceanic currents around the island also have an impact.

3.2.2 Animals

There are 400 species of insects, 50 species of arthropods, 2 species of lizard, and 90 species of bird. There are pigs, deer, goats, cats and rats introduced by humans on the island. There are 30 coral species, 60 crustacean species, 600 mollusc species, and 300 fish species. Some notable animals are the Bigeye Thresher Shark, the Blue whale, the brown Noddy (Figure 9), the greater Frigatebird, the hawksbill turtle, and the cocos finch.

3.2.3 Plants

There are 235 species of plant that live on the Islas de Coco. Amongst the more common plants are ferns, mosses, and liverworts. Some other plants are the coconut palms and the purple coral trees. There is a rainforest on the island. The canopy is made mostly of sacoglottis holdridgei (Figure 11), ocotea insularis, and cecropia pittieri . The understory is made up of mostly shrubs, sedges, grasses, ferns, and herbaceous plants. Reportedly there are coconut groves there.

3.2.4 Current Issues

The island faces problems with illegal poaching. The Costa RIcan government has been passive on the issue. The demand of shark fin soup and tuna

has caused many poachers to target Cocos Islands rich and diverse shark and fish population. As we build the roller coaster we must keep this in mind.

3.2.5 Geology

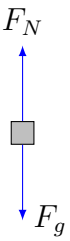
Cocos island was created by volcanic and tectonic factors. It is made mostly of basalt. Basalt is composed of mostly feldspar which is just one below the hardness of quartz a major component of granite rock. Additionally, the soil in Cocos island is very acidic and would runoff easily if not for the rainforest cover of the island. The island is between 1.91 and 2.44 million years old. It has cliffs with drops up to 300 feet and its summit is at Cerro Iglesias which is 634m tall. It has various mountains throughout its topography (Figure 13).

4 Preliminary Design

5 Calculations

5.1 Loops

Given: Loop of radius r.
Want: Find the minimum speed.
Know:



$F_N = 0$ when we lose contact with the track.
Need to calculate:

$$a_c = \frac{v^2}{r}$$

$$\sum F = ma$$

$$F_N = 0$$

at min speed.

Analysis:

$$\sum F = ma = F_N + F_g = F_N + mg$$

$$F_N + mg = \frac{mv^2}{r}$$

$$a = \frac{v^2}{r}$$

$$F_N + mg = \frac{mv^2}{r}, \text{Definition of Centripetal Acceleration.}$$

$$F_N = m(\frac{v^2}{r} - g)$$

$$F_N = 0$$

$$\Rightarrow \frac{v^2}{r} - g = 0$$

$$\frac{v^2}{r} - g = 0$$

$$\therefore v_{min} = \boxed{\sqrt{gr}}$$

6 Budget

7 Schedule and Decisions

8 Gantt Chart

9 Business Plan