Busch Gardens

Physics Day

Workbook

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Introduction

The principles of kinematics, dynamics and energy come alive at Busch Gardens. You can experience forces similar to the space shuttle astronauts on the Kumba, feel close to weightless as your log plunges down the incline on the Log Flume or confuse your senses as you turn upside down on the Montu.

General Guidelines:

1. Students should work in groups. It's nice if each group can have a handheld Vertical G Force Meter, a Horizontal G Force Meter, and a Stopwatch (or stopwatch cell phone app). **The hand held Force Meters can only be taken on the Scorpion, Log Flume, Bumper Cars, and the the stopwatch (or cell phone app) can only be used OFF the rides. (Note: If the students don't have the G Force meters, there is still plenty to do in the workbook.)**
2. Each ride has a Basic and an Advanced section. (The Bumper Cars have only a BASIC section, and Tigris only has an ADVANCED section.) The Basic section is designed to use less mathematics than the Advanced section and is appropriate for middle school students as well as high school students. Students may be assigned to do both Basic and Advanced sections of a particular ride, or they may do only the Basic or only the Advanced. There is no duplication if students do both. (If they do only the Advanced, there is a section entitled "What to do if you didn't do the Basic," and it indicates how to compensate for not doing the Basic section.)
3. Except for the height measurement on the Scorpion, which requires a Horizontal Force Meter, the Advanced sections require only the use of a stopwatch. If you want your students to be able to use the Horizontal and Vertical Force Meters, then assign them some Basic sections:

Vertical Force Meters are used on the following Basic rides:

Scorpion

Horizontal Force Meters are used on the following Basic rides:

Log Flume, Bumper Cars

Hand-held instruments are only allowed on Scorpion, Log Flume, Bumper Cars

4. If the students do not have Force Meters, they still can benefit from doing the Basic sections. Only a few of the questions in each section require Force Meter measurements. These questions can be made qualitative or left out. On Physics Days there also will be G Force Meters mounted on the Montu and Kumba.

5. An electronic accelerometer (a Vernier Low G accelerometer or a 3-axis accelerometer that is attached to a TI Calculator/CBL/Lab Pro) may be used on any of the rides in this workbook, as long it is contained in an approved vest, such as the Vernier Data Vest.
6. Please be courteous and obey all of the park rules. You will be allowed to carry the hand-held G Force Meters on rides indicated, but the Meters should be equipped with hand-straps for the safety of yourself and others.
7. No one will be able to complete the entire workbook in one day. Choose which rides to do and what level (Basic, Advanced or both) before coming to the park. Generally, four or five rides are sufficient to give the students a positive experience in the park.
8. Students are supposed to make three measurements of every data point. This could mean either a student making all three measurements or each student in the group making a measurement and combining results. It may be easy to make three time measurements while watching the ride from the side, but it may not be easy for each student to make three G Force measurements, as that would require riding the ride three times.

What to Do Before Coming to The Park:

1. Have the students complete the WHAT TO DOING BEFORE COMING TO THE PARK section for each ride that they are going to do. They will do sample problems and make predictions.
2. In class, go over the physics principles and do some of the pre-activities.

Making Measurements

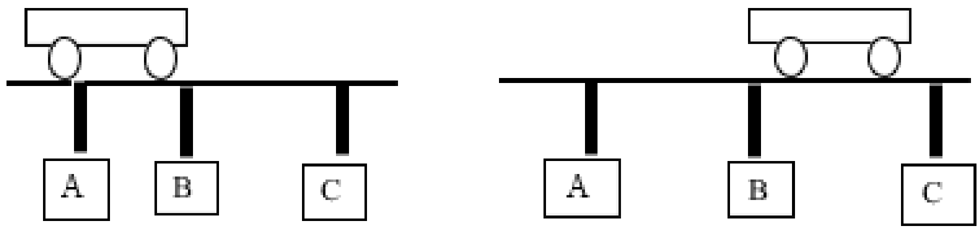
Three Measurements

The workbook calls for three measurements of most quantities, because a single measurement can be in error. The three may be a combination of three students making one measurement each or one student making three measurements. All three measurements should be consistent with each other. All the calculations should be made with the average of the three measurements.

Speed

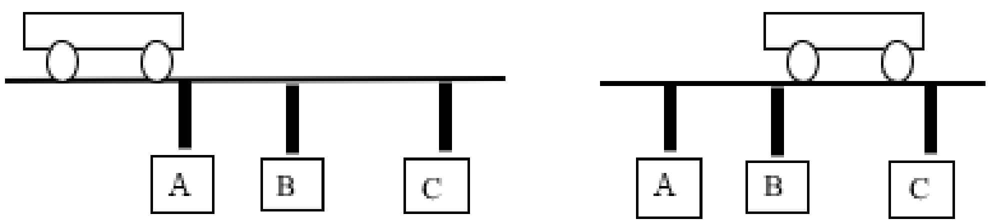
Usually, the average speed of a coaster at a point (usually a post or pole) is determined by timing the coaster passing by that point. The stopwatch is started as the front of the coaster arrives at Post B, and the stopwatch is stopped as the back of the coaster passes the same post. If the length of the coaster is known, then:

Average Speed = (Length of Coaster)/(Time)



Sometimes, if the speed is large and the car (or log) is small, this method of measuring speed will not be precise enough. The car then can be timed between two points of known separation. The stopwatch is started when the front of the car passes post A and stopped when the front of the car passes post C.

Average Speed= (Distance between A and C)/(time)



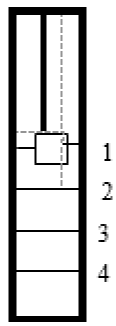
G Force

Forces that are experienced while on the rides can be measured with a G Force Meter.

When standing still on the surface of the earth or traveling at a constant speed in a straight line, the G Force is 1. This is called 1 “g.” If riders are accelerating, then they will experience a G Force other than 1. The G Force can be computed by taking the support force and dividing it by the weight. Support force is whatever force is preventing an object from falling. This could be the force of the track on the coaster divided by the weight of the coaster or the force of the seat on the rider divided by the rider’s weight. In each case the G Force will be the same.

A Vertical G Force Meter indicates forces due to accelerations that are parallel to your backbone, which is perpendicular to the track. The Meter is held or mounted so as to be parallel to your backbone. A reading of 2 g’s means you are experiencing a force equal to twice your weight. Thus, you will feel twice as heavy as normal. A force of 0.5 g's means that the force that you feel is one-half of your weight, and you will feel lighter. If you are in free fall (meaning only the force of gravity is at work), then the support force will be zero, and you will experience zero g's, or weightlessness.

The G Force Meter illustrated below is at rest, and the G Force is 1. An upward G Force will cause the weight to go down the tube, with the location of the weight indicating the G Force. If the Meter reads less than 1, this indicates that the rider appears to weigh less than normal.



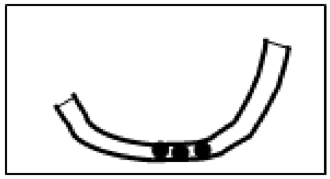
If you are traveling in a straight line at a constant speed, you will be experiencing 0 g's horizontally. If the coaster car or other ride slows down or speeds up, and the Horizontal G Force Meter reads 1, this means that you are experiencing a force equal to your weight, but pushing on you horizontally. The Horizontal G Force meter should be held parallel to the coaster car or boat and braced against the side of the car. A reading of 0.5 means that a force of one-half of your weight is pushing on you horizontally.

If the coaster car turns a corner quickly in an unbanked turn, a lateral G Force is experienced and can be measured by holding the Horizontal Force meter perpendicular to the direction of motion.

A Horizontal G Force Meter is often calibrated in degrees. As illustrated below, when acceleration is experienced, BBs will roll up a tube. The highest angle achieved relates to the G Force in the following way:

G Force = Tangent of the Angle
(i.e. Tan (60 degrees) = 1.7, so 60 degrees corresponds to 1.7 g's.)

The chart below can be used to determine the G Force from the angle on the Horizontal G Force Meter. A G Force to the right will cause the BBs to roll to the left.



Angle	10	15	20	25	30	35	40	45	50	55	60	65
G's	.18	.27	.36	.47	.58	.70	.84	1.00	1.19	1.43	1.73	2.14

Force Meter Construction

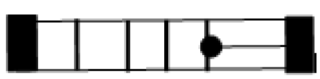
Vertical and Horizontal G Force Meters (sometimes called accelerometers) are available from Pasco Scientific (1-800-772-8700). Pasco sells a set of 15 vertical and horizontal accelerometers for about $70 (ME-9426). Sargent Welch (1-800-727-4368) also sells a set of 15 of each type of accelerometer for about $94 (CP32513-00).

These commercially purchased accelerometers come with a hand-strap. This hand-strap is required when using the G Force meters on the rides.

Meters may not be used on the KUMBA, MONTU, SHEIKRA or PHOENIX!!! You may also create your own G Force meters, but they must have no sharp edges or exposed heavy objects. The Horizontal G Force meters which are sold by Pasco and Sargent Welch are ideal in that they are made of cardboard, with BBs in a plastic tube.

You will not be able to use a homemade meter made of a protractor with a hanging weight.

As long as it has a hand-strap, homemade Vertical G Force meters will be allowed. They must conform to the standards of not being hard and of having no sharp edges or exposed weights. A Force Meter described in the Exloratorium Quarterly (Vol. 11, Issue 2) conforms to these standards. It is made of flexible plastic tubing with furniture end caps on the ends and a fishing weight hung from a rubber band in the middle.



You may also take a TI Calculator with CBL/LabPro and an accelerometer probe on any ride as long as it is contained properly in an approved vest (such as the Data Vest available from Vernier for $26). A complete description of how to use this electronic accelerometer probe is available at the Vernier website (www.vernier.com/cmat/datapark.html) by clicking on the "Download the Data Collection at the Amusement Park Manual" link. Graphs similar to those found at the end of this workbook can be produced and analyzed. Schools must provide their own computers to download the data from the Calculators/Lab Pros.

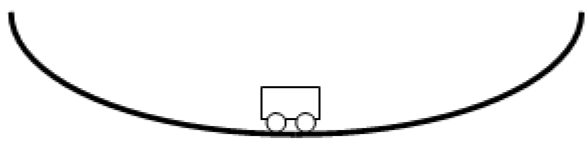
Problems

Finding the G Force for Vertical Acceleration

At the tops and bottoms of coaster hills, centripetal force (force acting in toward the center of a circle) is required to cause the acceleration of the coaster. Two forces act upon the coaster: the track and gravity. The resultant force of those two factors must provide the centripetal force, Fc=mv2/r. Toward the center of the circle is considered to be the positive direction. The G force will be equal to the support force of the track divided by the weight of the coaster.

G Force at the Bottom of a Hill

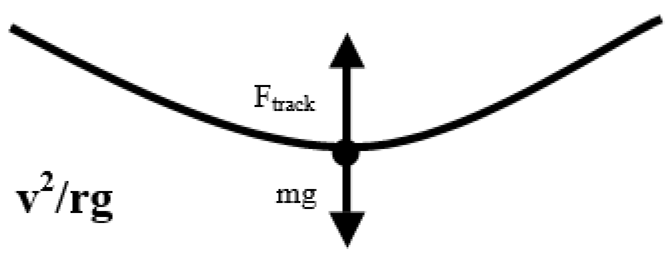
The force of the track is in toward the center of the circle and is therefore positive. The weight of the coaster, mg, is negative since it is away from the center of the circle.



$$F_{track} - mg = mv^2/r$$

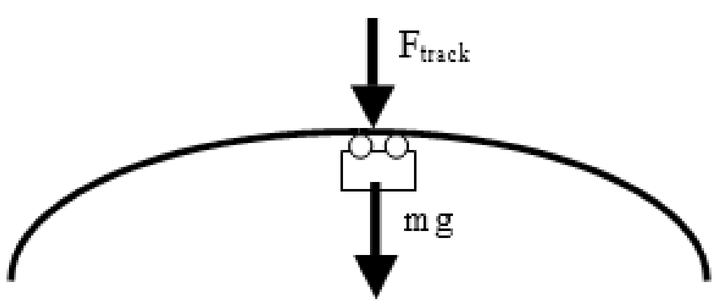
$$F_{track} = mg + mv^2/r$$

$$\text{G Force} = F_{track}/mg = \mathbf{1 + v^2/rg}$$



The force depends upon the velocity of the coaster and the radius of the turn, where g=9.8 m/s2. The velocity must be expressed in m/s and the radius in m.

G Force Upside Down at the Top of a Loop



At the tops of the loops, the procedure is similar, except that the track's force and the weight are in the same direction. Since both point toward the center of the circle, both are positive.

$$F_{track} + mg = mv^2/r$$

$$F_{track} = mv^2/r - mg$$

$$\text{G Force} = F_{track}/mg = \mathbf{v^2/rg - 1}$$

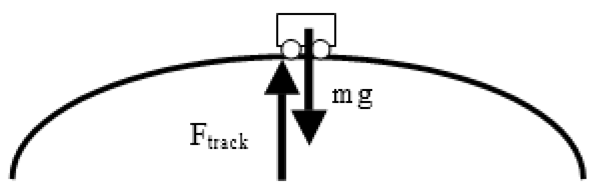
G Force at the Top of a Hill, When Right Side Up

The forces are in opposite directions, but the gravitational force now points in toward the center of the circle and is therefore positive.

$$mg - F_{track} = mv^2/r$$

$$Ftrack = mg - mv^2/r$$

$$\text{G Force} = Ftrack/mg = \mathbf{1} - \mathbf{v^2/rg}$$



Finding the G Force for Horizontal Acceleration

Acceleration can be computed by use of the kinematic equations:

$$v\text{^}2 - v_o\text{^}2 = 2ax \qquad v = v_o + at \qquad d = 1/2\ at\text{^}2 + v_o t$$

The horizontal force will then be given by "ma," and then the G Force can be computed

by dividing the Horizontal Force by the weight (mg).

G Force= ma/mg = a/g

Energy Conservation. Assume the energy is the same at the beginning as at the end and solve for the speed at the end.

½ mv^2 + mgh at top = ½ mv^2 + mgh at bottom

initial energy final energy

Energy Losses

Measure the speed and height at both the beginning and at the end and find out what percentage of the energy is lost or turned to heat.

(Initial energy - Final Energy)/(Initial Energy) * 100%

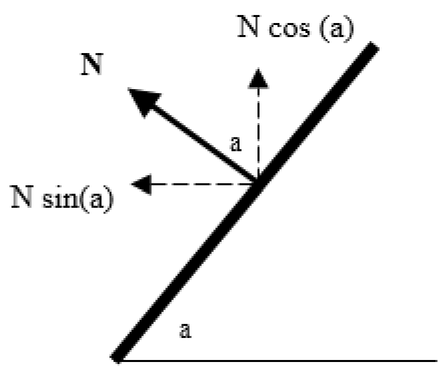
(½ mv0^2 + mgh0 - ½ mv^2 + mgh)/((½ mv0^2 + mgh0) * 100%

Since there is an "m" in every term it cancels, therefore the mass of the coaster is not needed to find the energy loss. The lowest point in the ride is taken as the reference for the height. The final equation is:

$$(\tfrac{1}{2}v_0^2 + gh_0 - gh - \tfrac{1}{2} v^2)/((\tfrac{1}{2}v_0^2 + gh_0) * 100\%$$

Banking Angle and G Force in Horizontal Circles

Horizontal circles are usually banked. If properly banked, the track will only exert a perpendicular force, called a normal force. The passengers are not thrown to the side. The vertical component of the normal force supports the weight of the coaster, and the horizontal component makes the coaster go in a circle.



Horizontal component will be equal to the centripetal force (N sin(a) = mv2/r) and the Vertical component will be equal to the weight (N cos(a) = mg) Dividing the first equation by the second yields an expression for the banking angle:

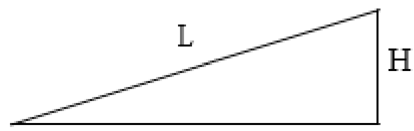
$$\tan(a) = v^2/rg$$

The G Force is given by:

$$1/\cos(a)$$

Power

P=Work/time. The work done is equal to the increase in potential energy as a coaster is pulled to the top of an incline by the chain drive. W = mgh



H may be computed by using trigonometry: H = L * sin (angle)

Pre-Activities

Practice Using the Force Meters

a. Go to the playground. The swings are a great place to experience 2 g's using the Vertical G Force Meter. A merry-go-round can be used to experiment with the Horizontal G Force meter.

b. On an elevator, the Vertical G Force Meter can show both greater than or less than 1. A bathroom scale also indicates how heavy or light the students feel in an elevator.

c. In a car or bus, the Horizontal G Force Meter can be used to measure the forces in stops and starts and also in the turns. The Force Meter should be perpendicular to the motion in a turn or parallel to the motion while speeding up or slowing down. The same thing can be experienced by speeding up, slowing down or turning a corner while running.

Practice Using a Stopwatch

a. Make measurements as a car drives by. Start the stopwatch when the front of the car passes a point, and stop the stopwatch when the back of the car passes the same point. A typical car is 15 feet long. Thus, if the car drives by at 10 miles/hour, the time for the car to pass a point will be close to 1 second. If it drives by at 15 miles/hour, then the time will be about 0.7 seconds. The coasters will be going four times faster than 15 miles/hour, but they will also be about four times as long, so the times will be comparable.

b. Have a chain of people walk by, and time them from front to back.

c. Time a student running between two points. Have several students time the same event and compare times. This will lead to a great discussion about the need to make multiple measurements.

Roller Coaster Video

Show the video entitled "Roller Coaster." This was a Nova presentation that deals with the construction and design of roller coasters along with some of the physics of roller coasters. This video may be obtained from WGBH at 1-800-255-9424. It sells for approximately $20.

Physics Principles

a. Upside down: Hang one of the class members upside down for a few seconds (only with their permission). Pick someone who is not very heavy, and use caution. Have the person who was held upside down indicate as many ways as possible that he could tell that he was upside down. Possible answers might include: hair fell down; blood rushed to the head; everyone looked upside down; the student felt the force of the hands holding them up.

b. Centripetal Acceleration: Bucket of water is swung in a vertical circle, and the water does not leave the bucket. The water tries to go in a straight line, and the bucket keeps applying a force toward the middle that makes it go in a circle.

c. Banking Angle: Hold a string with an object tied onto it at arm's length and spin around. The angle at which the weight hangs is the banking angle for that speed and radius of turn. Or take a book and place an object such as a pencil on it. Hold the book at arm's length with the object on top of the book. Start to spin slowly at first, and as you speed up, slowly incline the book, giving it a banking angle. Have students pay attention to how the banking angle depends on how fast you spin and how far out you hold the book.

Principles of Physics

Weightlessness

According to Einstein's Principles of Equivalence, an observer cannot tell the difference between the absence of gravitational forces and being in a state of free fall. In both situations, observers would experience "weightlessness."

If the force of gravity alone acts on an object, the object is in a state of free fall. Diving off a high dive or bungee jumping produce this sensation. When an upside-down cup of water is dropped, the water will not fall out. The water appears weightless, because it is falling, just like the cup.

After a football is kicked, it is in a state of free fall. It follows the path called a parabola. NASA trains astronauts to deal with weightlessness by putting them in a plane that flies in a parabolic path. A roller coaster can also achieve "weightlessness" if the track follows a parabolic path, like a Camelback hump. A steep coaster hill, which has the shape of a half-parabola, also produces a near-weightless sensation. The Camelback on the Kumba and the zero-g roll on the Montu produce near weightlessness for about 2.5 seconds. A steep coaster hill would have to be four times as high as the Camelback hump to produce the same weightless sensation for the same period of time.

Which Way Is Up?

As the students ride the roller coaster, they may have a hard time telling which way is up. When they are upside down in a loop, they will not feel like they are falling out, and up seems like down. When going around a turn that is steeply banked, students will not fall to the side, and up now seems to be sideways. Going over a parabolic hill, there seems to be no “up,” as students experience weightlessness.

Think of sitting in a chair. If you concentrate, you will notice the force of the chair pushing up on your seat. You can’t feel the gravitational force acting on any particular part of your body, but you know from experience that it exists. You know that you need this “up” chair force to keep you from falling “down.” “Up” is the direction of the felt force, which keeps you from falling down. This direction of “up” is therefore the same as the direction of the “chair force” or support force. This could also be the floor pushing up on your feet. The G Force that you feel is really a measure of the strength of the “chair force” or other support force. The G Force is equal to the support force (chair, floor, etc.) divided by the weight of the object.

Forces & Accelerations

Acceleration is a change in speed or a change in direction. Accelerations are produced by forces. Newton’s Laws of Motion describe the relationship between acceleration and forces.

Newton’s First Law

Objects at rest remain at rest and objects in motion remain in motion unless acted upon by an external force. A tablecloth can be pulled out from underneath a set of dishes if it is pulled quickly. This is because the dishes have what is called inertia, or a tendency to remain at rest. A bowling ball, on the other hand, once set in motion will continue in a straight line forever, unless it hits the pins or friction eventually supplies the force to slow it down.

Newton’s Second Law

Every acceleration, or change in speed or direction, requires a force. The greater the acceleration, the greater the required force. If two objects undergo the same acceleration, the more massive of the two will require a greater force.

At the bottom of a roller coaster hill, a force is required to accelerate the coaster cars and passengers back up the hill. Two riders side by side will experience the same acceleration, but if one has more mass than the other, they will experience a greater force. When we say that they experience a force of 3 g’s, this means that the force is three times their normal weight.

A horizontal acceleration of 9.8 m/s2 requires a horizontal force equal to the weight of the object (1 g). A vertical acceleration of 9.8 m/s2 requires a force equal to twice the weight of the object (2 g’s) since an upward force of 1 g is required simply to keep the object from falling through the floor.

A Dodge Viper can accelerate from 0 to 60 mph in 4.1 seconds. This is an acceleration of 6.4 m/s^2. Passengers in the car therefore experience a horizontal force of 2/3 g, and the car must produce a force equal to 2/3 the weight of the car to produce this acceleration.

A dragster has a much larger acceleration, and consequently the driver experiences a force of 3.5 g’s. A passenger in a commercial jet airplane which is taking off experiences only a force of 0.2 g’s.

A space shuttle astronaut will experience a maximum force of 3.5 g’s, whereas the Apollo astronauts experienced 7.5 g’s.

Newton’s Third Law

For every action there is an equal and opposite reaction. If two people are engaged in a tug of war, the rope pulls the same on each one, but in opposite directions. The loser is the one with the poorest footing. In order for a person in an elevator to accelerate upward, the elevator floor must push up on the feet with a force greater than the weight of the person, and the feet must push back on the floor with the same force. The person will feel heavy. (If the upward force were 1.5 g’s, then the person would feel 1.5 times heavier than normal.)

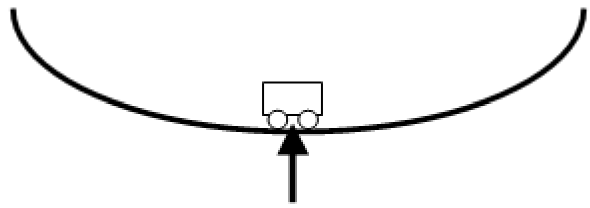
Application of Newton’s Three Laws

On a roller coaster, it is the acceleration that produces the thrills. Accelerations can be either changes in speed or changes in direction. While experiencing accelerations, passengers feel heavy or light, feel pushed back into their seats or thrown forward, or feel like they are thrown to the left or to the right.

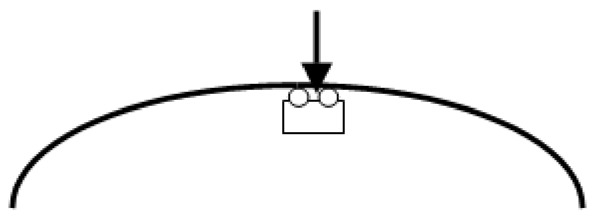
A force is required to make a coaster slow down. If the change in speed occurs quickly, the seat of the coaster car can’t produce enough force, and the passengers feel as if they are thrown forward. Actually, the coaster car stopped, and the passengers didn’t. Such forces are generally less than 1 g.

If the speed along the horizontal is increased, the back of the seats must push the passengers. They in turn feel pushed back into their seats. This sensation occurs for passengers in the last coaster car at the top of hills.

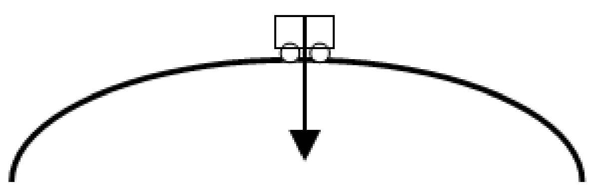
As a coaster train descends a hill, gravity provides the force to cause the acceleration. The closer the incline is to being vertical, the closer to weightless the passengers will feel. The passengers also feel weightless if the coaster track follows the same parabolic path in its descent that a freely falling coaster would naturally go.



An upward force is required to make the coaster change direction at the bottom of a hill. The coaster car seat pushes up on the passenger, so the passenger pushes down on the seat and feels heavy. On the Kumba and the Montu, this force exceeds 3 g’s on many of the hill bottoms. The maximum force experienced is generally around 4 g’s.



A downward force is required to make the coaster change its direction at the top of a loop. Gravity provides part of the force, but generally the coaster is designed to move fast enough at the top so that the track must also push down on the coaster. If the track does not push down at all, then the passengers would feel weightless at the top. On some loops the passengers feel light, less than 1 g, but never leave their seats. On other loops, the passengers will actually feel heavy at the top. Either way, down now seems to be up. If the riders keep their eyes closed on a loop, they will never know that they were upside down. Kumba riders experience seven inversions (the Vertical loop, the Dive loop, the Camelback Hump, twice on the Cobra Roll and two corkscrews).



At the top of a hill, a down force is needed to cause the change in direction. If the coaster is moving slowly enough, gravity can provide sufficient force to cause the change in direction. As a result, however, the passengers feel light. This is the same sensation experienced when a car goes over a large bump in the road, causing passengers to experience a tummy lifter. The Camelback humps on both the Montu and Kumba are designed so that the force experienced is very close to zero for over two seconds. If the coaster is traveling so fast that a force greater than gravity is required, then the shoulder harness holds the people in the car, and the second set of wheels below the tracks keeps the car on the tracks.

To turn a corner to the left requires a force to the left. The passengers feel like they are thrown to the right. In reality their inertia carries them forward as the coaster turns the corner. This makes it appear as if passengers were thrown to the right. The greater the speed or smaller the radius of the turn, the greater the force required. In the carousel on the Kumba, the forces are between 2 g's and 3 g's. When g forces are high, the turns are banked to keep passengers from being thrown to the left or the right.

Sometimes several kinds of acceleration are occurring at the same time. On the first drop of the Kumba and the Montu, the coaster cars are dropping but are at the same time turning a very tight corner at a high speed. As a result, the passengers feel heavy, even though they are dropping.

Energy

Roller coaster cars do not have a motor. Rather, a heavy-duty motor attached to a chain pulls them up the first hill. At the top of the first hill, the roller coaster cars have what is called Gravitational Potential Energy (GPE). It is computed with the equation: mgh. The cars have the greatest GPE when they are at their highest. After the center of mass passes over the top of the hill, the coaster cars begin to speed up. They begin to lose their GPE as gravity pulls them down the hill, and they gain Kinetic Energy (KE) or energy of motion

(KE= ½ mv2). The total amount of energy remains the same. As the cars go up the next hill, they slow down and lose Kinetic Energy while gaining Gravitational Potential Energy.

If the coaster had 10 units of GPE at the top of the hill, then it should have 10 units of KE at the bottom of the hill. This is called Conservation of Energy. The sum of GPE and KE should add up to the same number. In actual operation, however, the coaster may lose 10 units of GPE and gain only eight units of KE. It may appear that energy has been lost. What actually happened is that part of the energy has been changed into heat. As the coaster cars move over the track, friction between the wheels and the track and air friction produces heat energy. The coaster hills must become smaller as the ride progresses because of this heat production. The Kumba loses well over half its initial energy due to friction before it brakes at the end of the ride. Brakes must then convert any remaining energy of motion into heat at the end of the ride, or it will not stop at the station. Even through the coaster is traveling slower at the end of the ride because of friction, the ride can still be made exciting, by having sharper turns.

In order to find the percentage of energy converted to heat, the following equation can be used:

$$((GPE + KE)_{beginning} - (GPE + KE)_{end}) / (GPE + KE)_{beginning} \times 100\%$$

For example, the height of the first hill on the Kumba is about 40.9 meters (134 feet). If we assume no friction and a fairly slow speed at the top, then the speed at the bottom of this coaster would be about 28.3 m/s (63 mph). In actuality, friction makes this maximum speed of 27.0 m/s, or an energy “loss” of about 9 percent.

In-Park Activities

LOG FLUME: Basic

INSTRUMENTS REQUIRED

Stopwatch, Horizontal G Force Meter

WHAT TO DO BEFORE COMING TO THE PARK

1. Construct Horizontal G-Force Meter with hand-strap.
2. Predictions
   a. At the bottom of the hill, when the log makes a big splash, will you: feel pressed back into your seat; slide forward; neither
   b. Which makes a bigger splash: an empty log; a log with two in the front; a log with two in the back; a log with four; all are the same
   c. Where will you feel close to weightless : coming down the big hill; at the bottom of the hill; nowhere

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. At the splash at the bottom of the last hill, note whether you feel pressed back into your seat or you slide forward. Pay attention to your feelings on the last drop.

2. With the Horizontal G Force Meter, measure the largest angle to which the BBs in the tube will rise at the splash at the bottom of the last hill. Hold the meter parallel to the log, and brace it against the side.

WHAT TO MEASURE OFF THE RIDE

1. Measure the time for the log to go between point A (the light pole) and point B (the beginning of the splash).
2. Observe the splash of several logs. Do they all make the same splash, or does it depend upon how many people are in the log and where they are seated?

Data Table

	#1	#2	#3	Average
Angle of the BBs In G Force meter				
Time from A to B				

Questions

1. Did you ever feel close to weightless? If so, where?

2. Did you feel thrown forward or backward at the splash at the bottom of the hill?

3. How does this drop compare with the drop on the Scorpion?

4. What loading of the log produces the maximum splash? Why?
   a. Two in front
   b. Two in back
   c. Four in log
   d. Empty log

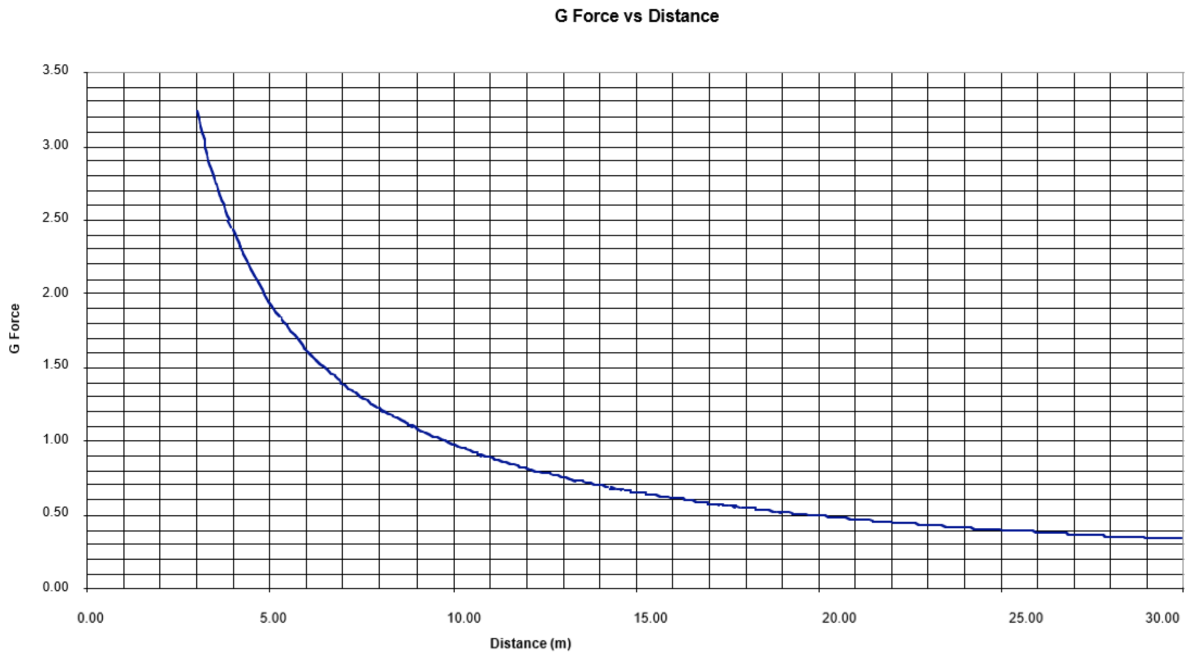
5. What was the horizontal G Force experienced at the splash? Use the chart below to convert from degrees to G Force.

Angle	10	15	20	25	30	35	40	45	50
G Force	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.2

Problems

1. Using your measured time from A to B, compute the speed at the bottom of the last hill. The distance from A to B is 11.6 m.

2. The chart below represents the relationship between the horizontal G Force at the splash and the distance of the splash. It assumes that the log has zero speed at the end of the splash.



a. Given that the narrow portion of the trough is 14.5 m, what should the G Force be? Why will this number be different than the actual G Force?

b. What is the minimum stopping distance that would be safe?

c. When the distance is doubled, what happens to the G Force?

Doubled **Stays the same** **½ as much** **⅓ as much**
¼ as much **1/5 as much**

d. What is the G Force at 60 meters?

e. Is it possible for the G Force to be equal to zero?

LOG FLUME: Advanced

INSTRUMENTS REQUIRED

Stopwatch

WHAT TO DO BEFORE COMING TO THE PARK

1. Problems:
   a. A log has an initial velocity of 15 m/s and slows down to 3 m/s in a distance of 20 meters. What is the G Force?
   b. A log has an initial velocity of 12 m/s and slows down to 2 m/s in a time of 5 seconds. What is the G Force?
   c. A log whose velocity at the top of the hill is 2 m/s comes down a hill of height 10 m and has a speed of 12 m/s at the bottom of the hill. What fraction of energy was converted to heat on the way downhill?
2. Predictions:
   a. What will be the percentage of energy lost (converted to heat) coming down the last hill?

10% **20%** **30%** **40%** **50%**

WHAT TO MEASURE OFF THE RIDE

1. Time the log from the beginning of the splash to the end. This will be during the period that the log is in the narrow portion of the trough at the end of the hill.
2. Measure the time that it takes the log to pass a point at the end of the trough.

DATA TABLE

	#1	#2	#3	Average Time
Time from beginning to end of splash				
Time for the log to pass a point at the end of the trough				

IF YOU DIDN'T RIDE THE LOG FLUME: BASIC

1. Measure the time on the last drop for a log to go between light pole A and the beginning of the splash B. (See picture on the front page of Log Flume: Basic)

Time from A to B				Average Time

2. Using your measured time from A to B, compute the speed of the log at the bottom of the hill. The distance from A to B is 11.6 m.

Problems

1. Find the energy converted to heat coming down the hill.

   Height of hill = 12.2 m   Speed at the top of hill = 1.2 m/s

   Speed at the bottom of the hill =___________________ (use the value that you computed based on the time between A and B)
2. Compute the speed at the end of the splash. Length of log = 2.9 m

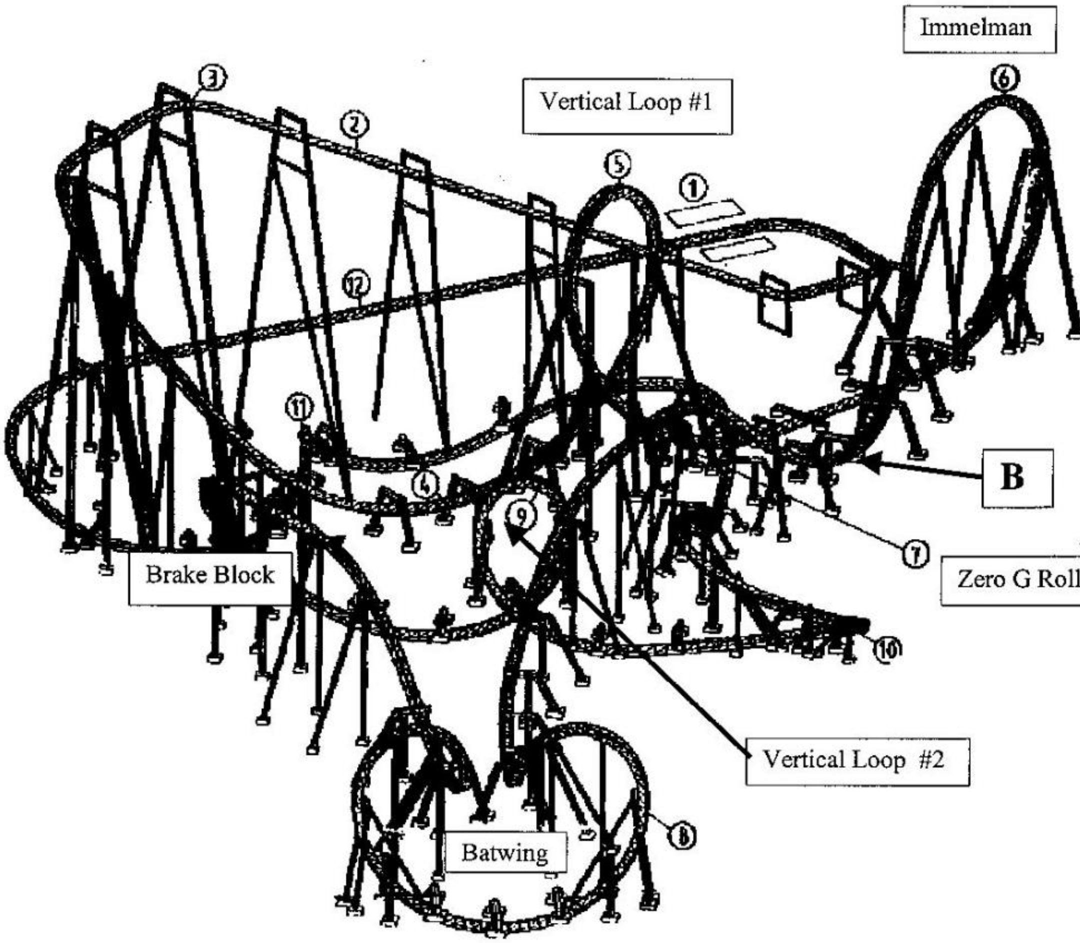
3. Find the deceleration of the log at the splash by using the speed before the splash, the speed after the splash, and the distance of the splash. (The distance of the splash is approximately equal to the length of the narrow portion of the trough, which is 14.5 meters.) What is the horizontal G Force indicated by this deceleration?

4. Find the deceleration of the log at the splash by using the speed before the splash, the speed after the splash, and the time of the splash. What is the horizontal G Force indicated by this deceleration?

5. How do these two G Forces (problems 3 and 4) compare with each other and with the value obtained by the G Force Meter in LOG FLUME: Basic (if measured)?

SCORPION: Basic

MONTU: Basic



The Montu is known as an inverted roller coaster. It features a 40.0 m first drop; seven inversions; a maximum g force of about 4, and approximately seven occasions where the g force exceeds 3; and a zero g roll, where passengers come close to weightlessness. In the 27 m tall Immelman, named after a German stunt pilot, the riders start over the top of the loop in an inverted position and then are rotated 180 degrees to an upright position as they come down the loop. In the Batwing, riders go over the top of both loops upside down, disappearing underground in the middle. With maximum speeds over 60 miles per hour, one of the largest-ever vertical loops on an inverted coaster (32 m), ¾ mile of track, and the whole experience being spent seated under the track with your feet dangling, the Montu is an intense experience.

INSTRUMENTS REQUIRED

Stopwatch (No instruments allowed on the ride!)

WHAT TO DO BEFORE COMING TO THE PARK

1. Predictions:
    a. Will you ever leave your seat when you are upside down? Yes No
    b. Where will the heaviest feeling on the ride be experienced?

    Top of the Vertical Loops　　Top of the Immelman Zero-G Roll　　Middle of the Batwing　　Bottom of the First Hill　　Brake Block
2. Problems: Given that the coaster is 11.6 m long, find its speed if it takes .75 second to pass a post.

WHAT TO NOTICE ON THE RIDE

1. Pay attention to your feelings when you are upside down. Do you ever leave your seat? Do you feel upside down?
2. Where on the ride do you feel the heaviest? Given that you experience approximately 3.5 g's at the bottom of the first hill, make an estimate of the g force at the heaviest point. Record your estimate and that of two friends. (On Physics Days only, sit in the second row, and check the G Force Meter to find the heaviest point. Record the actual G Force instead of just an estimate.)
3. Where on the ride do you feel heavy for the longest period of time? Where on the ride did you feel normal?
4. Ride once near the front of the coaster and once near the rear. Notice differences.

On the Ride Estimate

	#1	#2	#3	Average
Maximum G Force				

WHAT TO DO OFF THE RIDE

1. Measure the time for the coaster to pass the top of the second vertical loop (#9). (Start the stopwatch when the front of the front car reaches the top of the loop and stop the stopwatch when the back of the last car reaches the top of the loop.)

DATA TABLE

	#1	#2	#3	Average Time
Time for the coaster to pass the top of the loop (#9)				Sec

Questions

1. Describe the places on the ride where you felt normal and explain why. Where did you feel the heaviest? Where did you feel the lightest?

2. Explain your experiences in the inversions. Which of them felt light? Did you ever leave your seat?

3. At the bottom of the first drop, the speed is 27 m/s. Just before the flat spin at the end of the ride, the speed is 18 m/s. The force factor at both places is 3.4. How can the force be so strong at the end of the ride when the speed is much slower?

4. Why is the second vertical loop much smaller than the first vertical loop?

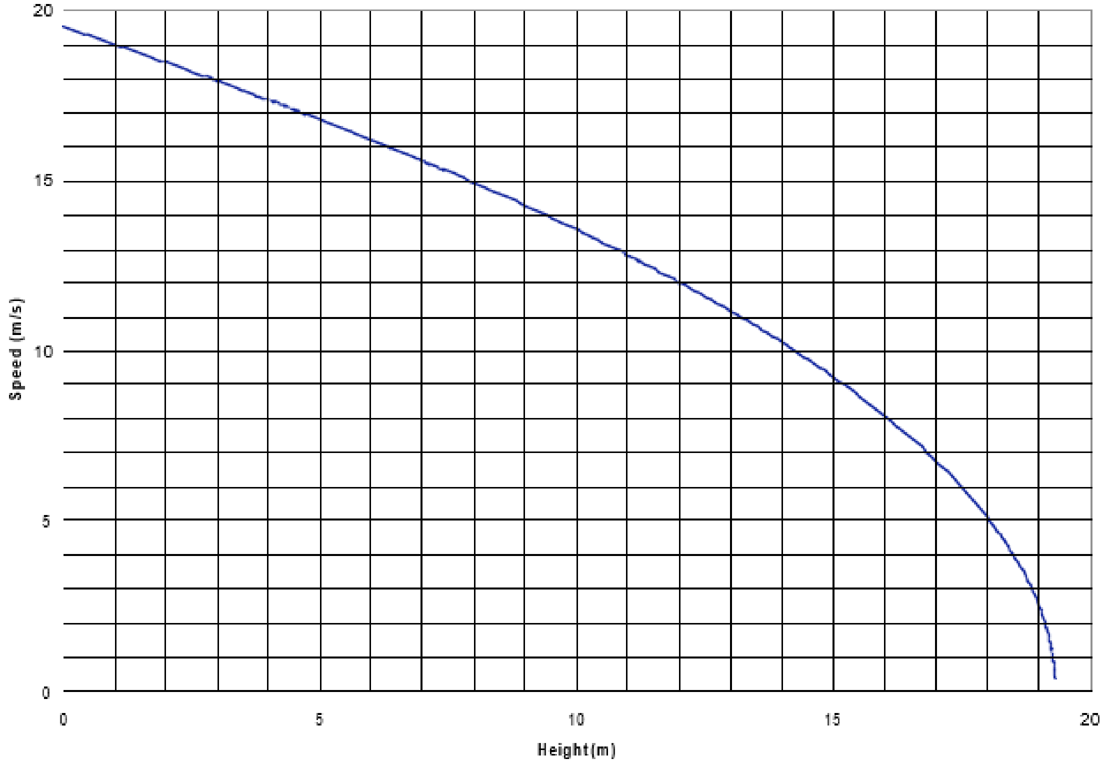
5. How is riding in the front car different from riding in the last?

Problems

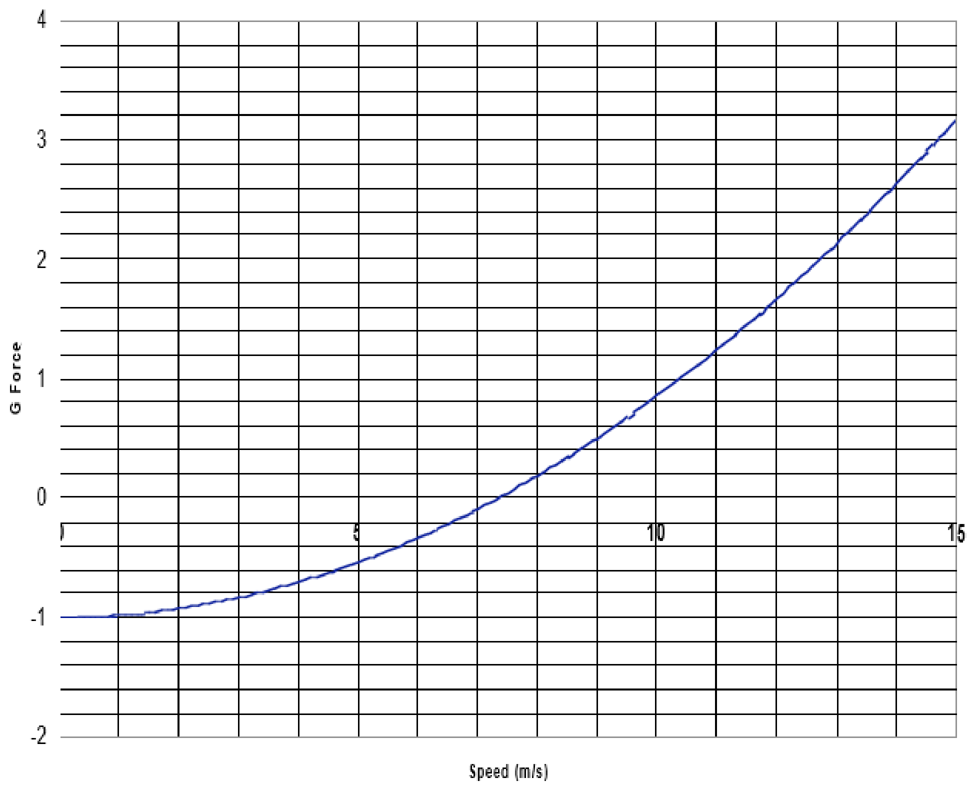
1. Using the average time for the coaster to pass the top of the vertical loop, compute the speed at the top of the second Loop (#9). The coaster length is 11.6 meters.

2. The graphs on the next page represent the top of the second vertical loop (#9). The graph to the right indicates how the force factor at the top of the loop depends upon the velocity at the top with a fixed radius of 5.5 m. The graph to the left indicates how the speed at the top of the loop depends upon the height of the loop above the ground level. (The actual loop is 13 meters above the ground level, with the base of the loop in a trench 6 meters deep.)

Speed vs Height



G Force vs Speed



a. What range of velocities would produce a light feeling at the top of the loop (g force less than 1 and greater than 0)?

b. What is the minimum velocity required to get the coaster through the loop without it falling off? (In reality, the coaster has wheels underneath the track and the passengers have safety harnesses, so neither the car nor the passengers could fall out even if the G Force were negative.)

c. Find the height of a loop for which this minimum value of velocity is obtained.

d. What height of the loop would prevent the coaster from reaching the top?

e. A coaster designer has proposed to redesign the loop with a height of 8 meters. What would be the velocity at the top and the resulting g force at the top?

3. Answer the following questions based on the graph of G Force vs. Time at the end of the workbook. (This graph was obtained with a CBL, TI-83 Calculator and a Low-g accelerometer)
    a. Where on the ride will you feel normal?
    b. Which points on the ride have the greatest g forces? Where is the g force the greatest, and how does this compare with your guess?
    c. On which upside-down point do you experience the lowest g forces?
    d. On which upside-down points do you feel heavier than normal?
    e. How do these graphical readings compare to your experiences?

MONTU: Advanced

INSTRUMENTS REQUIRED

Stopwatch (No instruments allowed on the ride!)

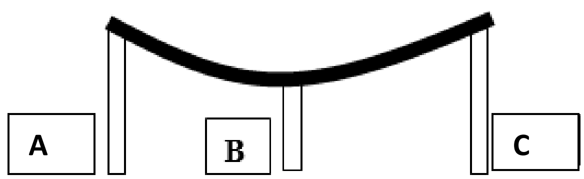
WHAT TO DO BEFORE COMING TO THE PARK

1. Problems:
    a. Compute the G Force experienced by passengers at the top of a vertical loop of radius 6 m, where the velocity is 10 m/s.
    b. Compute the G Force experienced by passengers at the bottom of a hill where the radius is 30.0 m and the speed is 25 m/s.
    c. A roller coaster descends a hill of height 30.0 m. If its speed at the top is small, and its speed at the bottom is 22 m/s, what is the percentage energy loss?
2. Prediction: What will be the energy loss of the coaster just prior to the braking at the end of the ride?

30% **40%** **50%** **60%** **70%** **80%**

WHAT TO DO OFF THE RIDE

1. Measure the time for the coaster to pass between post A and post C at the hill bottom following the Immelman, where Post A is the second post in the grass and post B is the lowest point of the track. (Start your stopwatch when the front car passes post A, and stop it when the front car passes post C).



Time to pass between A and C				**Average Time**

WHAT TO DO IF YOU DIDN'T RIDE MONTU: BASIC

1. Measure the time for the coaster to pass the top of the second vertical loop (#9).

Time to pass the top of the vertical loop				Average Time

2. Given that the length of the coaster is 11.6 m, find the speed of the coaster at the top of the loop.

WHAT TO DO ON THE RIDE (Physics Days Only)

1. Sit in the second row where you can see the mounted accelerometer, and note the G Force at the bottom of the hill following the Immelman and at the top of the second loop. Take three readings yourself or use your reading and that of two friends.

DATA TABLE

	#1	#2	#3	Average
Bottom of hill				
Top of loop				

Problems

1. Find the speed of the coaster at point B, just after the Immelman. Use the time to go between posts A and C, and the fact that the distance between posts A and C is 22.0 m.

2. Compute the G Force at the bottom of the hill following the Immelman. Use your computed speed and a radius of 30.0 meters. Compare your answer with the value obtained from the G Force vs. Time graph at the end of the workbook and to the G Force Meter reading (if measured).

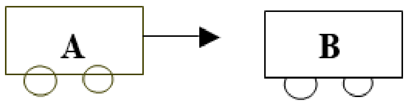
Computed value of G Force	Value from graph	Average G Force reading (if measured)

3. Compute the G Force at the top of the second loop. Use your computed speed and a radius of 5.5 meters. Compare your answer with the value obtained from the G Force vs. Time graph and to the accelerometer reading (if obtained).

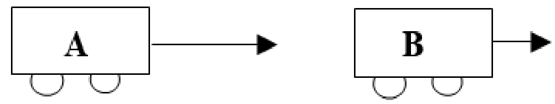
Computed value of G Force	Value from graph	Average G Force reading

4. The first hill is 39.9 m above the ground level. Near the end of the ride, where the coaster is near ground level, the speed of the coaster is 16 m/s. What has been the percentage energy loss (converted to heat) at this point?

UBANGA-BANGA BUMPER CARS: Basic



Stationary collision



Moving collision

INSTRUMENTS REQUIRED

Horizontal G Force Meter; Stopwatch

WHAT TO DO BEFORE COMING TO THE PARK

1. Predictions:
   a. When you strike a car from the rear, you feel pushed:
      forward backward left right
   b. When you are struck from the rear, you feel pushed:
      forward backward left right
   c. When you are struck on the left side, you feel pushed:
      forward backward left right
   d. When you strike a car on its side, you feel pushed:
      forward backward left right
   e. A stationary collision will have a (larger or smaller) G Force than a moving collision.
   f. What is the maximum speed of the bumper cars?
      3 mph 5 mph 7mph 9mph
2. Construct a Horizontal G Force Meter with hand-strap.

WHAT TO MEASURE ON THE RIDE

1. Using the Horizontal G Force Meter, measure the maximum angle to which the balls roll in a stationary collision. (Hold the Horizontal G Force Meter parallel to your direction of motion.) Note both the magnitude and direction of the motion of the balls in the tube. Pay attention to striking and also to being struck.

2. Using the Horizontal G Force Meter, measure the maximum angle to which the balls roll in a moving collision. (Hold the Horizontal G Force Meter parallel to your direction of motion.) Note both the magnitude and direction of the motion of the balls in the tube. Pay attention to striking and also to being struck

3. Pay attention to the motion of the balls when you are struck from the side. In that situation, you will need to hold your G Force Meter perpendicular to your car's original motion.

WHAT TO MEASURE OFF THE RIDE

1. Measure the time that it takes the cars going full speed to pass between two posts.

DATA TABLE

	#1	#2	#3	Average
Stationary collision angle				
Moving collision angle				
Time between posts				

Questions

1. Using the chart below, determine the Horizontal G Force in a stationary and a moving collision. How do these forces compare to the Log Flume?

Angle	20	25	30	35	40	45	50	55	60
G Force	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.4	1.7

2. How does the force of being hit compare with the force of hitting?

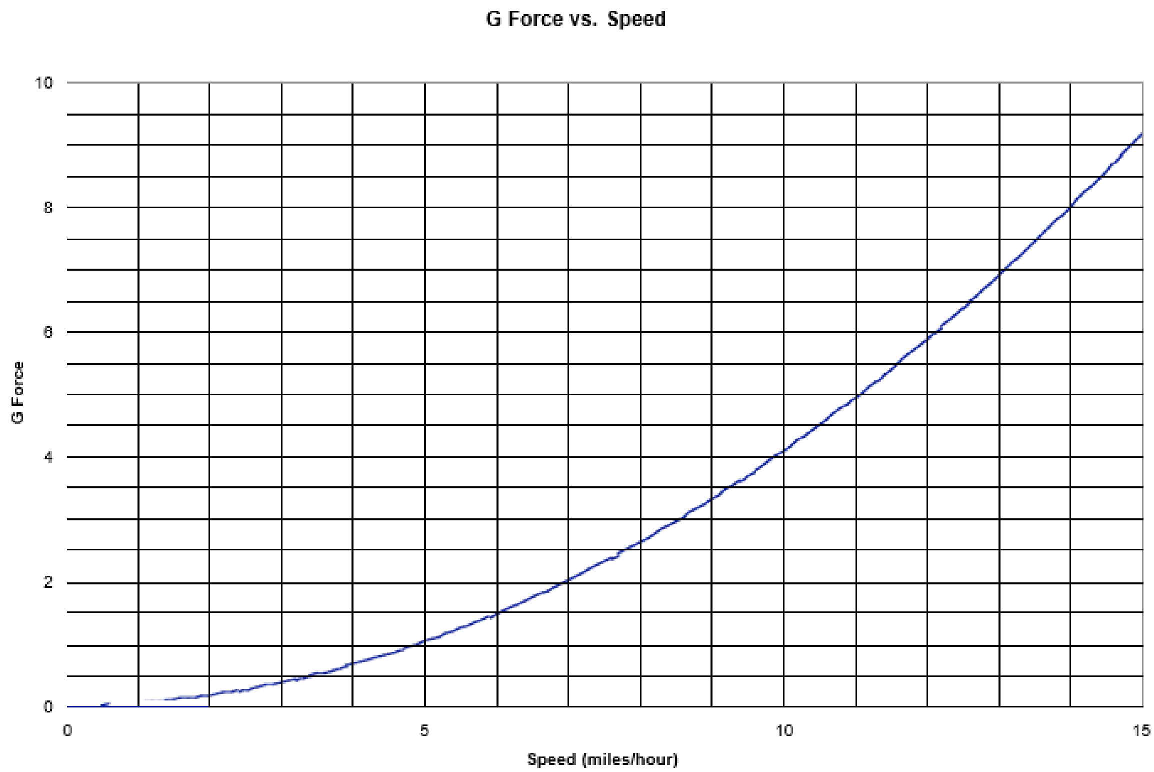
3. Answer the following:
    a. When you strike a car from the rear, you feel pushed: forward backward left right
    b. When you are struck from the rear, you feel pushed: forward backward left right
    c. When you are struck on the left side, you feel pushed: forward backward left right
    d. When you strike a car on its side, you feel pushed: forward backward left right

4. Which of the following conditions would produce greater forces?(circle all that apply)
   Harder bumpers Softer bumpers Higher Speeds Lower Speeds

Problems

1. Using the time between posts, compute the speed of the bumper cars in m/s. In addition, compute the speed in miles/hour by multiplying the m/s speed by 2.24. The posts are 7.6 m apart.

2. The graph below indicates the relationship between the G Force in a stationary collision between bumper cars and the speed of the collision. This graph assumes that the final speed is zero.

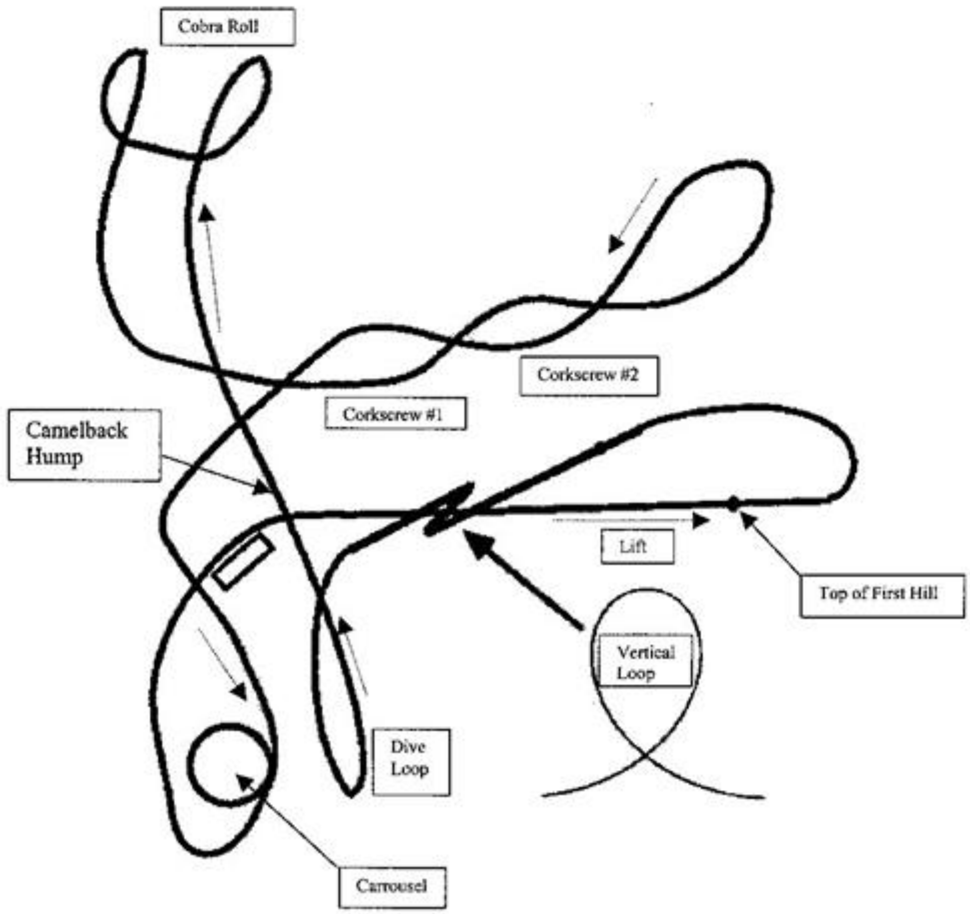


a. What happens to the force of the collision when the speed is doubled?

b. What happens to the force of a collision when the speed is quadrupled?

c. What would be the maximum safe speed in a bumper car collision?

KUMBA: Basic



The Kumba features a double corkscrew; a Cobra Roll; a 33 m tall Vertical Loop that takes the ride around the original lift hill; a Dive Loop that mimics a stunt plane's maneuver; and a 42.9 m drop on the first hill. In addition, the Kumba has a highly banked circular turn called the carousel, which produces heaviness for several seconds, and a Camelback Hump that does just the opposite, giving the riders a few seconds of near weightlessness. The coaster has three wheels: a Road Wheel above the track to ride on; a Guide Wheel beside the track to keep the train from rocking side to side; and an Uplift Wheel beneath the track to ensure that the train stays on the track through all its twists and turns. With maximum speeds of up to 62 miles/hour, seven inversions, and multiple opportunities to experience forces of greater than 3 g's, the Kumba is an awesome physics experience

INSTRUMENTS REQUIRED

Stopwatch (No instruments allowed on the ride!)

WHAT TO DO BEFORE COMING TO THE PARK

2. Problems:
   Find the speed of a coaster train whose length is 20 m and which takes .75 seconds to past a post.
3. Predictions:
   1. As the coaster goes around the carousel near the end of the ride, will you feel:
      pushed to the outside   pushed to the inside   not pushed to the left or the right
   2. As the coaster goes around the carousel, you will feel:
      Heavy   Light   Normal
   3. When the coaster cars are inverted, you will feel:
      Heavy   Light   Like you are falling Sometimes Heavy and Sometimes Light
   4. What is the average speed of the coaster, expressed in miles/hour?
      15   20   25   30   35   40   45   50   55
   5. What is the highest G Force on the ride?
      3.0   3.2   3.4   3.6   3.8   4.0   4.2
   6. How many times does the coaster ride exceed 3 G's?
      2   3   4   5   6   7   8   9

WHAT TO NOTICE ON THE RIDE

1. Pay attention to your feelings during the carousel section of the ride, near the end. Estimate how heavy you feel and whether you feel pushed to the left or right. Can you get your feet off the floor?

2. You will be inverted seven times. Pay attention to the similarities and differences in these inversions, i.e., do you feel heavy or light; do you ever leave your seat; etc.

3. The G Force at the bottom of the first hill is about 3.4. Where on the ride is the G Force greater than this? Where is the G Force the greatest, and what is that value? What is the value of the G Force in the carousel?
On Physics Days only, sit in the second row in view of the mounted G Force Meter. Record the measured value instead of estimates.

WHAT TO MEASURE AND NOTICE OFF THE RIDE

1. Time the coaster from the point where the middle car passes the top of the first hill until the middle car reaches the top of the second corkscrew.

2. Measure the time for the coaster to pass the top of the first corkscrew. (Start the stopwatch when the front of the first car reaches the top of the corkscrew, and stop the stopwatch when the back of the last car reaches the top of the corkscrew.)

3. Watch the ride from the beginning to the end to determine where it moves the fastest and where it moves the slowest.

DATA TABLE

	Time #1	Time #2	Time #3	Average Time
Time it takes the coaster to go from the top of the first hill to the top of the second corkscrew				
Time it takes the coaster to pass the top of the first corkscrew				

On the Ride Estimates

	#1	#2	#3	Average
Heaviest point				
carousel				

Questions

1. Describe the differences in the times that you were upside down. Did you ever leave your seat? Which time did you feel the lightest?

2. Where did you feel the heaviest during the ride? Where you able to pick up your feet in the carousel? Were you thrown to the left or right or were you upright in the carousel?

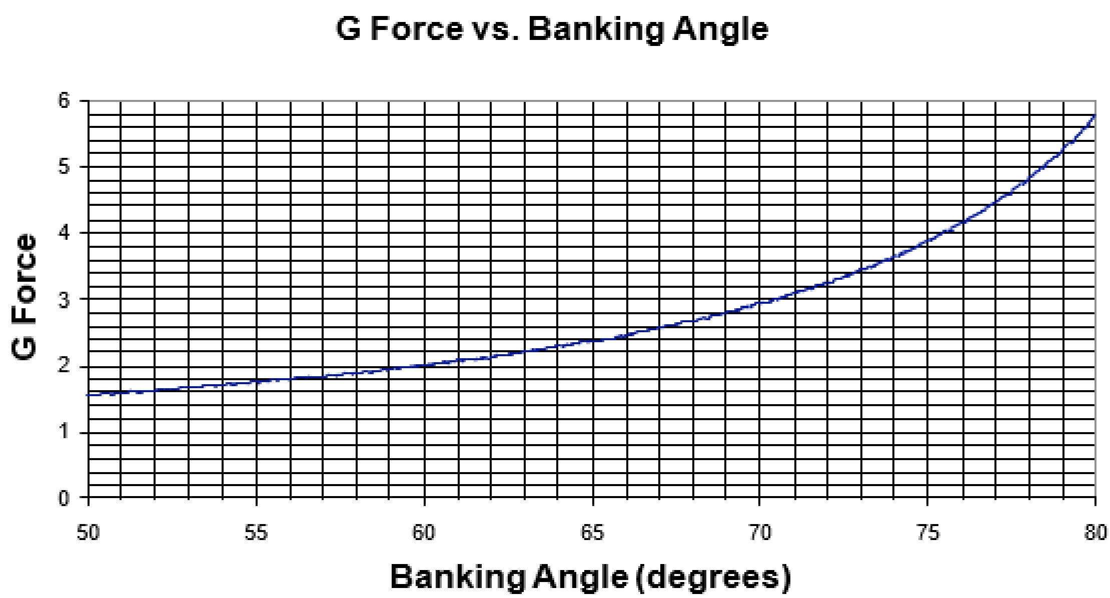
3. The Kumba has so many twists and turns that it can be disorienting. It is hard to tell where you are or whether you are upside down or not. This is especially true because your eyes will tell you that you are upside down, but you may not feel upside down. You also go from being light to being heavy many times. Where were your senses the most confused?

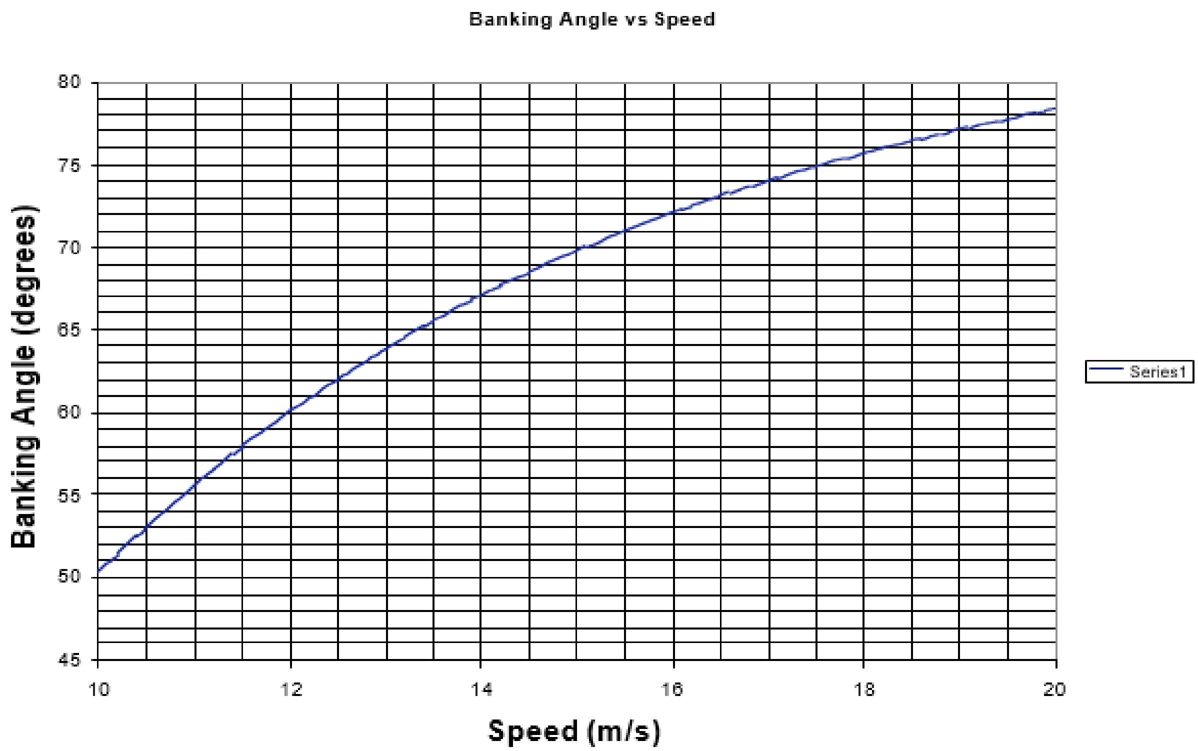
4. Give a general explanation for where on the ride you go fast and where slow.

5. Generally speaking, where do you feel heavy and where do you feel light — at the tops of hills, at the bottoms, on the curves, going down hills, being upside down, etc.?

Problems

1. The graphs below are based on the carousel, which is the horizontal circle near the end of the coaster ride.





a. The velocity in the carousel is 15 m/s. What is the banking angle?

b. What is the G Force that corresponds to this banking angle? How does this compare with your estimate (or measurement) of the G Force in the carousel?

c. If you wanted to design a coaster that experienced 2 g's in the carousel, what would the speed of the coaster need to be?

d. What is the maximum safe banking angle? Why did you pick this angle?

1. Using the time it takes the coaster to pass a point at the top of the corkscrew, compute the speed of the coaster at the top of the corkscrew. Coaster length = 13.1 meters

2. Using the time for the coaster train to go from the top of the first hill to the top of the second corkscrew, compute the average speed of the coaster. The distance between those two points is 770 meters. Find the average speed in miles/hour by multiplying m/s by 2.24.

3. List the G Forces on the inversions as obtained by the G Force vs. Time graph at the end of the workbook. This graph was produced with a CBL, TI-83 calculator and a Low-G Accelerometer. How does this compare with your feelings on the ride?

Top of Vertical Loop	Top of Immelman	Camelbac k Hump	Cobra Roll Inversion #1	Cobra Roll Inversion #2	First Corkscrew	Second Corkscrew

4. List the maximum forces at the bottoms of the hills. How do these figures compare with your estimations (or your measurements with the G Force Meter) of where the force was the greatest?

Vertica l Loop bottom	Going into Dive Loop	Going into Camelback	Going into Cobra Roll	Middle of Cobra Roll	Coming out of Cobra Roll	Corkscre w Bottom #1	Corkscre w Bottom #2	carousel

KUMBA: Advanced

INSTRUMENTS REQUIRED

Stopwatch **(No instruments allowed on the ride!)**

WHAT TO DO BEFORE COMING TO THE PARK

1. Problems:
   a. Compute the G Force acting on a rider who is upside down at the top of a loop of radius 10 m whose speed is 12 m/s.
   b. Compute the G Force acting on a rider who is at the bottom of a hill of radius 40 m whose speed is 30 m/s.

WHAT TO DO ON THE RIDE

1. Ride the coaster near the front and then again near the back. Notice the differences at the tops and bottoms of the hills, especially in the Cobra Roll and in the Vertical Loop.
2. **On Physics Days Only:** Sit in the second row, in view of the mounted G Force Meter, and record the G Force at the following locations: bottom of the first hill; top of the vertical loop; top of the first corkscrew; carousel.
   Record three readings if possible (or use yours and those of two friends) and find the average.

WHAT TO MEASURE OFF THE RIDE

1. Time the descent of the first car from the top of the Cobra Roll to the lowest point. Then do the same thing for the last car. (This is most easily done on the bridge to the Congo)
2. Measure the time it takes the coaster to pass the top of the vertical loop. (Start the stopwatch when the front of the first car reaches the top of the loop, and stop the stopwatch when the back of the last car reaches the top of the loop.)

DATA TABLE

	#1	#2	#3	Average Time
Time of descent of first car				
Time of descent of last car				
Time to pass the top of the vertical loop				

Physics Day Only Ride Data

	#1	#2	#3	Average
Bottom of first hill				
Top of vertical loop				
Top of first corkscrew				
carousel				

WHAT TO DO IF YOU DIDN'T DO KUMBA: BASIC

1. Measure the time it takes the coaster to pass the top of the first corkscrew.

Time to pass the top of the corkscrew				Average time

2. Compute the speed at the top of the corkscrew using the measurement of the time it takes to pass the top of the corkscrew. Length of the coaster = 13.1 m

3. Looking at the Banking Angle vs. Speed graph in Kumba: Basic, determine the banking angle for a speed of 15 m/s. Then use the G Force vs. Banking Angle graph to determine the G Force. These graphs are based upon the radius of curvature of the carousel, which is the horizontal loop near the end of the Kumba.

Banking angle = ________________ G Force = _________________

Questions

1. How was riding in the front car different from riding in the back car?

2. Why are the two descent times measured on the Cobra Roll so different? Is the descent time also different for the first and last cars on the other hills (Dive Loop, First Drop, etc.)?

Problems

1. Compute the banking angle and the G Force in the carousel based upon a speed of 15 m/s and a radius of curvature of 8.5 m. Compare your calculated values with the values obtained from the G Force vs. Banking Angle and the Banking Angle vs. Speed graphs in Kumba: Basic. How do your G Force calculations compare with the G Force vs. Time graph at the end of the workbook and the value from the G Force Meter (if measured)?

	Calculated	Two graphs in Kumba: Basic	G Force vs. Time graph	G Force from the G Force Meter
G Force				
Banking Angle			XXXXXXX XXXXXXX XXXX	XXXXXXX XXXXXXX XXXX

2. Compute the speed of the coaster at the top of the vertical loop. The length of the coaster is 13.1 m

3. Using the just-computed speed of the coaster at the top of the vertical loop, compute the G Force at the top of the vertical loop. The radius of curvature at the top is 7.2 m.

4. Using the speed at the top of the corkscrew, compute the G Force at the top of the corkscrew, given a radius of curvature of 7.6 m.

5. Compute the G Force at the bottom of the first hill. The velocity at this point is 27.5 m/s, and the radius of the curvature of the track is 29 m.

6. Find the percentage of energy converted to heat by the time the coaster reaches the top of the vertical loop. Elevation of the first hill above lowest point = 40.8 m

   Elevation of the Vertical Loop above lowest point = 30.9 m
   Speed up the incline = Speed at top of first hill = 2.3 m/s.

7. The vertical loop is called a clothoid. It has a variable radius, with the radius large at the bottom and small at the top. To investigate what would happen if the loop were a circle, assume that the loop has the same height (30.9 m), but also that it had a constant radius (r = 15.5 m). The velocity at the top would still be the same as you measured earlier, and the velocity at the bottom would also be the same as at the bottom of the first hill (27.5 m/s). Based on this information, explain why vertical loops are not circles. (Hint: Compute the G Force at the bottom and at the top.)

8. Compare your calculations for the G Forces at the top of the vertical loop, at the top of the first corkscrew, and at the bottom of the first hill with the values indicated on the G Force vs. Time graph and with the mounted G Force Meter (if obtained). Why are the values different? (The graph was made with a CBL, Low G accelerometer and a TI 83 Calculator on the Kumba in the first car.)

	G force at bottom of first hill	G force at top of vertical loop	G force at the top of the first corkscrew
From calculation			
From graph			
From mounted G Force Meter			

SHEIKRA: Basic

INSTRUMENTS REQUIRED

Stopwatch (No instruments allowed on the ride!)

WHAT TO DO BEFORE COMING TO THE PARK:

1. Predictions:

   a. How long will you feel "weightless" on the big drop? .5 sec. 2.5 sec. 5 sec.
   b. Will you ever feel weightless when you are upside down? Yes No

2. Problems: Given that the coaster takes .75 seconds to go from post A to post B, which are 20 meters apart, what is the speed of the coaster?

WHAT TO NOTICE ON THE RIDE

1. Estimate the time that you are "weightless" on the big drop. Estimate to the nearest ½ second. (Practice counting: One thousand one, one thousand two, etc., or one- Mississippi, two-Mississippi, etc.) Use your count and that of two friends.

	#1	#2	#3	Average
Estimated time of big drop				

2. There are at least two other places on the ride where you feel weightless. Where are they?

WHAT TO DO OFF THE RIDE

1. Measure the time for the coaster to "free fall" down the first hill. Start your stopwatch at the instant the coaster begins to fall (it will hang at the edge for approximately 4 seconds before falling), and stop your stopwatch when the coaster arrives at the top of the blue post that supports the track. The track begins to curve after this point.

DATA TABLE

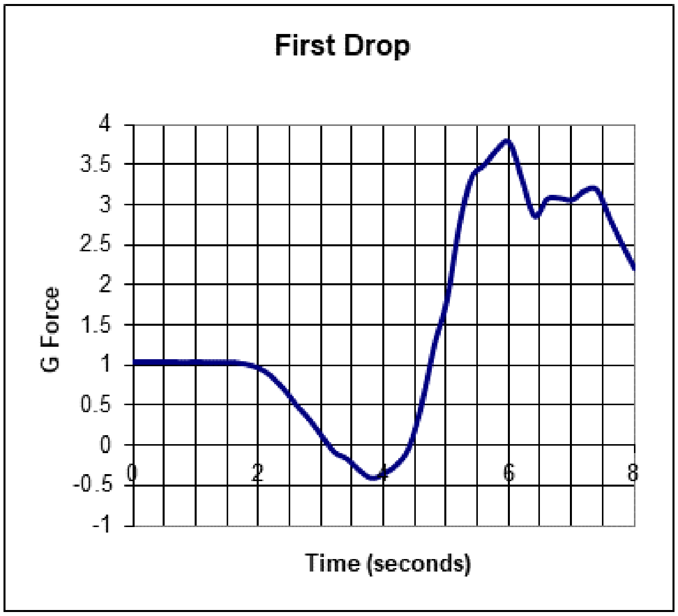
	#1	#2	#3	Average time
Time of fall				

Questions

1. How does the time you estimated on the ride compare with the time you measured?

2. On the G Force graph below, estimate the time of weightlessness by finding the time spent with a G Force of less than 1 G.

3. How long does it take for the G Force to increase from 1 to its highest level?

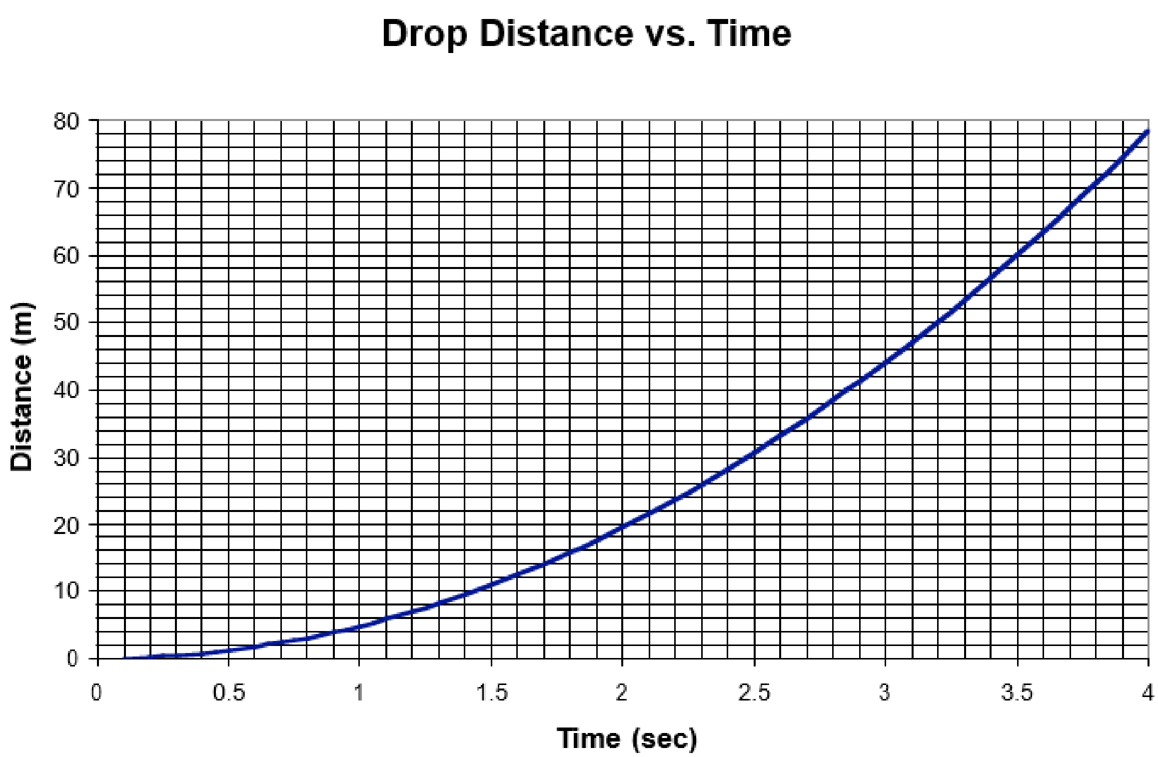


4. a. From the Drop Distance vs. Time graph on the next page, determine how far the coaster dropped in the time measured with the stopwatch.

b. If the coaster dropped the entire 61 meters to the ground, how long would the falling time be? (In reality, such a drop is not possible, because the coaster track must begin curving before it reaches the ground.)

c. Using the Drop Distance graph, what should the "free fall" time be? (It is 32.7 meters from the top of the hill to the blue post.)

5. From the complete SheiKra G Force graph at the end of the workbook, find where else on the ride you are weightless. Which weightless period is the longest? How does this graph compare with your observations?



SHEIKRA: Advanced

INSTRUMENTS REQUIRED

Stopwatch (No instruments allowed on the ride!)

WHAT TO DO BEFORE COMING TO THE PARK

1. Predictions:
   a. What will the G Force be at the bottom of the hill? 2 3 4
   b. What is the maximum speed of SheiKra? 50 mph 60 mph 70 mph

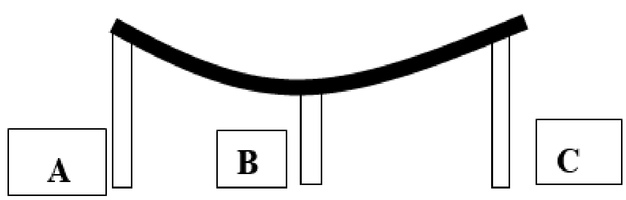
2. Problems:
   a. What is the G Force experienced when a coaster is at the bottom of a hill of radius 10 m, with a speed of 20 m/s?
   b. What is the percentage energy loss when the coaster decreases its speed from 30 m/s to 15 m/s?

WHAT TO NOTICE ON THE RIDE

1. Notice your feelings as the coaster “splashes” through the water.
2. Pay attention to which point on the ride has the most intense G Forces.

WHAT TO NOTICE OFF THE RIDE

1. Time the coaster at the bottom of the first hill between posts A and C.



2. After the coaster goes underwater, time it between the two blue posts at its highest point.
3. Time the splash of the water brake.

DATA TABLE

	#1	#2	#3	Average
Between A and C				
Between two blue posts				
Water brake				

Questions

1. The speed at the bottom of the hill of the Immelman (26.5 m/s) is less than the speed at the bottom of the drop after the brake block (28 m/s). Why?

2. Referring to the SheiKra G Force graph at the end of the workbook, why is the G Force at the middle of the water brake close to 1 G?

3. Referring to the SheiKra G Force graph, which of the high G Force portions of the ride — the bottom of the first hill or coming out of the Immelman — is the most intense? Which lasts the longest at high G Force? How does this compare with your experience?

Problems

1. Compute the velocity at the bottom of the first hill. The distance between posts A and C is 20.7 meters.

2. Compute the G Force at the bottom of the first hill. The radius of curvature is 38.1 m. How does your computed G Force compare with the G Force indicated on the SheiKra G Force graph?

3. Compute the velocity at the top of the hill after going underwater. The distance between posts is 15 meters.

4. Compute the energy loss at this point, compared with at the top of the first hill. At the top of the first hill, the velocity is zero and the height is 61 m. At the point measured at the top of the hill after going underwater, the height is 23.1 m.

5. In the water brake, the speed decreases from approximately 24 m/s to 22 m/s. How much of the remaining energy is lost?

6. Using your time of splash, what is the Horizontal G Force experienced in the water brake? Did you feel a significant force during the water brake?

CHEETAH HUNT: Basic

ELEMENTS OF THE RIDE:

1st Launch:	Acceleration in the Station
Overbanked Turn:	Immediately after 1st launch. Big looping turn.
2nd Launch:	Acceleration before the Tower
Tower:	You'll come down the tower and into a trench
Outbound Twister:	Parabolic Hill with a twist up top. You're going over the Sky Ride.
Heartline Roll:	Upside down with the heart line as the pivot
Brake Block:	Relatively flat, where the coaster can be stopped if needed
Serpentine turns:	Like a snake, undulating back and forth
3rd Launch:	Acceleration before Air Time Hill
Air Time Hill:	Parabolic Hill with a weightless sensation
Inbound Twister:	Sometimes called the over and under Train Track Hill, and then Sharp Left Turn into the brakes at the end.

INSTRUMENTS

Stopwatch

WHAT TO DO BEFORE COMING TO THE PARK

Problems

If the Cheetah hunt takes 1.5 seconds to pass between two posts that are 20 meters apart, how fast is the coaster train moving?
What is the acceleration of a car that goes from 0 to 20 meters per second in 4 seconds? (Assume a constant acceleration)

Predictions

a. If you are in a car making a hard turn to the right, which direction do you feel pushed? (Note: This is because of a lateral or sideways acceleration.)

Right Left

b. There are three launches on the coaster. Which do you think will be the most intense?

First (at station) Second (before the Tower) Third (near the end of the ride)

WHAT TO DO AND NOTICE ON THE RIDE

1. Note where you are when you feel pushed to the side. One easy way is to pay attention to your legs, especially if they are slightly raised off the ground.
2. Pay attention to where you feel the greatest periods of weightlessness.
3. Notice where on the ride you feel the heaviest.

WHAT TO MEASURE OFF THE RIDE

1. Time the coaster train between the highest two posts on the Air Time Hill. (This is just after the third launch and is easily visible behind the Pit Stop near the entrance to Rhino Rally.) Make three measurements and compute the average.
2. Watch the Cheetah Hunt coaster do its "serpentine" turns down the canyon.
3. Draw a sketch of the Air time hill, including the locations of the posts at the top.

AIR TIME HILL

	#1	#2	#3	Average
Time between Posts of Airtime Hill				

Questions

1. Look at the Cheetah Hunt RR4 Vertical G Force (RR4) graph (RR4=Right Rear seat of the fourth coaster car) at the end of the workbook. This lists the Vertical G forces on the ride.
   a. List four elements with the largest g force with their respective g force. Indicate whether the high g's occurred entering the element or leaving it. (i.e Leaving Launch 4, Entering Air Time Hill, etc.

Element   g's

________________________________   ________

________________________________   ________

________________________________   ________

________________________________   ________

b. Do the highest g forces correspond to where you felt the heaviest?

2. a. From the same RR4 graph, list which elements had the longest "air time". Air time might be defined as when you experience less than 1 g. (Consider only those elements whose lowest g force value was zero or beyond.) Air time usually occurs at the top of a hill, or coming down a steep slope. Be as specific as you can in describing where the events happened.

Element	Approximate Time
______________________________	__________
______________________________	__________
______________________________	__________
______________________________	__________

b. Do these measurements from the graph correspond to your experiences on the ride? Which element did you feel had the "best" airtime?

3. a. There are three types of acceleration on the Cheetah Hunt: *Vertical Acceleration* which results in heaviness or lightness; *Lateral Acceleration* which is left/right. *Forward/Backward Acceleration* which includes launches and braking. Looking at the Cheetah Hunt Lateral G Force (RR4) graph at the end of the workbook, list the three most intense events that produce lateral g force, and list the magnitude of the g force. Note that these G forces are much less than the vertical g forces. Make a note of whether these forces are positive or negative.

	G force
1.______________________________	__________
2.______________________________	__________
3.______________________________	__________
4.______________________________	__________

b. As you leave the station and make a hard left turn, you will note that the acceleration indicated on the graph is negative. Right turns should therefore be positive accelerations, as you can see from the right turn at the top of the tower that occurs at 20 seconds. Turning to the left should produce a feeling of being pushed to the right and vice versa. (Think about being in a car making a sharp turn). Do these four events listed above compare with your observations on the ride (i.e., were your feet "pushed" to the left with positive accelerations, did your most intense sideways feelings come when the graph indicated it, did positive accelerations correspond to right turns, etc.)?

c. The region where the serpentine turns occur is filled with lateral accelerations. From your observations of these turns, why is this the case?

Problems

1. Cheetahs are the world's fastest land animal. At Busch Gardens, the cheetahs have been timed at a speed of 36 mph. Maximum speed of cheetahs in the wild is 70 mph, but cannot be reached at Busch Gardens due to limited running space.

    a. A Cheetah can accelerate from 0 to 62 miles per hour (27.7 m/s) in just three seconds. Compare this to a Ferrari Enzo (660 Horsepower and $670,000), which requires 3.5 seconds. What is the acceleration of a Cheetah in m/s2?

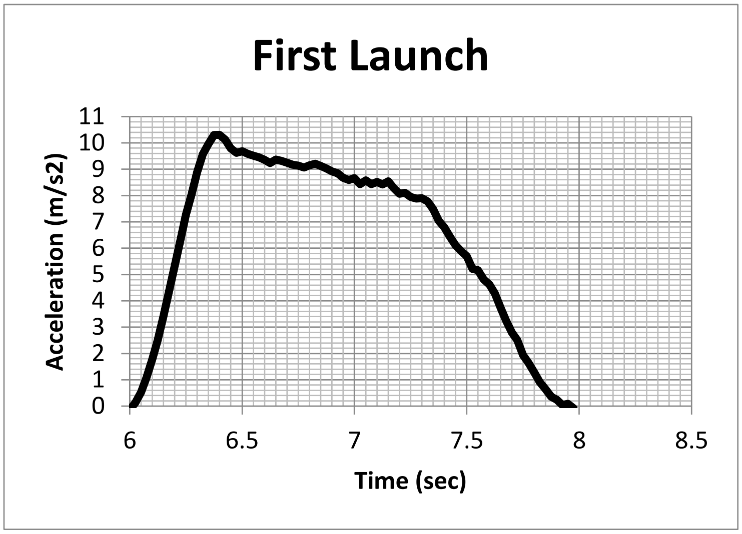
    b. Express this acceleration in "g's" by dividing by 9.8 m/s2.

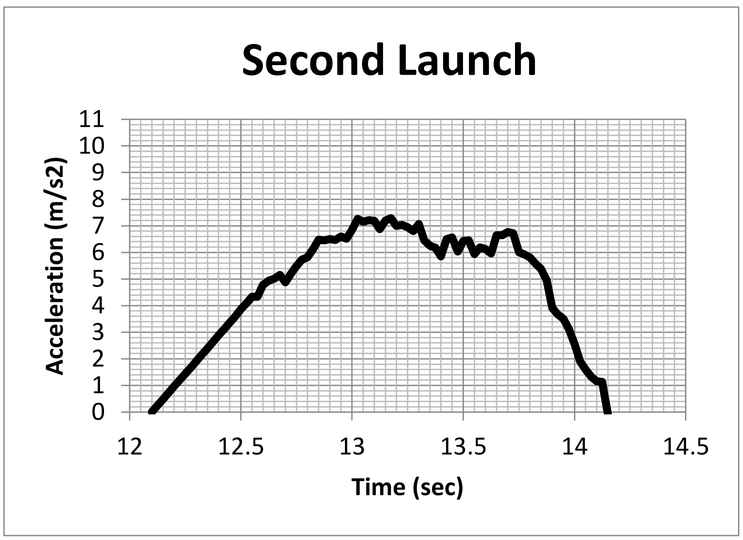
2. Look at the launch graphs on the next page. These measurements were made on the third or fourth coaster car in the three launches of the Cheetah Hunt.

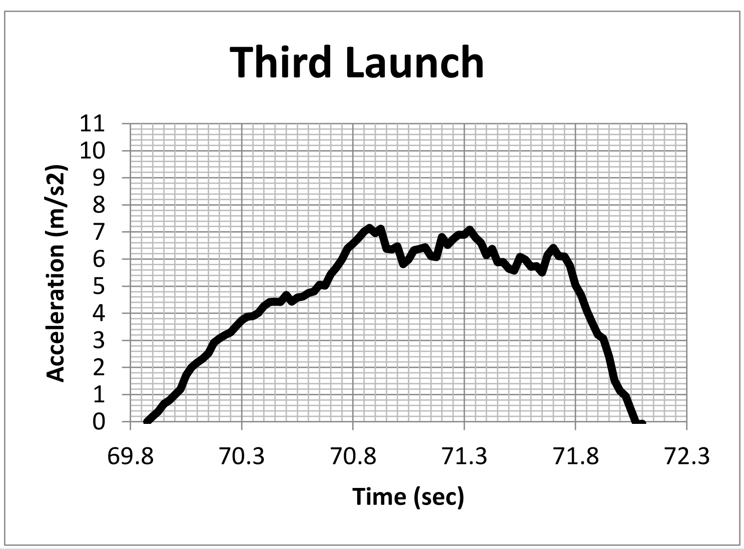
    a. Which of the three launches is for the longest amount of time? Which is for the shortest amount of time?

    b. Which of the launches is the most intense, with the highest acceleration? Which is the least intense? Compute the maximum "g'" of these three launches by dividing the maximum acceleration by 9.8 m/s2. Compare these accelerations to that of the Cheetah.

    c. Describe the three launches in terms of whether they have high accelerations in the beginning or the end.


First Launch
Acceleration (m/s2)
Time (sec)
0
1
2
3
4
5
6
7
8
9
10
11
6
6.5
7
7.5
8
8.5

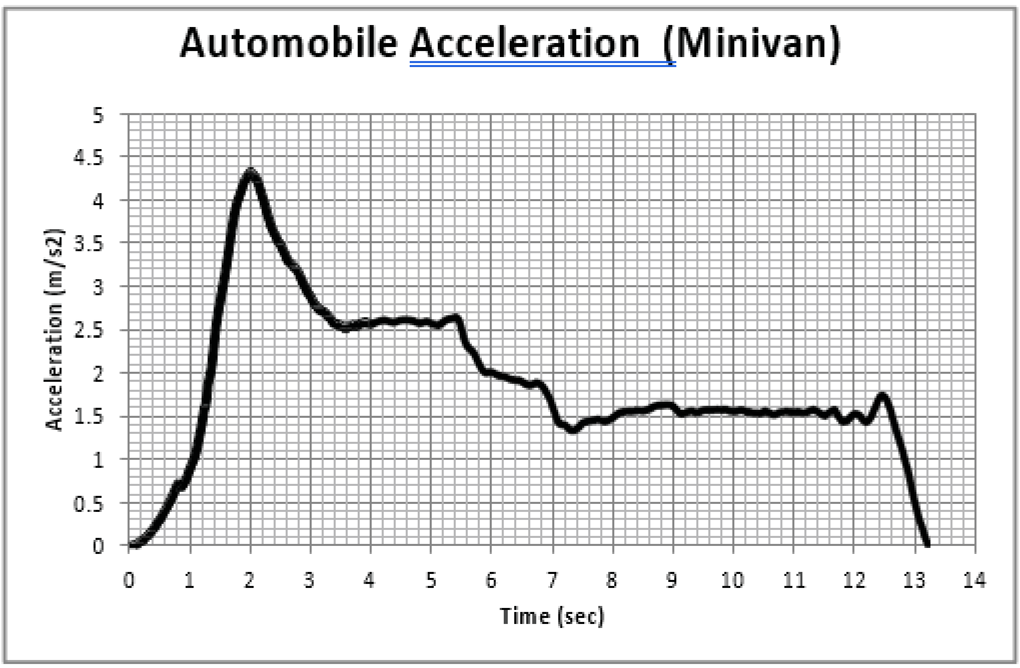

Second Launch
Acceleration (m/s2)
Time (sec)
0
1
2
3
4
5
6
7
8
9
10
11
12
12.5
13
13.5
14
14.5


Third Launch
Acceleration (m/s2)
Time (sec)
0
1
2
3
4
5
6
7
8
9
10
11
69.8
70.3
70.8
71.3
71.8
72.3

d. Which of the accelerations would you guess produces the greatest change in the velocity?

e. How do these graphs compare to how you felt in these three launches?

f. The acceleration below is of minivan accelerating between 0 and 55 mph. Indicate how it is similar and how it is different to the first launch

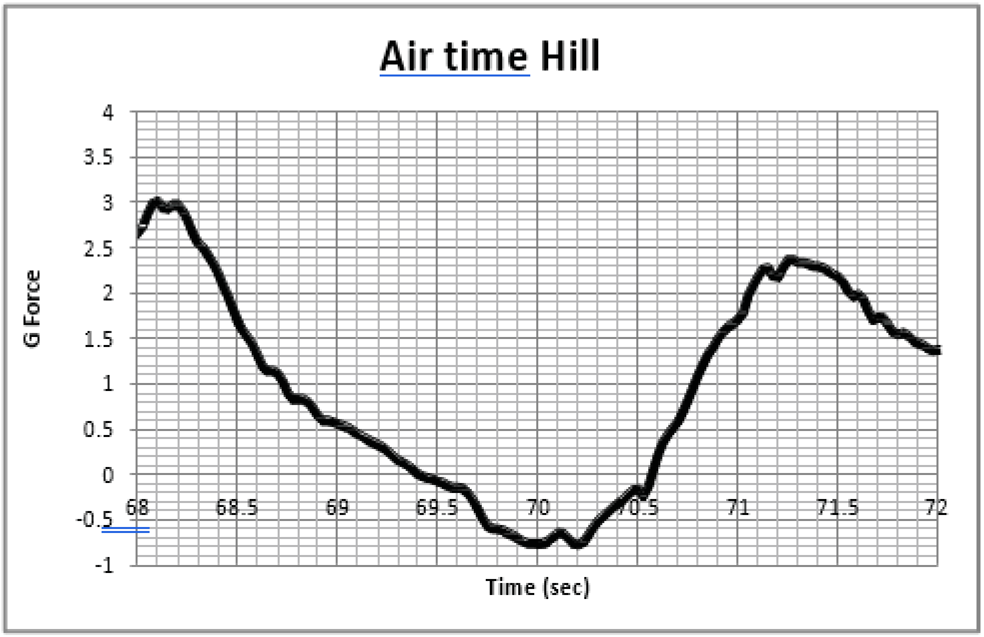


3. a. Using the time between posts that you measured, compute the speed of the coaster train on the Air Time Hill (just after Launch 3). The distance between posts is 15.0 meters.

Velocity=distance/time=

b. Using the graph below, compute how long you feel weightless in the Air Time hill. To do this, assume that weightlessness is experienced when the g force is less than 1 g.

Weightless time = second

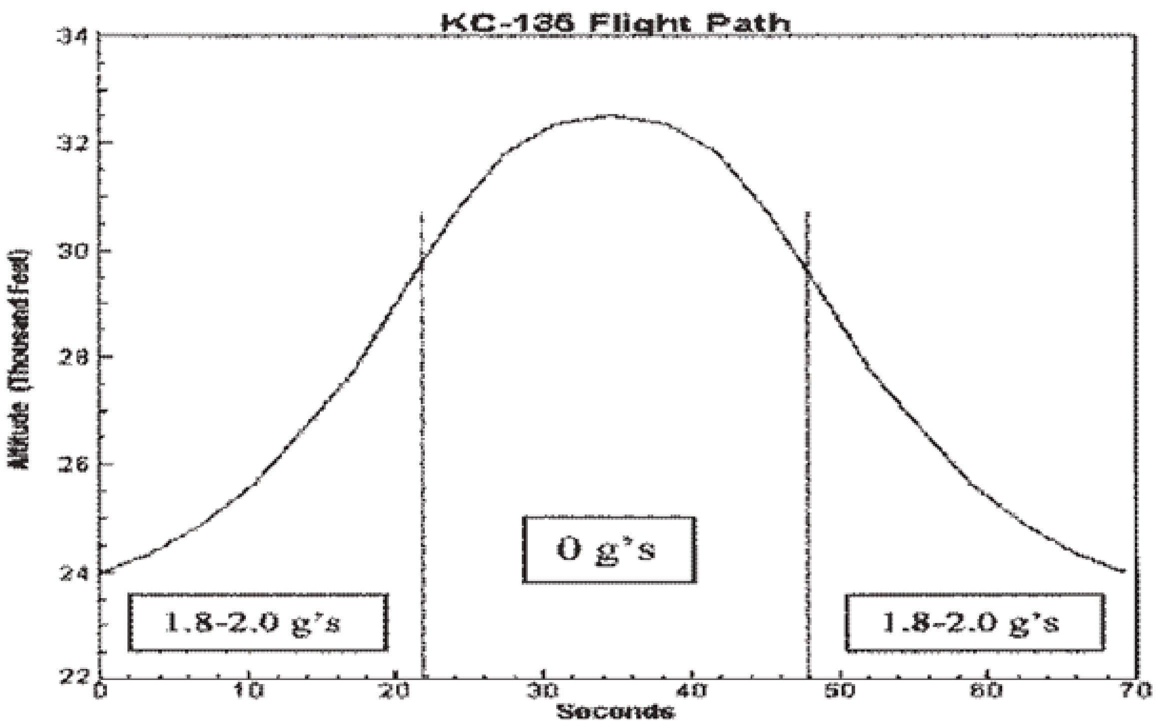


c. Draw a sketch below of what the Air Time Hill looks like. Include the posts in your sketch. What mathematical shape does it appear to be?

d. Is the weightless feeling experienced on the way up the hill, on the way down, or both?

e. What fraction of the "weightlessness" (<1g) occurs during the time between the two posts? The coaster is at zero g's or less for how long? What fraction of this sensation occurs between the posts?

f. When the astronauts train for space travel, they fly in an Air Force plane, KC135, that flies in a trajectory, as illustrated below. The plane is dubbed the "Vomit Comet". According to the graph, how long a period of weightlessness is achieved in the Vomit Comet? How does the shape of the Air Time Hill and its weightless period compare to the Vomit Comet?



CHEETAH HUNT: Advanced

ELEMENTS OF THE RIDE

1st Launch:	Acceleration in the Station
Overbanked Turn:	Immediately after 1st launch. Big looping turn.
2nd Launch:	Acceleration before the Tower
Tower:	You'll come down the tower and into a trench
Outbound Twister:	Parabolic hill with a twist up top. You're going over the Sky Ride.
Heartline Roll:	Upside down with the heart line as the pivot
Brake Block:	Relatively flat, where the coaster can be stopped if needed
Serpentine turns:	Like a snake, undulating back and forth
3rd Launch:	Acceleration before Air Time Hill
Airtime Hill:	Parabolic Hill with a weightless sensation
Inbound Twister:	Sometimes called the over and under **Train Track Hill**, and then **Sharp Left Turn** into the brakes at the end.

RF1 (Right Front seat of the 1st coaster car in the four-car train) RR4 (Right Rear seat of the 4th coaster car in the four car train)

INSTRUMENTS

Stopwatch

WHAT TO DO BEFORE COMING TO THE PARK

Problems

1. If the speed of a coaster car is 18 m/s, and the radius of curvature at the bottom of a hill is 20 m, what is the g force experienced by the riders?
2. If a coaster car has a speed of 12 m/s at the top of the hill, what will the speed be at the bottom of the hill that is 10 m lower?
3. If a coaster car has a speed of 15 m/s at the top of an airtime hill (parabolic) with a radius of curvature of 25 m, what would be the g force experienced by the passengers?

Predictions

1. Which coaster car will experience the most g's as the coaster train begins to go up the tower?
   1st Car 4th Car
2. Coming down the tower, which coaster car will experience the most g's as the train pulls out of the dive? 1st Car 4th Car
3. What is the longest time that you will feel heavy (more than 2 g's) on the ride?
   1.3 seconds 1.8 seconds 2.4 seconds 3.1 seconds

WHAT TO DO AND NOTICE ON THE RIDE

1. Ride in the first car of the train and the last car of the train. Notice any differences in where you feel the heaviest on the ride.
2. There are two trains loaded at a time. Ride in the front train, and later ride in the second train. Notice any differences on the first launch.

WHAT TO MEASURE OFF THE RIDE

1. Time the coaster train between the highest two posts off the Outbound Twister (this is just after you come down from the tower). Make three measurements and compute the average.
2. Measure the front to back time of the coaster train as it passes the first post at the top of the tower.

Data

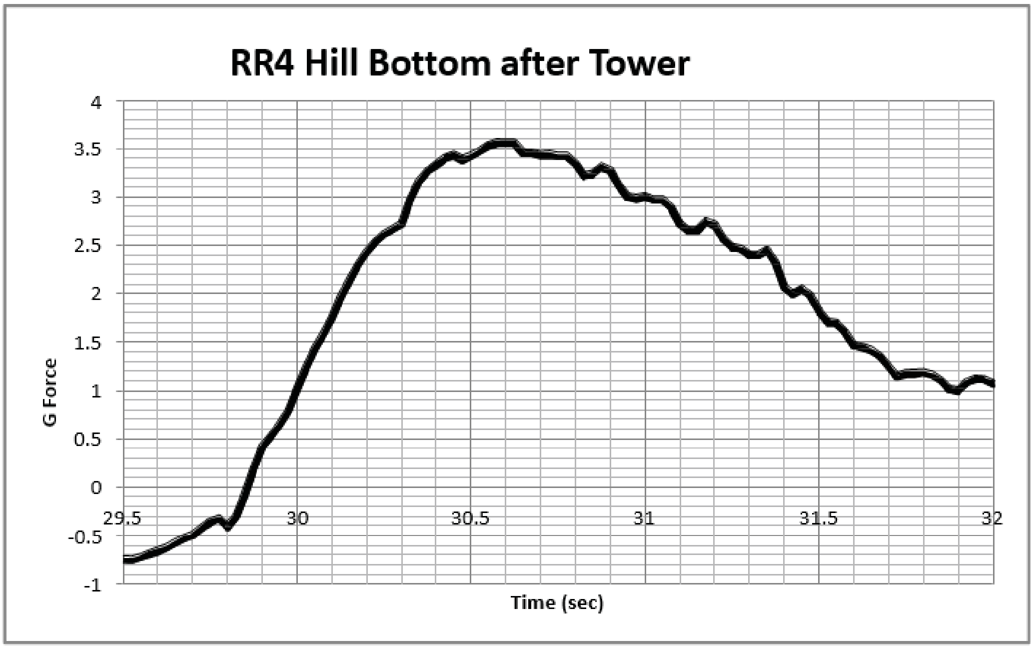
	#1	#2	#3	Average
Time between posts of the Outbound Twister				
Front to back time at the top of the tower				

Questions

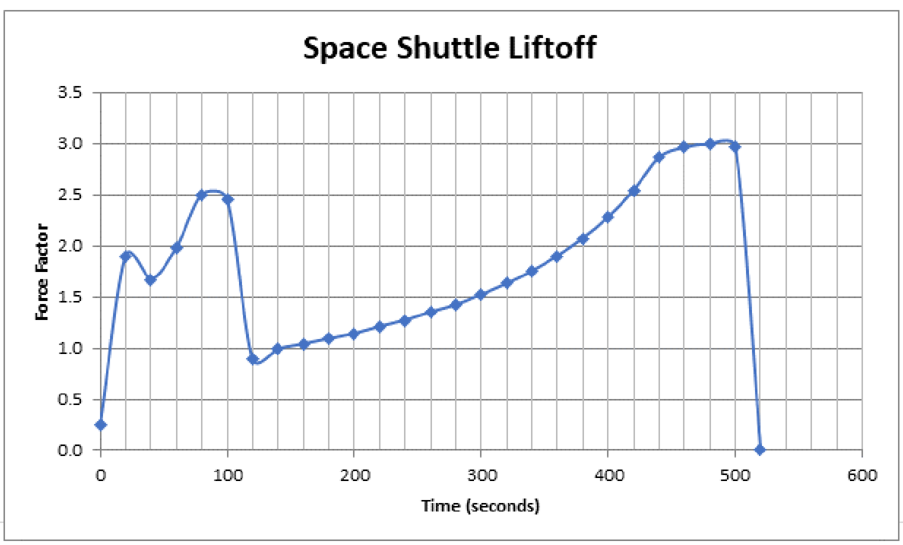
2.
   a. The element of the track that seems to have the highest g's for the longest time is at the bottom of the tower coming down. Looking at the graph at the top of the next page, list the maximum g's and estimate how long you felt heavy (heavy> 2.0 g's).

b. Looking at the Cheetah Hunt Vertical G Force (RR4) graph, which other three elements have more than 2 g's for the greatest time? How does this compare with your experiences on the ride? List the name of the element, the g force and the time that it was greater than 2 g's.

Name of Element	G Force	Time



c. Compare your heavy experiences on the Cheetah Hunt with the lift off of the Space Shuttle, illustrated below



3. The Cheetah Hunt is a Linear Synchronous Motor Coaster. There is a friction wheel system to get the coaster into and out of the station, but otherwise it is electromagnetically accelerated. There are permanent rare earth magnets mounted on the coaster, and three launch areas that contain powerful electromagnets. There is no physical contact between the permanent and electromagnets, thus no wear and tear on the system. These magnets operate at 400 V and thousands of amps. The system uses computer systems with sensors to keep the Cheetah Hunt exceptionally consistent. For example, we timed five launches just before the Tower with the aid of a radar gun. Each train had different loads, and yet three of the launches were exactly the same, and the other two were only 0.1 mph faster or slower than the other two.

    a. The system is set up so that if a car does not succeed in getting up the hill after the launch, the coaster will roll back into the launch area to be re-launched. Obviously, the re-launches for launch 2 and 3 will need to be more powerful, since it will be starting from zero, as opposed to already moving when it comes into the launch area. (Note: Re-launches are very rare.) Why do copper plates pop up in the middle of the track after the coaster has cleared the launch area? Also, why are there copper plates at the end of the ride?

    b. Why is it necessary to have a third launch, when the Airtime hill after the third launch is lower than the tower.

    c. Why is there a strap on the back of the last car that seems to drag along?

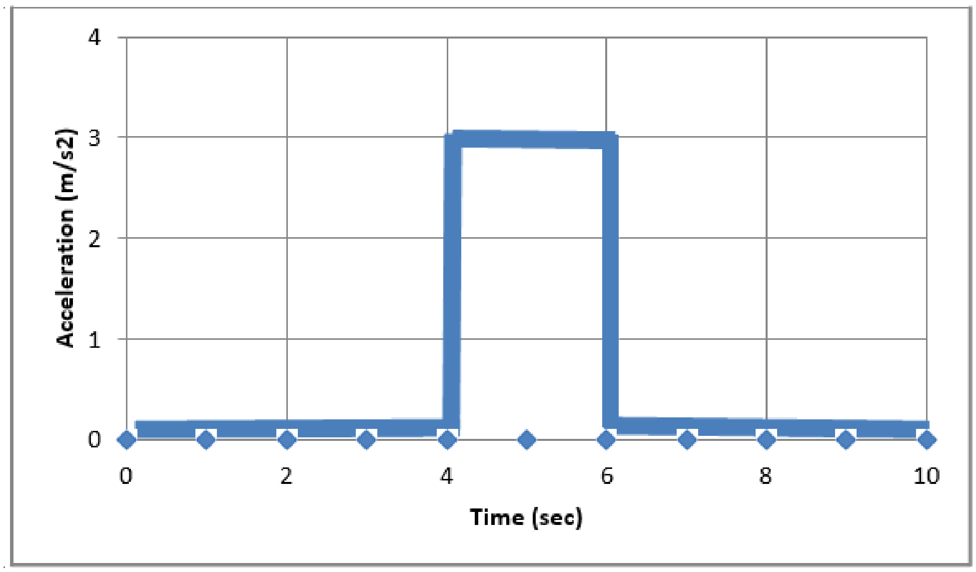
Problems

1. Two trains line up and load in the station at the same time. On the next page you will find the acceleration graphs of the 1st launch of the first train, and the 1st launch of the second train.

    a. How would you describe the differences in these two launches? Does this match your experiences of the first and second trains?

    b. Why do these two launches need to be different?

c. Look at the graph below of acceleration versus time.

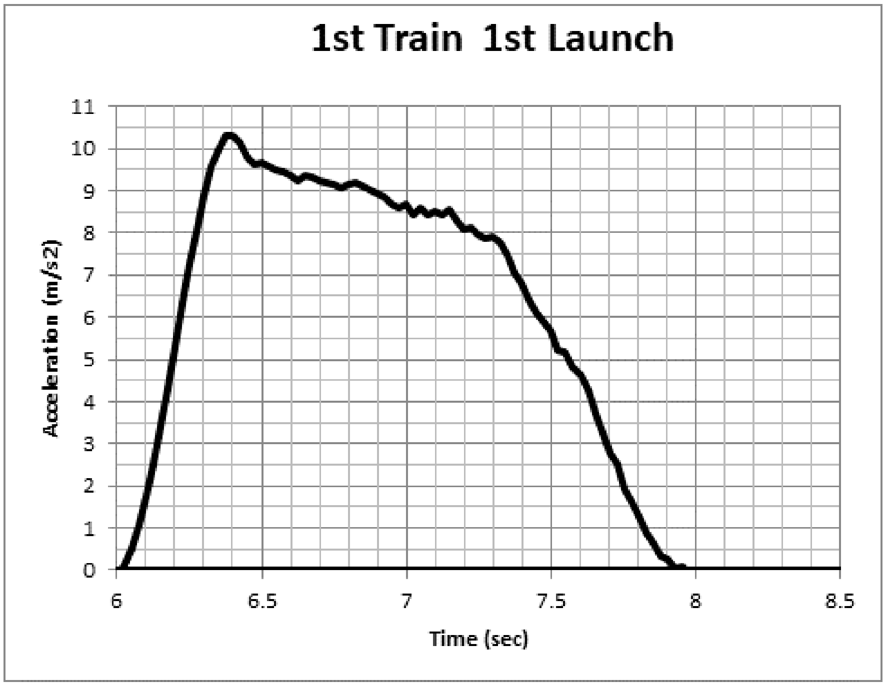


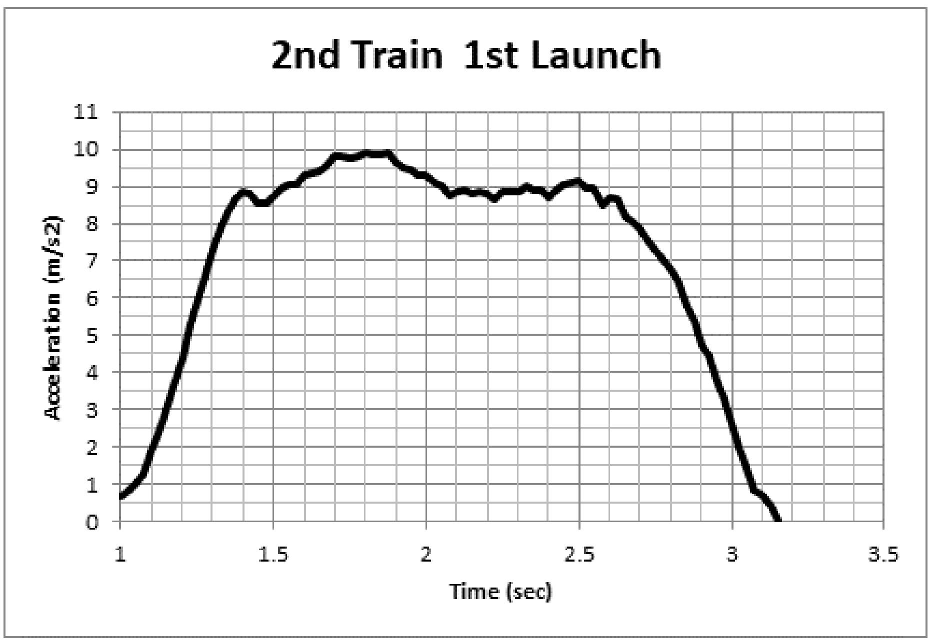
This object has an acceleration of 3 m/s2 for 2 seconds. The equation v=at produces a velocity of 6 m/s. If you look at the rectangle on the graph (formed between 4 and 6 seconds) it has an area (length x width) of 6 m/s.It turns out that the velocity change indicated on any acceleration versus time graph is the area under the curve, even when it is not a regular shape.

The graphs on the next page are of the 1st launches of the first train and the second train. You can approximate the area under the curve by counting the number of squares under each curve. You can also count partial squares to add up to the total. Each square is .1 sec by .5 m/s2 , which equals 0.05 m/s. (i.e. If there were 120 squares under the curve then the change in velocity would be 6 m/s.

ΔV (first train) = ______________squares=________________m/s

ΔV (second train)=____________ squares=________________m/s





2.

a. Compute the g force in the first coaster car as it begins to go up the tower following the second launch.

v= 25.9 m/s radius of the turn = 24.4 m

b. Compute the g force in the last coaster car as it begins to go up the tower following the second launch.
   v=21.9 m/s   radius of the turn =24.4 m

c. Why is the last coaster car moving at a slower speed than the first coaster car when it arrives at the tower?

d. At the bottom of the tower coming down, each car should experience a high g force. Look at the g force graphs for the 1st Car (Cheetah Hunt Vertical G Force (RF1)) and the 4th Car (Cheetah Hunt Vertical G Force (RR4)) and record the g force of each car. These graphs are found at the end of the workbook. Which is higher and why?

   1st Car _____________   4th Car_______________

e. Now examine the differences in the G force for the 1st Car and the 4th Car at the following points:

	1st Car	4th Car
Entering Launch 2	____________	____________
Leaving Launch 3	____________	____________

   Does this match your explanation for both going up and coming to the bottom of the tower?

   Does this also match your experiences on the coaster?

3.

a. Compute the velocity at the top of the Outbound Twister (this element is just after coming down the tower). The posts are 18 meters apart.

   V= 18 m/ (sec) = ___________________m/s

b. Given that the radius of curvature at the top of the hill is 34.0 m, compute the g force at the top of the hill. (1-v2/rg)

c. Compare this to the g force on the (RF1) G force graph. How does it compare to your feelings on the twister?

4.

a. Compute the speed of the coaster train at the top of the tower, by using the front to back time as it passes the first post at the top. The length of the train is 10.25 m.

V= 10.25 m/ (sec)=__________________________m/s

Using conservation of energy (KE at bottom=KE +PE at top) compute what the speed should be at the top. The speed at the bottom of the hill 25.9 m/s, and that the height of the tower is 31.9 meters above the Launch 2.

b. Using conservation of energy, explain why the coaster train is faster at the bottom of the tower going down, than after the second launch.

FALCON'S FURY: Basic

INSTRUMENTS REQUIRED:

None

WHAT TO DO BEFORE COMING TO THE PARK

1. Predictions:

a. How man seconds will you be falling before the you begin to slow down?   2 ½   3   3 ½   4

b. What will be the scariest part of the ride? Going up   Waiting at the top   Falling Face Down

WHAT TO DO ON THE RIDE (You may need to ride several times, or talk with a friend to get this information)

1. How long do you feel "weightless" on the ride? _________ seconds.

This is approximately your falling time until you begin to rotate back into a vertical position. This must be an estimation as stopwatches are not allowed on the ride! (i.e. 0 mississippi, 1 mississippi, 2 mississippi, etc.). If you were unable to do this on the ride, you can try it off the ride.

2. How heavy do you feel when slowing down?

Not heavy	A little Heavy	Moderately Heavy	Very Heavy
1 g	1.5 g	2.5 g	3.5 g

WHAT TO DO OFF THE RIDE

1. How high off the ground are the passengers heads, when the gondola begins to rotate back to vertical. Use the highest elevation of the heads, 86 meters, in making this estimation.

DATA TABLE

	#1	#2	#3	Average
1. Height off ground				

Falcon's Fury uses magnetic brakes. There are permanent rare earth magnets mounted on the gondola (passenger carrier) and metal fins (painted white) stretching up the tower. As the magnets pass through these metal fins there is an upward force on the gondola and the greater the speed, the greater the force. The magnetic brakes are very safe with no moving parts and also make for a very smooth deceleration. The brakes begin to slow you down very soon after you begin to rotate back into the vertical position.

Graph Questions (Use the graphs to answer the questions and note times to the nearest 0.1 seconds):

1. G force versus Time Graph

a. How long do you feel “weightless”. You should feel close to weightless as long as the G force is less than 0.5. _____________ seconds

How long was your on-the-ride estimation of weightlessness? _____________ seconds

b. As long as the G force is less than 1, the Gondola will be speeding up. At what time is the velocity the greatest? _____________ seconds

c. How long do you feel heavy? (This might be defined as feeling more than 1.5 g’s)

______________ seconds

d. What was the approximate maximum G force that the chart indicates you experienced?

___________g’s

Recalling you experience on the ride, does this number seem right?

2. Chart 4: Height versus Time graph (The height of the head above the ground)

a. Using the approximate time of the rotation of the Gondola as 2.6 seconds, use the Height versus

Time graph to find the height of the heads above the ground at this time.

___________ meters

How does this compare to your estimate in WHAT TO MEASURE OFF THE RIDE #1.

b. How far did you fall in 2.6 sec? (Distance fallen=Original height-final height) _________ meters

c. In the first 1.3 seconds, how far did you fall? Why is this distance not equal to half of the distance fallen in 2.6 seconds?

__________ meters

d. On a height versus time graph, you can tell your speed by looking at the slope of the line. Where the slope is the steepest, like an expert snow skier would enjoy, the speed is the greatest. Notice that the slope is very gentle at the beginning of the drop and towards the end. At what time is the speed the greatest? (This occurs just before the brakes are applied and you feel heavy).

___________ seconds

Does this time match with the time that you got in 1b?

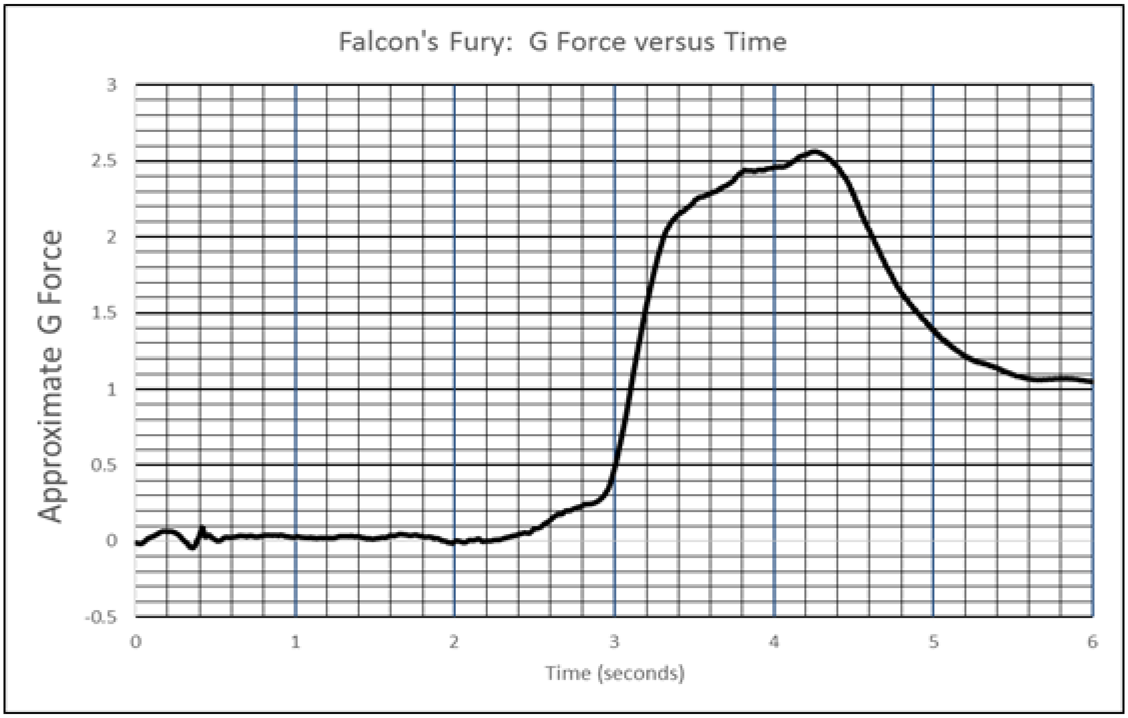
Questions

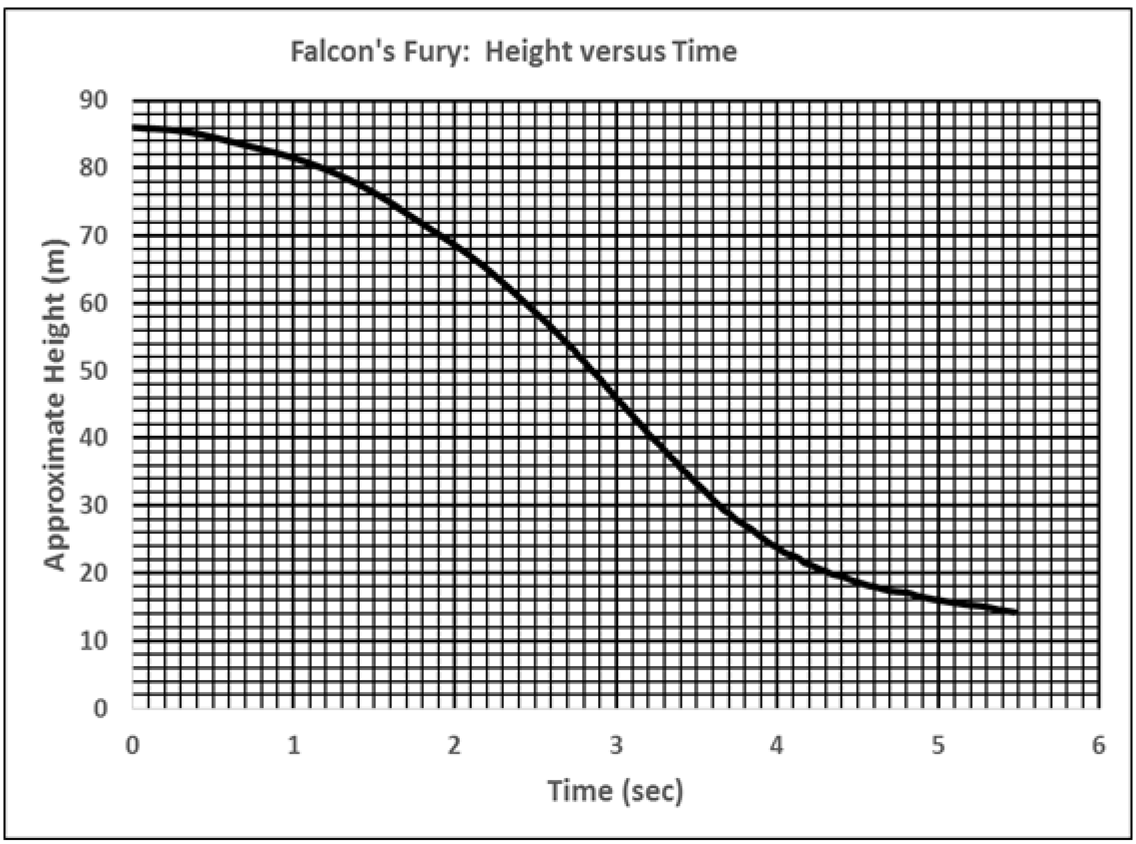
1. How do your weightless feelings on Falcon's Fury compare to those falling straight down on Sheikra?(You may refer to the G force versus time Graph of SheiKra at the end of the Physics Day booklet)

2.How does your heavy experience on Falcon's Fury compare to the coasters in the park? (i.e. Is it as intense as on the coasters? Does you heavy feeling last as long as with the coasters?) You may reference the G force graphs in the Physics Day booklet or use your experience riding the coasters.

3. What was the scariest part of the ride?
(going up, waiting at the top to drop, falling face down, rotating, etc.)

4. What is your estimate of the highest speed on the ride? 40 mph 50 mph 60 mph 70 mph
(Use the wind in your face, rate at which you appear to approach the ground, or viewing from the outside)


Falcon's Fury: G Force versus Time
Approximate G Force
Time (seconds)
3
2.5
2
1.5
1
0.5
0
-0.5
0
1
2
3
4
5
6


Falcon's Fury: Height versus Time
Approximate Height (m)
Time (sec)
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6

FALCON'S FURY: Advanced

INSTRUCTIONS REQUIRED:

Stopwatch (No instruments allowed on the ride)

WHAT TO DO BEFORE COMING TO THE PARK

Predictions:

1. How many seconds will you be falling face down? 1 ½ 2 2 ½ 3 4 5
2. What will be the maximum speed of the gondola? 40 mph 50 mph 60 mph 70 mph

Problems:

What is the G force experienced when a ride slows from 35 m/s to 5 m/s in 2 seconds?

WHAT TO DO ON THE RIDE

1. Estimate how long you fall face down, before you begin to rotate _________ seconds. (You may say, for example, zero Mississippi, one Mississippi, two Mississippi, etc.)
2. How long was the first braking time (Just after "free fall")? ___________ seconds
3. How heavy do you feel (1 g= normal) 2.0 g 2.5 g 3.0 g 3.5 g 4.0 g
   (For reference, the maximum G force on many of the coasters at Busch Gardens is approximately 4)

WHAT TO DO OFF THE RIDE

1. Using a stopwatch, time the descent of the gondola, between when it begins to drop and when the seats begin to rotate back toward the vertical. (You may estimate, if you don't have a stopwatch)
2. Estimate: How high off the ground are people's heads when they begin to rotate back to a vertical position. As a reference, use 86 meters as the height of the heads just before the drop.

DATA TABLE

	#1	#2	#3	Average
1. Drop time before rotation				
2. Height off the ground				

Falcon's Fury uses magnetic brakes. There are permanent rare earth magnets mounted on the gondola (passenger carrier) and metal fins (painted white) stretching up the tower. As the magnets pass through these metal fins there is an upward force on the gondola and the greater the speed, the greater the force. As the gondola slows down, it reaches a point where the upward force equals the weight. At this point the Gondola will move downward at a constant velocity. If the metal is changed to become more conductive, then the force increases, slowing the Gondola, until it once more reaches a constant velocity. The magnetic brakes are very safe with no moving parts and also make for a very smooth deceleration.

Graph Questions (Note times to the nearest 0.1 seconds)

1. Chart 1: Acceleration Versus Time Graph (6 seconds)
    a. How long are you in "free fall" (only gravity acting) ____________ seconds

(Your acceleration should be close to -9.8 m/s2. On the graph, this means between 9 and 10 m/s2 without a definite trend toward 0.)

b. Strictly speaking, free fall or a weightless feeling would be an acceleration of -9.8 m/s2, however anything less than -5 m/s2 should feel pretty much the same as weightlessness. How long are you falling with an acceleration of less than -5 m/s2.

_____________ seconds

c. What happens between the time that "free fall" ends (1a) and the slowing down begins?

d. How many seconds is the gondola slowing down at first braking segment?

(The gondola will not begin to slow down until the acceleration is a positive number. After it starts slowing down, the acceleration graph will eventually be fairly flat, which would indicate a constant velocity)

Starts slowing down_________ sec Stops slowing down _________ sec

Total slowing down time _____________ seconds

e. What is the greatest braking G Force experienced? _____________ G

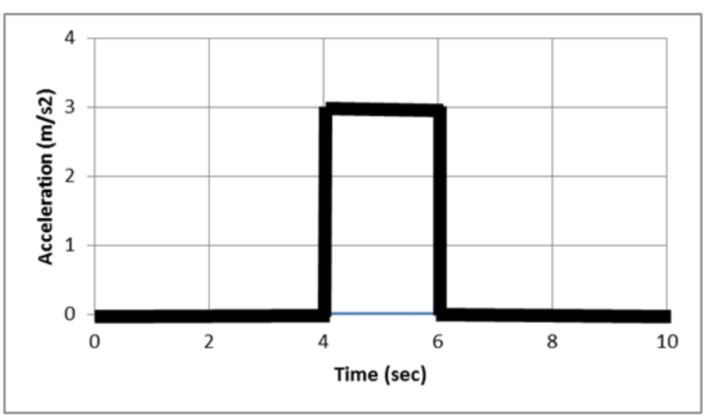
(Remember that the G force calculation will only be approximate. When the acceleration is 0, the G Force will be 1. To obtain the greatest G Force, you will need to take the greatest acceleration, divide by 9.8 and then add 1)

How do your estimate, made on the ride, compare to the braking G force? Does your estimated time of braking also match what you found in 1d?

f. How long do you feel heavy? This might be approximated as experiencing a G Force of greater than 1.5 G.

_____________ seconds

g. Computing the Velocity using an Acceleration versus Time Graph



This object depicted in the graph above,   has an acceleration of 3 m/s2 for 2 seconds. The equation v=at produces a velocity of 6 m/s. If you look at the rectangle on the graph (formed between 4 and 6 seconds), it has an area (length x width) of 6 m/s.   It turns out that the velocity change indicated on any acceleration versus time graph is the area under the curve, even when it is not a regular shape.

The Falcon's Fury acceleration versus time graph (Chart 1) can be used to find the maximum velocity of the gondola. You can approximate the area under the curve by counting the number of squares under the curve. In the case of speeding up, it will be the area between the curve and the x axis.

The object will only speed up as long as the acceleration is downward (negative). You can also count partial squares to add up to the total. Each square is 0.2 seconds by 1 m/s2, which equals 0.2 m/s. (i.e. If there were 120 squares under the curve then the change in velocity would be 24 m/s)

Total number of squares __________ Maximum Speed of the Gondola __________ m/s

2. Chart 3: Velocity versus Time Graph
   a. At what time does the graph indicate that the gondola begins to slow down? How does this time compare to the number that you got in 1d?
      ________________ sec
   b. The slope of a velocity versus time graph is equal to the acceleration?   Find the slope of the line between 0 and the point of greatest velocity.   Slope =rise/run = change in velocity/change in time.

      ________________ m/s2

      Why is this number not the -9.8 that you would expect from free fall?

   c. Between about 5 and 7 seconds, the velocity appears to be fairly constant.   Does this match what you see on the Chart 2: Acceleration versus Time (12 seconds)

   d. The graph changes its slope at 8 seconds. What does this mean?   Does Chart 2 explain what is going on?

   e. According to this graph, what is the maximum speed of the gondola?

      Maximum speed=__________________ m/s
      Maximum speed in miles/hour= m/s * 2.24 =_______________ mph
      How does this speed compare to the speed that you got in step 1g?

f. Does the straight section of the line between 3 and 5 seconds appear to be steeper or more gentle than between 0 and 3?

   Compute the slope, using the same technique that you used in step 2b. Does this match up with the acceleration on Chart 1 between 3 and 5 seconds?

   Slope=________________ m/s2.

g. The G Force experienced in the slowdown computed in step f can be computed by taking the slope (acceleration), dividing by 9.8 and then adding 1. What is the G Force, and how does it compare to the maximum G force that you computed in step 1e.

   G Force___________

Questions

1. Why does the gondola take so long (about 1 minute) to get to the top of the tower? Is it just to give you a view of the park?

2. Look at Chart 5: Elevator G Force. This elevator is going from a 2nd floor to a 1st floor. The elevator is dropping, but in a different way than Falcon's Fury.

   a. What is the G force experienced when the elevator stops at the bottom? How does the time of stopping and the G Force compare to Falcon's Fury?

   b. What is the minimum G force when the elevator first starts going down? How does the time of stopping and the G Force compare to Falcon's Fury?

   c. In addition to the observations above, how else are the elevator G Force graph different from Falcon's Fury? How is Chart 4: Elevator Velocity Graph different from Chart 3?

3. Describe your feelings when the Gondola was moving at a nearly constant velocity? (This happened while going up the tower, and also after the first braking coming down.)

4. How does estimate of drop time before rotation compare with your measurements made off the ride?

Problems

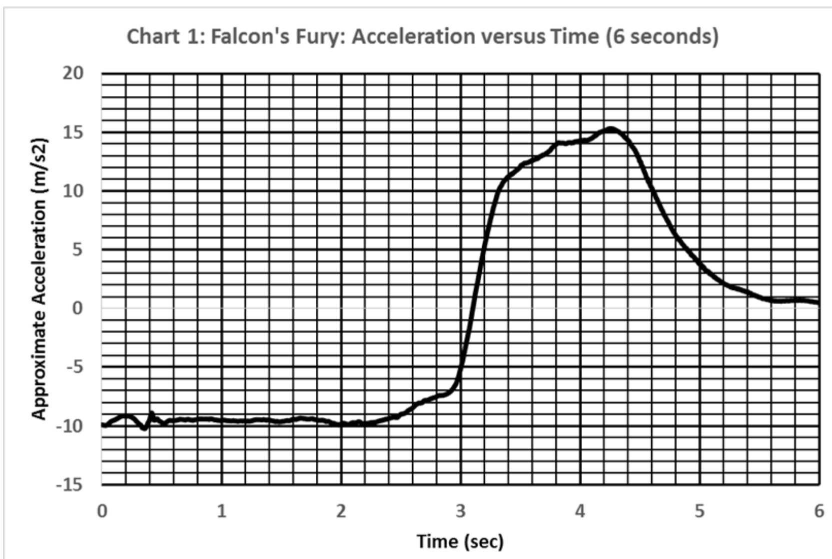
1. Compute the distance that the Gondola fell before the rotation occurred. Use the time that you measured off the ride. You can estimate that the acceleration of the gondola was approximately 9.8 m/s2.

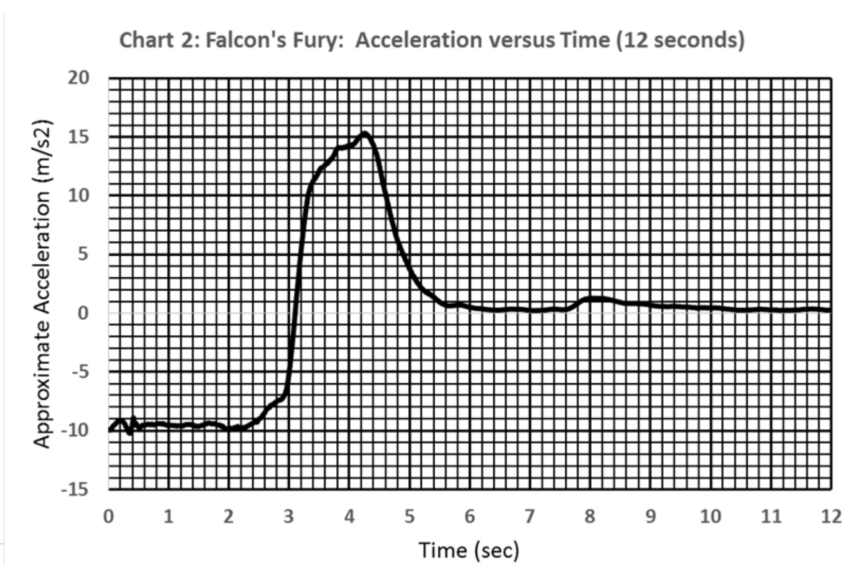
   Computed Distance = 1/2 at2= ___________m

   Compare this to your estimation of the falling distance obtained off the ride.

   Falling distance=Original height - Final height

   Why are these two distances different?





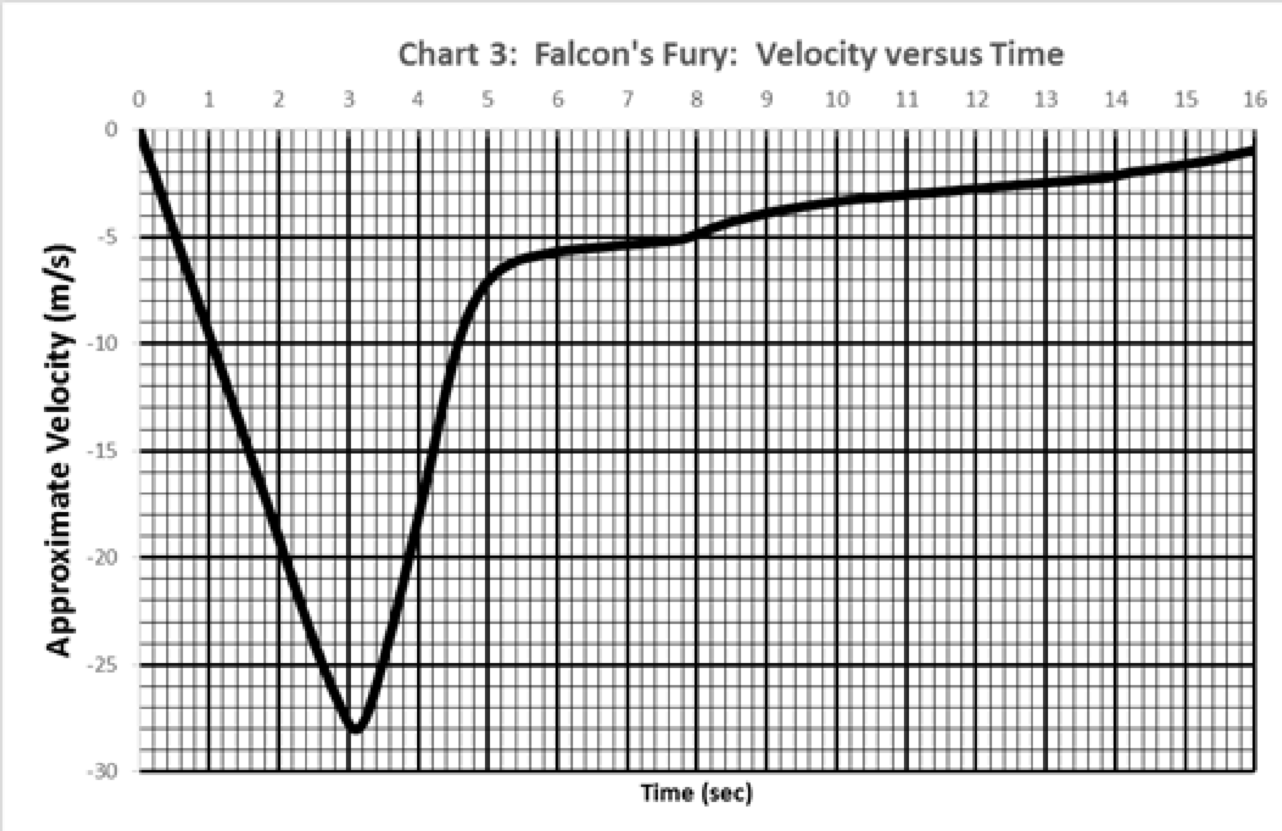


Chart 3: Falcon's Fury: Velocity versus Time
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
0
-5
-10
-15
-20
-25
-30
Approximate Velocity (m/s)
Time (sec)

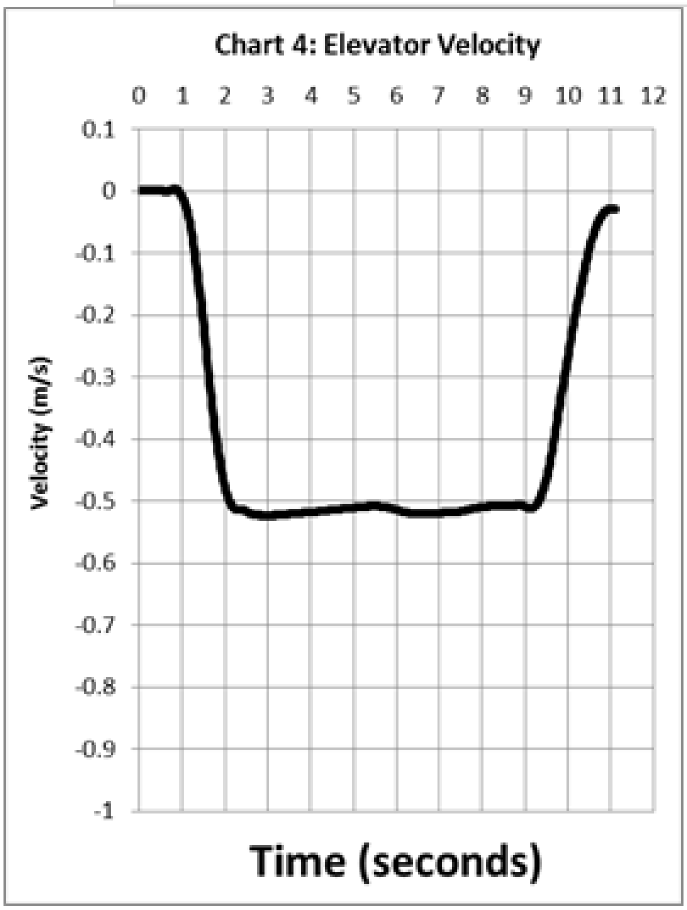


Chart 4: Elevator Velocity
0 1 2 3 4 5 6 7 8 9 10 11 12
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
Velocity (m/s)
Time (seconds)

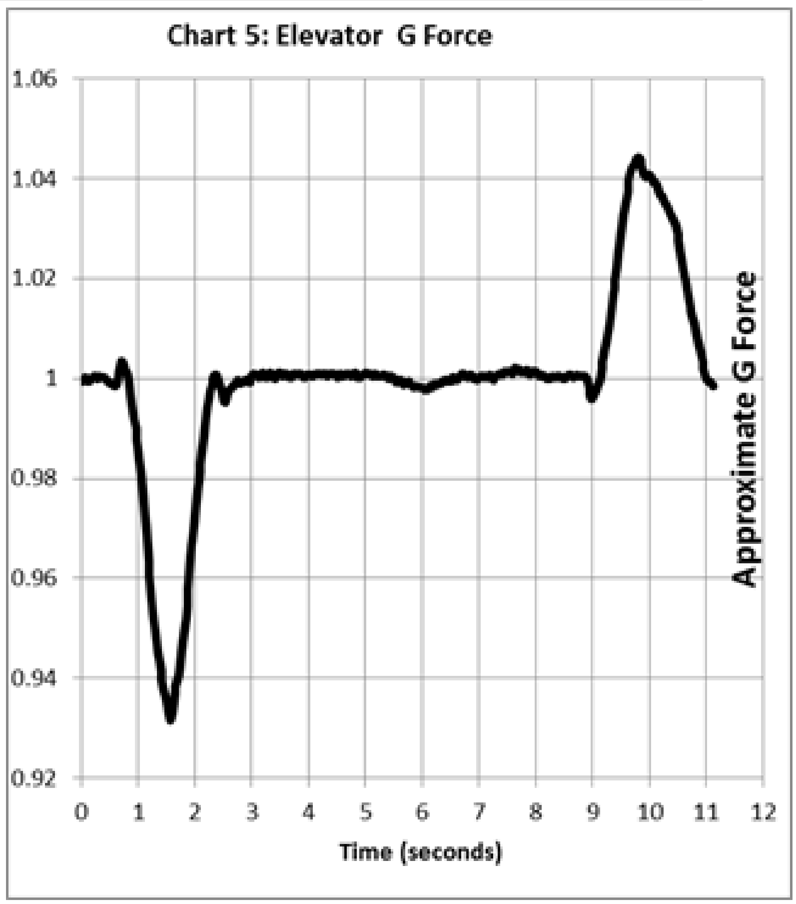


Chart 5: Elevator G Force
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0 1 2 3 4 5 6 7 8 9 10 11 12
Approximate G Force
Time (seconds)

COBRA'S CURSE: Basic

INSTRUMENTS REQUIRED: Stopwatch to use off the ride.

WHAT TO DO BEFORE COMNG TO THE PARK

Problems:

a. What is the velocity of a coaster train (m/s) that passes between two posts that are 40 meters apart in 2 seconds.

80 lm/s   20 m/s   38 m/s   1/20 m/s

b. When a ball is tossed at an angle, what path does it follow:

Hyperbola   Straight Line   Parabola   Ellipse

Predictions:

a. Will you feel close to "weightless" on Cobra's curse.

Yes, multiple times   Yes, but only once or twice   No

b. You will feel heavy (greater than 2.5 g's) on this ride many times. Where will this occur?

At the tops of the hills   At the bottom of the hills   Going up lift hills

WHAT TO DO ON THE RIDE

1. Pay attention to where you feel heavy and light. Especially note the point of greatest heaviness and the point of greatest "weightlessness".

2. If possible ride the ride at least twice, and note if the coaster car rotates differently each time. Make a note of how many people were in the car each time in front and back seats. You may also observe this from the ground.

3. Pay attention to the difference in riding forward, backward and in spinning.

WHAT TO DO OFF THE RIDE

1. Stand on the sidewalk at the bottom of the first hill. Measure the time that it takes a coaster's back wheels to go between points A and B. Do this three times. Post A is the support post just to the left of the sidewalk (marked by a white arrow below and on the previous page) and post B is on your right as illustrated. This distance is about 40 meters. The time will be somewhere between 2 and 3 seconds.

Data Table 1:

	#1	#2	#3	Average
Time of passage between Posts A and B				

2. Watch coasters go through the entire stretch of track. Make a note, if you see any hills that have the same shape as a ball tossed at an angle. These are sometimes called Camelback hills or air-time hills. If there are some of these hills, make a note of how many there are, and where on the ride they are located

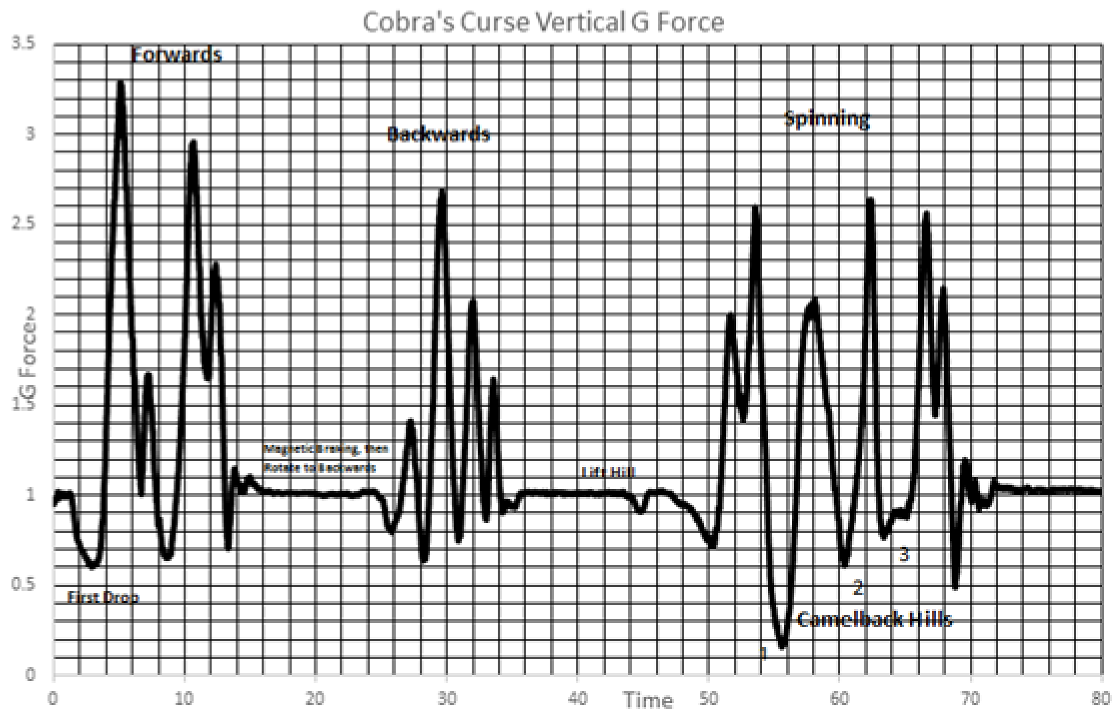
3. Find camelback hump hill #1. This is the first camelback hill after the second lift, and it goes over the sidewalk just after coming out of a trench. The two posts are 9 meters apart (indicated by the double arrow) Time the coaster passing between these two posts. The picture indicates the starting position, and the stopping position is when the front of the coaster reaches the second post. (This coaster is going from right to left. Coaster cars in this picture have simply rotated to be backwards.)

Data Table 2:

	Time #1	Time #2	Time #3	Average Time
Time between the two posts				

Questions:

1. A Vertical G force versus Time graph for Cobra's Curse Roller Coaster is included below.



a. How many times does the G Force dip below 1 G by at least 0.2G's.

b. What is the minimum G Force (closest to zero)?

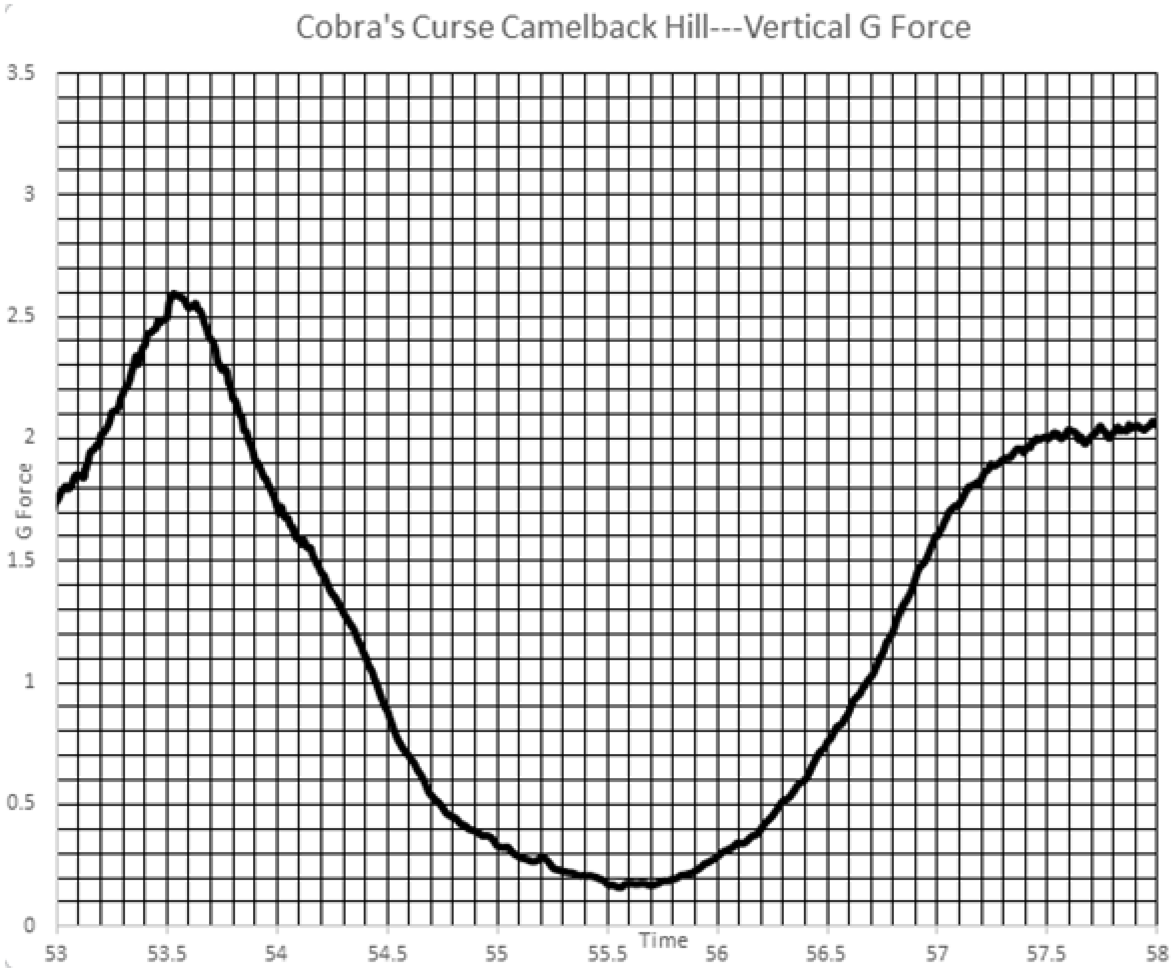
c. Where on the ride does the graph indicate the minimum G Force occurs? Does this match your experience on the ride?

d. How many camelback hills did you see on the ride? Do the locations of these hills match with the places on the graph where you were feeling light (less than 1 G).

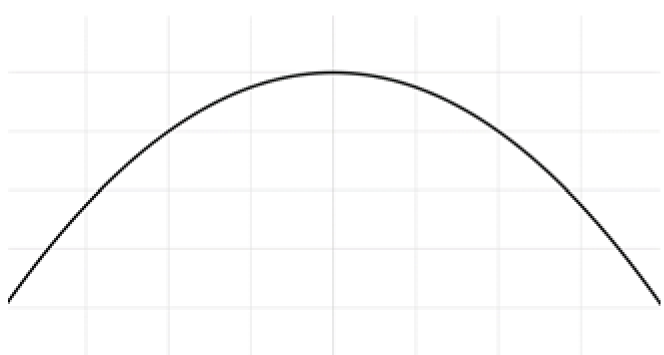
e. How many seconds (to the nearest 0.1 sec) does the coaster stay below 1 G on the Camelback hill that had the closest to 0 G? (See the expanded version of this part of the ride below.)

How many seconds does it stay below 0.5 G's.

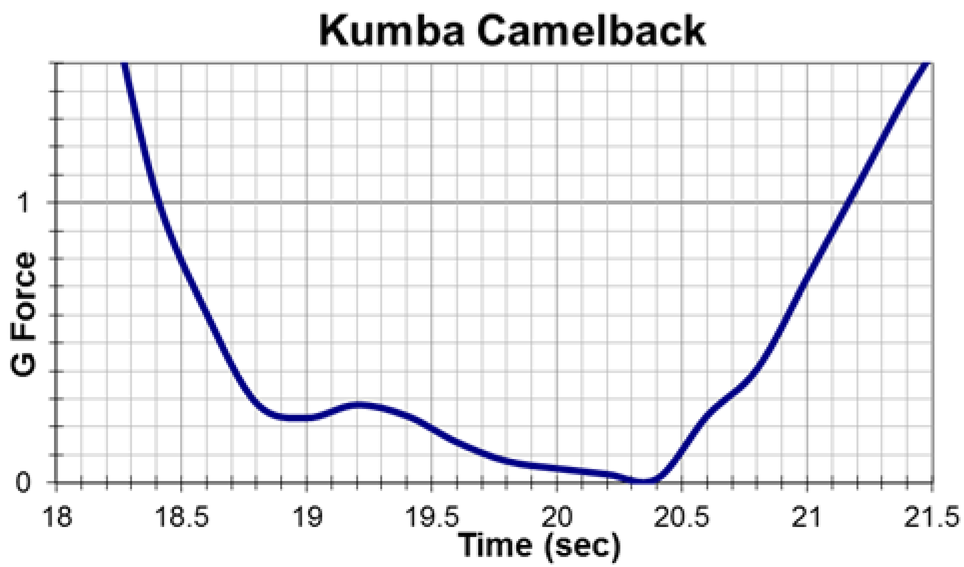
How long does it stay below 0.3 G's



f. Coaster enthusiasts call this feature, where you feel very close to weightless, a Camelback hill. The coaster track at this point in the ride looks very much like the mathematical figure illustrated below, which mathematicians call a parabola. A parabola is the natural path of anything that is just affected by gravity and no other force



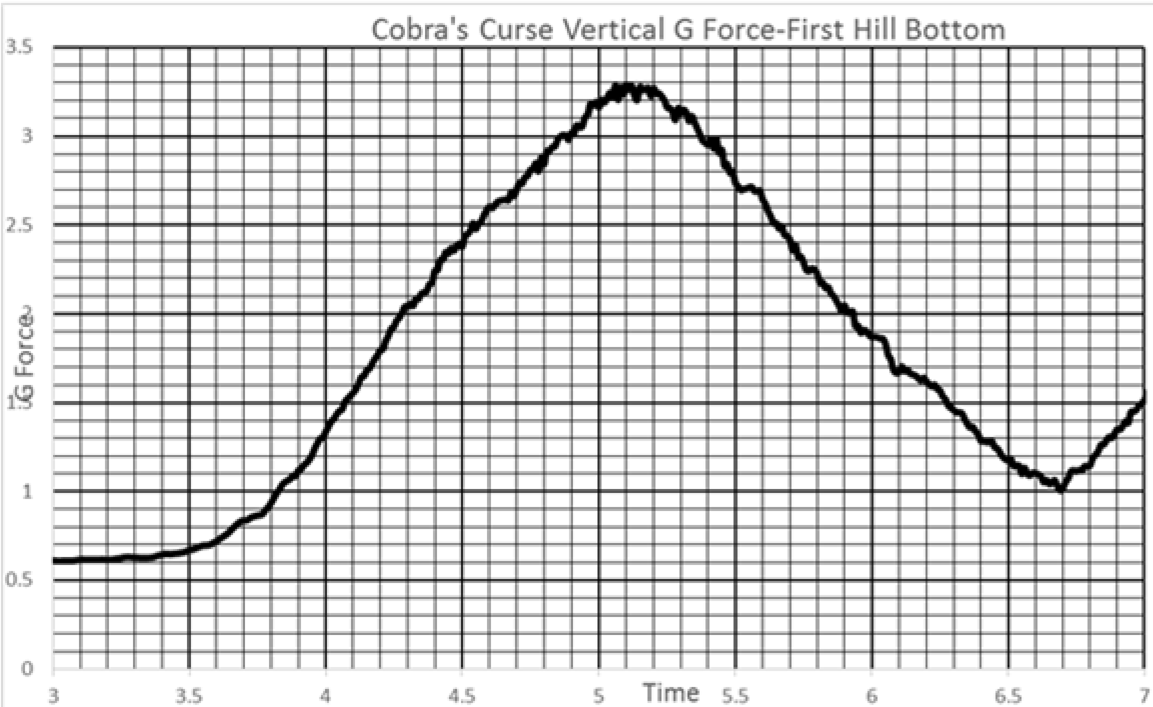
g. The G force for the camelback hill on the Kumba is illustrated below. How does it's G force and duration of low G's compare to that of Cobra's Curse?



g. The first drop of Sheikra and Cheetah Hunt have a G force very close to zero. Why doesn't the first drop of Cobra's Curse ever dip below 0.6 G's?

2a. Where on the ride does the graph of "Cobra's Curse Vertical G Force" indicate that you will feel the heaviest? Does this match with your feelings on the ride?

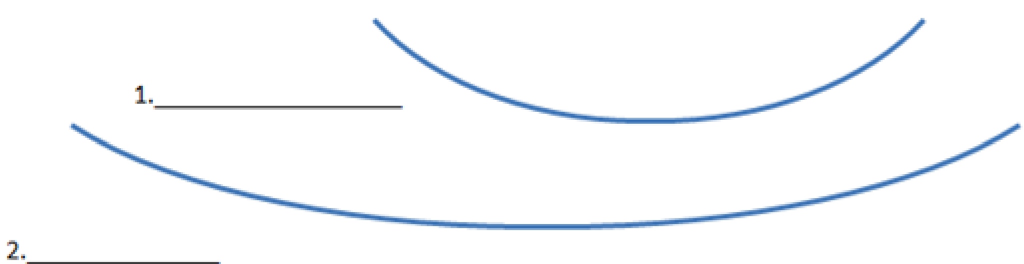
b. Using the graph below, find how many G's you experience there? Approximately how many seconds do you feel heavier than 2.5 g's? How long do you experience at least 2 G's?



c. According to the graph “Cobra's Curse Vertical G Force”, how many times do you feel greater than 2.5 G's. How does this compare to Sheikra and Montu?

3. This coaster is very different from the other coasters in the park, because you ride for about 1/3 of the ride forwards, 1/3 backwards and 1/3 spinning. Describe the differences in your experiences on each segment of the ride.

4. The coaster is also different, because the original lift is straight up, just like an elevator. This is how the coaster gains energy for the thrills of the ride. The first drop is only about 18.2 meters, compared to a drop of 42.7 meters on Kumba, and yet the G force at the bottom of the first hill is almost the same on both rides? It's because the curvature at the bottom of one of these rides is tighter or more curved than the other. Label the two graphs below of hill bottoms, Cobra's Curse or Kumba.



5. Based upon your observations while riding and/or watching others ride the coaster, do you think that the coaster cars always spin the same? If not, does it depend on how many people are in each car or perhaps something else?

Problems:

1a. Using Data Table 1, compute the average time for the coaster to pass between the two posts at the bottom of the first hill.   Now use this time to compute the average velocity of the coaster at the bottom of the hill. The distance between the two posts is 40 meters.

v = d/t=   40m/ _________=   _____________m/s

Compute this speed to miles/hour by multiplying the number of m/s by 2.24.

Average velocity at the bottom is ________________ mph.

The top speed at the bottom of the first hill is supposed to be 40 mph. Why is your number lower than that?

1b. The highest velocity of Cobra's Curse is much smaller than the 72 miles/hour top velocity for SheiKra at the bottom of its first hill.   Obviously, speed is not the only thing that produces thrills on a roller coaster.   What about Cobra's Curse makes it an exciting coaster?

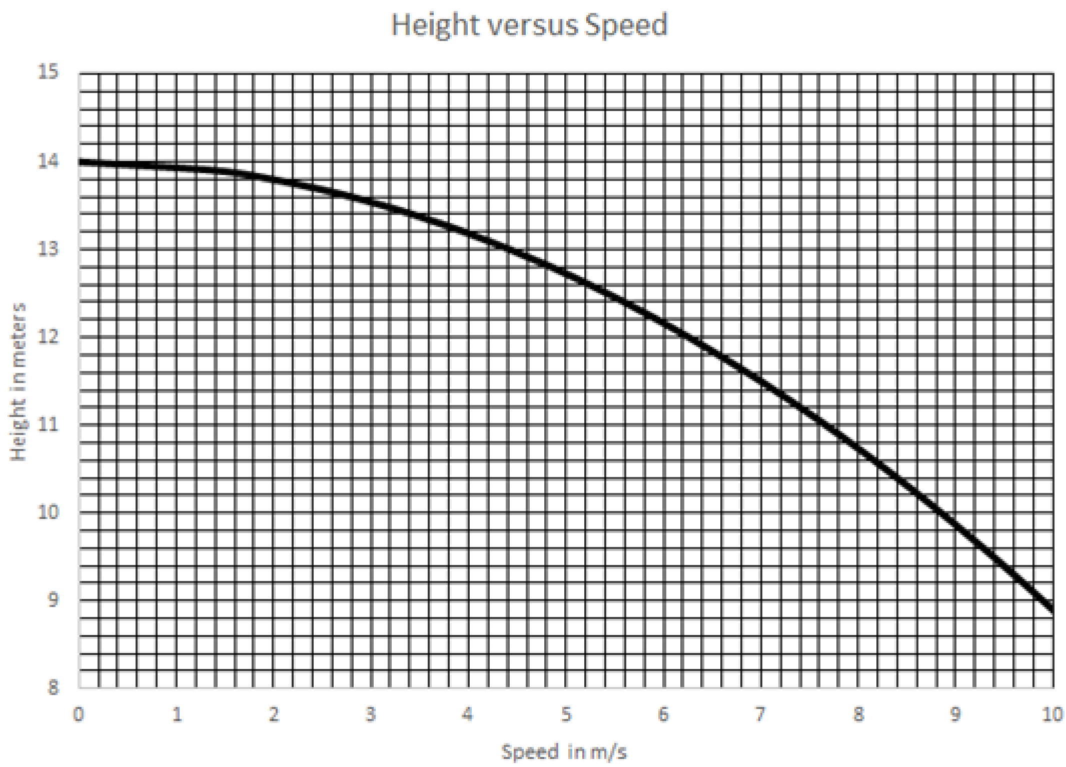
2.Using Data Table 2, compute the average time between posts on the Camelback Hill #1 and use this time to compute the speed at the top of this hill.

V=d/t= 9 m/ _______ =   _____________ m/s

Convert this to miles/hour by multiplying m/s by 2.24.

The average speed at the top of Camelback Hill #1 is ______________ mph

The Coaster gains energy by going up lift hill #2 which is about 14.0 meters above ground level. It then speeds up coming down the hill into the trench, then slows down when it goes up the camelback hill. The graph below indicates the speed the coaster should have at a particular height.   Use the graph to estimate the speed of the coaster at the top of the camelback hill, which is 11.7 meters above the ground level.



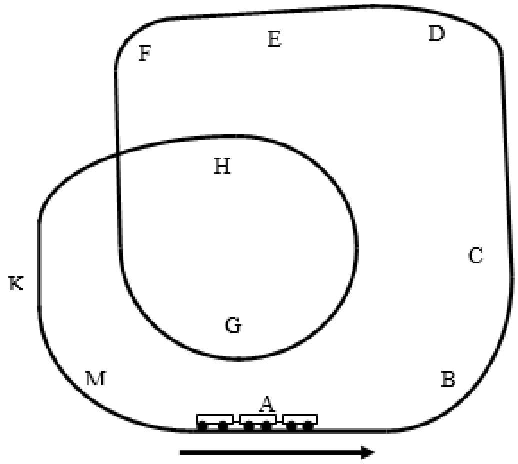
Speed at the top of the camelback hill, estimated with the aid of the Height versus Speed graph.

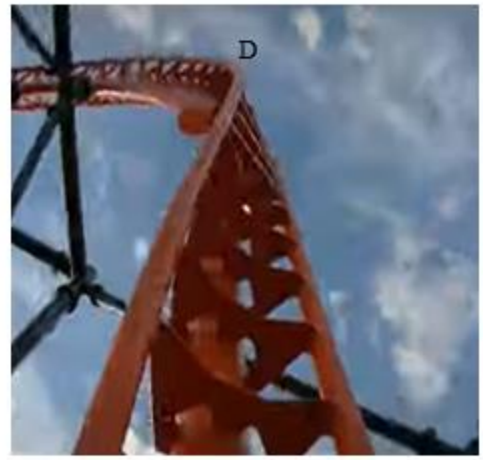
_____________ m/s

Why is your computed speed (using the stopwatch) lower that which is predicted by the graph?

Tigris-Advanced

Equipment Needed: None





WHAT TO DO BEFORE COMING TO THE PARK

Predictions: Circle your answers before riding the ride or making any measurements. Draw a line under your answer after you complete the questions and calculations.

a. Where will the greatest G Force occur (Heaviest Point)

B C G M

b. There are three places where you will experience a negative G Force? Which one of the following places does not have a negative G Force?

D E F G

c. What is approximately the highest speed on Tigris?

40 ph 50 mph 60 mph 70 mph

Problems:

Make these computations in preparation for coming to the park.

a. If the radius of a track at the bottom of the hill is 30m, and the G force is 3, what is the velocity of the coaster?

b. A launch coaster has a velocity of +10 m/s ⟶ when it arrives at one of the launches , but its acceleration is -4 m/s2 ⟵ (Remember that the direction of the acceleration is the same direction as the force that causes the acceleration.) It this coaster going to speed up or slow down?

What to do and notice on the ride.

1. Make a note of where you feel heavy, where you feel light (weightless) and where you feel a negative G Force where you lifted out of your seat.
2. How do the horizontal accelerations (magnetic launches) compare to each other.

3. Tigris is just 50 second long, but it really packs a punch. Prepare to rate you top three experiences in order. (i.e. Launches, negative g's, slow roll up top, zero g's, large g's, etc.)

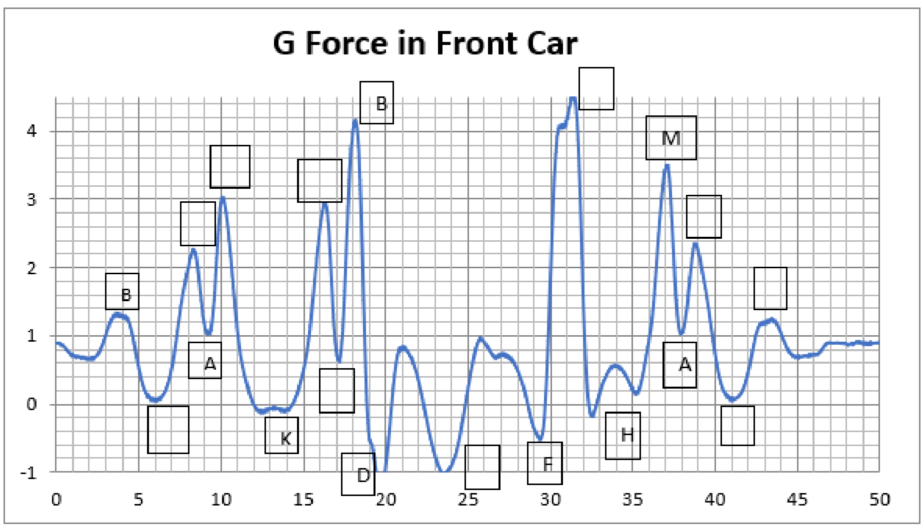
Pay attention to the various elements. You may want to ride twice, just to keep track.

What to do and notice off the ride.

1. Make a notice of what happens at point E. Point E is called a heartline roll, because you are rotating about an axis at approximately heart level. At point E will you feel weightless, experience -1g (a feeling that you are upside down and would fall out, if not for the excellent restraints), or something else. Are there points up top when you will be feeling 1 g or normal gravity, like standing in line?

Questions:

1. Label the graph below, of the G Force in the Front Car using the sketch of Tigris on the first page to find the "letters". Figure 1 is a graph of the vertical G Force versus time.



2. Whenever the coaster train passes through its original position on the horizontal portion of the track "A", the G Force is 1. Why is that? (The Chart below is a magnified portion Figure 1.)

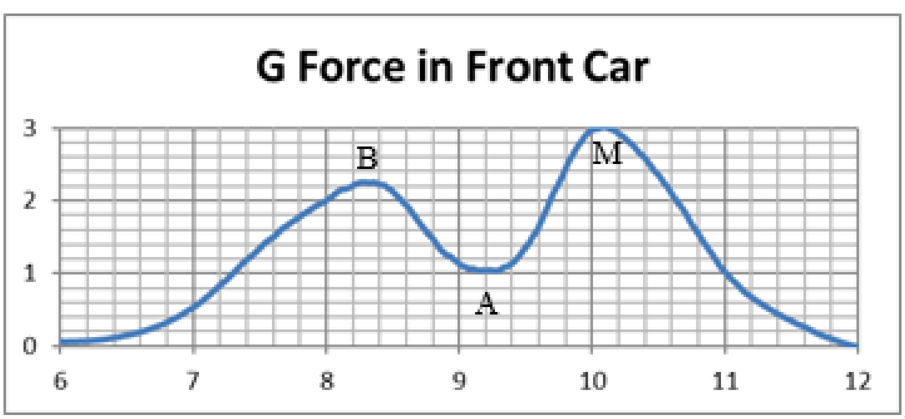


Figure 2

3. The maximum speed occurs approximately at point B, after the third launch. The radius of the track at that point is approximately 23 m. What is the G Force at that point, according to Figure 1. ___________ Using this G Force, Compute the speed of the coaster G Force=v2/rg + 1

   v= ______________________

4. The G Force at point G is greater than at point B, even though the speed is lower (it is higher up, and friction has robbed the train of speed by this point as well). Why is that? (Hint: the equation for the G Force in this situation is G Force=v2/rg +1).

5. In general, at what points on the ride did you feel heavy? Why did you feel heavy at those points?

6.
   a. There were three types of experiences on this ride that made you feel close to zero, or negative g's. What were they?

   b. On Cobra's Curse there is basically only way to have a near zero g experience. What is that?

7. Other than the experiences at the top at slow speed, at what point do you feel weightless for the longest period of time? What does the chart indicate for the time at zero g's. How would you describe your experience? (Note: several other places on the ride are close to zero for a period of time, but not nearly as consistently zero.)

   T=________

8. Why are there three launches to get to the top, instead of just one launch? Couldn't they just have designed it to have a single more powerful launch? (The picture to the right shows the magnetic launch track, which is in white. It's called a Linear synchronous Motor)

9. How do the G Forces compare to the larger coasters in the park?

10. Do you feel upside down, when you are upside down on Tigris? How does this compare with being upside down on Sheikra, Montu, Kumba? Why are these upside down experiences so different? How about the Heartline Roll on Cheetah Hunt?

11. Rate your top 3 experiences on Tigris, in order of preference. Include the details

12. How did the acceleration of the five launches compare to each other? The higher the Horizontal G Force, the greater the acceleration and the more force you will feel. You can find the Horizontal G

Force of the five "launches" by examining the Horizontal G Force versus time graph (Figure 3). The times of the launches are indicated by the arrows on Figure 3. This G Force is only easy to read off the graph at times where the coaster is moving in the horizontal direction, which it is doing during all of the launches. (The graphs underneath the main graph are close-ups of the second and the fifth launch, just to show that the G Force was approximately the same for a period of time, and not just at one point, as it appears to be in Figure 3). Record them to the nearest tenth (i.e. +0.3, -0.5, etc.) These magnetic launches will either be speeding up the train or slowing it down.

	Launch 1	Launch 2	Launch 3	Launch 4	Launch 5
Velocity	→	←	→	→	←

If the velocity and acceleration have different signs, then it is slowing down. If the velocity and acceleration have the same sign then it is speeding up. The acceleration is always in the same direction as the force that causes it.

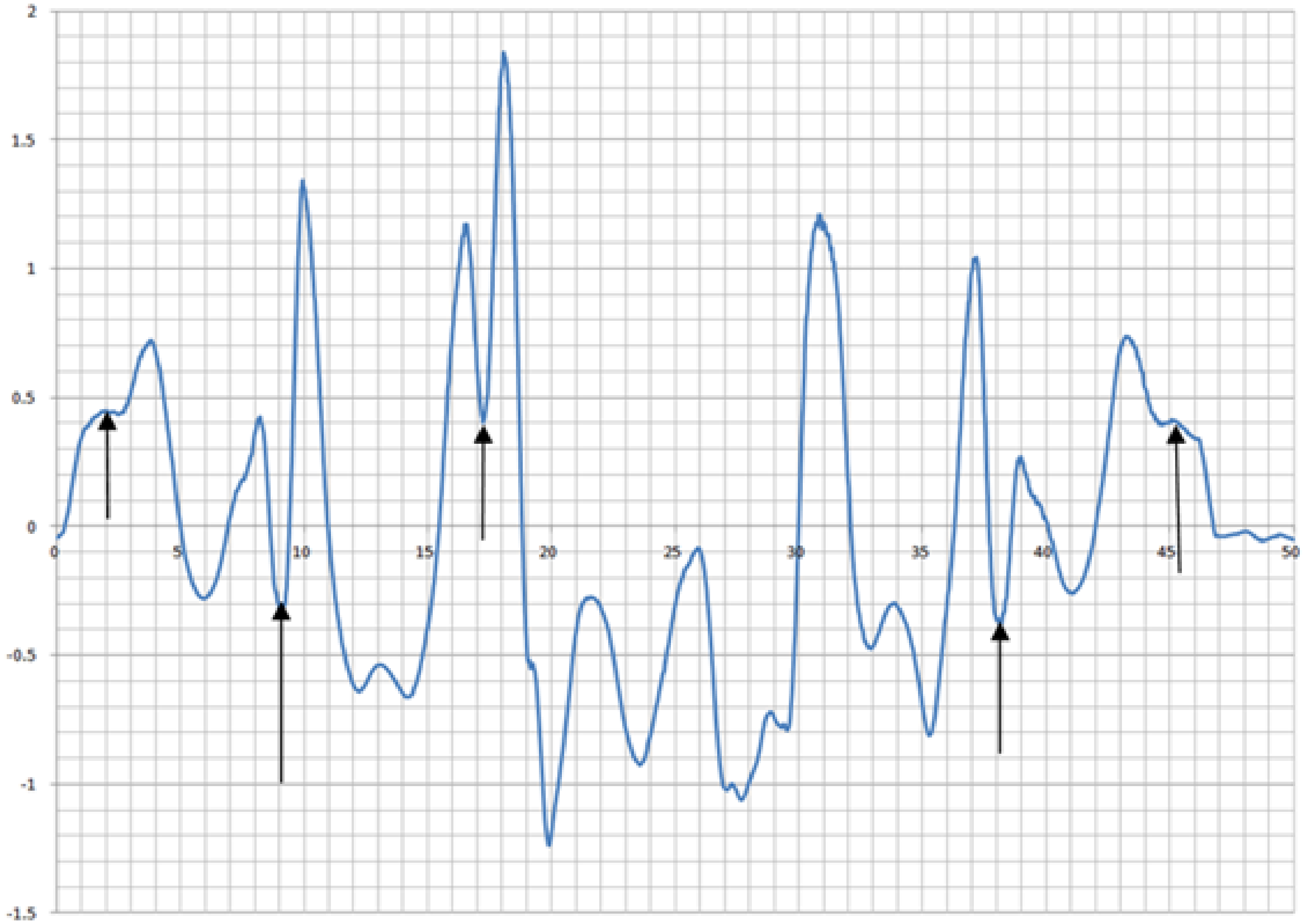
The first three launches are speeding up the coaster and the last two are slowing it down. Does the data verify that is what is happening?

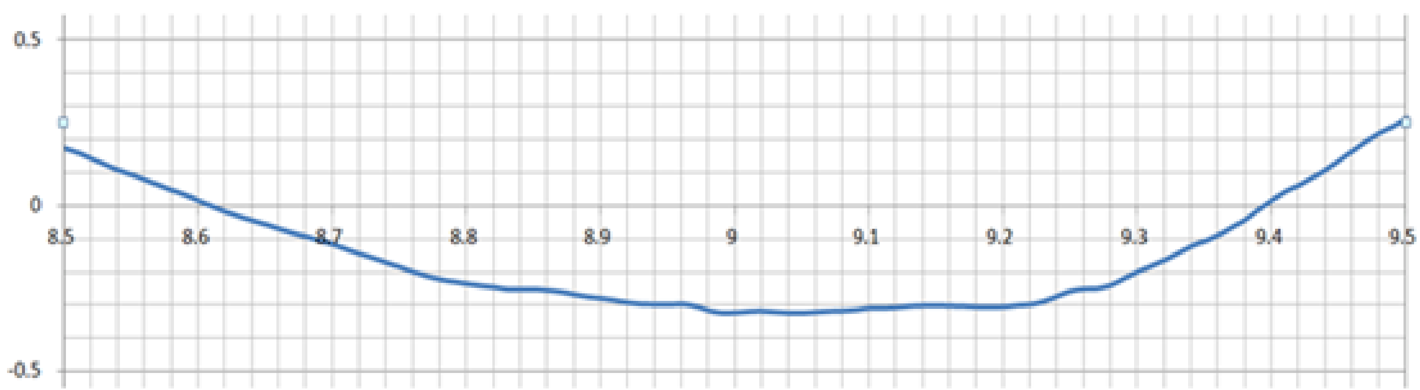
(Examples: Speeding up v → a → v ← ← a
Slowing down v → ← a ← v → a)

If you have been on Cheetah Hunt, compare the value of these accelerations to the second and third magnetic launches on Cheetah Hunt. (Note: These two launches have a maximum of about 0.7 g's. These launches don't take place with a constant acceleration, so the average G force on the on Launches 2 and 3 is both about 0.5 g's.)

Figure 3 Horizontal G Force versus Time

Launch 2





Launch 5

Iron Gwazi-Basic

Instruments: none

90 Degree banking Angle at a Hilltop.

WHAT TO DO BEFORE COMING TO THE PARK

Predictions (Circle your answers before coming to the park and riding the ride.)

a. How will you feel if you were riding in the coaster car on Iron Gwazi pictured above?

Weightless   heavy   like you will fall down

b. When will you feel heaviest on Iron Gwazi (circle all that apply)

at the top of the hills   at the bottom of the hills   horizontal turns at high speeds

c. The G forces along the way in the ride

are consistently strong throughout the ride   start strong and get weaker as the ride progresses.

become stronger near the end of the ride.

2. View the Coaster: Bring up “Iron Gwazi POV” on a computer browser and watch it a couple of times.

There are two graphs at the end of this Iron Gwazi workbook section. They are “G force” versus time for row 1 of Iron Gwazi and row 12 of Iron Gwazi. The Hill tops are labeled A through K and the Hill bottoms are labeled 1 through 12. 1 is the bottom of the first drop, and A is the hill top following the first drop. G is called a Zero –g stall, and it is the place where you are upside down for a period of time. D is the hilltop close to the ride station (the track dips under the lift hill just after D). B is the Hill that ends with a corkscrew coming down.

What to do on the ride

1. Estimate how long are you upside down in the zero-g stall.
2. Where do you feel weightless for the longest period of time?

3. Ride in the front car and near the last car and describe the differences.

4. In general, where do you feel heavy over the course of the ride?

5. Pay attention in particular to how you feel on the 91 degree first drop, when you are in the overbanked turn at the top of the first hill after the big drop (A), the overbanked turn on the third hill (C), the wave turn on the fourth hill (D) banked at 90 degrees, and when you are upside down in the zero-g stall (G).

Definitions: A zero-g stall, is an inversion where the track twists 180 degrees during ascent, and at its crest, remains inverted for a short section of track. It then twists another 180 degrees during descent, usually in the opposite direction of the initial twist. An overbanked turn is a turn or curve in which the track tilts beyond 90 degrees, usually in the 100-120 degree range. (Note: it isn't considered an inversion unless the angle is more than 135 degrees.) It is sometimes included at the top of a camelback hill, which is the case in several of these hills.

Questions:

1.Use the graph of row 1 to answer the following questions:

a. How many times does the graph indicate that the G force is above 3 g's. Where on the ride do you experience these heavy times (Options: Hill tops, Hill bottoms, horizontal turns at high speed).

b. How does this number of very heavy times compare to other coasters in the park.

c. On the average, how far apart are these heavy times. Do this for the entire ride, and for the period between heavy times 5 and 12.

d. What is the time on the Row 1 graph, between the first drop low point, and peak 12. Count the total number of peaks(High G force) and valleys (apparent weightlessness). Include the starting and ending points in this time interval. What is the average time between events (G force to weightlessness, or vice versa)

e. How does you answer to c and d add to your appreciation for the intensity of the ride.

2. Let's assume that a G force of less than +0.5 would feel close to a weightless sensation. A G force of-1 would actually feel like you are motionless and upside down, or like you are being pulled out of your seat. For purposes of this question, please include all events that go below a G force of + 0.5 as being a weightless sensation. This weightless sensation is sometimes called "air time". Use the Row 1 graph to answer the following questions.

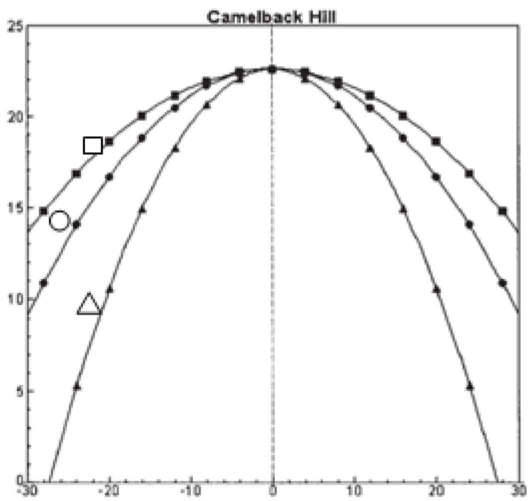
a. What hilltop has the longest weightless sensation? Did this match your experience on the ride? What four other places on the ride had significant "air time" of about 2 seconds?

b. What was your feeling on the first drop at 91 degrees?

c. Which Hilltops have the greatest feel of negative g's?

d. According to the graph, how many times on the ride should you experience the weightless sensation. Will some be more intense than others? What were your experiences?

3.The perfect shape of a hill for zero g's would be a parabola, with the actual of parabola depending upon the speed of the coaster. This is because the natural path of an object (baseball, football, etc.) ,when only gravity acts, is a parabola. The graph below shows three parabolas with the vertical and horizontal axes measured in meters.



a. Which of these graphs represents a hill for the fastest coaster (circle, square or triangle)

b. If a coaster was going faster than the shape designed for that speed, and if it had wheels that constrained it to follow the track, like Iron Gwazi does, what would be the results:

Riders would still feel weightless Riders would feel heavy Riders would experience negative g's

c. Going faster than the shape for zero g's is done on purpose. It provides a special kind of thrill. How many of the hill tops on the Row 1 graph have significant negative g's (less than -0.5 g).

d. How many on Row 12 have significant negative g's.

4.The coaster is called a hybrid coaster, because the main structure is made of wood, but the track, what is underneath the track, and some structural supports are metal. About 25 % of the structure and 75 % of the foundations are from the old Gwazi. Most of the structure is wood, except in the case of the lift hill, where it is pretty much all metal. A 206ft tall lift hill, would certainly require a serious amount of wood. The wood is Pressure Treated Southern Yellow Pine. It is strong, stiff and dense. This is a very common variety of treated wood. It is also a very common choice for the constructing of roller coasters, because its strength to weigh ratio is very high. Even though it is a "softwood", because it is from a conifer, it is exceptionally dense. It also take pressure treatment better than many other woods, and this is critical to help it withstand the elements (rain, snow, wind). Density=m/V and it is measured in kg/m3. The density of water is 1000 kg/m3.

a. To find the density of SYP, you can measure a sample. I bought a 1" x 4" x 6' SYP treated board. It is actually 72.125" long, 3.625" wide and 0.75" thick. I measured the board to have a mass of 1.790 kg. What is the density of the board?

Note: You will need to find the number of cubic inches of this board, convert cubic inches to cubic meters, and then find the density. (1"= 0.0254 m, so cubing both sides indicates that 1 in3= 0.0000164 m3)

b. How does it compare to other softwoods?

Douglas Fir 410 kg/m3 White Pine 340 Spruce 370

c. How does it compare to hardwoods (from deciduous trees)

Maple 570 Black Oak 560 Black Walnut 510 Cherry 470

5a. Several Hilltops have the track banked between 90 and 135 degrees. These banking angles occur at or near the top of hills A,C,D and F. How did you feel on the ride at these points?

A

C

D

a. Generally, banked turns on roller coasters produce a G force of 2 or more g's. Why do you feel weightless on these hilltops with the big banking angles? What is going on? (Hint: What is the shape of these hills? What is the shape of an "airtime "or weightless hill?) Does the graph of coaster Row 1 confirm this feeling?

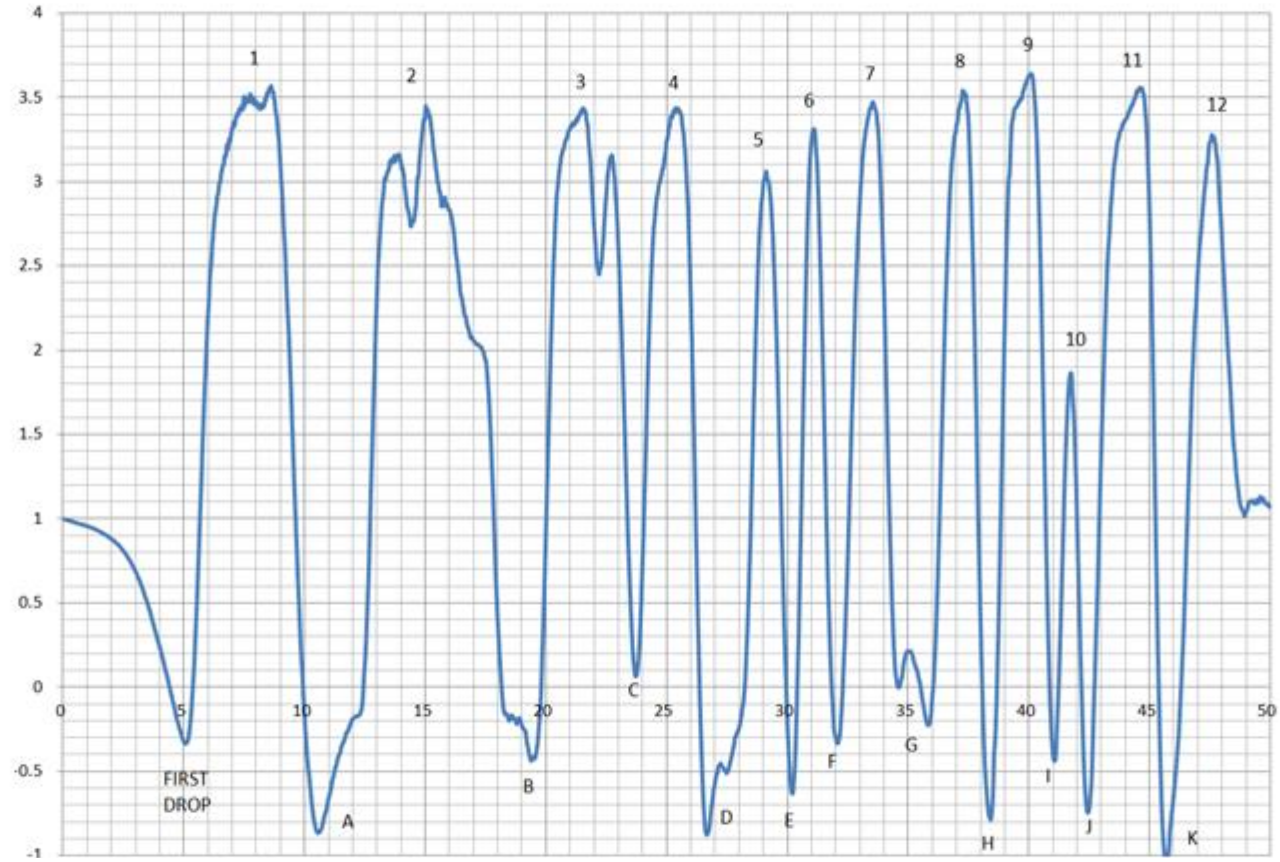
b. How long were you upside down on the zero-g stall? What was your feeling when you were upside down in the zero-g stall? (This is "G" on your graph and it also occurs on a parabolic hill) Does your answer to question 4b also explain these phenomena, and does the graph confirm that your feeling was correct? What would be the G force of the upside down segment happened on a horizontal track?

6. According to the G Force graphs, the first drop time is different for rows 1 and 12. (This is the time for when the G force starts to drop, until it reaches it smallest value.) List the times of each drop, and explain why there is such a difference.

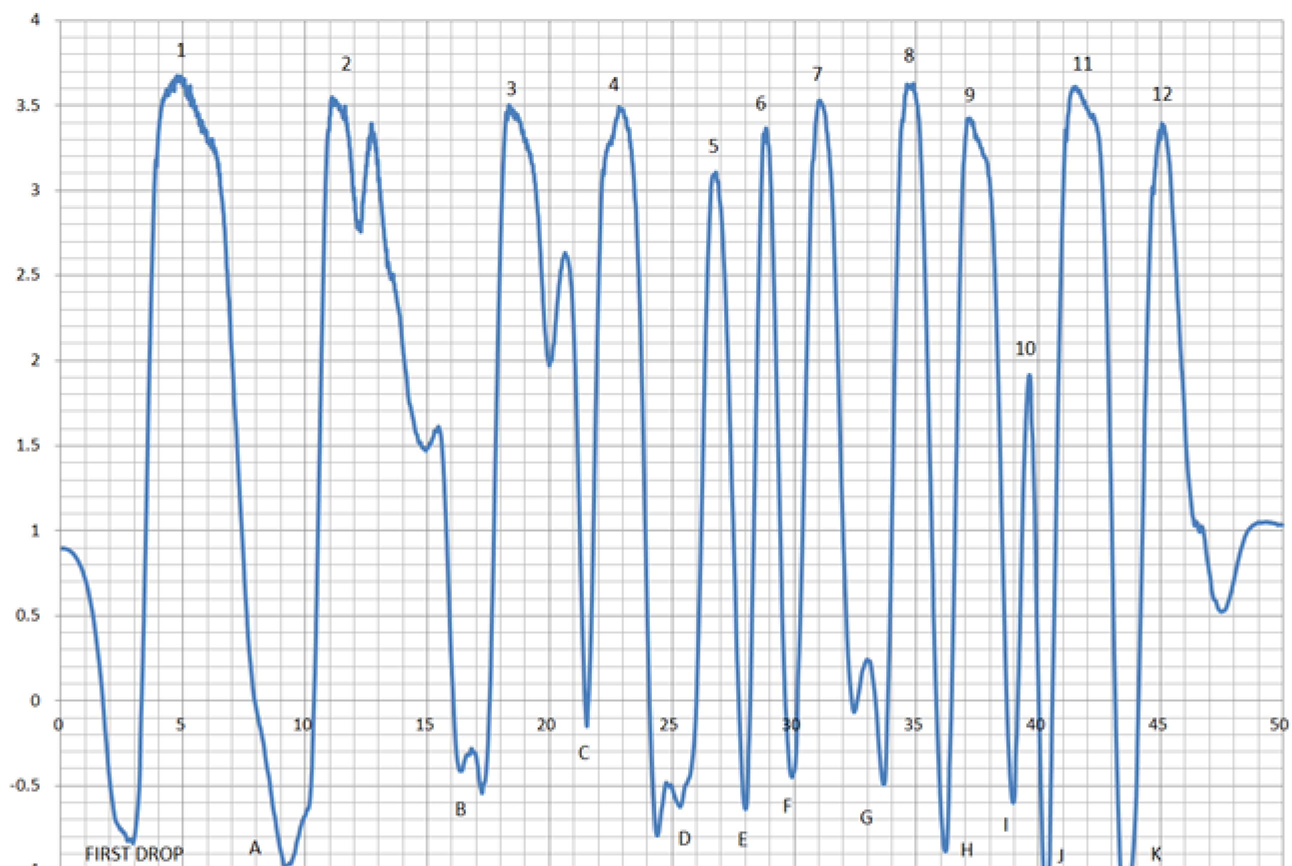
7. a. Check the graphs for Row's 1 and 12 and list some of the differences between Row 1 and Row 12

b. If you rode close to the front once and then in close to the back, describe which differences you experienced and note if these differences are seen in the graphs.

Iron Gwazi Row 1 G Force versus Time



Iron Gwazi Row 12 G Force versus Time



Iron Gwazi: Advanced

INSTRUMENTS REQUIRED: TO BE USED OFF THE RIDE! Stopwatch or Cell Phone Stopwatch, Protractor with hanging weight or free cell phone protractor app (i.e. Rigid Level , iLevel, etc.)

First Hill after the Big Drop (A)

WHAT TO DO BEFORE COMING TO THE PARK

Predictions (Circle your answers before coming to the park and riding the ride.)

a. How would you feel if you were riding a coaster at the top of the hill pictured above?
   Weightless   heavy   like you will fall down   1 g-Normal
b. When will you feel heaviest on Iron Gwazi (circle all that apply)
   at the top of the hills   at the bottom of the hills   in horizontal turns at high speeds.
c. The G forces along the way in the ride
   are consistently strong throughout the ride   start strong and get weaker as the ride progresses.   become stronger near the end of the ride.

Problems (Complete these problems in preparation for coming to the park.)

a. If an 18 wheel truck, which is 22 m long, takes 1.5 seconds to pass by you on the street. How fast is it going?
b. If you experience 3.5 g's at the bottom of the hill, and the speed of the coaster is 30 m/s, what is the radius of curvature of the track?
c. If a coaster car is traveling at 34 m/s at the bottom of the first drop, and then near the end of the ride, the coaster 3 m above the level of the first drop and has a speed of 17 m/s, what fraction of its initial energy has it lost.

There are two graphs at the end of this Iron Gwazi workbook section. They are "G force" versus time for row 1 and for Row 12 of Iron Gwazi. The Hill tops are labeled A through K and the Hill bottoms are labeled 1 through 12. 1 is the bottom of the first drop, and A is the hill top following the first drop. G is called a Zero –g stall, and it is the place where you are upside down for a period of time. D is the hilltop close to the ride station (the track dips under the lift hill just after D). B is the Hill that ends with a corkscrew coming down.

View the Coaster: Bring up "Iron Gwazi POV" on a computer browser and watch it a couple of times.

WHAT TO DO ON THE RIDE

1. Pay attention in particular to how you feel on the 91 degree first drop, when you are in the overbanked turn at the top of the first hill after the big drop (A), the overbanked turn on the third hill (C), the wave turn on the fourth hill (D) banked at 90 degrees, and when you are upside down in the zero G stall (G).
   Definitions: A **zero-g stall** , is an inversion where the track twists 180 degrees during ascent, and at its crest, remains inverted for a short section of track. It then twists another 180 degrees during descent, usually in the opposite direction of the initial twist
   An **overbanked turn** is a turn or curve in which the track tilts beyond 90 degrees, usually in the 100-120 degree range. (Note: it isn't considered an inversion unless the angle is more than 135 degrees.) It is sometimes included at the top of a camelback (parabolic) hill, which is the case in several of these hills.

2. Where do you feel weightless for the longest period of time?
3. Ride in the front car and near the last car, and describe the differences.
4. In general where do you feel heavy over the course of the ride?

WHAT TO DO OFF THE RIDE

1. Measure the time it takes for the coaster train to pass the top of the first hill (A) after the first drop. This will be used to find the coaster speed. This is visible between the Cue Entrance (labeled Iron Gwazi) and the Watering Hole refreshment shop to the left of the entrance. This is called a "time of passage" Make at least three-time measurements (You can also use measurements used by your classmates.)

2. Measure the time of passage of the coaster train as close to the top of the 4th hilltop (D) as possible, as it passes behind Iron Gwazi sign #2. (Iron Gwazi sign #1 is where the cue line starts. Iron Gwazi sign #2, which looks the same as #1, is to the right of the other sign. It is just to the left of the lift hill and closer to the Zaroga Café.) Make three measurements.

3. Measure the time of passage of the coaster past some point on the lift hill, in order to find the speed of the lift hill chain.
   Note: When you are working with speeds in m/s, and you want to get a better idea of how "fast" that it is in terms that you can relate to, you can change the speed from m/s to miles/hour by multiplying by 2.24.

4. Measure the angle of the top of the lift hill with a "protractor" or electronic level, from close to the fence surrounding the ride. You will be close to Iron Gwazi sign #2. Now walk back toward the lockers, counting the number of steps. Get as close to the lockers as you can and still see the top of the lift hill. Measure the angle again at this new distance. (Note: If you don't know your stride length, you can measure it by pacing the distance along the fence, between the gate to your right and the first lamp post. The distance is 20.5 meters. (Number of feet along the fence)/(number of steps)=Stride length Make the angle measurements more than once to ensure that they are "correct" . You may also compare with a classmate.


Gate


Lamp post


Lockers

	Time 1	Time 2	Time 3	Average
1.Hilltop A				
2.Hilltop D				
3.Lift Hill				
	Stride Length	Number of Steps	Distance	Angles:near&far
4. Height				

Questions:
(Note Questions 1 and 2 are the same questions that are found on Iron Gwazi Basic workbook pages.

1. Use the graph of row 1 to answer the following questions:
   a. How many times does the graph indicate that the G force is above 3 g's. Where on the ride do you experience these heavy times (Options: Hill tops, Hill bottoms, horizontal turns).
   b. How does this number of very heavy times compare to other coasters in the park.
   c. On the average, how far apart are these heavy times. Do this for the entire ride, and also for the period between heavy times 5 and 12.
   d. What is the time on the Row 1 graph, between the first drop low point, and peak 12. Count the total number of peaks(High G force) and valleys (apparent weightlessness). Include the starting and ending points in this time interval. What is the average time between events (G force to weightlessness, or vice versa)
   e. How does you answer to c and d add to your appreciation for the intensity of the ride.

2. Let's assume that a G force of less than +0.5 would feel close to a weightless sensation. A G force of-1 would actually feel like you are motionless and upside down, or like you are being pulled out of your seat. For purposes of this question, please include all events that go below a G force of + 0.5 as being a weightless sensation. This weightless sensation is sometimes called "air time".
   Use the Row 1 graph to answer the following questions.

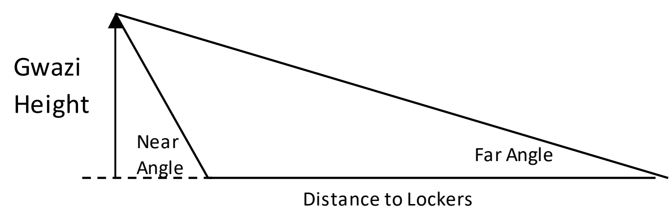
   a. What hilltop has the longest weightless sensation? Did this match your experience on the ride? What four other places on the ride had significant "air time" of about 2 seconds?
   b. What was your feeling on the first drop at 91 degrees?
   c. Which Hilltops have the greatest feel of negative g's?
   d. According to the graph, how many times on the ride should you experience the weightless sensation? Will some be more intense than others? What were your experiences?

3. How does the velocity at the hilltops through the ride vary? Use hilltops A,C,D and K to help answer this question. Use your measurements of the time of passage at hilltop A and D to find their speed. You may also use data from other groups to help answer this question. The time of passage on Hill top C is 0.66 sec and the time of passage of hilltop K (the last hilltop) is 0.84 sec. The length of the coaster is 13.45 meters.
   a. What speeds did you find for the four hilltops? Speed=(Length of coaster)/(time of passage)

b. Does you result help describe why the coaster feels so relentless in its journey, never seeming to slow down. How do they manage to keep the coaster speed fairly constant on hilltops?
c. Two of the hill tops are slower than the other two. Which two and why?

4. Using your measurements of the time of passage on Hilltops A and D and on the lift hill, find the speed of the coaster at these hilltops and on the lift hill. Using 0.66 sec as the time of passage at hilltop C, find the speed there. Then using the heights of these hills above the bottom of the big drop, and their speeds at these points, determine what percentage of the initial energy was lost (actually converted into heat) by the time the coaster reached the top of A, C and D. Coaster Length= 13.45 m. Distances above the bottom of the big drop:
Lift Hill=206 ft Hill A=148 ft Hilltop C= 93 ft Hilltop D= 62 ft
The reference for initial energy will be the combination of the kinetic energy and potential energy at the top of the lift hill, with the lift hill speed being used to find the KE.
Note: Height in ft * 0.3048 m/ft =Height in meters

5. Find the height of the lift hill above the base by using your angle measurements and distance between measurements. Compare it to the actual height of 203 ft (61.9 m) above the baseline (the baseline is the same as the level from which you make your measurements). The lift hill is 206 ft tall, because there is a 3 ft trench dug at the bottom of the first drop)

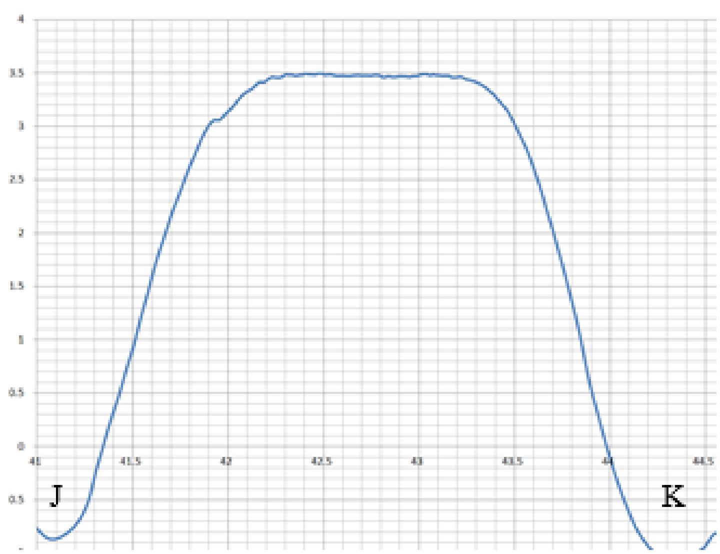


You can draw a scale diagram to find the height of the lift hill. Example of a Scale Drawing: If your distance to the lockers is 30 m, you can draw a diagram with a triangle with the same angles that you measured, and a baseline that is 10 cm, based on a scale of 1 cm of drawing= 3 meters in the real world. (Note: You can pick any scale you wish, that will allow the scale diagram to be big and still fit on the paper.)

If your Gwazi height on your drawing= 19.6 cm, then you would use the proportion the scale that 1 cm=3m to find that the actual height of the coaster was 19.6 cm x (3m/1cm)= 59 m. (Indicate to the nearest meter) Once you find your "answer" by using your scale drawing, you must add in your own height (distance from the ground to your eyeballs), since you are making the measurements standing up.

You can also use trigonometry if you wish. It involves the Law of Sines (A/Sin (a)= B/Sin(b)) and the definition of Sin function (Sin (c)=Opposite /Hypotenuse) You will also use the fact that all of the angles of a triangle add up to 180 degrees, and use the principle of supplementary angles.

6. After the Zero-G Stall, there are several sweeping turns that are roughly horizontal. Between Hilltops J and K, there is a circle of radius 12.3 m. It is labeled "11" on the graph. At the location of the white dot, the speed is about 19.8 m/s. Elsewhere on the coaster, steep banking angles have been used to create thrills at hilltops where the G force is close to 0 because they occurred on parabolic hills. In these horizontal turns, however, these banking angles prevent large lateral movements. Passengers will be pressed into their seats and feel heavy, as opposed to being thrown to the left or right.
    a. What is the banking angle is this turn? Is this bigger or smaller than the banking at Hilltops C and D?
    b. What G force is created in this turn? How does this match the G force found on the graph of Row 7 (below)?



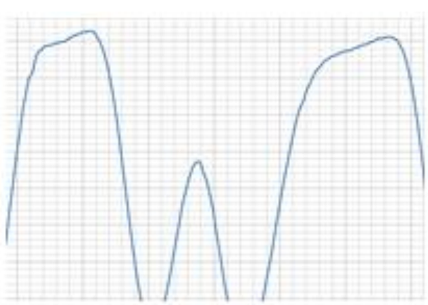
Graph of G Force versus Time from Row 7

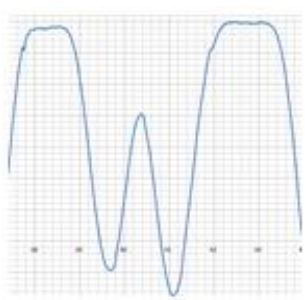
The horizontal section of the graph shows that the speed and radius of the turn were fairly constant

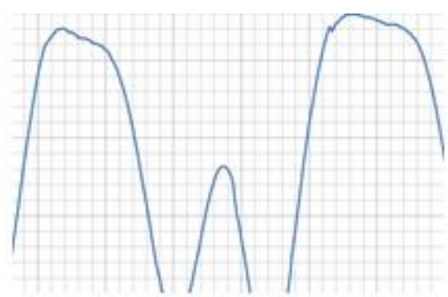
Equations for banking angle in a turn: Tan (angle) = v2/rg G force = 1/cos (banking angle)

7. Using the graph of Row 1, find the radius of the track at the bottom of the hill. Here you can assume that the speed of the coaster at the bottom of the hill is 76 miles/hour, which you will convert to m/s. What would the radius of the track be, if you wanted to have a less intense coaster with just 2 g's at the bottom of the hill?

8. There are a lot of differences between Row 1 and Row 12. Illustrated below, are Graphs from Row 1, Row 7(close to the middle of the coaster) and Row 12,. These graphs each include hill bottoms 9, 10 , and 11. 9 and 11 are not just hill bottoms, but they are sweeping banked turns where there is piece of the turn that is fairly horizontal and is banked at the appropriate angle to prevent much lateral movement of the passengers. The G force in these banked turns depends upon the radius of the turn and the speed of the coaster. If the speed and the radius of the turn are constant then the G force will remain the same.


Row 1


Row 7

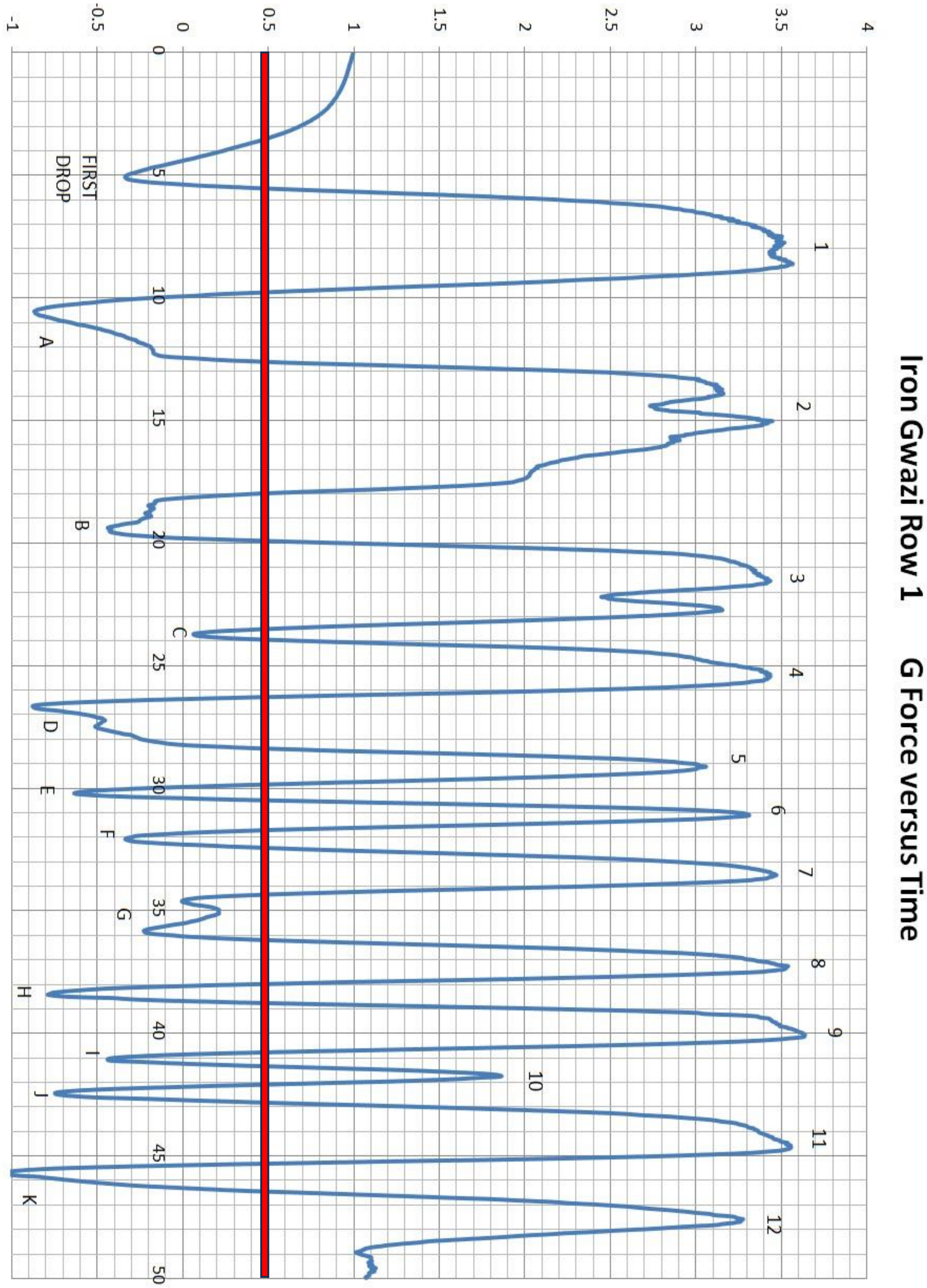

Row 12

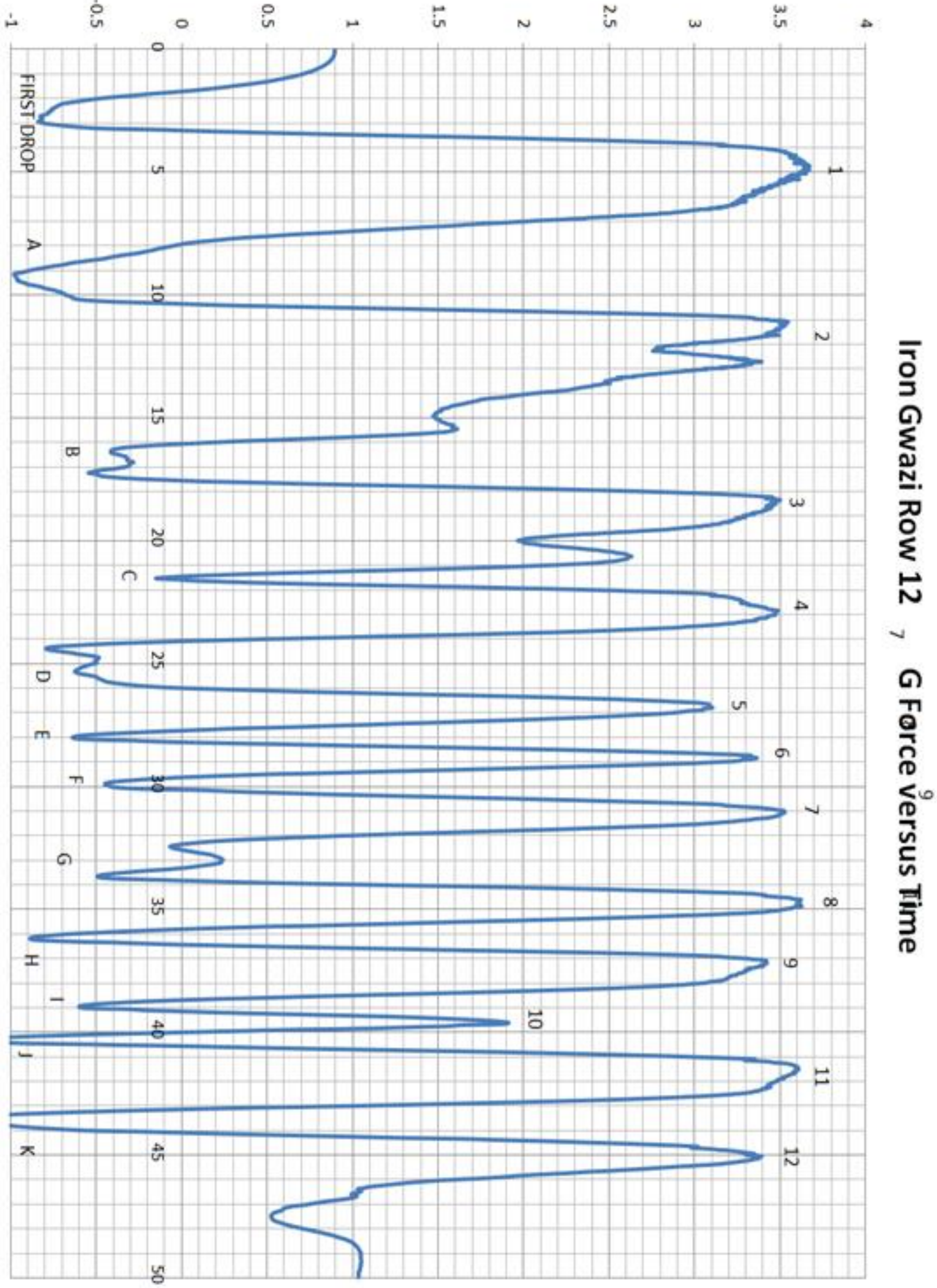
Row 7 has a constant G force during the turn, and thus a fairly constant speed throughout the turn.
Row 1 has an increasing G force during the turn, meaning that it is speeding up through the turn
Row 12 has a decreasing G force during the turn, meaning that it slowing down during the turn.

The turn is between two hill tops. Row 1 reaches the turn while the coaster train is still speeding up. Row 12 enters the turn at a high speed and then begins to slow down as the first row begins to climb the next hill.

Row 7, is in the middle of the train, and therefore maintains a fairly constant speed throughout the turn.

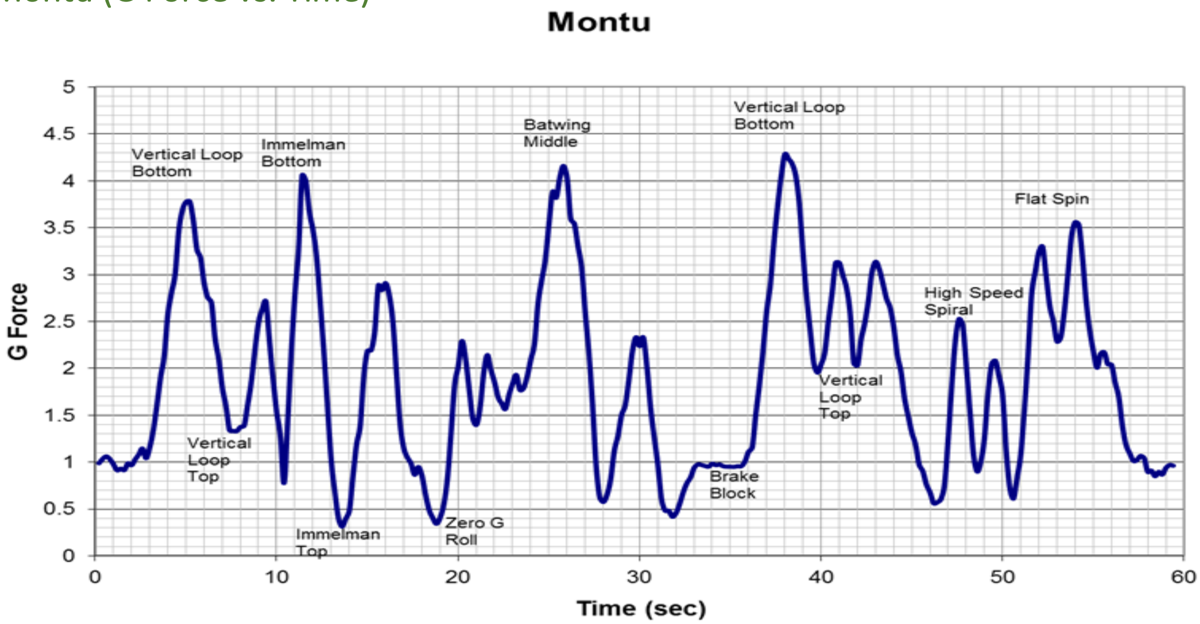
What other differences can you find between Row1 and Row 12? Can you explain any of these differences? If you rode in both the front and the back of Iron Gwazi, what differences did you notice in the ride?



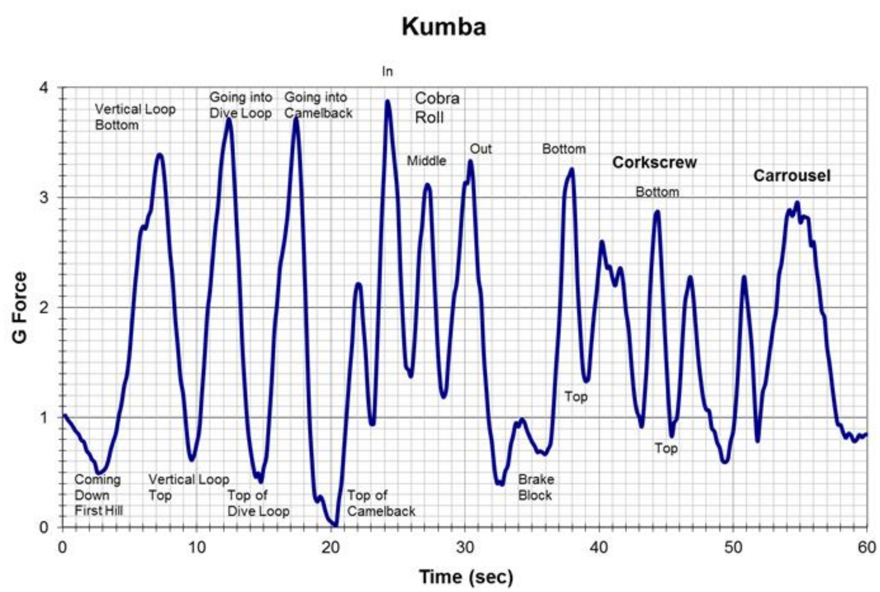

Iron Gwazi Row 12 G Force versus Time
FIRST DROP
1
2
3
4
5
6
7
8
9
10
11
12
A
B
C
D
E
F
G
H
I
J
K
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
0
5
10
15
20
25
30
35
40
45
50

Additional Graphs

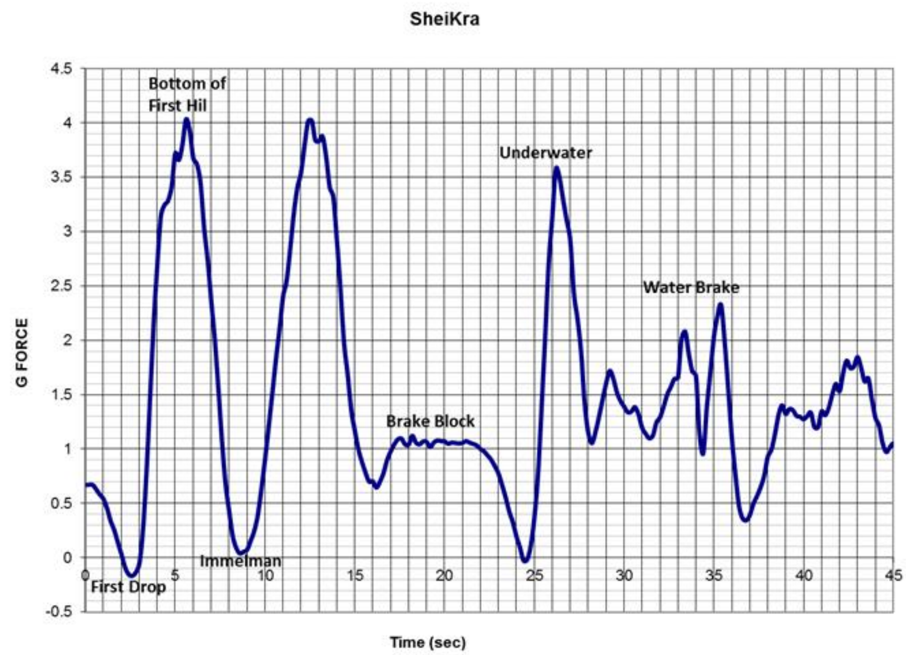
Montu (G Force vs. Time)



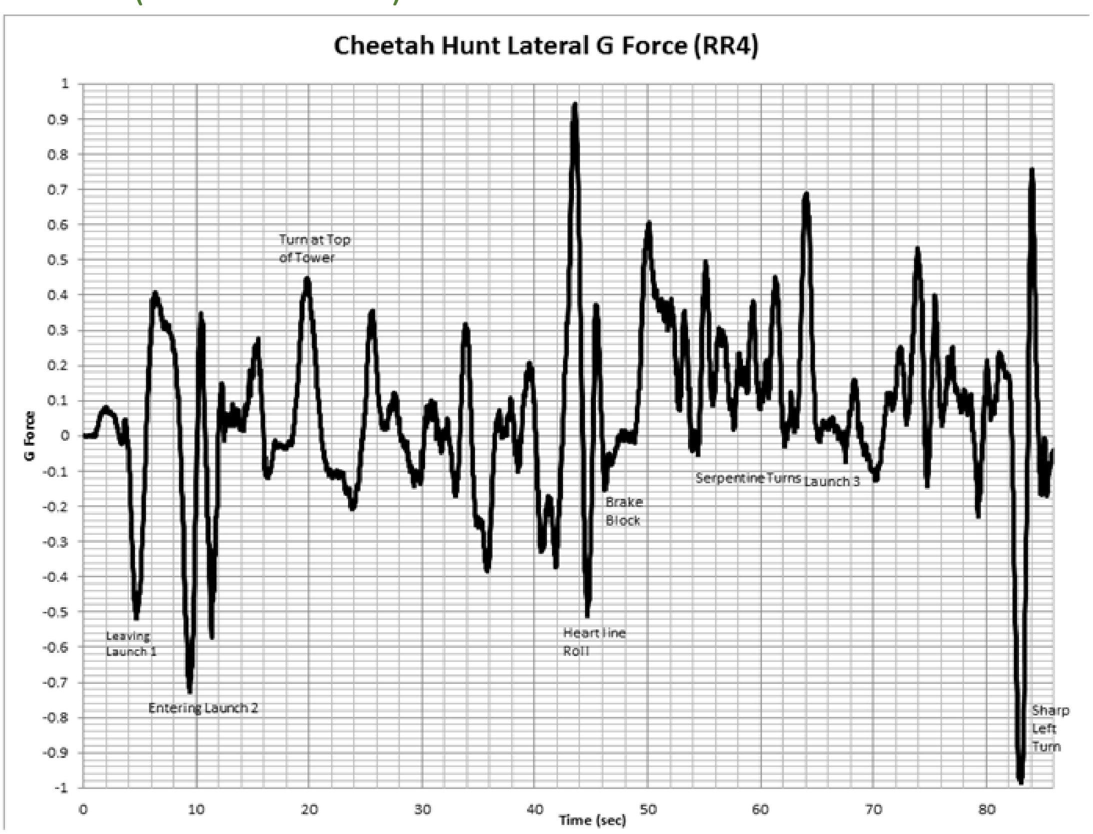
Kumba (G Force vs. Time)



SheiKra (G Force vs. Time)



Cheetah Hunt (G Force vs. Time) RR4



Cheetah Hunt (G Force vs. Time) RF1