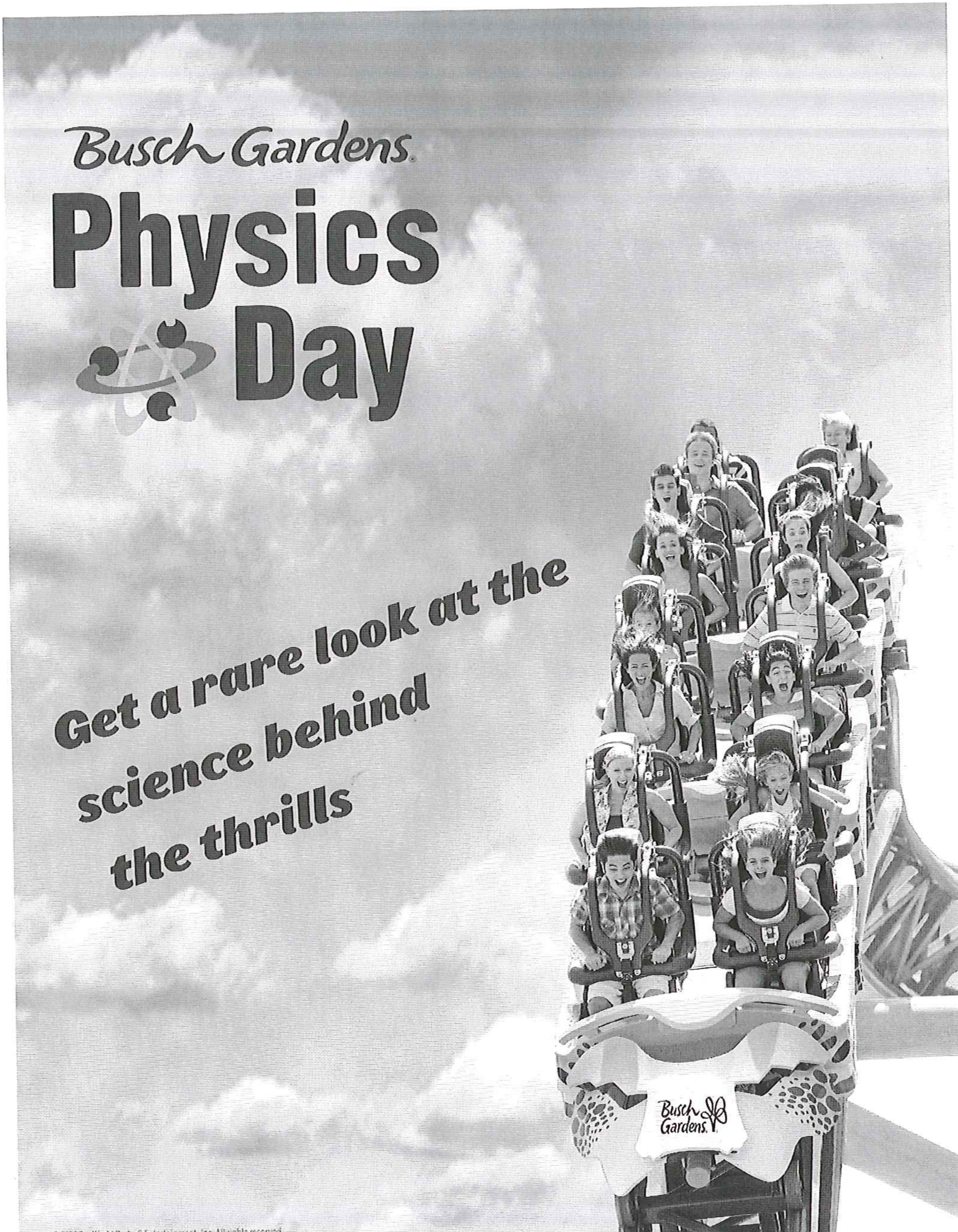

Busch Gardens
Physics Day
Get a rare look at the science behind the thrills
Busch Gardens

Table of Contents

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 the effects of inertia as you rapidly decelerate on the Tidal Wave, 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. Each group should have a Vertical G Force Meter, a Horizontal G Force Meter, and a Stopwatch. **These instruments can not be taken on the Montu, Kumba, Phoenix, Gwazi or SheiKra.**
2. Each ride has a Basic and an Advanced section. (The Bumper Cars have only a BASIC section, and the Phoenix only has an ADVANCED section. There are a couple of Advanced questions on the SandSerpent.) 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, SandSerpent

Horizontal Force Meters are used on the following Basic rides:

Log Flume, Tidal Wave, Bumper Cars, SandSerpent

Hand-held instruments are not allowed on the Kumba, Montu, Phoenix, Gwazi or SheiKra.

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, Kumba, Phoenix, and Gwazi.
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

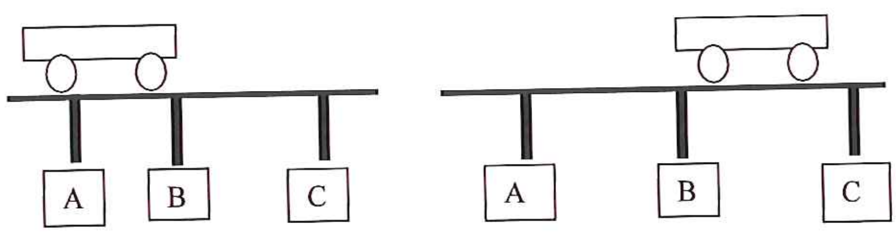
Three Measurements

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 of the calculations should be made with the average of the three measurements.

Speed

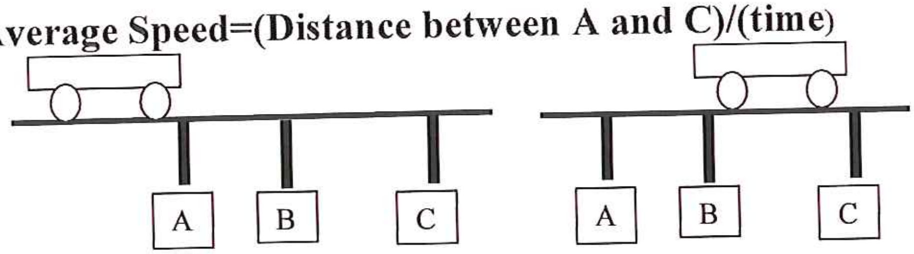
Usually the average speed of a coaster at a point (usually a post or pole) is determined by timing the coaster passing by that point. The stopwatch is started as the front of the coaster arrives at Post B, and the stopwatch is stopped as the back of the coaster passes the same post. If the length of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



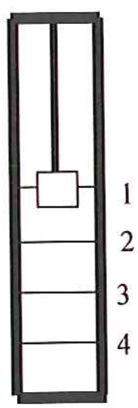
G Force

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.

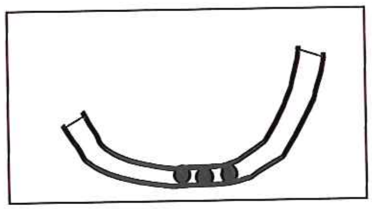
If the coaster car turns a corner quickly in an unbanked turn, a lateral G Force is experienced and can be measured by holding the Horizontal Force meter perpendicular to the direction of motion.

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

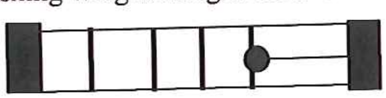
Vertical and Horizontal G Force Meters (sometimes called accelerometers) are available from Pasco Scientific (1-800-772-8700). Pasco sells a set of 15 vertical and horizontal accelerometers for about $70 (ME-9426). Sargent Welch (1-800-727-4368) also sells a set of 15 of each type of accelerometer for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

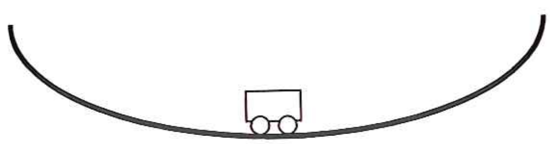
Problems

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, $F_c=mv^2/r$. 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 theBottom of a Hill

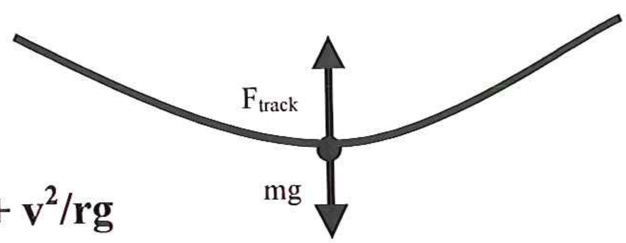
The force of the track is in toward the center of the circle and is therefore positive. The weight of the coaster, mg, is negative, since it is away from the center of the circle.



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

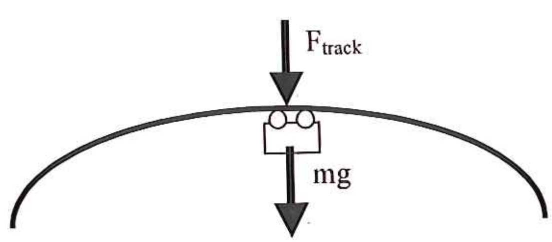
$$F_{track} = mg + mv^2/r$$

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



The force depends upon the velocity of the coaster and the radius of the turn, where $g=9.8\ m/s^2$. 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.

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

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

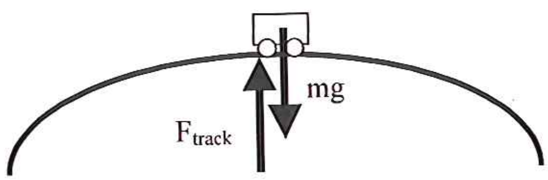
$$\text{G Force} = F_{track}/mg = \mathbf{v^2/rg - 1}$$

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.

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

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

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



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).

$$\text{G Force} = \mathbf{ma/mg = a/g}$$

2. 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 $\qquad$ 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.

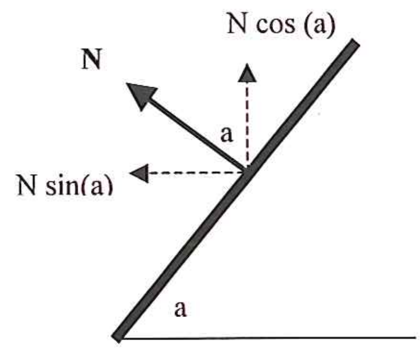
(Initial energy - Final Energy)/(Initial Energy) * 100%
$(\frac{1}{2} mv_0\text{^}2 + mgh_0 - \frac{1}{2} mv\text{^}2 + mgh)/((\frac{1}{2} mv_0\text{^}2 + mgh_0) * 100\%$

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:

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

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



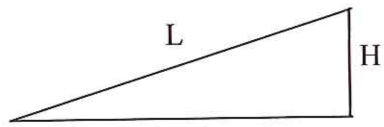
Horizontal component will be equal to the centripetal force ($N \sin(a) = mv^2/r$) and the Vertical component will be equal to the weight ($N \cos(a) = mg$) Dividing the first equation by the second yields an expession for the banking angle:

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

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 g. A bathroom scale also indicates how heavy or light the students feel in a 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 desirgn 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 AND 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/s^2 requires a horizontal force equal to the weight of the object (1 g). A vertical acceleration of 9.8 m/s^2 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.

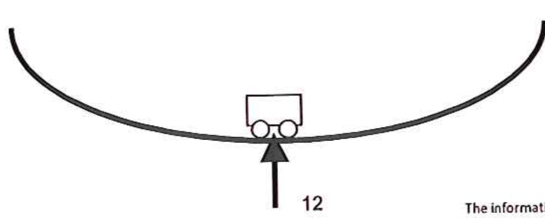
Newton's Third Law
For every action there is an equal and opposite reaction. If two people are engaged in a tug of war, the rope pulls the same on each one, but in opposite directions. The loser is the one with the poorest footing. In order for a person in an elevator to accelerate upward, the elevator 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

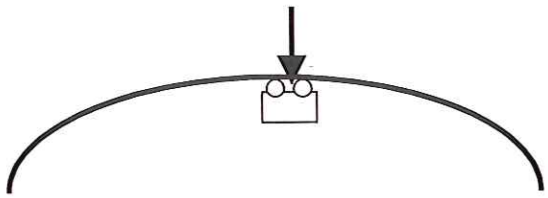
On a roller coaster, it is the acceleration that produces the thrills. Accelerations can be either changes in speed or changes in direction. While experiencing accelerations, passengers feel heavy or light, feel pushed back into their seats or thrown forward, or feel like they are thrown to the left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

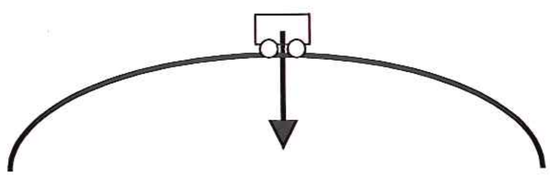
If the speed along the horizontal is increased, the back of the seats must push the passengers. They in turn feel pushed back into their seats. This sensation occurs for passengers in the last coaster car at the top of hills.
As a coaster train descends a hill, gravity provides the force to cause the 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 carrousel 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
($KE= \frac{1}{2} mv^2$). 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:

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

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

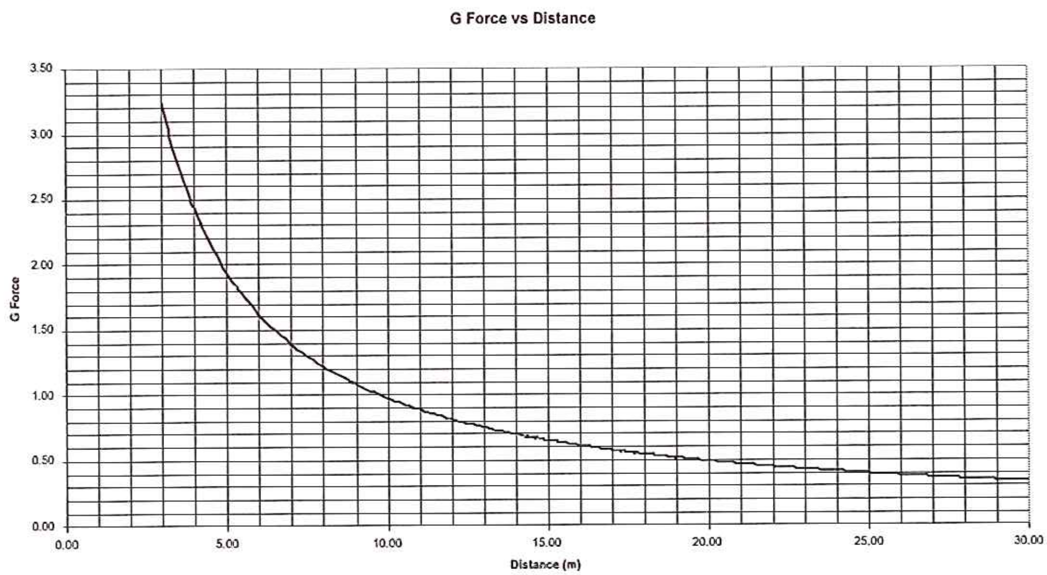
5. What was the horizontal G Force experienced at the splash? Use the chart below to convert from degrees to G Force.

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)

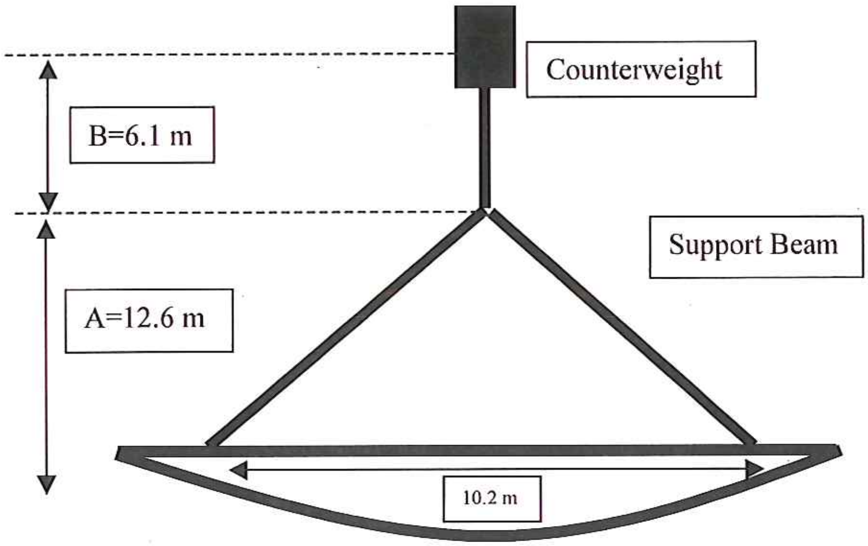
2. Compute the speed at the end of the splash. Length of log = 2.9 m

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)?

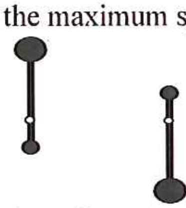
PHOENIX: Advanced



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

WHAT TO DO BEFORE COMING TO THE PARK

1. Problems:
   a. Compute the maximum G Force on a pendulum whose length is 20 m and whose maximum speed is 15 m/s.
   b. An 8 m long rod which has a large mass on top and a smaller mass underneath is pivoted about a point 5 meters from the large mass. What is the maximum speed of the large mass as it swings down to the bottom? The large mass is 10 kg, and the small mass is 6 kg.



2. Predictions
   a. What is the maximum G Force experienced at the bottom of the swing?
      1 g **1.5 g's** **2.0g's** **2.5 g's** **3.0g's**
   b. Will you feel upside down at the top? **Yes** **No**

WHAT TO NOTICE ON THE RIDE

1. Notice where the ride makes you feel heavy and where the ride makes you feel light.
2. When you are upside down, pay attention to your observations and feelings.
3. ***__PHYSICS DAYS ONLY:__** Sit on the row in the middle of the boat and note the largest G Force, as indicated on the mounted G Force Meter. (Use your measurement and that of two friends) Record it below.

	#1	#2	#3	Average
G Force				

WHAT TO MEASURE OFF THE RIDE

1. Measure the time for the Phoenix to pass a point at the bottom of its swing. (Measure from one support beam to the other.)
2. Measure the drop time for the Phoenix. (Pick a cycle where the ride moves slow at the top but doesn't stop.)

DATA TABLE

	Time #1	Time #2	Time #3	Average Time
Time to pass at bottom				
Drop time				

Problems

In all of the problems, consider the zero reference level for the potential energy to be the bottom position of the center of gravity of the boat.

1. Using the principle of energy conservation, and assuming the counterweight to have no mass, compute the speed of the boat at the bottom of the swing.

2. Given that the mass of the counterweight is 12,500 kg, and that the mass of the boat is 8,250 kg, find the speed of the boat at the bottom of the swing. Assume that an average person has a mass of 68 kg, and the boat has 50 people (Hint: At any point, the velocity of the boat is about twice the velocity of the counterweight because of their distances from the rotational point.)

3. Compute the speed at the bottom of the swing using the time measurement for the boat to pass a point at the bottom (from one beam to the other, which is 10.2 m).

4. Using the speed computed in Problem 3, compute the G Force as the bottom of the swing and compare it with the maximum G Force on the graph of G Force vs. Time. Compare it also with G Force from the mounted G Force Meter (if measured).

5. Does the period ever match the theory of a pendulum of length 12.6 m? Why does the period change? Period = 2*pi*Sqrt(L/g) where L is the Length, and $g = 9.8 \text{ m/s}^2$.

Questions

1. Name as many ways as you can to tell whether you are upside down. How is being upside down on the Kumba or Montu different than on the Phoenix?

2. Where did you feel the heaviest? Why? How did you feel when the Phoenix was dropping?

3. When the Phoenix is upside down, its center of gravity is about 25.2 m above its position when it is right side up. That's higher than the major hill on either the Scorpion. Why then is it much slower at the bottom than either of those two coasters?

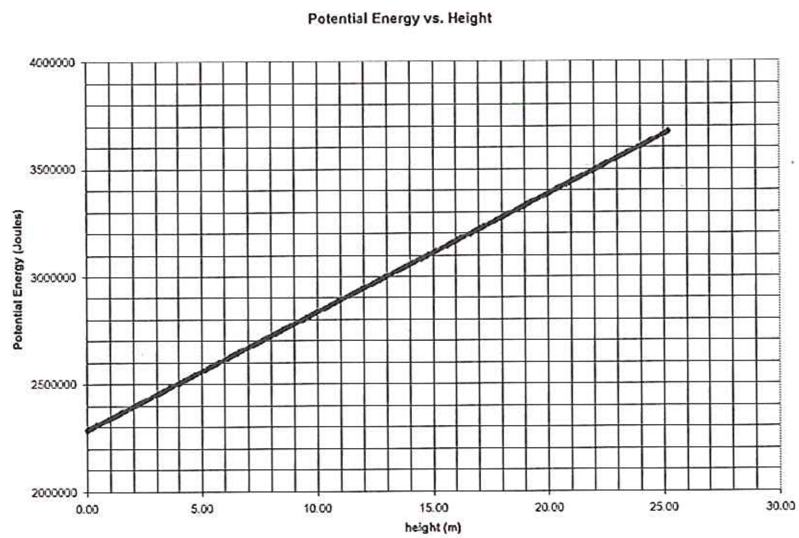
4. How does the drop time compare with the drop time of the Scorpion? Why

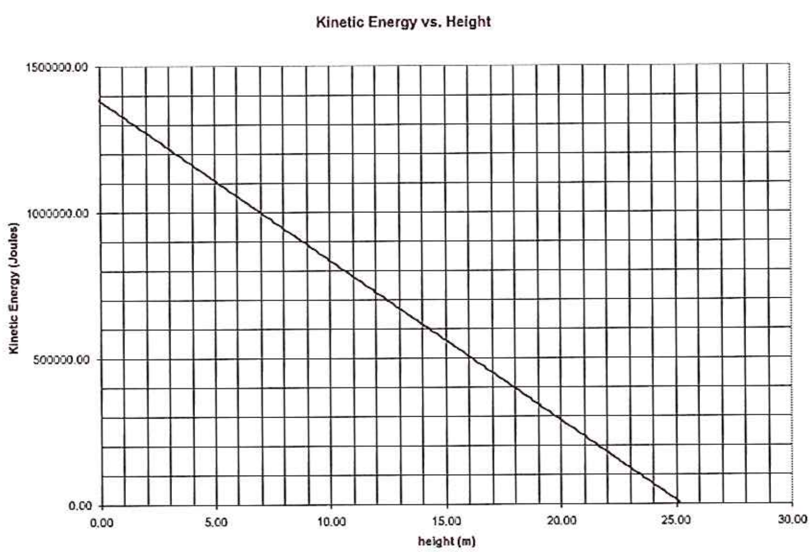
5. Examine the G Force vs. Time graph; describe what the boat is doing at points A and B. When the graph crosses the 0 line, where is the boat?

6. Looking at the graph, do you ever feel 'normal" or 1 g? What does a negative G Force mean?

7. Where does the energy come from to get the boat up high?

8. Look at the Potential Energy vs. Time and the Kinetic Energy vs. Time graphs. The height measures the center of gravity of the boat.





a. Why isn't the potential energy zero when the height of the center of mass of the boat is zero?

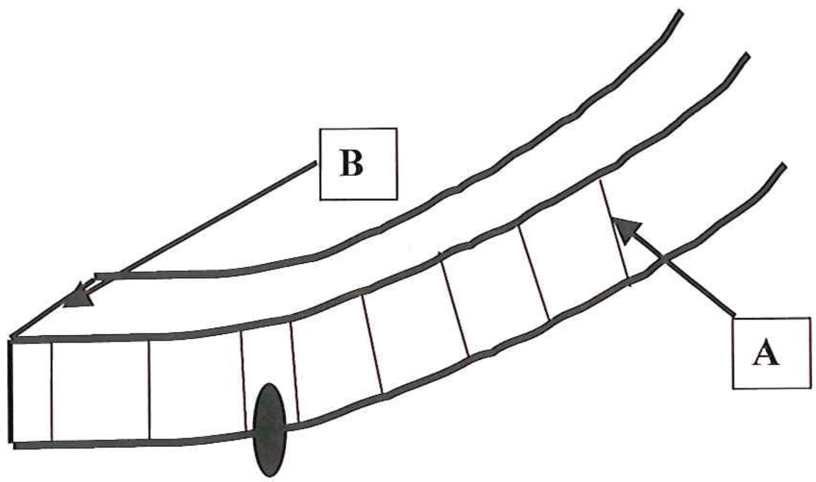
b. What is the total energy at h = 0? What is the total energy at h = 10 meters? What is the total energy at h = 25 m?

c. At what height is the Kinetic Energy equal to half the maximum Kinetic Energy?

d. How will the speed at the bottom compare with the speed at that point of half Kinetic Energy?

1. **Four times as big**
2. **Two times as big**
3. **The square root of 2 times as big**

TIDAL WAVE: Basic



INSTRUMENTS NEEDED
Stopwatch; Horizontal G Force Meter

WHAT TO DO BEFORE COMING TO THE PARK

1. Build a Horizontal G Force Meter with hand-strap.
2. Predictions:
   a. What is the Horizontal G Force at the splash at the bottom of the hill:
      0.4g 0.6g 0.8g 1.0g 1.2g 1.4g 1.6 g 1.8 g
   b. Which boat makes the biggest splash?
      Fully loaded Empty Loaded in front only Loaded in back only
3. Problems:
   a. Compute the speed of a boat that goes between two points, 11 meters apart, in a time of 0.75 seconds.

WHAT TO DO ON THE RIDE

1. 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. Make sure to aim the horizontal accelerometer parallel to the motion and brace it against the side of the boat.
2. Notice whether you feel thrown forward or pushed backward at the splash.

WHAT TO MEASURE OFF THE RIDE

1. Time the boat from A to B at the bottom of the drop.
2. Time the splash.
3. Observe several boats splash at the bottom, and make a note of what kind of mass distribution of the boat corresponds to what kind of splash.

DATA TABLE

	#1	#2	#3	Average
Largest Angle of BBs in tube				
Time from A to B				
Time of the splash				

Questions

1. Did you feel thrown forward or pushed backward at the splash? Why?

2. Did all of the boats make the same size splash? If the splashes were different, describe which boat made the biggest splash and why?

Problems

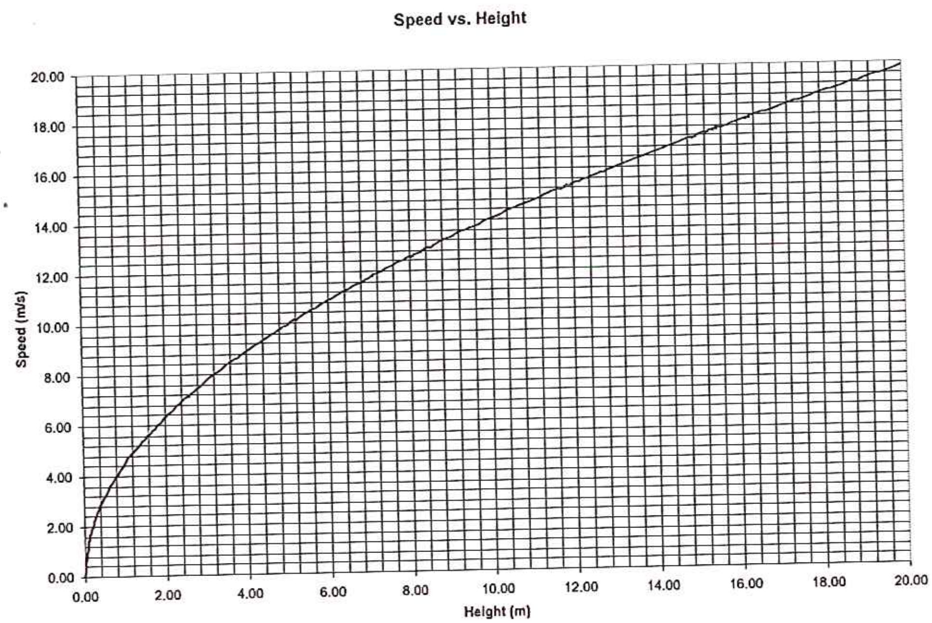
1. Compute the speed at the bottom of the hill by using the time it takes the boat to go between point A and B. The distance from A to B is 10.9 meters.

2. Compute the G Force at the bottom of the hill by using the chart below to convert G Force Meter angular measurement to G Force.

Angle	25	30	35	40	45	50	55	60	65
G Force	0.5	0.6	0.7	0.8	0.1	1.2	1.4	1.7	2.1

How does this compare with the G Force experienced on the Bumper Cars or the Log Flume?

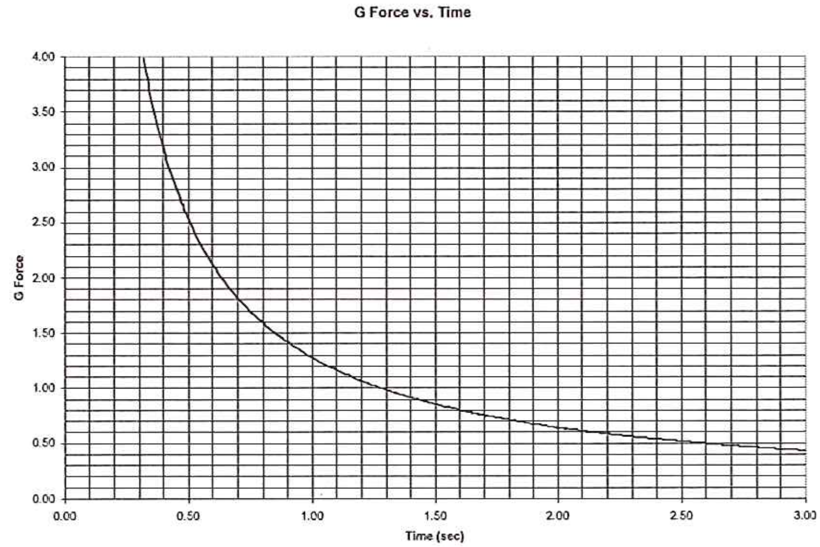
3. The graph below gives the speed at the bottom of a hill if there is no friction coming down the hill and a very small speed at the top.



a. The Tidal Wave hill is 15.2 m tall. What should be the speed at the bottom of the hill? How does this compare with the speed that you measured?

b. What size hill, without friction, would be required to produce a speed equal to the actual speed of the Tidal Wave that you computed in Problem #1?

4. The graph below represents the approximate G Force experienced at the bottom of the Tidal Wave, depending on the time of the splash.



a. What is the G Force predicted by your splash time? How does this compare with the G Force that you measured?

b. How would the ride be different if the splash took 3 seconds?

c. What is the shortest splash that you think would be safe? (Remember that this is a horizontal G Force.)

TIDAL WAVE: Advanced

INSTRUMENTS NEEDED
Stopwatch

WHAT TO DO BEFORE COMING TO THE PARK

1. Problems:
   a. Given that a boat slows down from 10 m/s to 2 m/s in 15 meters, compute the acceleration of the boat and the horizontal G Force experienced.
   b. A boat comes down from a hill of height 12 meters and has a speed of 13 m/s at the bottom of the hill. What is the percentage energy loss?
2. Predictions
   a. How much energy will be lost (converted to heat) coming down the big drop?
   10% 20% 30% 40% 50%

WHAT TO DO OFF THE RIDE

1. Measure the distance of the splash. (The posts in the water are 0.8 meters apart.)
2. Measure the time that it takes the boat to pass a fixed point after the splash is over.

DATA TABLE

	#1	#2	#3	Average
Distance of the splash				
Time to pass a fixed point after the splash				

IF YOU DIDN'T DO TIDAL WAVE: BASIC

1. Time the boat from A to B at the bottom of the drop. (See picture on front page of Tidal Wave: Basic.)

Time from A to B				Average Time

2. Given that the distance from A to B is 10.9 m, compute the speed of the boat at the bottom of the hill.

Speed at bottom of hill____________

3. Ask someone for their Horizontal G Force Meter measurement.

Horizontal G Force ____________

Problems

1. Compute the speed of the boat after the splash. Length of the boat = 4.7 m

2. Compute the acceleration and G Force of the boat at the splash by using the speed before and after the splash and the distance of the splash.

3. How does the value of the G Force computed in Problem 2 compare with the G Force measured with the Horizontal G Force Meter? (If you didn't measure this yourself, you can get the measurement from someone who did.)

4. Given that the Tidal Wave hill is 15.2 m high, and the speed at the top is 1.5 m/s, compute the percentage of energy loss in the boat coming down the hill.

5. What would be the speed of the boat with no energy loss?

SCORPION: Basic

INSTRUMENTS REQUIRED

Vertical G Force Meter; Stopwatch

WHAT TO DO BEFORE COMING TO THE PARK

1. Construct a vertical G Force meter with hand-strap.
2. Problem: If a coaster train of length 15 m passes a point at the bottom of the hill in .75 seconds, how fast is the coaster moving?
3. Predictions:
   a. The Scorpion hill is about half the height of the Montu hill. If the Montu achieves a speed of 60 mph, what will be the approximate speed of the Scorpion?
      20 mph 30 mph 40 mph 50 mph 60 mph
   b. What will be the maximum G Force experienced on the Scorpion?
      2 g's 2.5 g's 3.0 g's 3.5 g's 4.0 g's

WHAT TO MEASURE ON THE RIDE

1. Measure the G Force at the bottom of the first hill.
2. Measure the G Force at the top of the vertical loop.
3. Measure the G Force while moving through the top horizontal loop.
4. Notice whether you ever felt upside down.
5. Estimate the banking angle in the two horizontal loops near the end of the ride.

(Use your estimate along with estimates of two friends)

6. Do you feel pushed to the side in the two horizontal loops? If so, which way?

WHAT TO MEASURE OFF THE RIDE

1. Measure the time for the coaster to pass a point at the bottom of the first hill

DATA TABLE

	#1	#2	#3	Average
G Force at bottom of first hill				
G Force at the top of the vertical loop				
G Force in the top horizontal loop				
Time to pass a point at the bottom of the hill				
Banking angle				

Questions

1. The speed of Scorpion at the bottom of its first drop is about 10 m/s (22mph) slower than the speed of Kumba at the bottom of its first drop, but their G Forces at this point are very similar. Why?

2. As the coaster goes into the banked turns, do you feel pressed up against the sides of car or do you feel you're sitting upright? If you do feel pressed up against the sides, indicate whether you're pressed against the inside or outside of the car. Why is the banking angle so critical?

Problems

1. Using the measurement of the time to pass a point at the bottom of the hill, compute the speed of the coaster at the bottom of the hill. The length of the coaster is 10.7 meters.

2. The graphs on the next page indicate the banking angle of the carrousel (the horizontal circles near the end of the Scorpion), and the G Force experienced there. These graphs are based upon the actual speed of the coaster in those turns.
   a. The actual radius of the carrousel is 8.1 meters. According to the graphs, what should the banking angle be? How close does this come to your estimate of the banking angle?

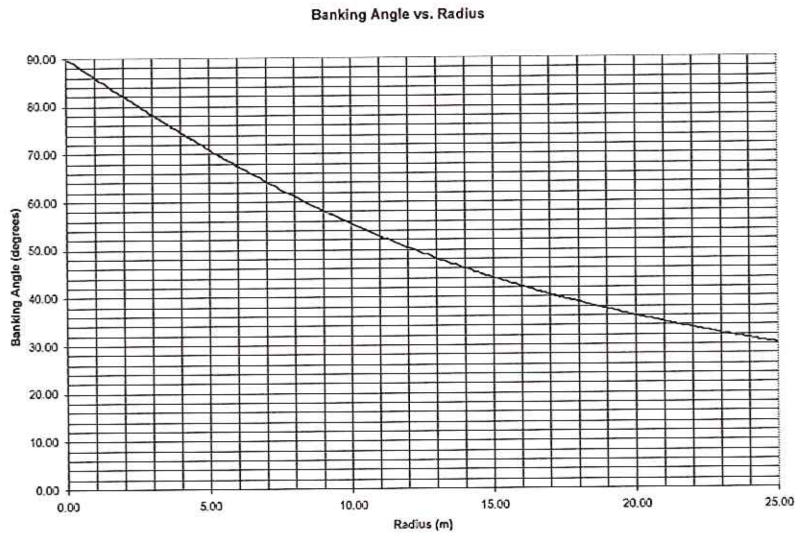
   b. What is the G Force associated with this radius of 8.1 meters? How does that compare with your measured value of G? How does it compare with the value from the graph of G Force vs. Time found a the end of the workbook?

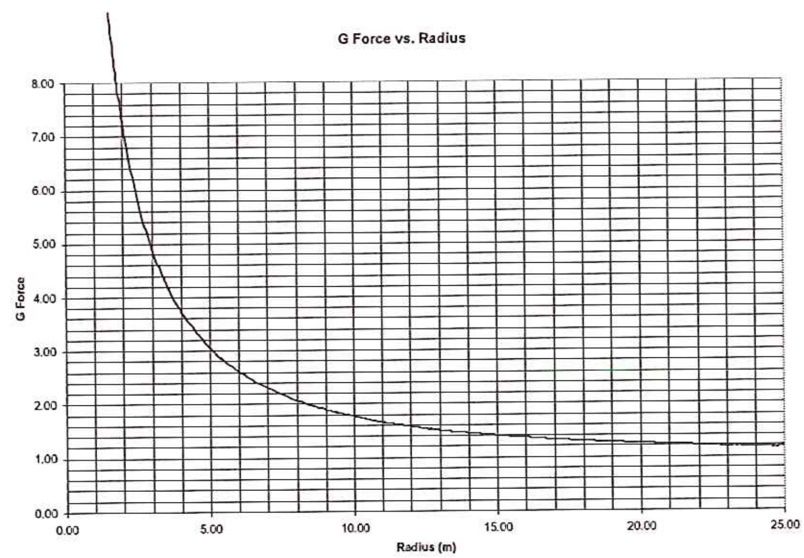
   c. If the radius is doubled to 16.2 m, what happens to the banking angle and G Force?

   d. If the radius is cut in half, to 4 m, what happens to the banking angle and G Force?

   e. What banking angle corresponds to a G Force of 5?

   f. What is the smallest radius of curvature that would be safe?





3. The graph of G Force vs. Time at the end of this workbook was produced with a CBL and TI-83 calculator and a Low-g accelerometer probe.
   a. How do your G Force readings for the bottom of the first hill and the top of the vertical loop compare to the graph?

   b. How long does the graph indicate that you felt heavy (greater than 2 g's) in the carrousel?

SCORPION: Advanced

INSTRUMENTS REQUIRED
Horizontal G Force Meter; Stopwatch

WHAT TO DO BEFORE COMING TO THE PARK

1. Problems:

a. Compute the percentage of energy loss experienced if the height of a coaster hill is 15.0 m and the velocity at the end of the ride is 8 m/s. Assume a zero speed at the top.

b. The top of the coaster appears at an elevation of 50 degrees. When you walk back an additional 15 meters, it is now at an elevation of 30 degrees. What is the height of the coaster

2. Predictions: How much energy will be lost (converted to heat) coming down the first hill? **10%** **20%** **30%** **40%** **50%**

3. Construct a Horizontal G Force Meter with hand-strap.

WHAT TO MEASURE OFF THE RIDE

1. Measure the time for the coaster to pass a point at the top of the vertical loop.
2. Measure the time for the coaster to pass a point on the top horizontal loop near the end of the ride.
3. Measure the angle of elevation of the top of the coaster hill; walk back a fixed distance and then measure the new angle of elevation

DATA TABLE

	#1	#2	#3	Average
Time to pass a point at the top of the loop				
Time to pass a point on the top horizontal loop				
Initial angle				
Fixed Distance				
Final angle				

WHAT TO DO IF YOU DIDN'T DO SCORPION BASIC

1. Measure the time for the coaster to pass a point at the bottom of the first hill.

Time to pass a point at the bottom of the hill				Average Time

2. Find the speed of the coaster at the bottom of the first hill given that the length of the coaster = 10.7 m

Problems

1. Compute the G Force at the bottom of the first hill. Radius of the hill bottom = 14.1m. Compare this number to that on the G Force vs. Time graph at the end of this workbook.

2. Compute the velocity of the coaster at the top of the vertical loop. Length of the coaster is 10.7 meters. Using this velocity, compute the G Force at the top of the vertical loop. Radius of the top of the loop = 5.4 m. Compare this number to that on the G Force vs. Time graph at the end of this workbook.

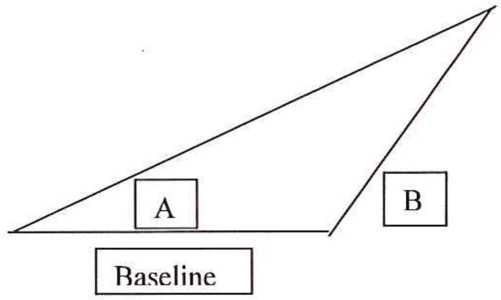
3. Compute the velocity in the horizontal loop. Compute the banking angle, and find the G Force in the horizontal loop, given that the radius of the loop is 8.1 m. Compare this value of the G Force to the value from the G Force vs. Time graph at the end of this workbook.

4. Compute the percentage of energy converted to heat coming down the first hill. The velocity at the top of the hill is approximately 1 m/s. Top of hill is 19.8 m above the ground. Lowest point is 0.8 meters above the ground.

5. Compute the percentage of energy converted to heat by the end of the ride, just before the brakes. The speed at this point is 11.8 m/s, and the track is .8 m off the ground.

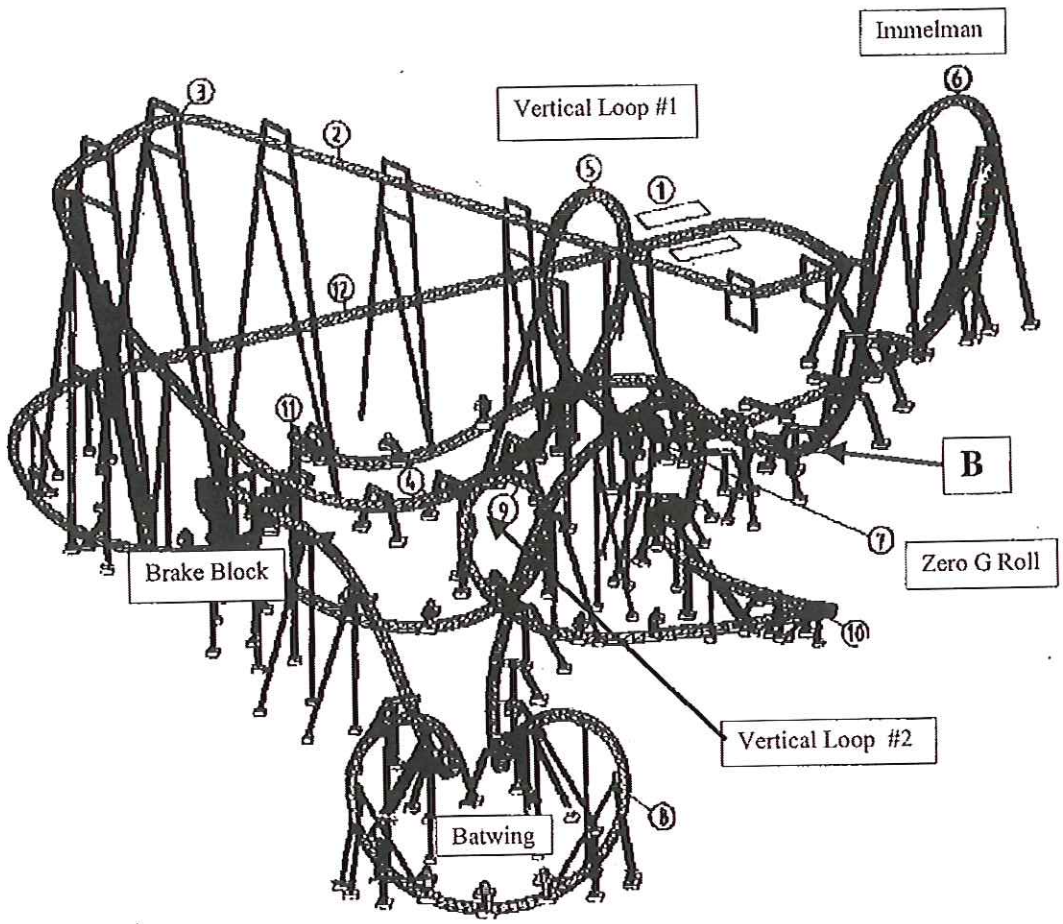
6. Find the height of the top of the first hill using your angle measurements.

H= (baseline)*sin (B)*sin(A)/(sin(B-A))



7. The radius of the top of the vertical loop is 5.4 m, and the radius of the bottom of the loop is 14.1 m. Compute the G Force at the bottom of the vertical loop if the loop were a circle of radius 5.4 meters, instead of the teardrop or clothoid that it is.

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
   a. 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?

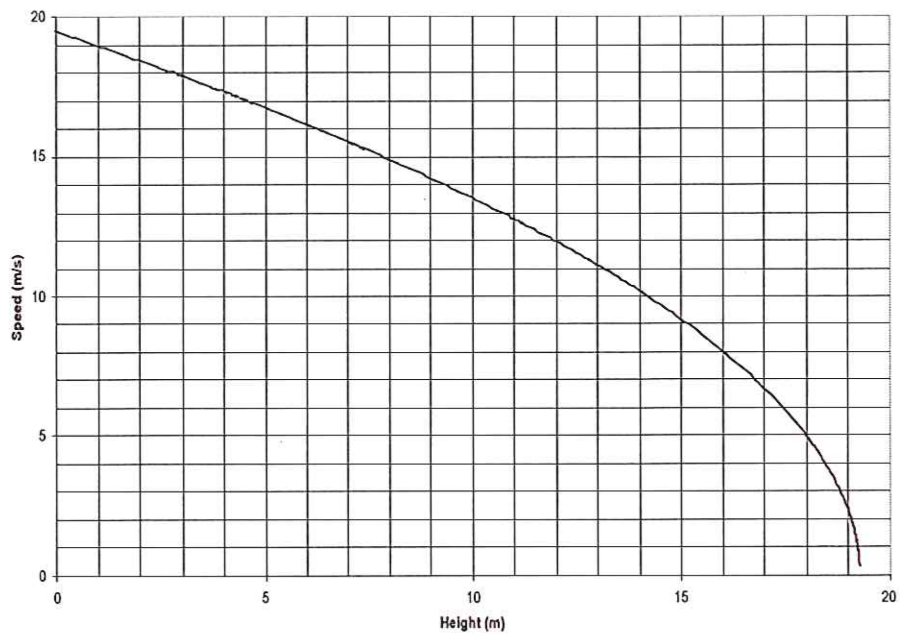
5. How is riding in the front car different from riding in the last?

Problems

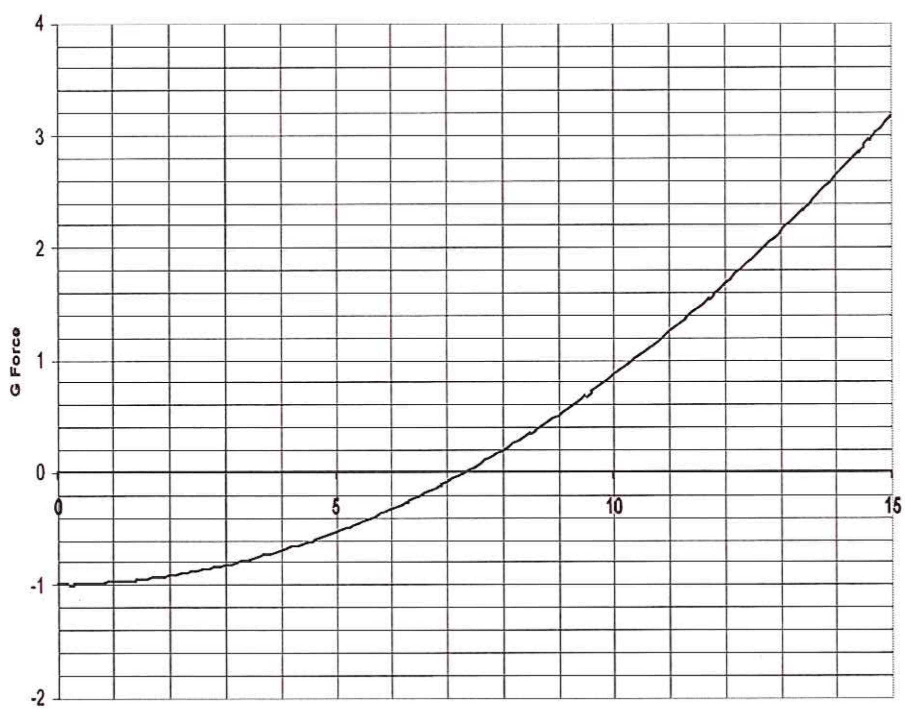
1. Using the average time for the coaster to pass the top of the vertical loop, compute the speed at the top of the second Loop (#9). The coaster length is 11.6 meters.

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

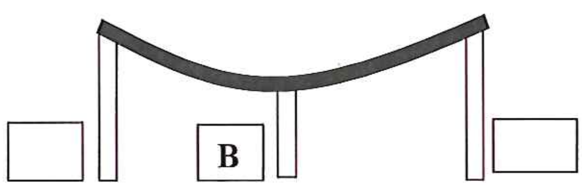
Stopwatch (No instruments allowed on the ride!)

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).

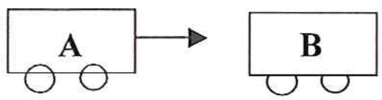
Computed value of G Force	Value from graph	Average G Force reading (if measured)

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).

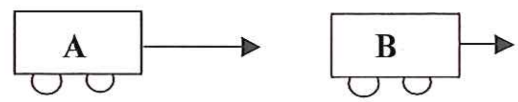
Computed value of G Force	Value from graph	Average G Force reading

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 Tidal Wave and 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

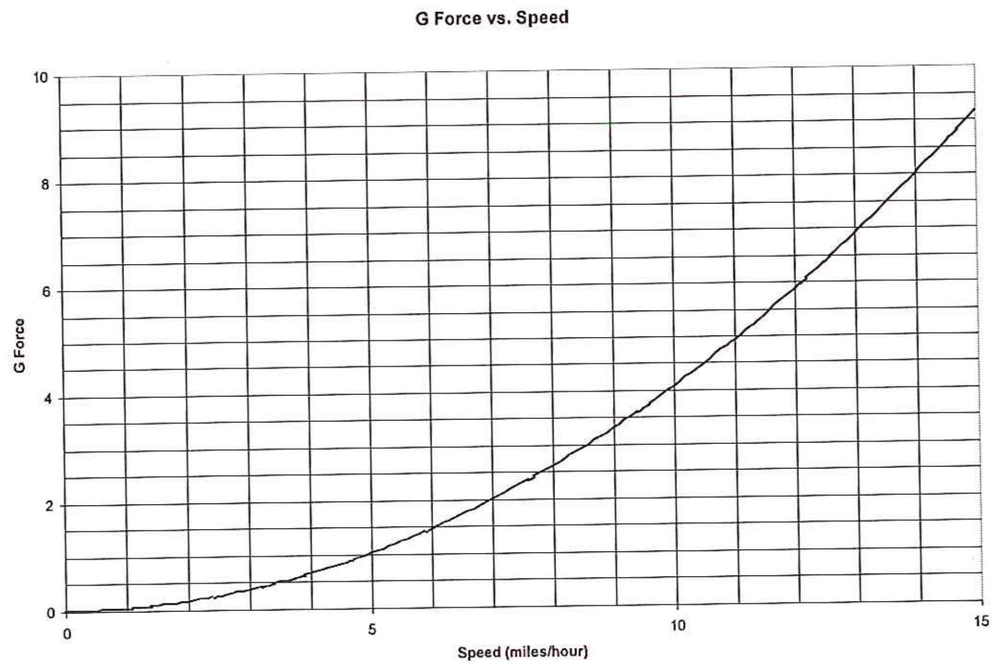
4. Which of the following conditions would produce greater forces?(circle all that apply)

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.

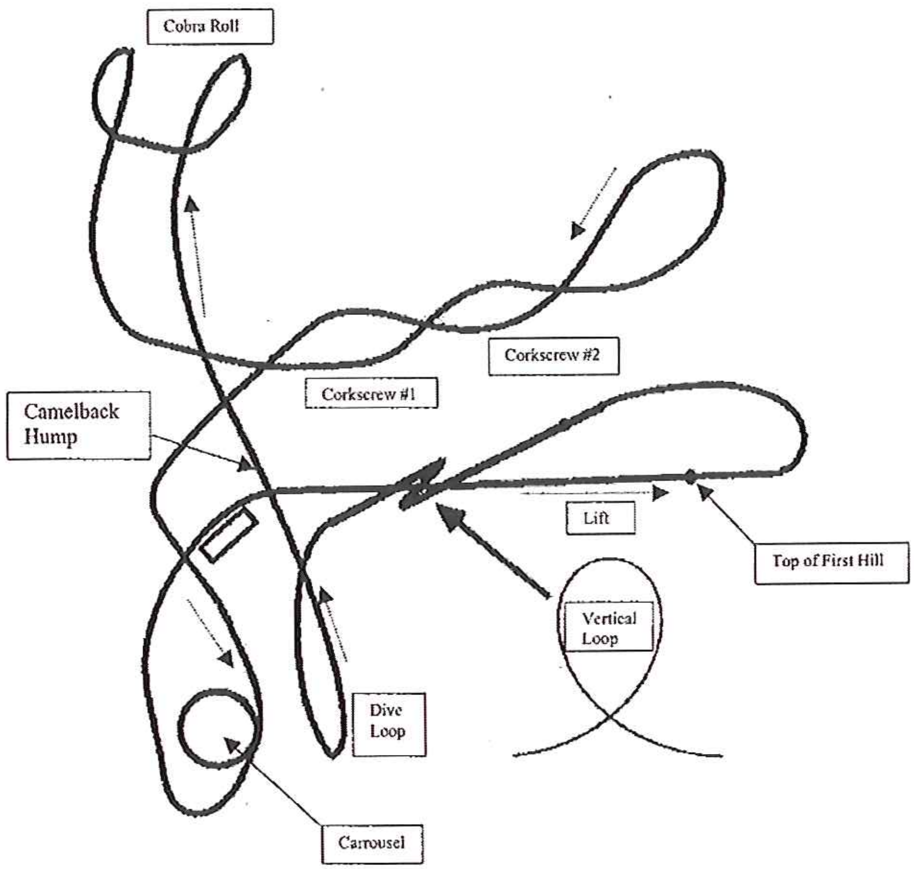


a. What happens to the force of the collision when the speed is doubled?

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 carrousel, 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

1. Problems:
   Find the speed of a coaster train whose length is 20 m and which takes .75 seconds to past a post.
2. Predictions:
   a. As the coaster goes around the carrousel 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
   b. As the coaster goes around the carrousel, you will feel:
      Heavy   Light   Normal
   c. When the coaster cars are inverted, you will feel:
      Heavy   Light   Like you are falling
      Sometimes Heavy and Sometimes Light
   d. What is the average speed of the coaster, expressed in miles/hour?
      15   20   25   30   35   40   45   50   55
   e. What is the highest G Force on the ride?
      3.0   3.2   3.4   3.6   3.8   4.0   4.2
   f. 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 carrousel 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 carrousel?

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				
carrousel				

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 carrousel? Were you thrown to the left or right or were you upright in the carrousel?

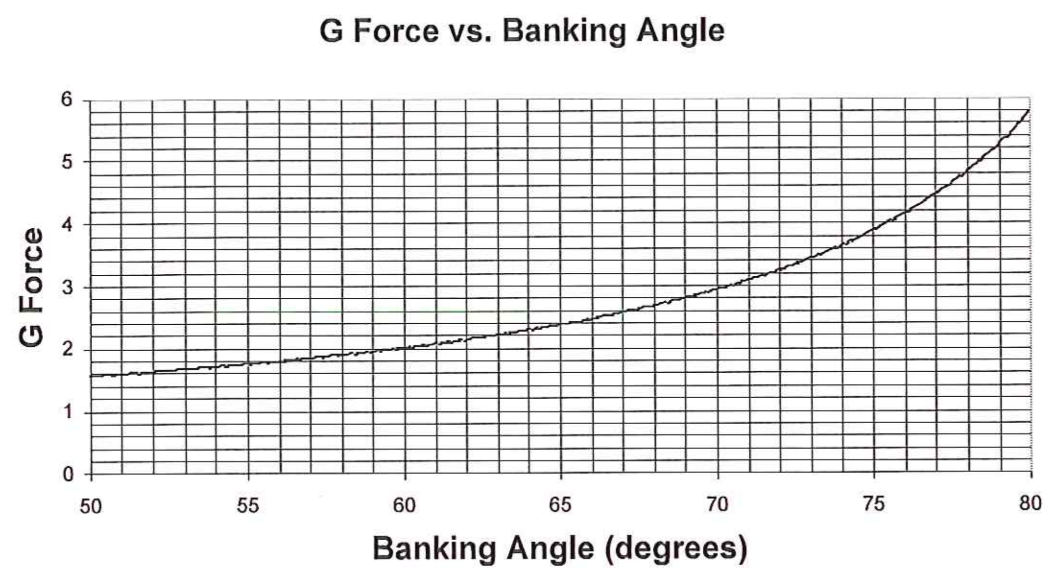
3. The Kumba has so many twists and turns that it can be disorienting. It is hard to tell where you are or whether you are upside down or not. This is especially true because your eyes will tell you that you are upside down, but you may not feel upside down. You also go from being light to being heavy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

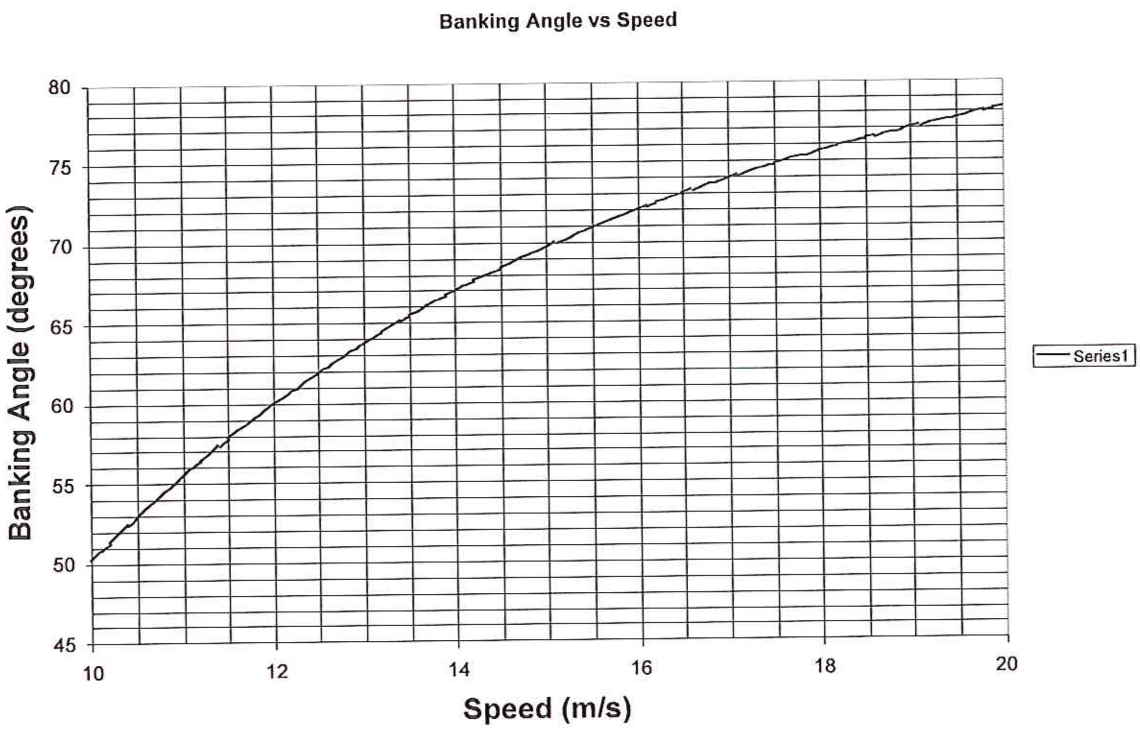
4. Give a general explanation for where on the ride you go fast and where slow.

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 carrousel, which is the horizontal circle near the end of the coaster ride.





a. The velocity in the carrousel 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 carrousel?

c. If you wanted to design a coaster that experienced 2 g's in the carrousel, 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	Camelback 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?

Vertical Loop bottom	Going into Dive Loop	Going into Camelback	Going into Cobra Roll	Middle of Cobra Roll	Coming out of Cobra Roll	Corkscrew Bottom #1	Corkscrew Bottom #2	carrousel

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; carrousel.
   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				
carrousel				

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 carrousel, 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 carrousel 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

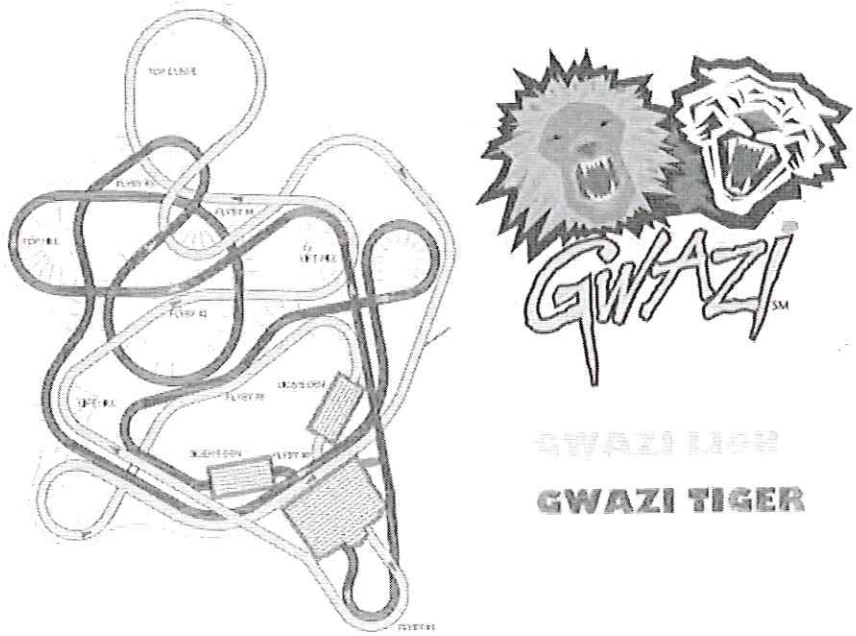
   Elevation of the Vertical Loop above lowest point = 30.9 m
   Speed up the incline = Speed at top of first hill = 2.3 m/s.

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			

GWAZI: Basic



The Gwazi Lion and Tiger cross six times. The first time is just after leaving the station and before the lift hill. The second time is at the bottom of the first hill. The third time is at the bottom of the second hill. The fourth time is when banking at a 51-degree angle, making a sharp turn. The fifth time is next to the station, while going over a camelback hump. The sixth time is at the brakes at the end of the ride. See if you can manage to see all six crossings.

INSTRUMENTS REQUIRED
Stopwatch (No instruments allowed on this ride!)

WHAT TO DO BEFORE COMING TO THE PARK

1. Problem:
   a. Find the speed of a coaster train whose length is 11 m and which takes .63 seconds to pass a post.
2. Predictions:
   a. On the diagram above, the Lion track is gray and the Tiger track is black. The arrows indicate direction of motion. Up to the point in the ride where the white and black circles are placed on the diagram, both rides have been very similar except for what? (Look at the radius of the turns, and observe whether they are turns to the right or turns to the left.)

   b. After the white and black circles, how are the Lion and Tiger rides the same; how are they different?

c. Where will you feel light on the ride?

Tops of the hills　　　　Bottoms of the valleys

d. Which car will experience the greatest G Forces on the ride?

Front car　　　　Last car

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Where do you feel light? Do you ever leave your seat?
2. Notice where on the ride you felt heavy.
3. **On Physics Days Only**: Sit in the third row, in view of the G Force Meters, and record the G Force at the heaviest point. Record your value and that of two friends — or ride the Gwazi more than once.

	#1	#2	#3	Average
Greatest G Force				

4. Ride both the Gwazi Lion and the Gwazi Tiger and make note of the differences.

WHAT TO MEASURE AND NOTICE OFF THE RIDE

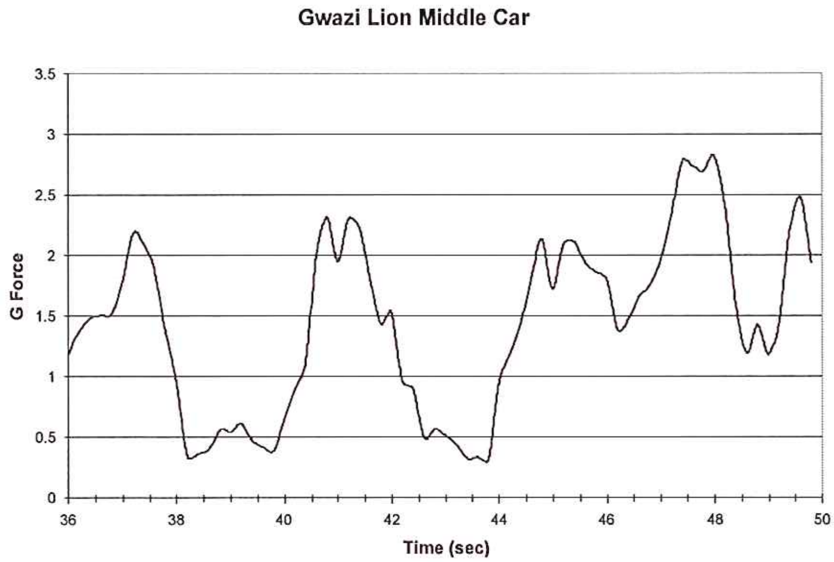
1. As you exit the ride, you will pass by the Photo Shop, which is indicated by a "P" on the diagram. Both the Tiger (further away and going to the right) and the Lion (closer and going to the left) pass by you at this point. Find the time for the Lion coaster to pass by one of the posts at the lowest point.

	Time #1	Time #2	Time #3	Average time
Time for the Lion to pass by a post at its lowest point				

Questions

1a. After the Lion coaster (yellow) passes the low point by the Photo Shop, it will immediately go up over a hill. Draw a sketch of the shape of this hill. What is the mathematical name for this shape?

1b. On the Gwazi Lion Middle Car graph below, this hill starts about time = 42 seconds. What does the graph indicate that riders experience while on this hill? How long until they experience it?



☐

1c. In general, where did you feel light on this ride?

2. On the Gwazi Lion Middle Car graph, the low point that you timed appears just after t = 40 seconds. What is the G Force experienced by the riders at this point? How long do they feel heavy?

3. At what points on the ride did you feel heavy? At which point did you feel the heaviest?. (Indicate the G Force for this heaviest point, if you made the measurement.)

4. After riding both the Lion and the Tiger, indicate any differences in the two coasters.

Problems

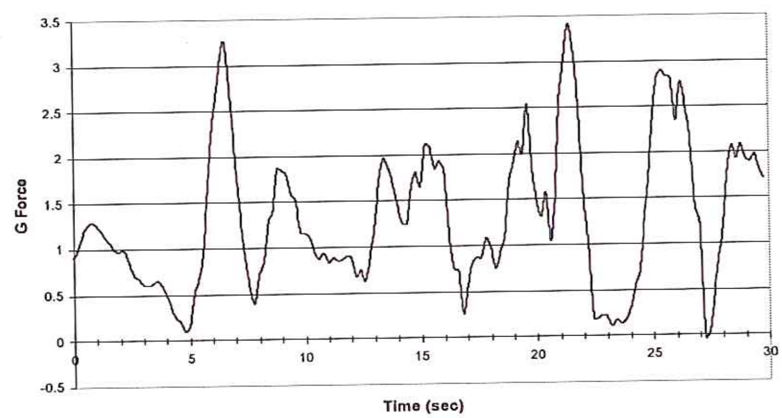
1. Compute the speed of the Gwazi Lion (by the Photo Shop) in meters/second. (Note: The length of the coaster train is 12.9 m.)

2. Answer the following questions based upon the graphs below, which were produced with a CBL, TI-83 and Low G Accelerometer. All of the graphs below start with the drop down the first hill. They show the first 30 seconds of an approximately 50-second long journey to the brakes at the end.
   a. According to the graphs below, name two differences between the ride in the front car and the ride in the back car on the Gwazi Lion.

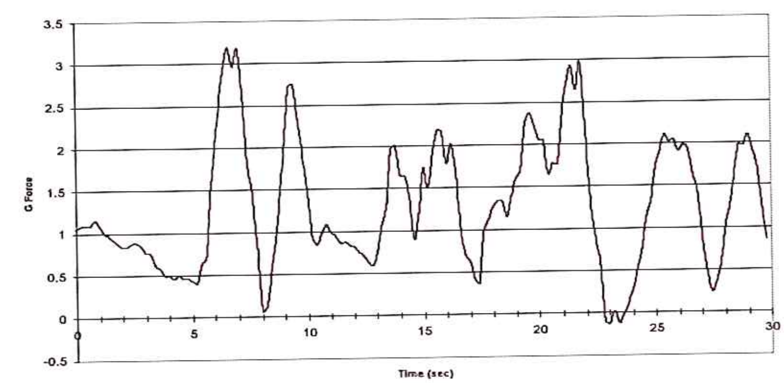
   b. Which ride would you consider more exciting? Which had the greatest G Forces?

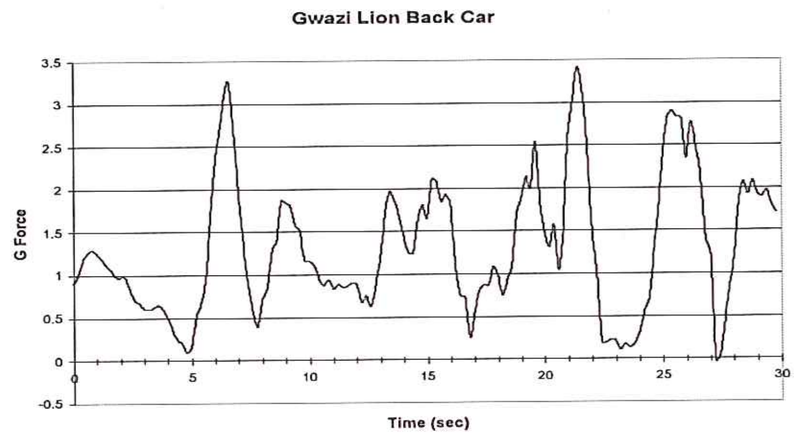
   c. Compare the back car of the Lion to the back car of the Tiger. What are the differences? What are the similarities?

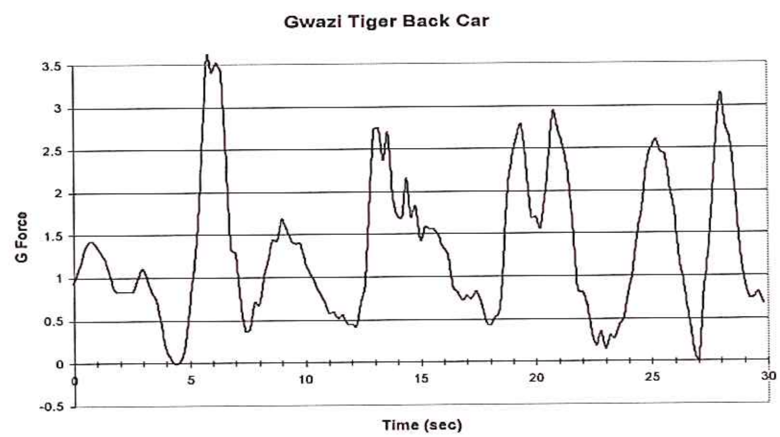
Gwazi Lion Back Car



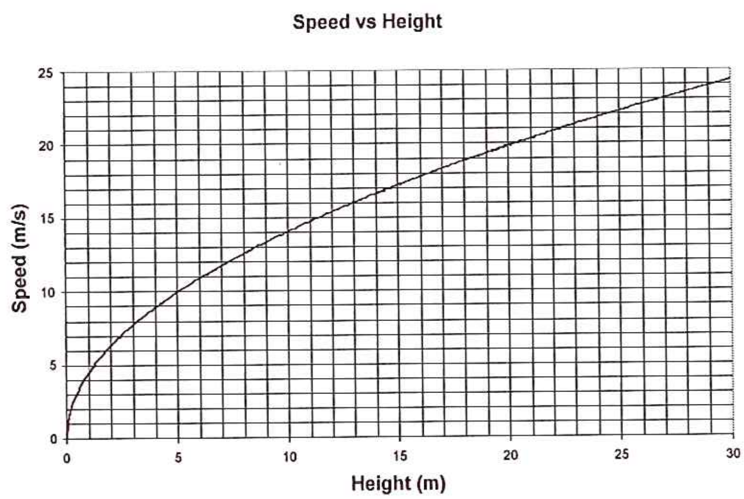
Gwazi Lion Front Car





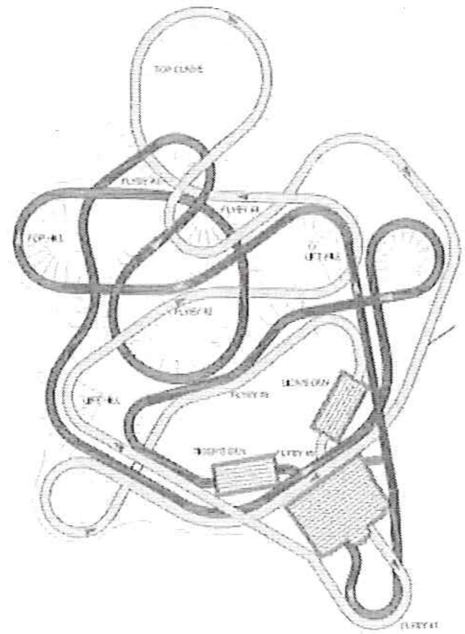


3. Using the Speed vs. Height graph, find what height is required to produce a speed equal to the speed you computed near the Photo Shop.



(Note: The actual height of the lift hill is 27.4 m above the ground level. It is higher than your computed value because of frictional losses along the way. Also, you are computing how high above this point in the track the highest hill would have to be, and the track at this point is not at ground level.)

GWAZI: Advanced



INSTRUMENTS NEEDED

Stopwatch (No instruments are allowed on the ride!)

WHAT TO DO BEFORE COMING TO THE PARK

1. Problems:
    a. Compute the G Force of a coaster going in a horizontal circle with a radius of 10 meters and a speed of 15 m/s.
    b. Find the energy loss of a coaster whose height originally was 30 m and whose speed at the end of the ride is 16 m/s, where the height is 3 m. Assume a mass of 1 kg.
2. Predictions:
    a. The energy loss at a point near the end of the ride will be:

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

    b. The greatest G Forces will be felt
       At the bottom of the first hill Somewhere else

WHAT TO DO ON THE RIDE

1. Ride one of the two trains — the Lion or the Tiger — in both the back car and the front car. Notice the differences.

2. Do you feel heavy at the bottoms of the hills, in the turns, or both? Where do you feel the lightest?
3. **On Physics Days Only**: Sit in the third row in view of the mounted accelerometer on the Gwazi Lion. Record your measurement and that of two friends.
   Note the G Force in the donut (the large horizontal circle near the end of the ride indicated by a "D" on the diagram) of the Gwazi Lion.

	#1	#2	#3	Average
Donut G Force				

WHAT TO DO OFF THE RIDE

1. The "D" on the diagram on the first page indicates a large horizontal circle — the Donut — that the Lion goes around near the end of the ride. Measure the time that it takes for the coaster to pass a post near the middle of the Donut. This may be seen by the Water Wars or on the sidewalk beyond that point.

	Time #1	Time #2	Time #3	Average time
Time for the Lion to pass by a post near the middle of the Donut				

WHAT TO DO OFF THE RIDE IF YOU DIDN'T DO GWAZI:BASIC

1. As you exit the ride, you will pass by the Photo Shop, indicated by "P" on the Gwazi diagram. Both the Tiger (further away and going to the right) and the Lion (closer and going to the left) pass by you at this point. Find the time it takes for the coaster to pass by one of the posts at the lowest point of the track.

	Time #1	Time #2	Time #3	Average time
Time for the Lion to pass by a post at its lowest point				

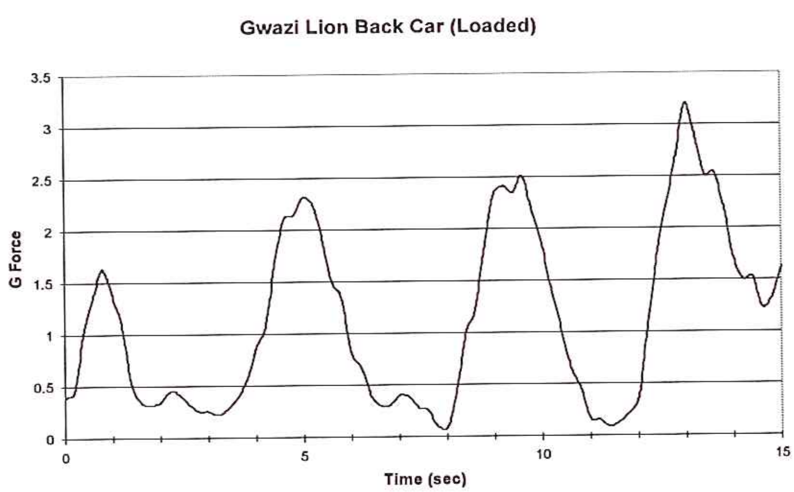
Questions

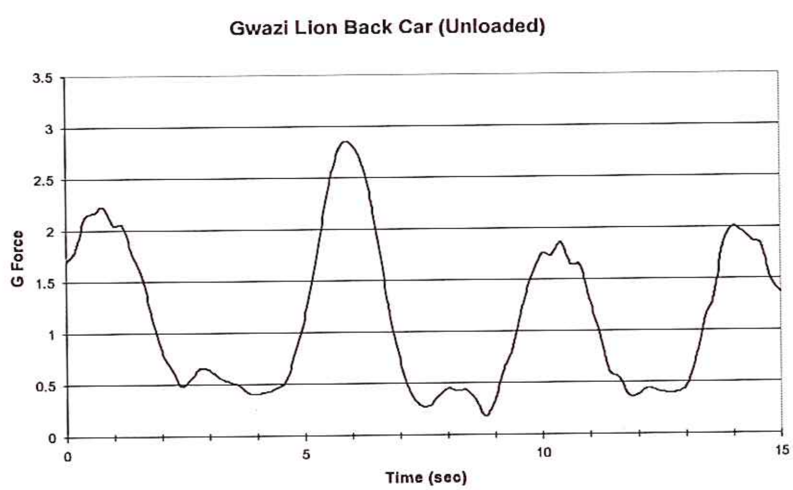
1. The two CBL graphs below, obtained with a TI-83 Calculator and Low G accelerometer, are of a 15-second portion of the ride that involves three Camelback humps, or parabolic hills. The middle of these three humps is right on top of the station. The spike at about 10 seconds is the valley (low point) near the Photo Shop where you made your measurement of speed. The "Unloaded" graph was made early in the morning with a single rider. The "Loaded" graph was made on a full coaster several hours later.

   a. Describe differences in the two graphs, and indicate your best "guess" to explain those differences.

b. Determine the time difference between the first spike and the last spike for these two graphs. (The difference in these two graphs is not just a statistical error.) Which of the two coasters is going faster and why? (The spikes indicate valleys in the track, where high G Forces occur.)

c. Out of six runs timed with a CBL, the average time difference between loaded and unloaded coasters for the entire ride is about 1.4 seconds. The entire ride, which is between the top of the first hill to the brake blocks at the end of the ride, takes about 50 seconds. How much faster (expressed in percentages) is the (loaded, unloaded) train.





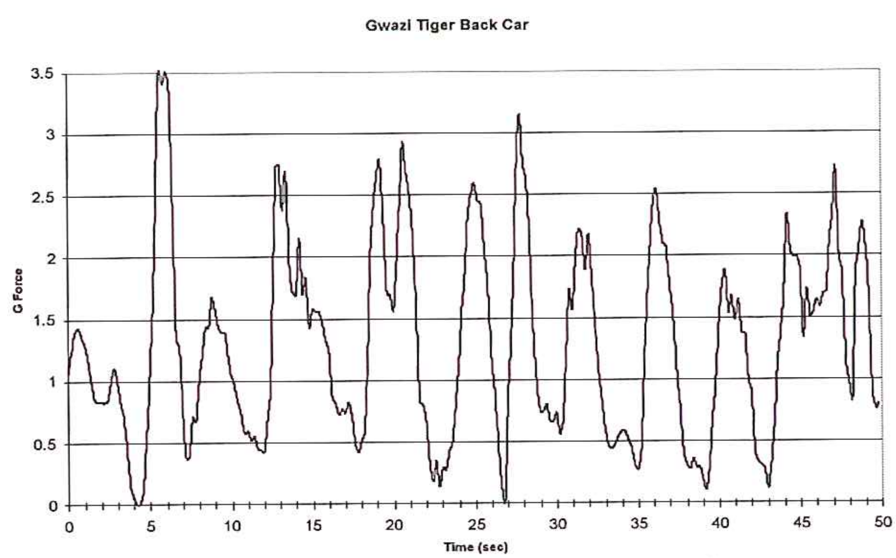
2. Using the Gwazi Lion Middle Car CBL graphs at the end of the workbook, answer the following questions:
   a. At what point on the ride do you experience the longest "low G" time? ("Low G" refers to less than 1 G) How many seconds?

   b. What is the next longest "low G" time, and where does it occur?

   c. Which point has the lowest G Force? (Choose one where the low G Force is sustained for at least 1 second)

   d. What point on the ride has the highest "G Force"? What is the G Force at this point? Where does the second highest G Force occur?

   e. Where does the Tiger back car have its highest G Force? (See below) What is the magnitude of the force? What is the magnitude of the G Force at the point in the Tiger back car ride that corresponds to where the Lion middle car had its highest G Force?

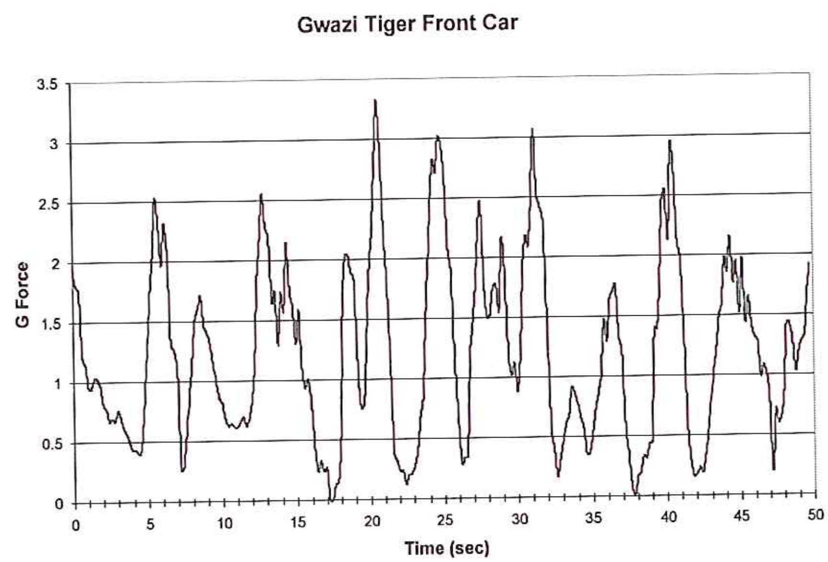


   f. Why do some of the hill bottoms, or valleys, have two peaks on the graph? (See the bottoms of the first and second hill on the Lion Middle Car graph.)

g. Where does the longest sustained high G Force (>1) occur on the Lion?

3a. Describe the differences that you experienced between riding in the front car and the back car on the (Lion, Tiger).

3b. Use the graph below of the Tiger front car to compare with the graph above of the Tiger back car. Describe the differences in the ride indicated by these two graphs. Do the differences match your actual experiences?



Problems

1a. Compute the speed of the Lion in the Donut. (Length of the coaster is 12.9 m.)

1b. Find the banking angle and the G Force of the coaster in the Donut. Compare your G Force answer with the Gwazi Lion Middle Car graph at the end of the workbook and with the G Force obtained using the mounted G Force Meter (if measured). The coaster is going through the circle between 44 and 48 seconds. Even though it is not a complete circle, ¾ of the donut has the same radius of 11.0 m.

1c. Why doesn't the entire donut have the same G Force?

2a. Compute the speed of the coaster train at the low point, near the Photo Shop.

2b. Estimate the height of the track, in meters at this point, and compute the total energy (potential plus kinetic) of the coaster train at this point (Use 1 kg for the mass of the coaster in this and the next problem.).

2c. The height of the first hill is 27.4 m, and the speed of the coaster train at the very top is 2.2 m/s, due to the lift chain. Compute the percentage of energy that has been lost (changed into heat by friction) by the time the coaster train gets to the Photo Shop . (This point occurs approximately 80 percent of the way through the ride.)

SandSerpent : Basic

INSTRUMENTS NEEDED
Horizontal and Vertical G Force Meters

WHAT TO DO BEFORE COMING TO THE PARK

1. Construct a Vertical and a Horizontal G Force Meter with hand-straps.
2. Predictions:
   a. Will the horizontal forces in the turns increase, decrease or stay the same as you go around the six sharp turns on the top level? **Increase** **Decrease** **Stay the Same**
   b. Will the greatest forces on the ride be horizontal or vertical?
   Horizontal **Vertical**
   c. Where should someone sit in the car to avoid having their seatmate push against them in the turns?
   Left side of the car **Right side of the car** **You can't avoid being pushed**

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. With the Horizontal G Force Meter, measure the largest angle to which the BBs in the tube will rise on the third and fourth turns on the top level. Also note the direction that the BBs move. Indicate which seat you sat in: right or left. .NOTE: You must hold the accelerometer perpendicular to the motion.

2. With the Vertical G Force Meter, measure the maximum G Force experienced in the dips. Hold the Force Meter parallel to your spine.

	#1	#2	#3	Average
Angle: Turn 3				Direction: R or L
Angle: Turn 4				Direction: R or L
G Force: Dip				

Note: Ride the ride three times or get data from a friend.

Questions

1. Compute the G Force in the two turns using the average angle and the following chart:

Degrees	33	35	37	39	41	43	45	47	49	51	53	55	57	59
G Force	.6	.7	.8	.8	.9	.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.7

G Force (measured) Turn #3 __________ BBs to (left, right)

Turn #4 __________ BBs to (left, right)

2. What are the values of the G Force obtained from the G Force vs. Time graph at the end of the workbook. How close are your values to that of the graph?

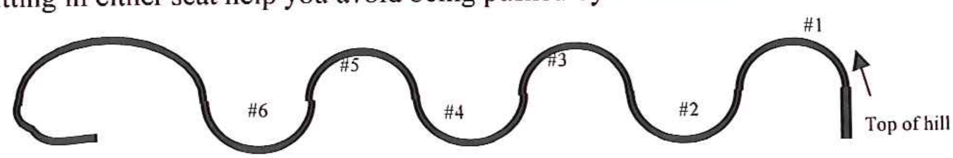
G Force Graph Turn #3 ________ Turn #4 ___________

3. What is the largest vertical G Force obtained from the CBL graph? How does it compare with your measured value? How does this compare with the G Forces experienced on the Montu and Kumba? How can the G Force be so large when the speed is small?

G Force (G Force Graph) _________ G Force (Measured) __________

4. From your experience on the ride, how did the horizontal forces in the six sharp turns on the top level compare with each other? Were they about the same, steadily increasing, steadily decreasing or randomly changing? How does this compare with what the graph indicates?

5. The direction of the force is opposite the direction that the BBs slide. Indicate the direction of the force on the passengers in the six turns illustrated below. (Use arrows.) Does sitting in either seat help you avoid being pushed by a seatmate?

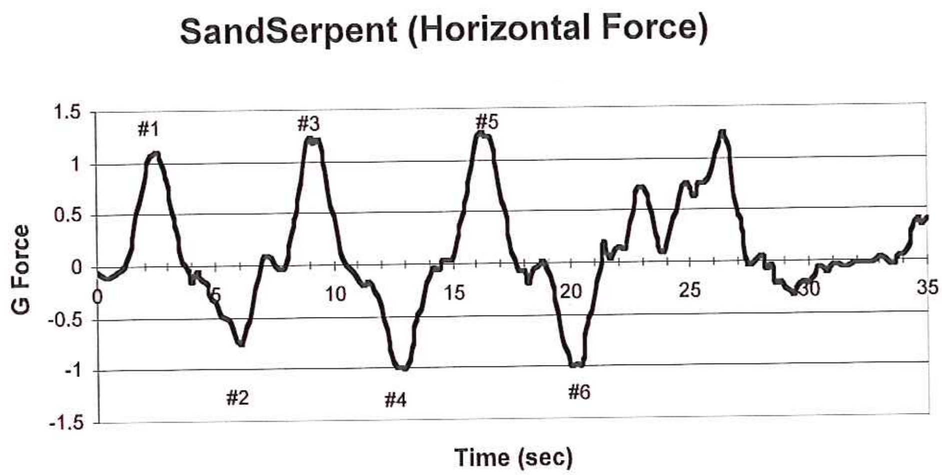


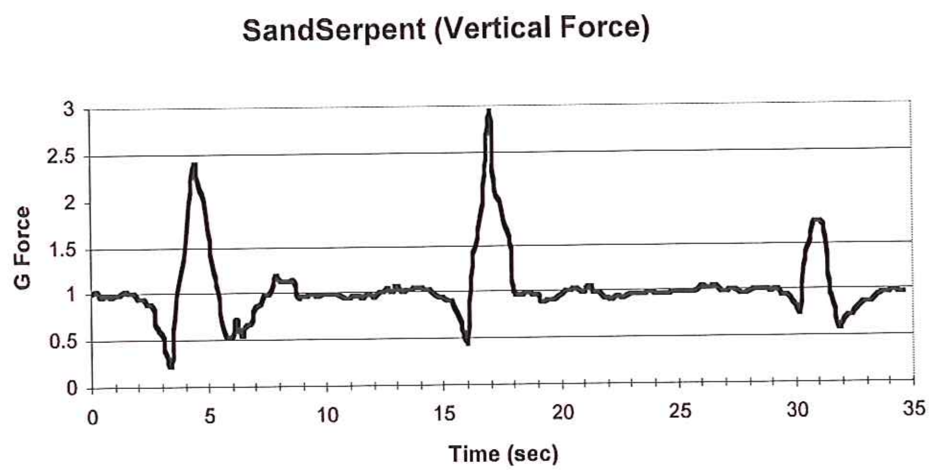
6 (Advanced)*. The radius of each of the turns is the same. R = 2.36 m. Taking the average Horizontal G Force in each of the turns from the G Force graph, compute the speed of the coaster car. $F=mv^2/r$, where F = (G Force) * mg

7. Did the car seem to speed up, slow down, or remain at about the same speed throughout the six turns? The track on the top level slopes downward gradually. Why?

8 (Advanced)*. Because the turns are not banked, there is a considerable sideways force. If the track were banked at an appropriate angle, then the passengers would feel heavy in the turns but would not feel pushed to the side. Based upon your answer to question No. 6, what should this banking angle be, to avoid sideways forces? Tan (angle) = v^2/rg

9 (Advanced)* In your experience, was a greater force experienced by the person on the outside of the turn or the inside, or are they both the same? What do the graphs indicate? (The accelerometer that produced the graphs was in the right-hand seat.)





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

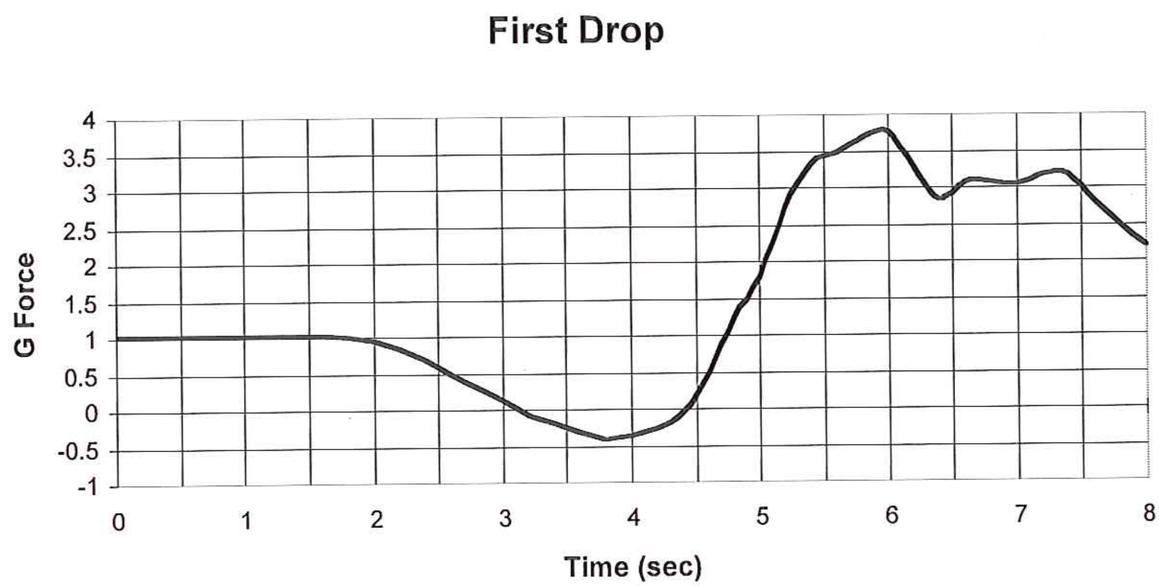
	#1	**#2**	**#3**	**Average time**
Time of fall				

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?

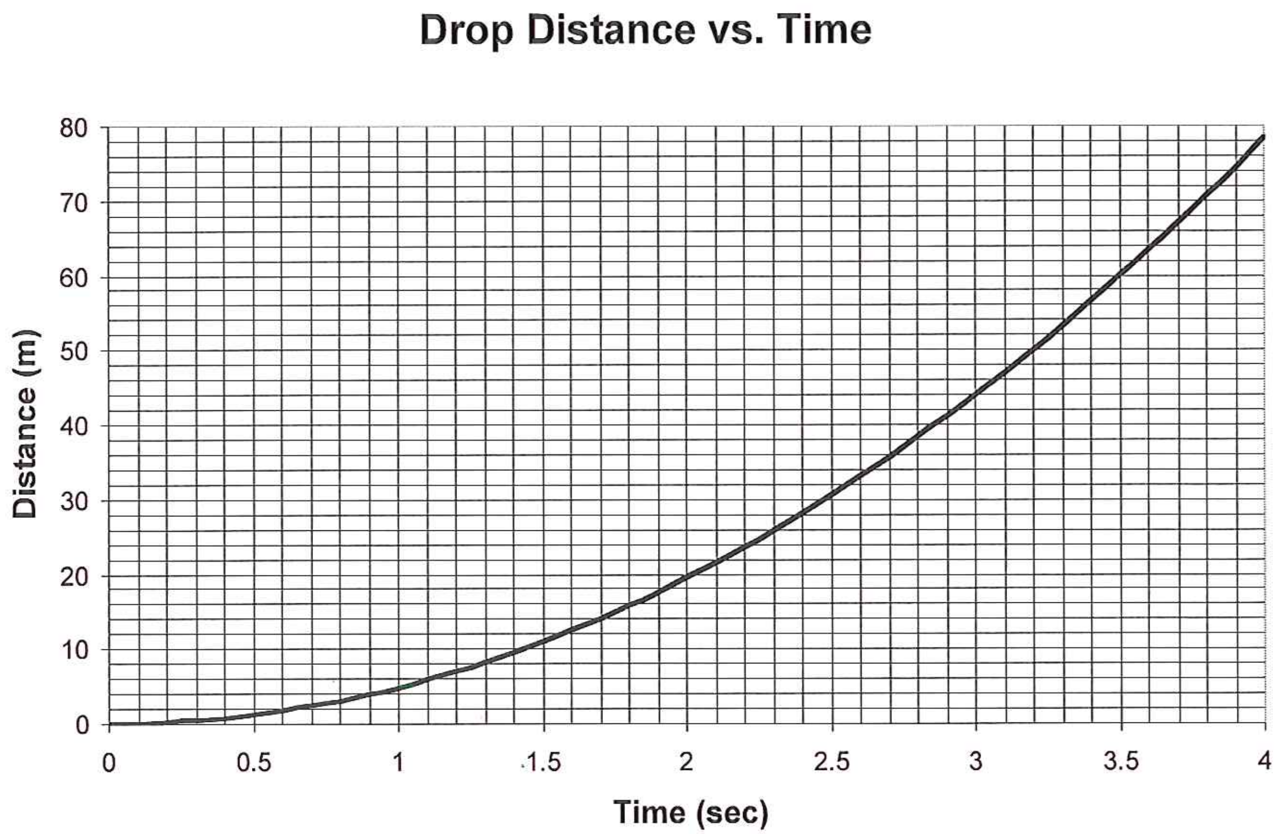


4a. From the Drop Distance vs. Time graph on the next page, determine how far the coaster dropped in the time measured with the stopwatch.

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

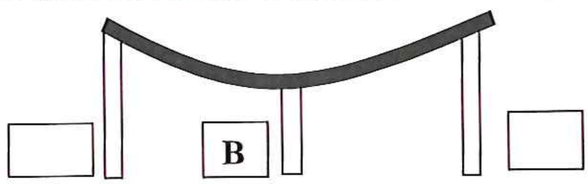
2. Problems:
   a. What is the G Force experienced when a coaster is at the bottom of a hill of radius 10 m, with a speed of 20 m/s?
   b. What is the percentage energy loss when the coaster decreases its speed from 30 m/s to 15 m/s?

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 skyride.
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

a. 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?
b. 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/s^2?

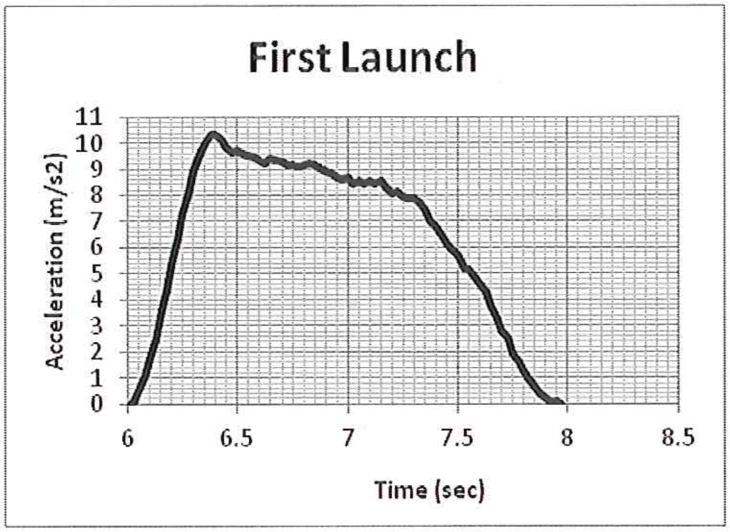
   b. Express this acceleration in "g's" by dividing by 9.8 m/s^2.

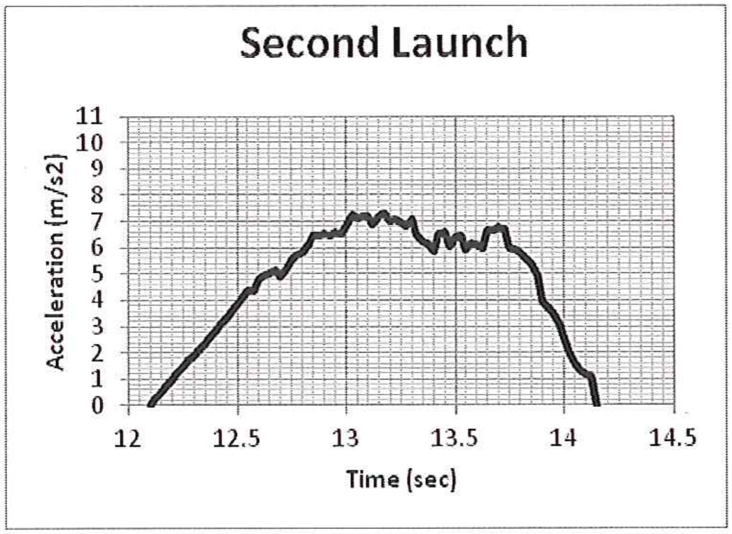
2. Look at the launch graphs on the next page. These measurements were made on the third or fourth coaster car in the three launches of the Cheetah Hunt.

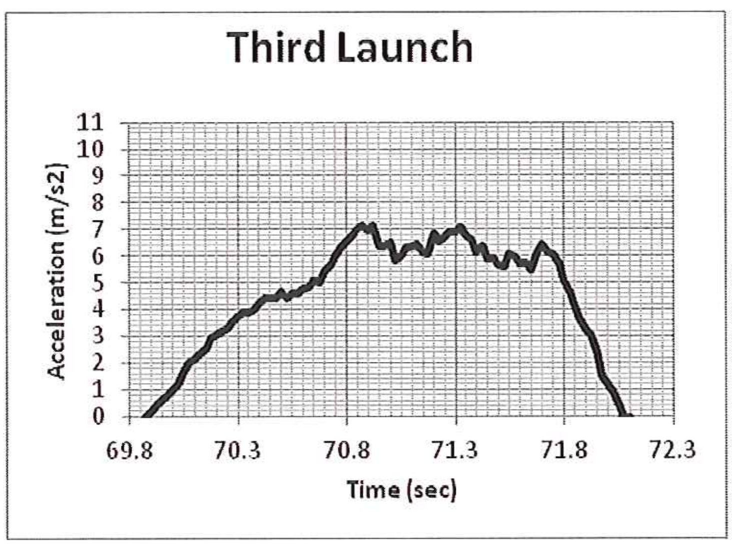
   a. Which of the three launches is for the longest amount of time? Which is for the shortest amount of time?

   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/s^2. 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)
11
10
9
8
7
6
5
4
3
2
1
0
6
6.5
7
7.5
8
8.5
Time (sec)

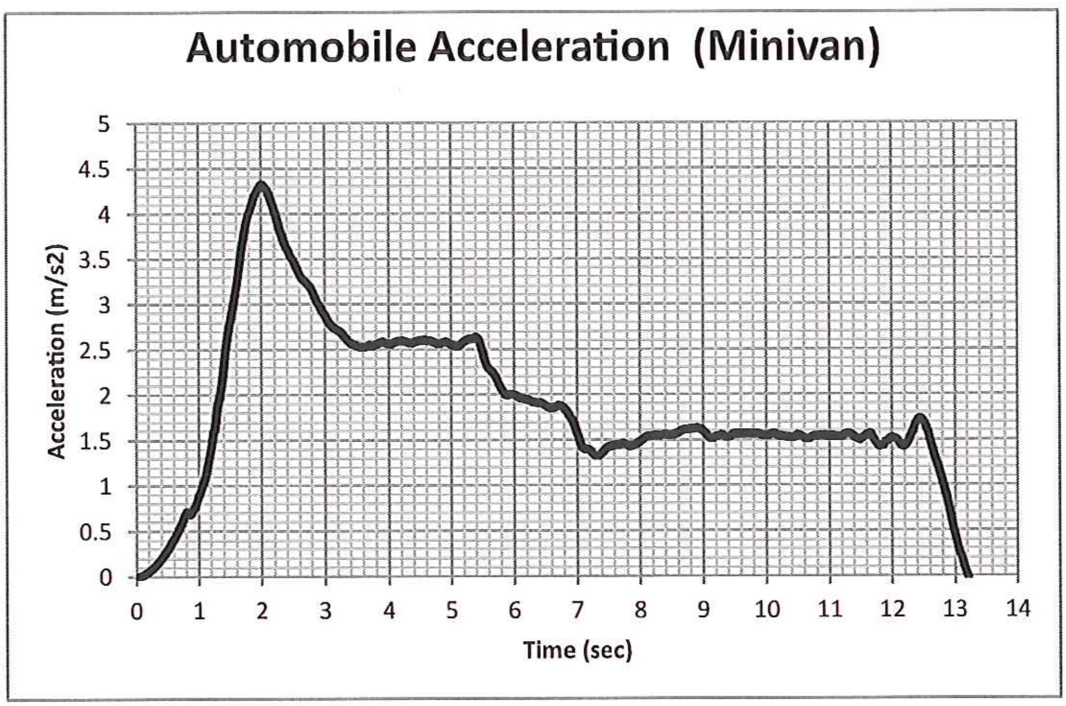

Second Launch
Acceleration (m/s2)
11
10
9
8
7
6
5
4
3
2
1
0
12
12.5
13
13.5
14
14.5
Time (sec)


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

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.

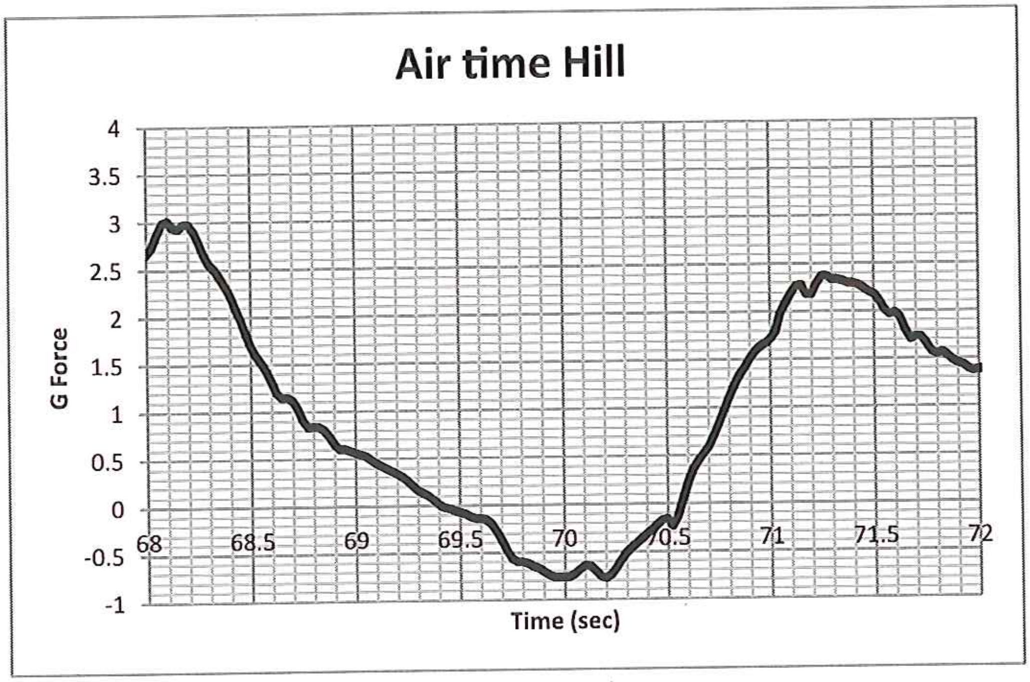


3.a. Using the time between posts that you measured, compute the speed of the coaster train on the Air Time Hill (just after Launch 3). The distance between posts is 15.0 meters.

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

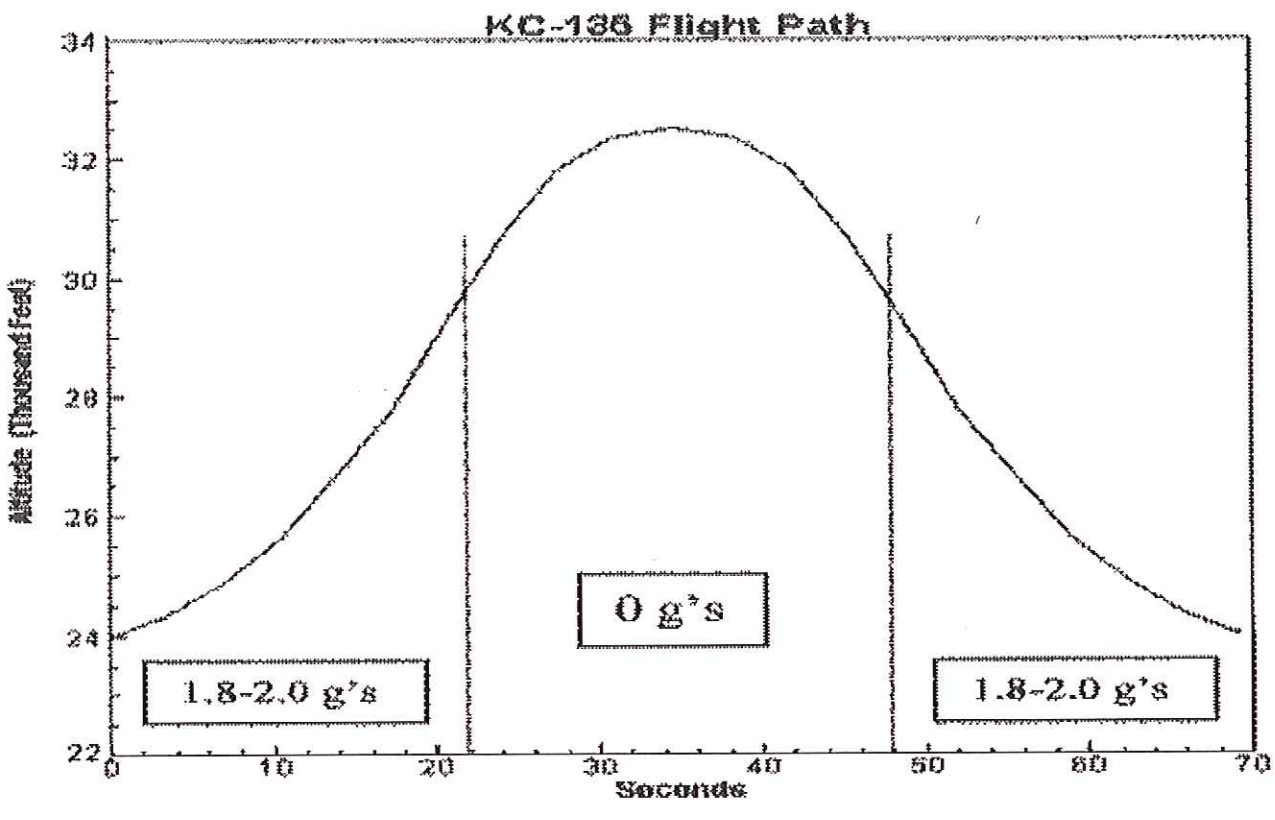


c. Draw a sketch below of what the Air Time Hill looks like. Include the posts in your sketch. What mathematical shape does it appear to be?

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 skyride.
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.

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

a. 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?
b. 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?
c. 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

a. Which coaster car will experience the most g's as the coaster train begins to go up the tower?
1st Car 4th Car

b. 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

c. 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

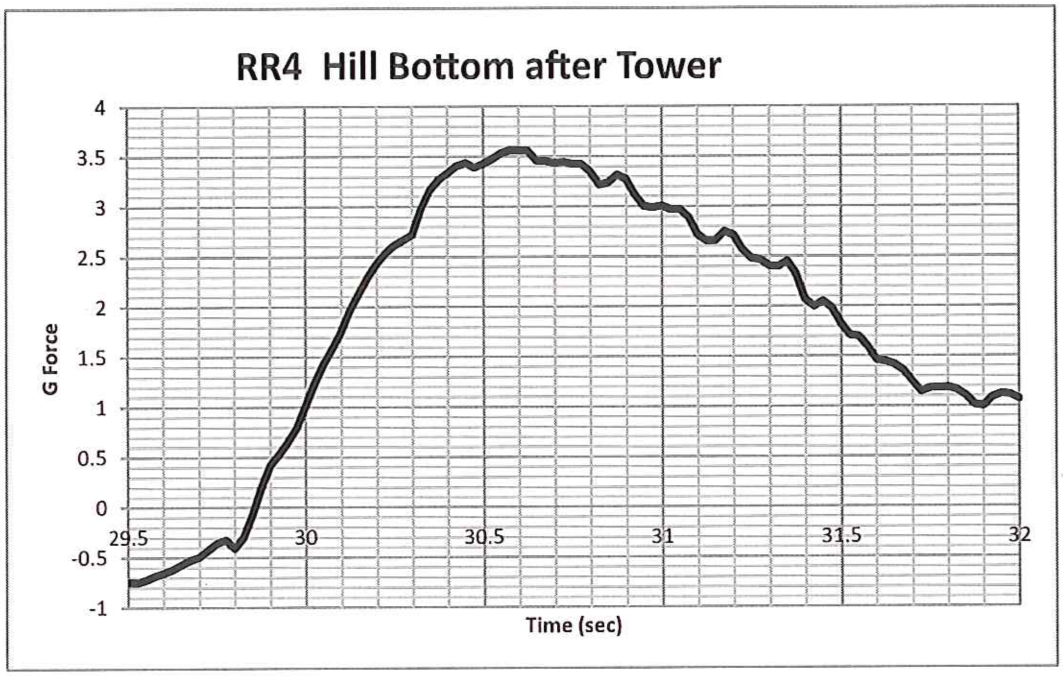
	#1	#2	#3	Average
Time between posts of the Outbound Twister				
Front to back time a the top of the tower				

Questions

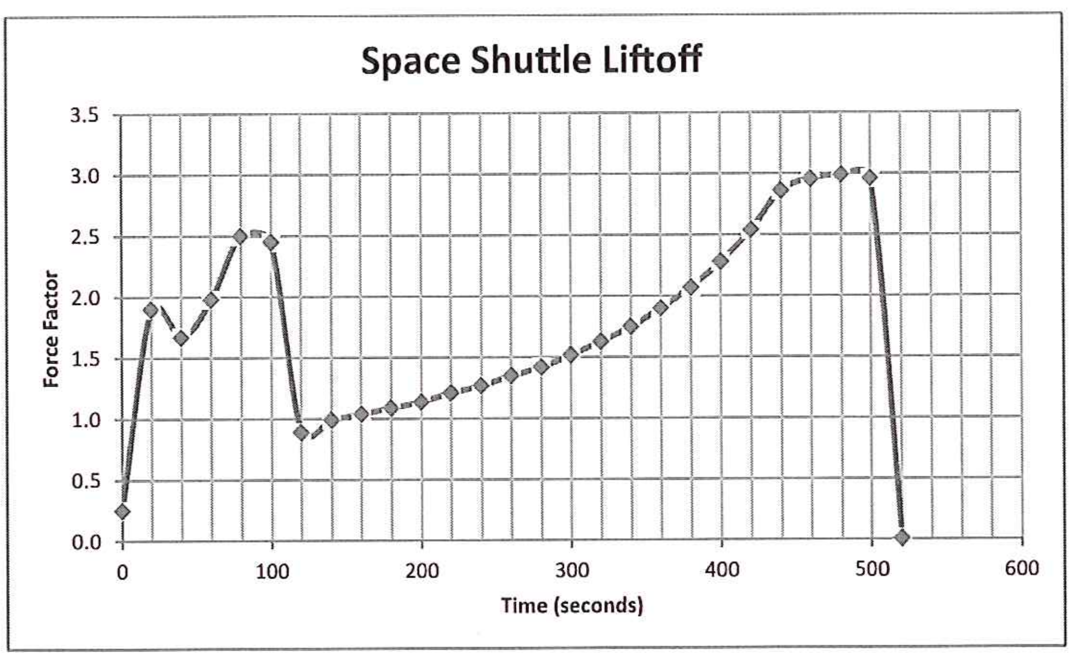
1. a. The element of the track that seems to have the highest g's for the longest time is at the bottom of the tower coming down. Looking at the graph at the top of the next page, list the maximum g's and estimate how long you felt heavy (heavy> 2.0 g's).

   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.



2. 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 Air Time 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?

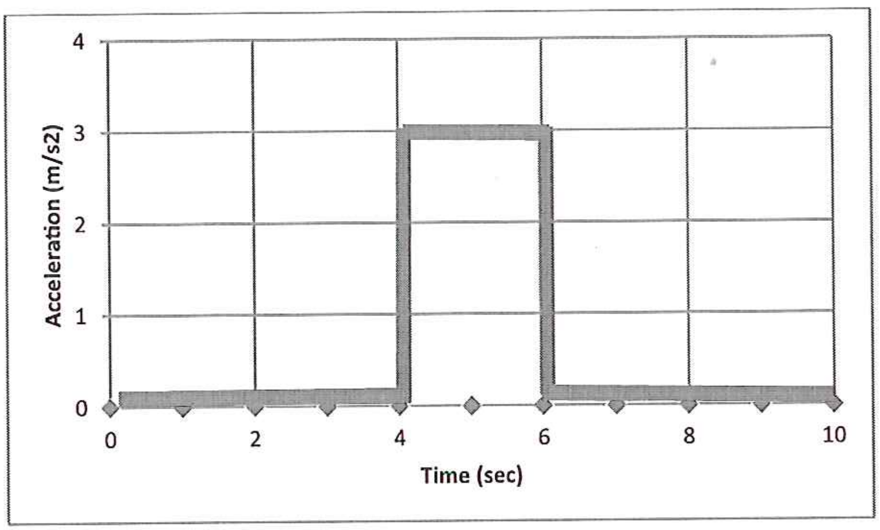
Problems

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.

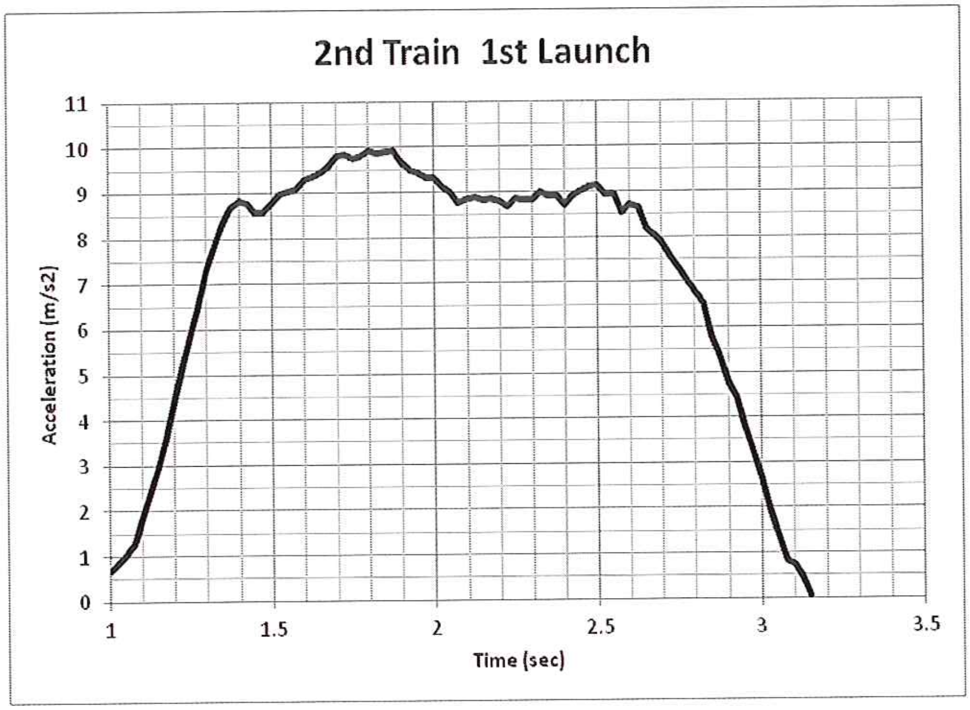


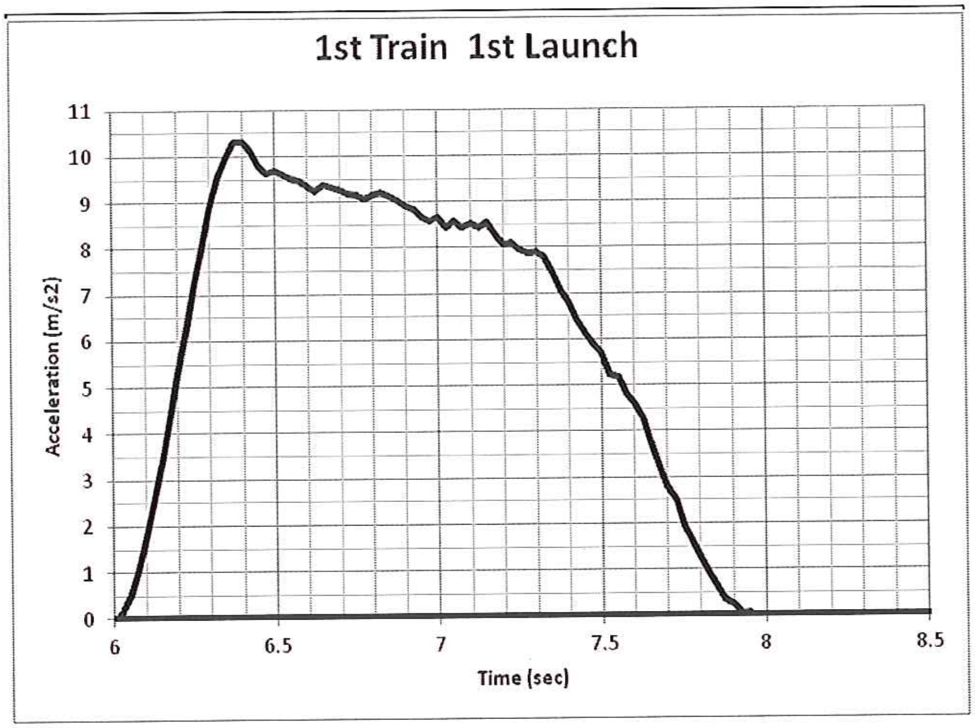
This object has an acceleration of 3 m/s^2 for 2 seconds. The equation v=at produces a velocity of 6 m/s. If you look at the rectangle on the graph (formed between 4 and 6 seconds) it has an area (length x width) of 6 m/s. It turns out that the velocity change indicated on any acceleration versus time 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


2nd Train 1st Launch
Acceleration (m/s2)
Time (sec)
0
1
2
3
4
5
6
7
8
9
10
11
1
1.5
2
2.5
3
3.5


1st Train 1st 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

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. $(1\text{-}v^2/rg)$

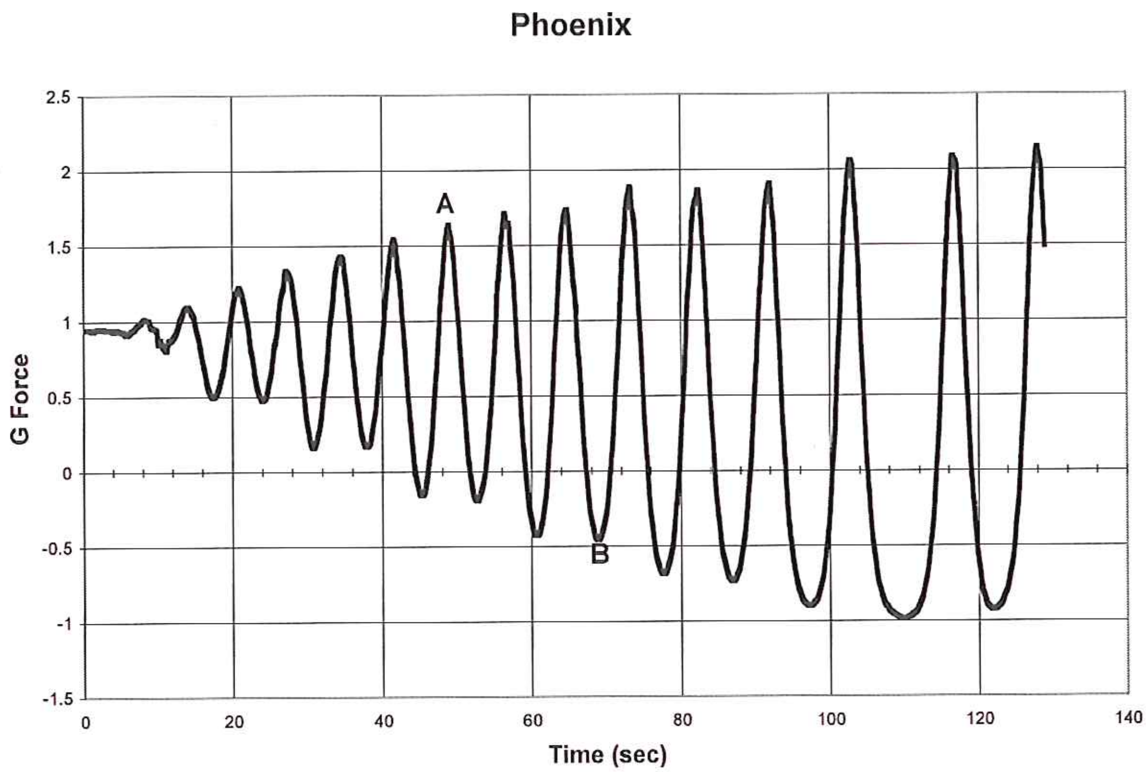
c. Compare this to the g force on the (RF1) G force graph. How does it compare to your feelings on the twister?

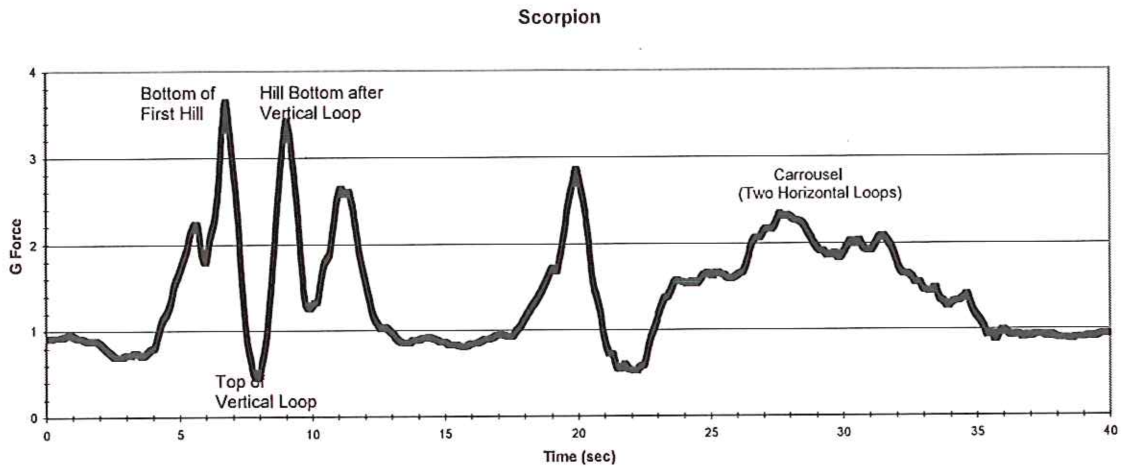
4. a .Compute the speed of the coaster train at the top of the tower, by using the front to back time as it passes the first post at the top. The length of the train is 10.25 m.

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

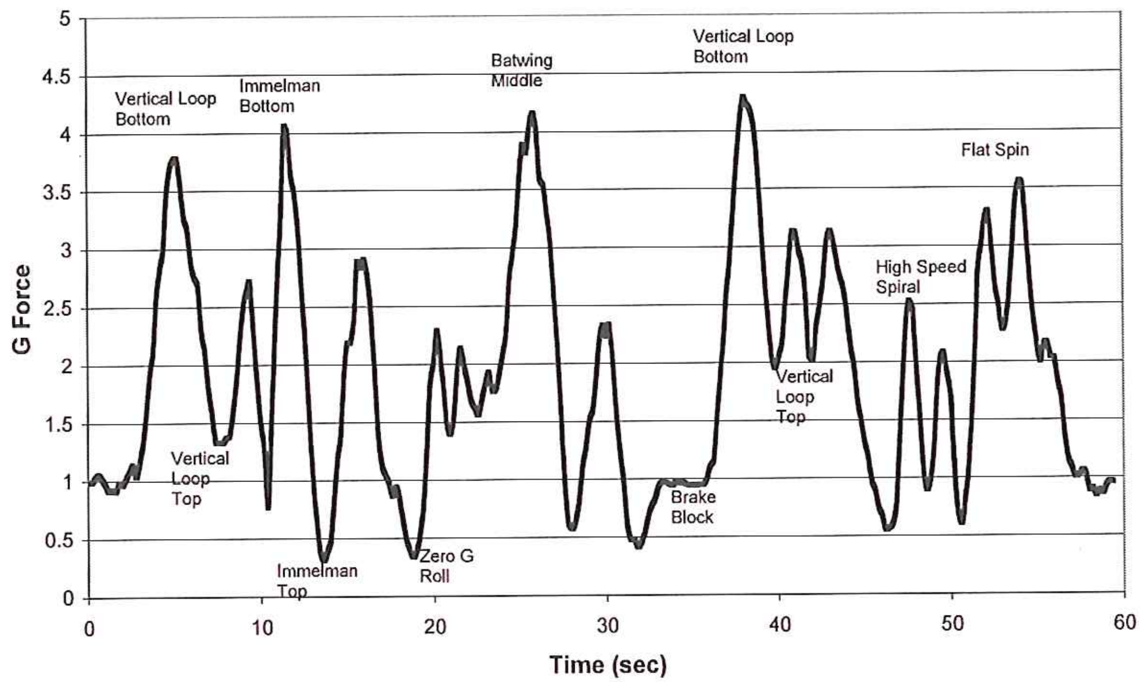
Using conservation of energy (KE at bottom=KE +PE at top) compute what the speed should be at the top. The speed at the bottom of the hill 25.9 m/s, and that the height of the tower is 31.9 meters above the Launch 2.

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.

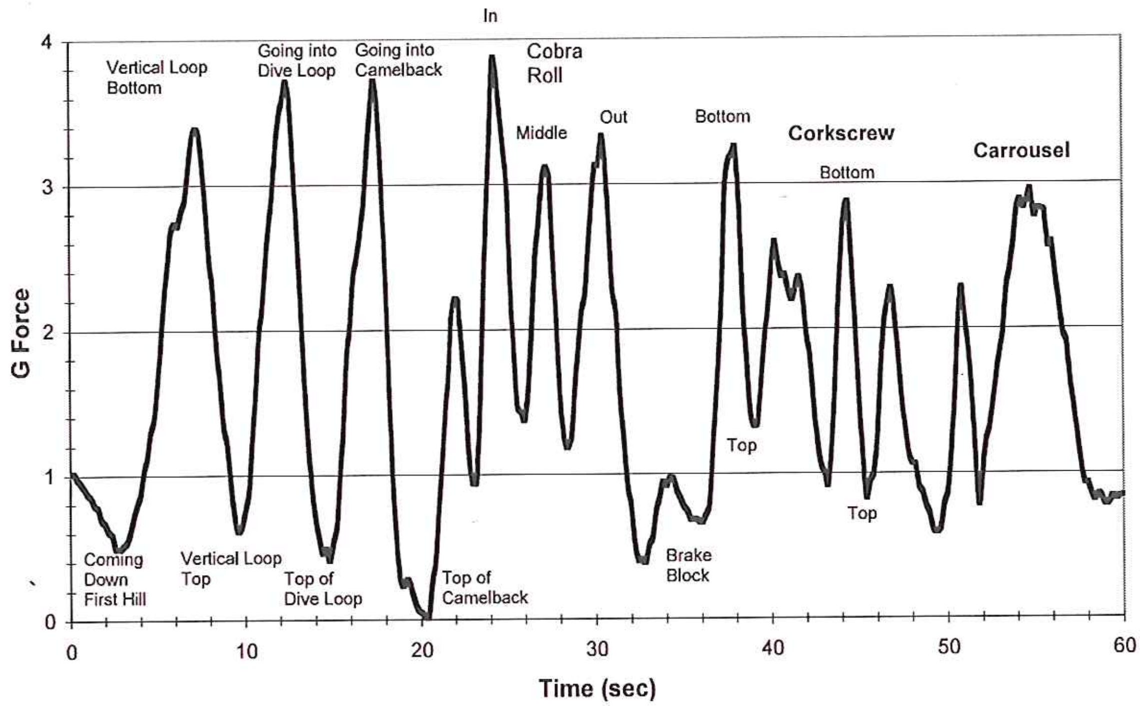

Phoenix
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
G Force
A
B
0
20
40
60
80
100
120
140
Time (sec)

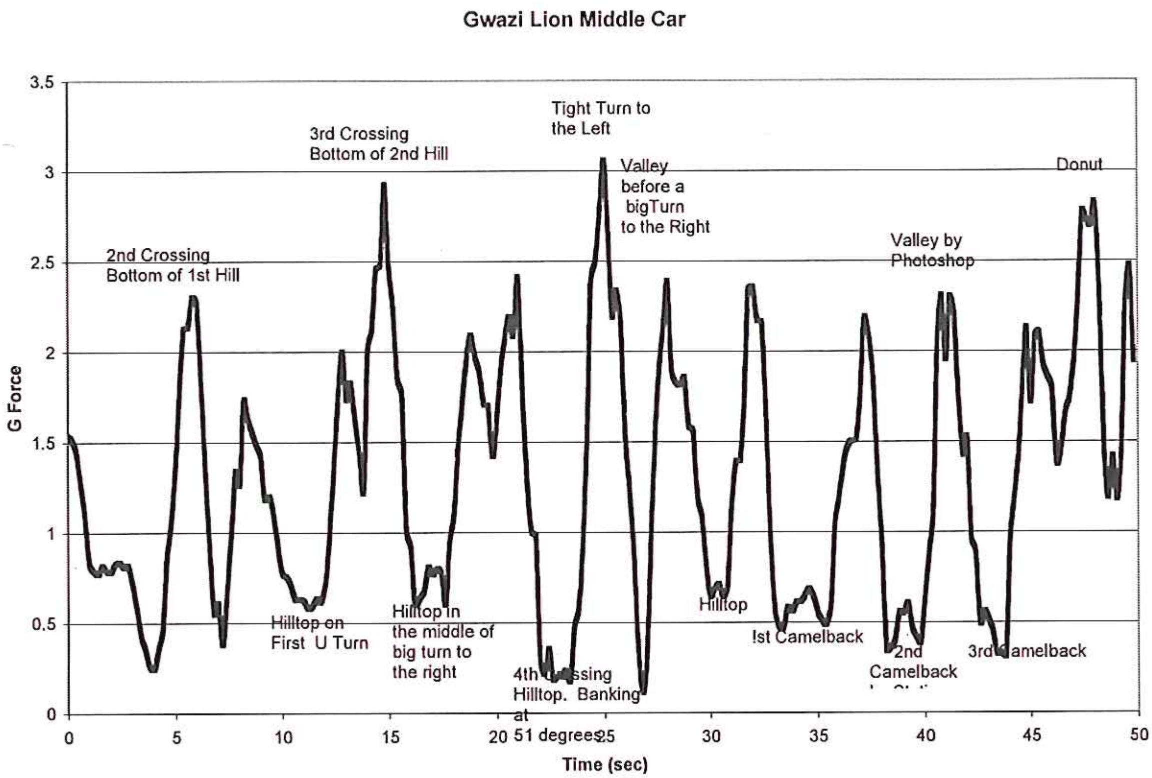

Scorpion
Bottom of First Hill
Hill Bottom after Vertical Loop
Top of Vertical Loop
Carrousel (Two Horizontal Loops)
G Force
Time (sec)
0
1
2
3
4
0
5
10
15
20
25
30
35
40

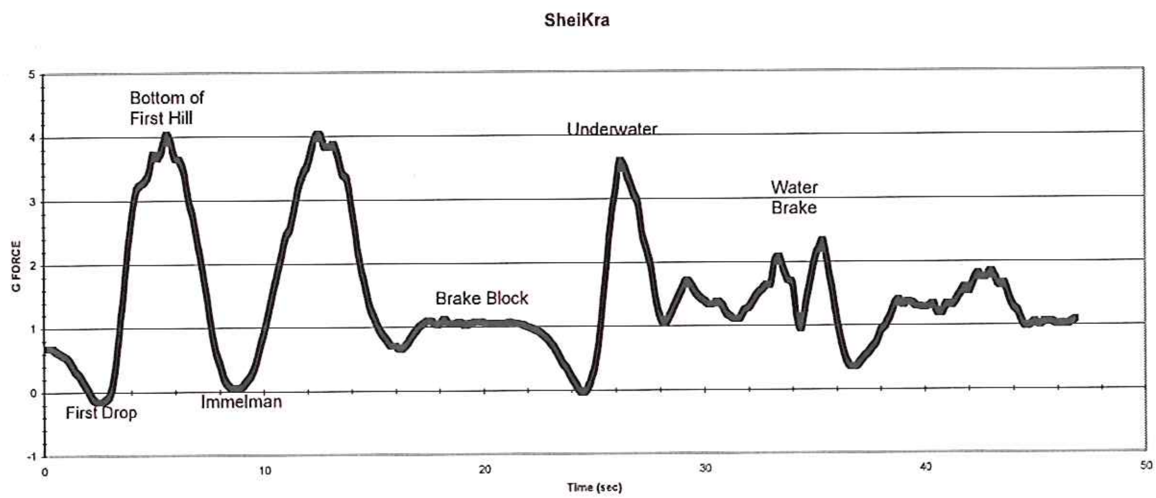
Montu


Montu
Vertical Loop Bottom
Immelman Bottom
Batwing Middle
Vertical Loop Bottom
Flat Spin
High Speed Spiral
Vertical Loop Top
Immelman Top
Zero G Roll
Brake Block
Vertical Loop Top
G Force
Time (sec)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60

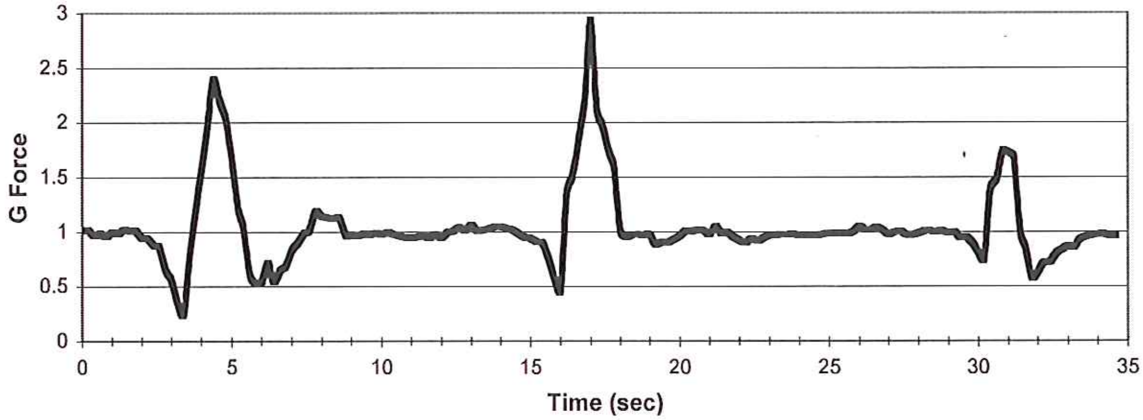
Kumba


In
Cobra Roll
Vertical Loop Bottom
Going into Dive Loop
Going into Camelback
Middle
Out
Bottom
Corkscrew
Bottom
Carrousel
Top
Top
Coming Down First Hill
Vertical Loop Top
Top of Dive Loop
Top of Camelback
Brake Block
G Force
Time (sec)
0
1
2
3
4
0
10
20
30
40
50
60

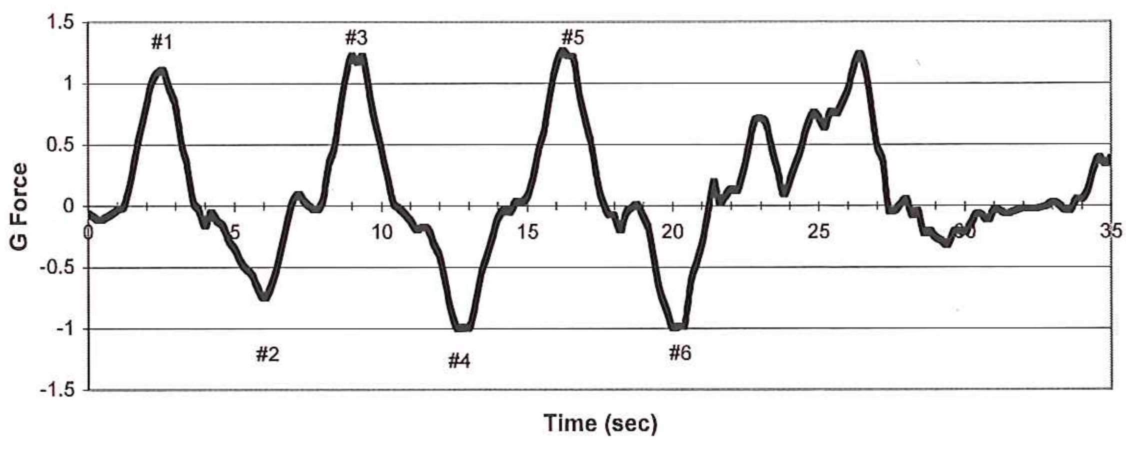

Gwazi Lion Middle Car
G Force
Time (sec)
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
2nd Crossing
Bottom of 1st Hill
Hilltop on
First U Turn
3rd Crossing
Bottom of 2nd Hill
Hilltop in
the middle of
big turn to
the right
4th Crossing
Hilltop. Banking
at
51 degrees
Tight Turn to
the Left
Valley
before a
bigTurn
to the Right
Hilltop
!st Camelback
2nd
Camelback
Valley by
Photoshop
3rd Camelback
Donut

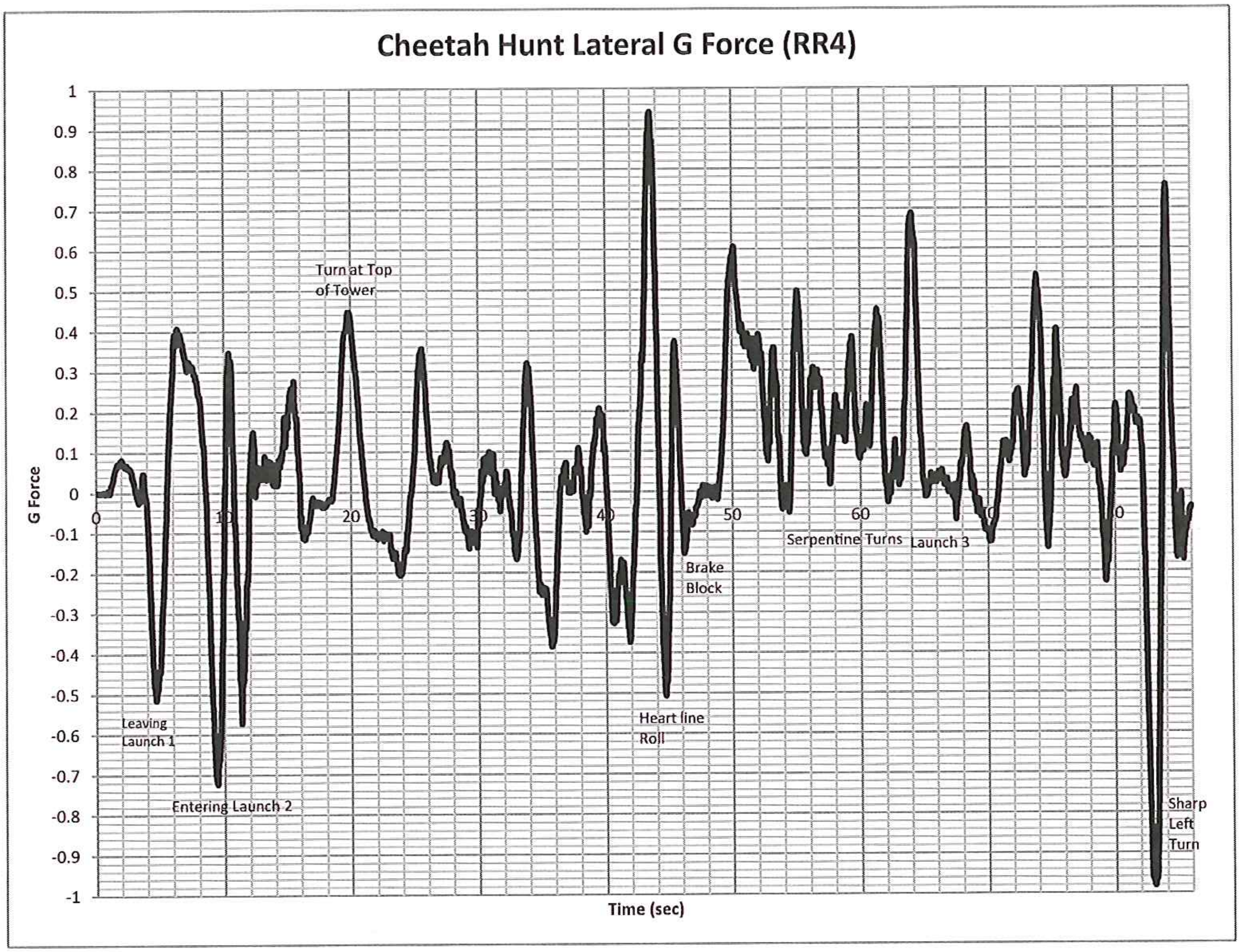

SheiKra
Bottom of
First Hill
Underwater
Water
Brake
Brake Block
First Drop
Immelman
G FORCE
Time (sec)
5
4
3
2
1
0
-1
0
10
20
30
40
50

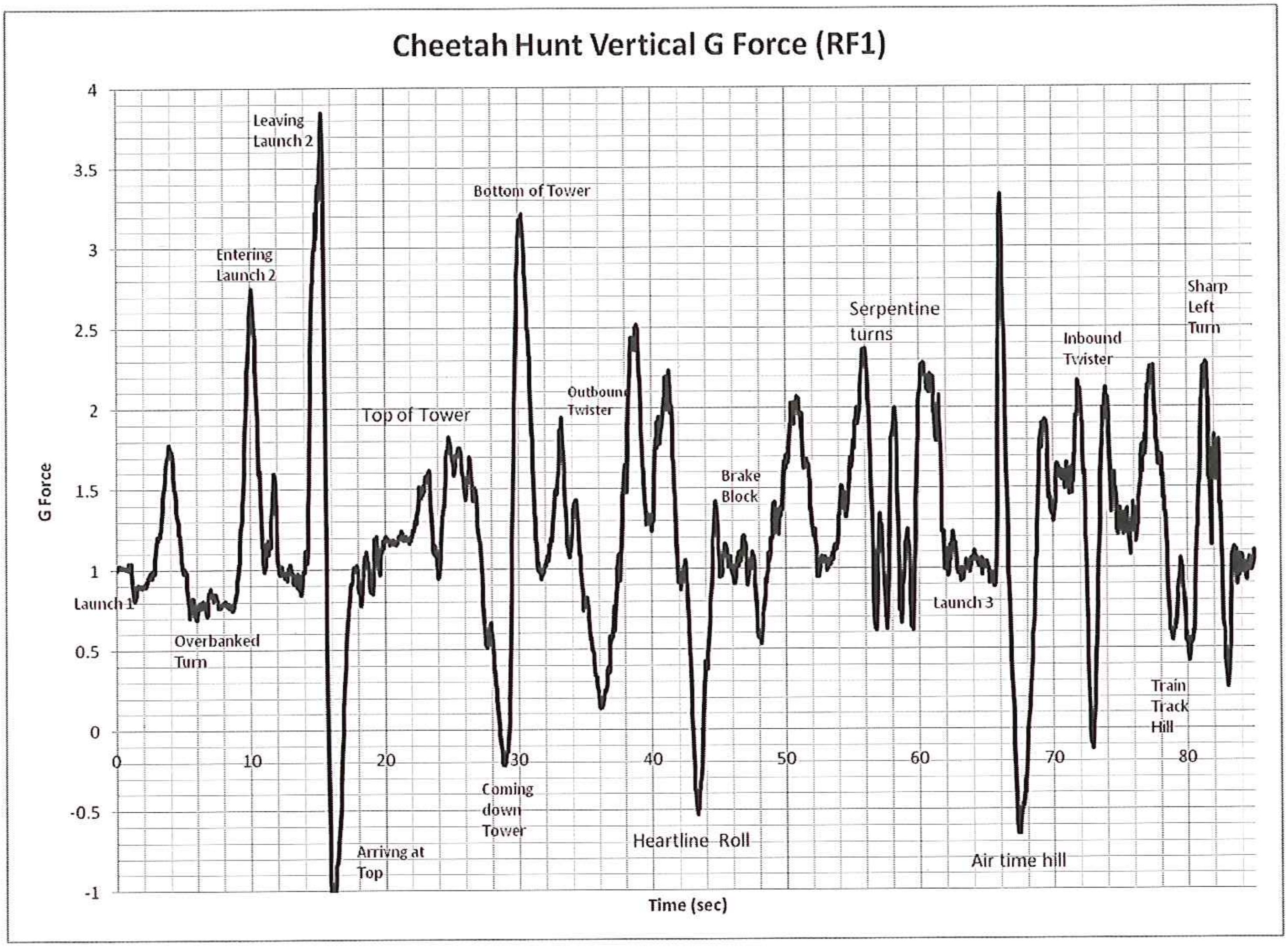
SandSerpent (Vertical Force)

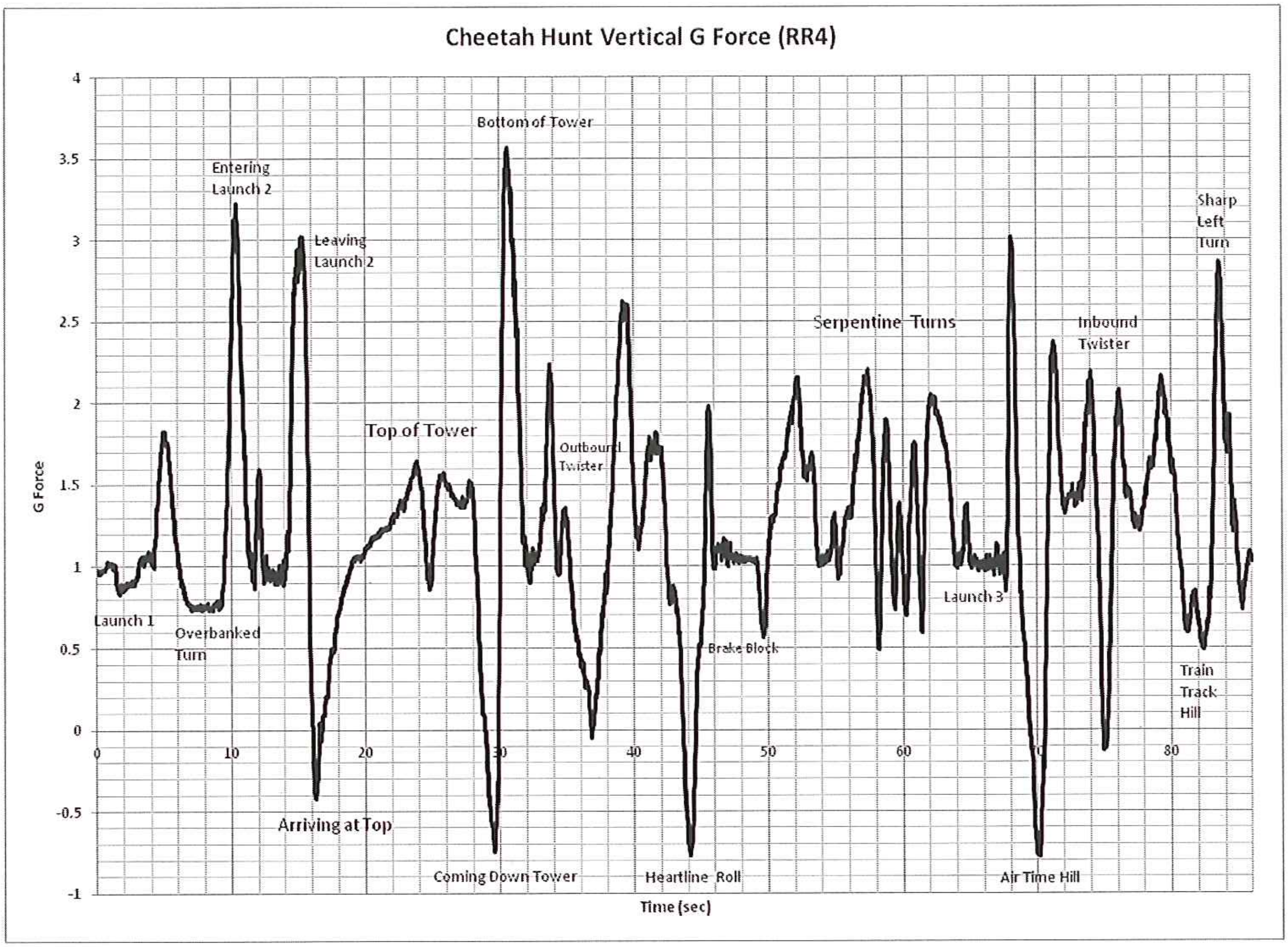


SandSerpent (Horizontal Force)




Cheetah Hunt Lateral G Force (RR4)
G Force
Time (sec)
Leaving Launch 1
Entering Launch 2
Turn at Top of Tower
Heart line Roll
Brake Block
Serpentine Turns
Launch 3
Sharp Left Turn


Cheetah Hunt Vertical G Force (RF1)
G Force
Time (sec)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
10
20
30
40
50
60
70
80
Leaving Launch 2
Entering Launch 2
Launch 1
Overbanked Turn
Top of Tower
Arrivng at Top
Bottom of Tower
Coming down Tower
Outbound Twister
Heartline Roll
Brake Block
Serpentine turns
Launch 3
Air time hill
Inbound Twister
Train Track Hill
Sharp Left Turn


Cheetah Hunt Vertical G Force (RR4)
G Force
Time (sec)
Launch 1
Overbanked Turn
Entering Launch 2
Leaving Launch 2
Arriving at Top
Top of Tower
Coming Down Tower
Bottom of Tower
Outbound Twister
Heartline Roll
Brake Block
Serpentine Turns
Launch 3
Air Time Hill
Inbound Twister
Train Track Hill
Sharp Left Turn

The information from the Physics Day program collateral is not based on any scientifically accurate accelerometer testing of the amusement rides. In fact, the testing was done solely for the purpose of providing this program with information necessary to complete vital academic experiments, and does not in any way reflect the actual ride conditions.

Busch Gardens.

Physics Day