Physics Day

The Worlds of Busch Gardens
TAMPA BAY, FL

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Introduction

The principles of kinematics, dynamics and energy come alive at Busch Gardens. You can experience forces similar to the space shuttle astronauts on the Kumba, feel 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 Cheetah Chase.) 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, Cheetah Chase

Horizontal Force Meters are used on the following Basic rides:

Log Flume, Tidal Wave, Bumper Cars, Cheetah Chase

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.

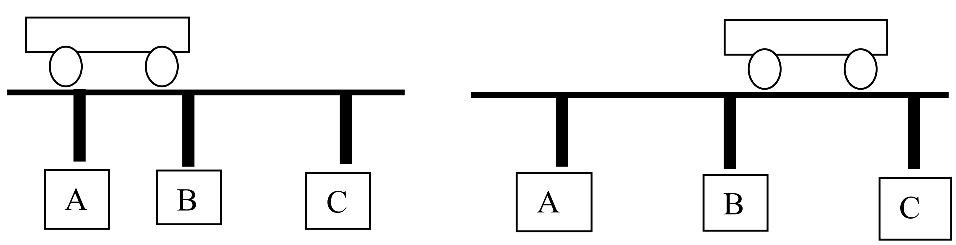
What to do before coming to the park:
1. Have the students complete the WHAT TO DOING BEFORE COMING TO THE PARK section for each ride that they are going to do. They will do sample problems and make predictions.
2. In class, go over the physics principles and do some of the pre-activities.

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.

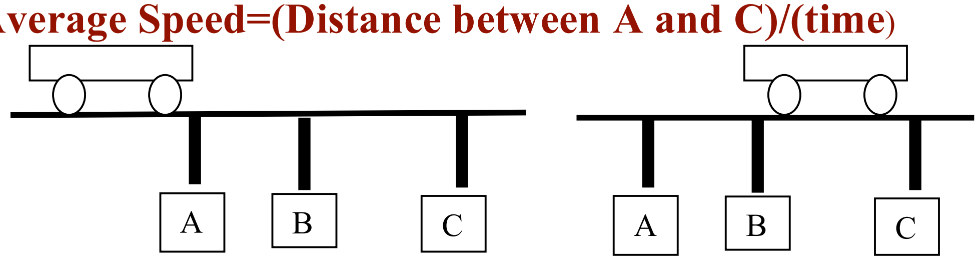
Speed
Usually the average speed of a coaster at a point (usually a post or pole) is determined by timing the coaster passing by that point. The stopwatch is started as the front of the coaster arrives at Post B, and the stopwatch is stopped as the back of the coaster passes the same post. If the length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



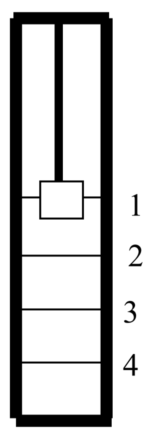
G Force

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.

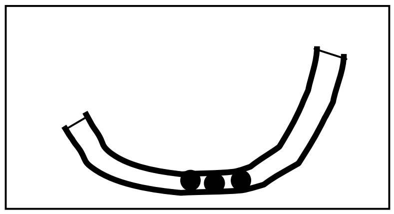
If the coaster car turns a corner quickly in an unbanked turn, a lateral G Force is experienced and can be measured by holding the Horizontal Force meter perpendicular to the direction of motion.

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

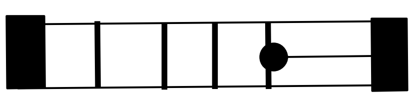
Vertical and Horizontal G Force Meters (sometimes called accelerometers) are available from Pasco Scientific (1-800-772-8700). Pasco sells a set of 15 vertical and horizontal accelerometers for about $70 (ME-9426). Sargent Welch (1-800-727-4368) also sells a set of 15 of each type of accelerometer for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

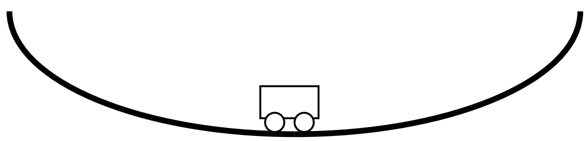
Problems

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, $Fc=mv^2/r$. 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

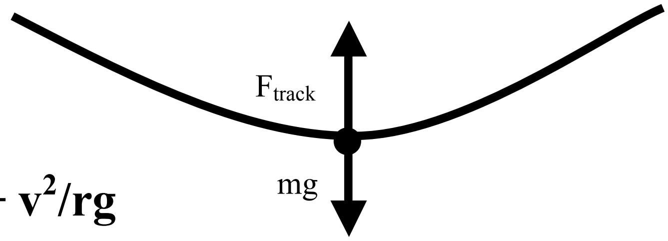
The force of the track is in toward the center of the circle and is therefore positive. The weight of the coaster, mg, is negative, since it is away from the center of the circle.



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

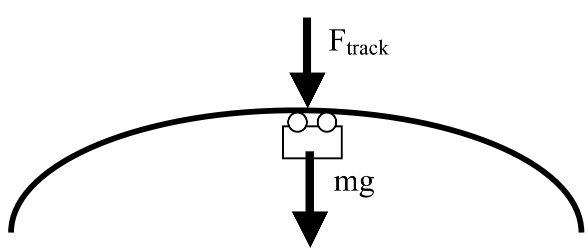
$$F_{track} = mg + mv^2/r$$

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



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.

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

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

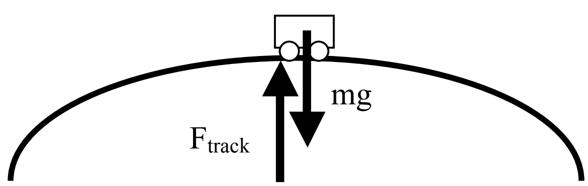
$$\text{G Force} = F_{track}/mg = \mathbf{v^2/rg - 1}$$

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:

$v^2 - v_o^2 = 2ax$ $\quad$ $v = v_o + at$ $\quad$ $d = 1/2\ at^2 + v_o t$

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 $\quad$ 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%

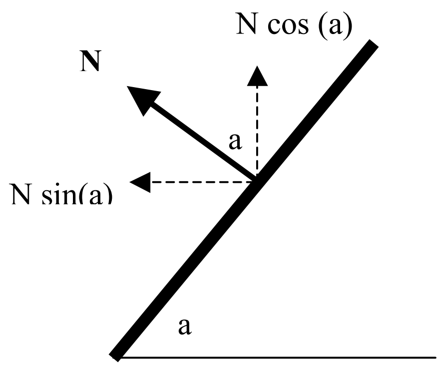
$(\frac{1}{2} mv_0^2 + mgh_0 - \frac{1}{2} mv^2 + mgh)/((\frac{1}{2} mv_0^2 + mgh_0) * 100\%$

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



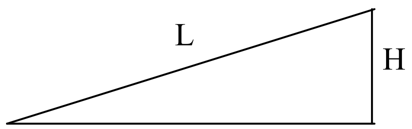
Horizontal component will be equal to the centripetal force ($N \sin(a) = mv^2/r$) and the Vertical component will be equal to the weight ($N \cos(a) = mg$) Dividing the first equation by the second yields an expession for the banking angle:

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

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.

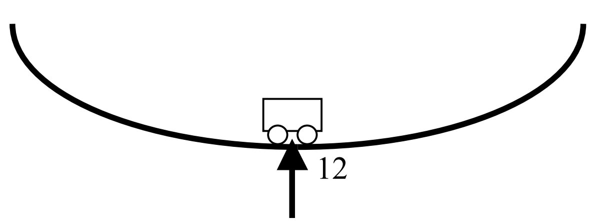
Newton's Third Law
For every action there is an equal and opposite reaction. If two people are engaged in a tug of war, the rope pulls the same on each one, but in opposite directions. The loser is the one with the poorest footing. In order for a person in an elevator to accelerate upward, the elevator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

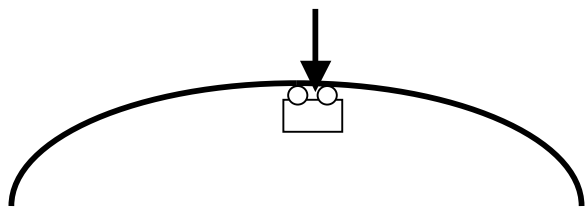
On a roller coaster, it is the acceleration that produces the thrills. Accelerations can be either changes in speed or changes in direction. While experiencing accelerations, passengers feel heavy or light, feel pushed back into their seats or thrown forward, or feel like they are thrown to the left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

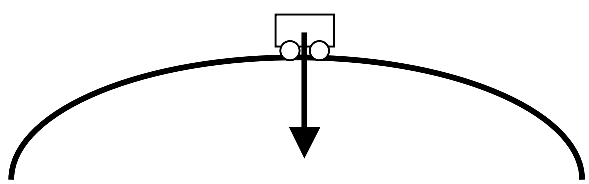
If the speed along the horizontal is increased, the back of the seats must push the passengers. They in turn feel pushed back into their seats. This sensation occurs for passengers in the last coaster car at the top of hills.
As a coaster train descends a hill, gravity provides the force to cause the 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.

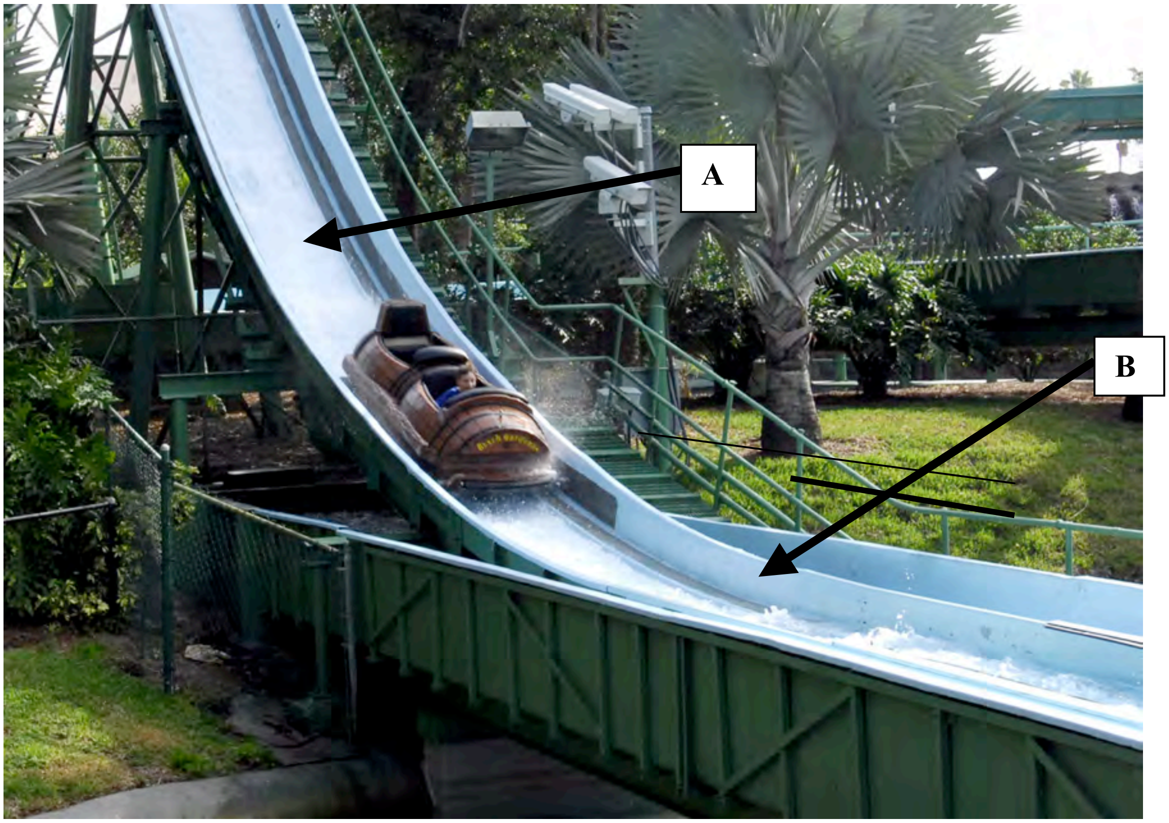
In order to find the percentage of energy converted to heat, the following equation can be used:

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

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 Python?

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

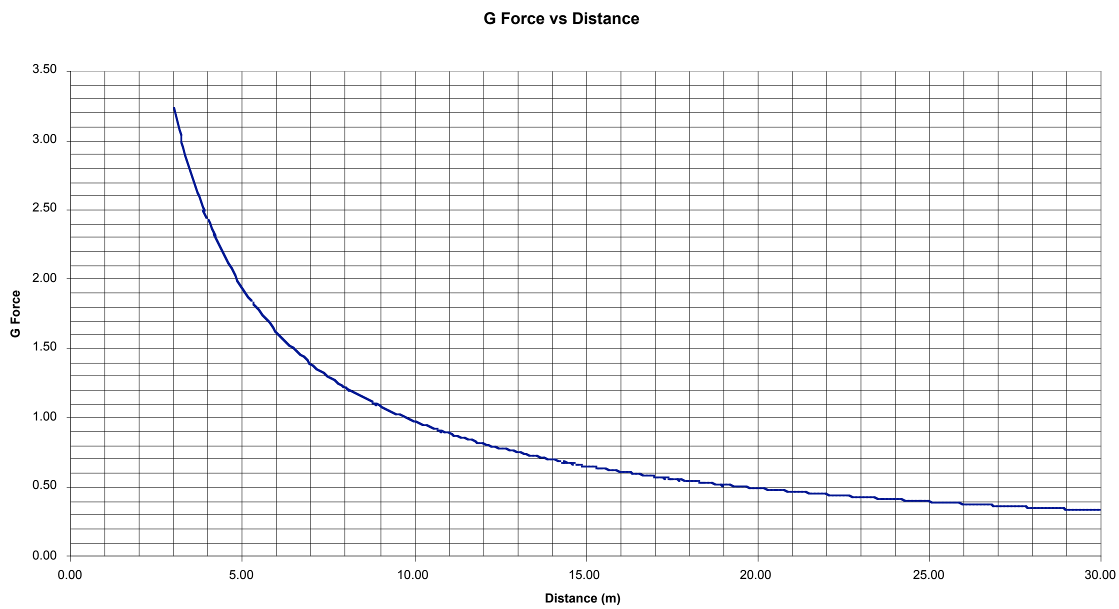
5. What was the horizontal G Force experienced at the splash? Use the chart below to convert from degrees to G Force.

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)

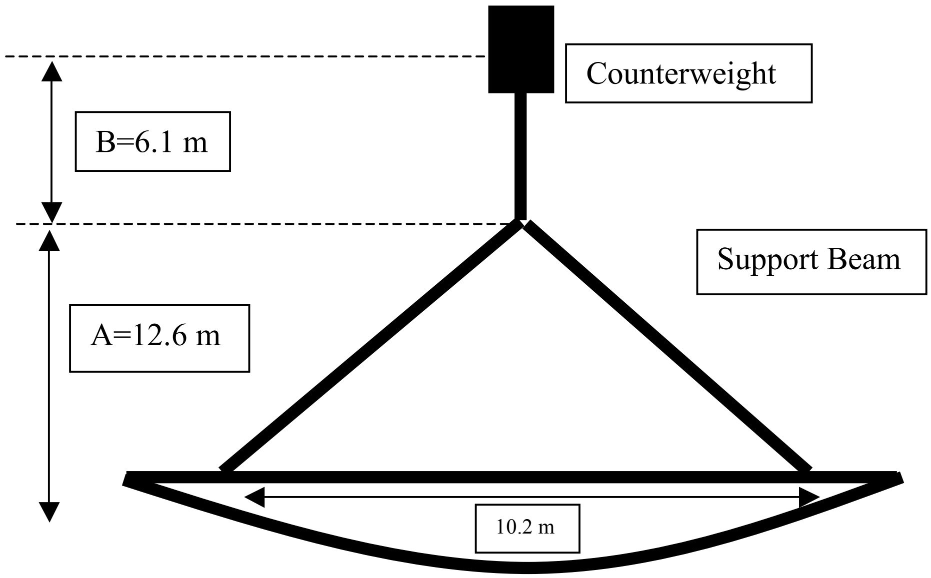
2. Compute the speed at the end of the splash. Length of log = 2.9 m

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

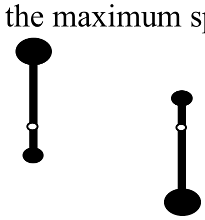


INSTRUMENTS REQUIRED

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 or the Python. Why then is it much slower at the bottom than either of those two coasters?

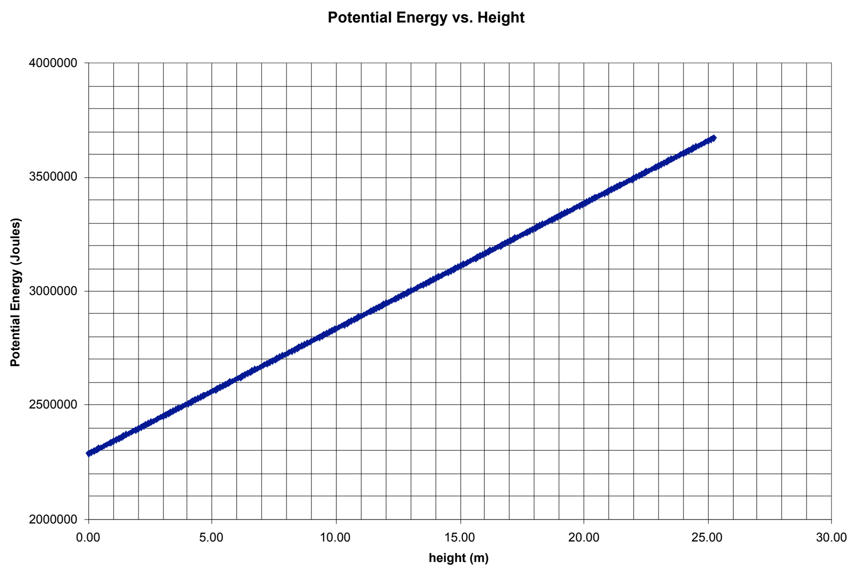
4. How does the drop time compare with the drop time of the Python or Scorpion? Why

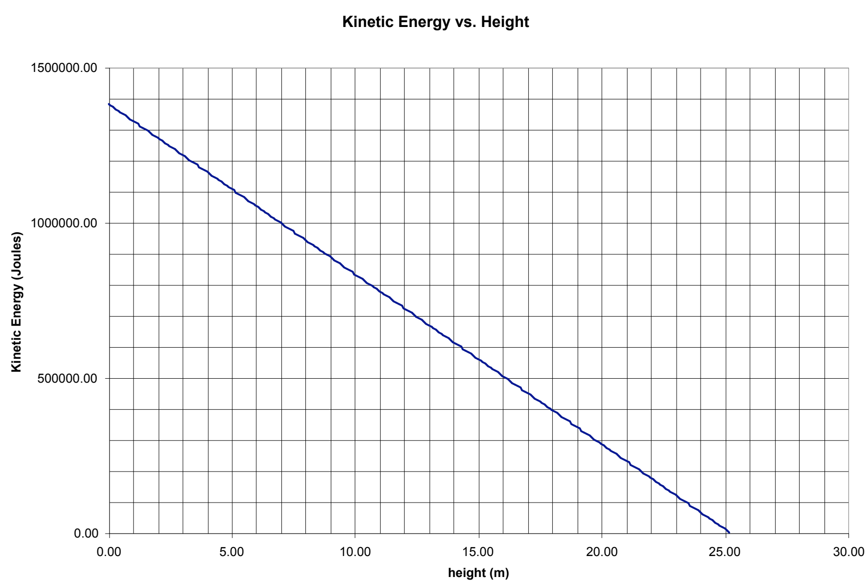
5. Examine the G Force vs. Time graph; describe what the boat is doing at points A and B. When the graph crosses the 0 line, where is the boat?

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?

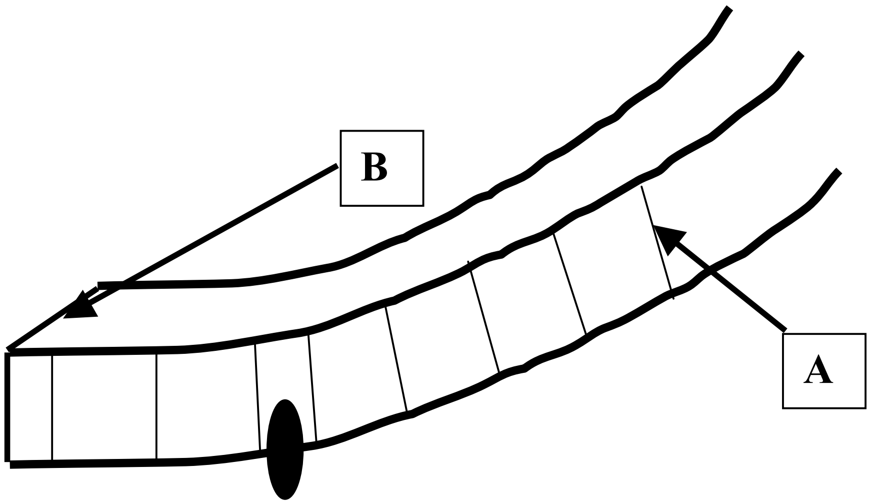
b. What is the total energy at h = 0? What is the total energy at h = 10 meters? What is the total energy at h = 25 m?

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

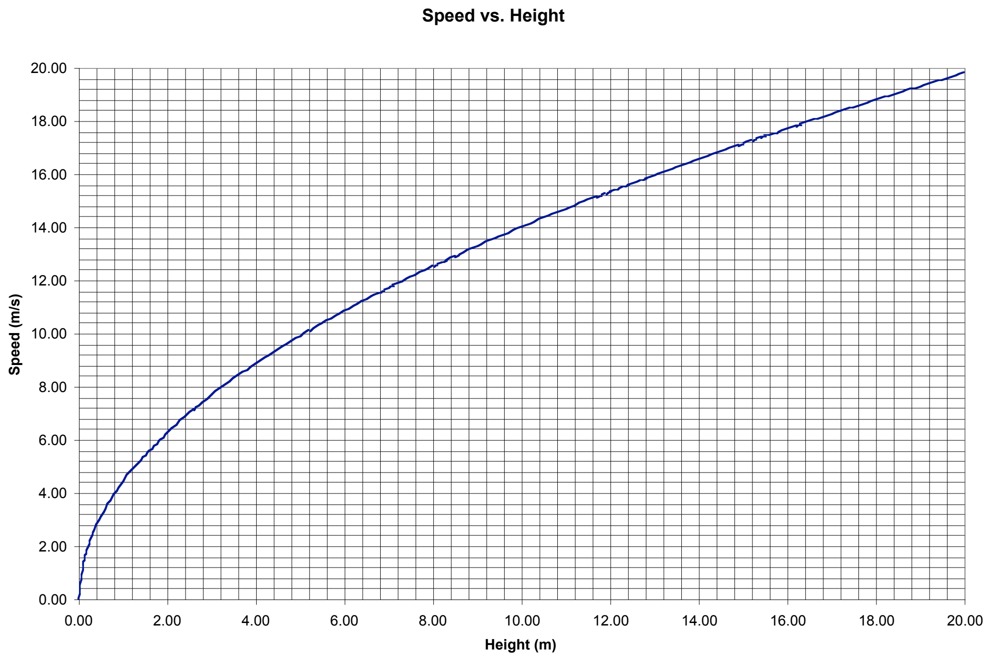
1. Compute the speed at the bottom of the hill by using the time it takes the boat to go between point A and B. The distance from A to B is 10.9 meters.

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?

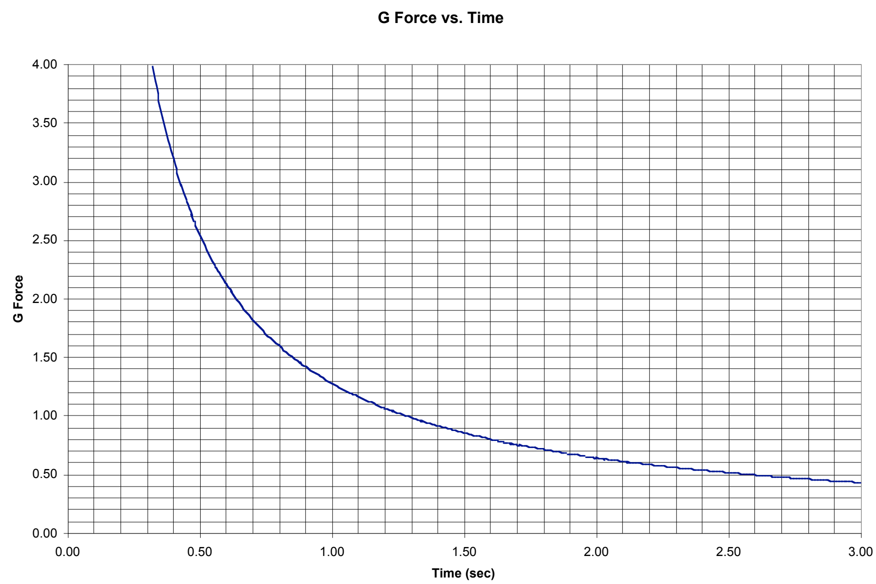
3. The graph below gives the speed at the bottom of a hill if there is no friction coming down the hill and a very small speed at the top.



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 major drop on the Python is shorter than the major drop on the Scorpion, yet their velocities at the bottom 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?

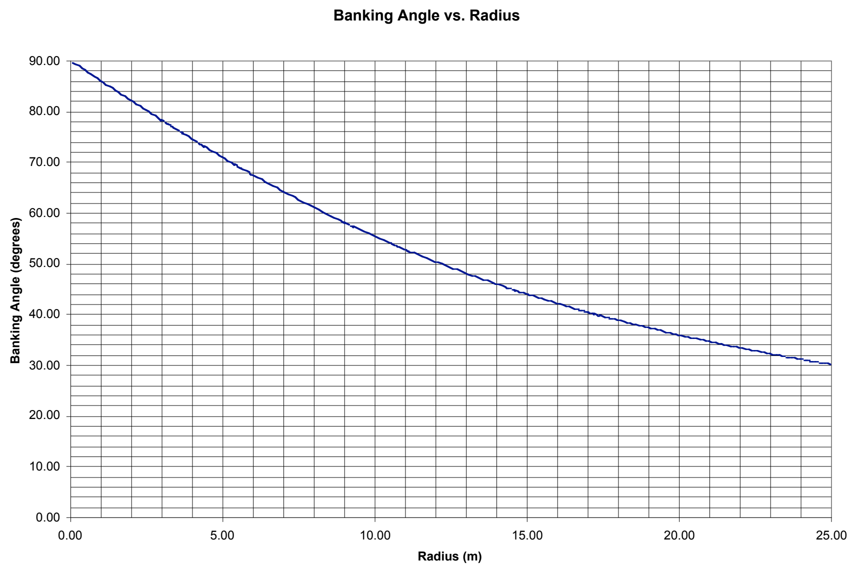
   b. What is the G Force associated with this radius of 8.1 meters? How does that compare with your measured value of G? How does it compare with the value from the graph of G Force vs. Time found a the end of the workbook?

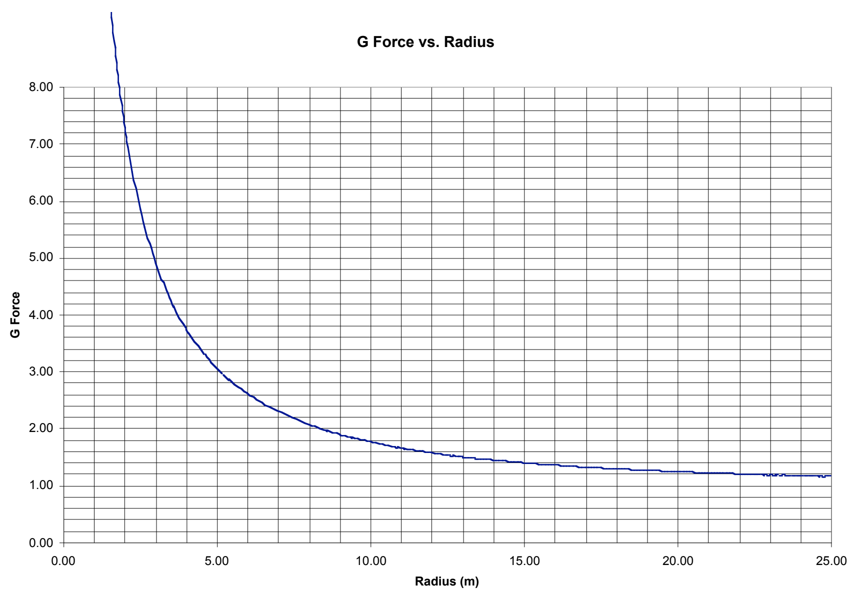
   c. If the radius is doubled to 16.2 m, what happens to the banking angle and G Force?

   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.

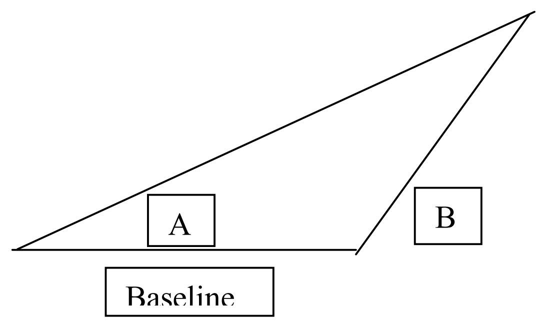
3. Compute the velocity in the horizontal loop. Compute the banking angle, and find the G Force in the horizontal loop, given that the radius of the loop is 8.1 m. Compare this value of the G Force to the value from the G Force vs. Time graph at the end of this workbook.

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.

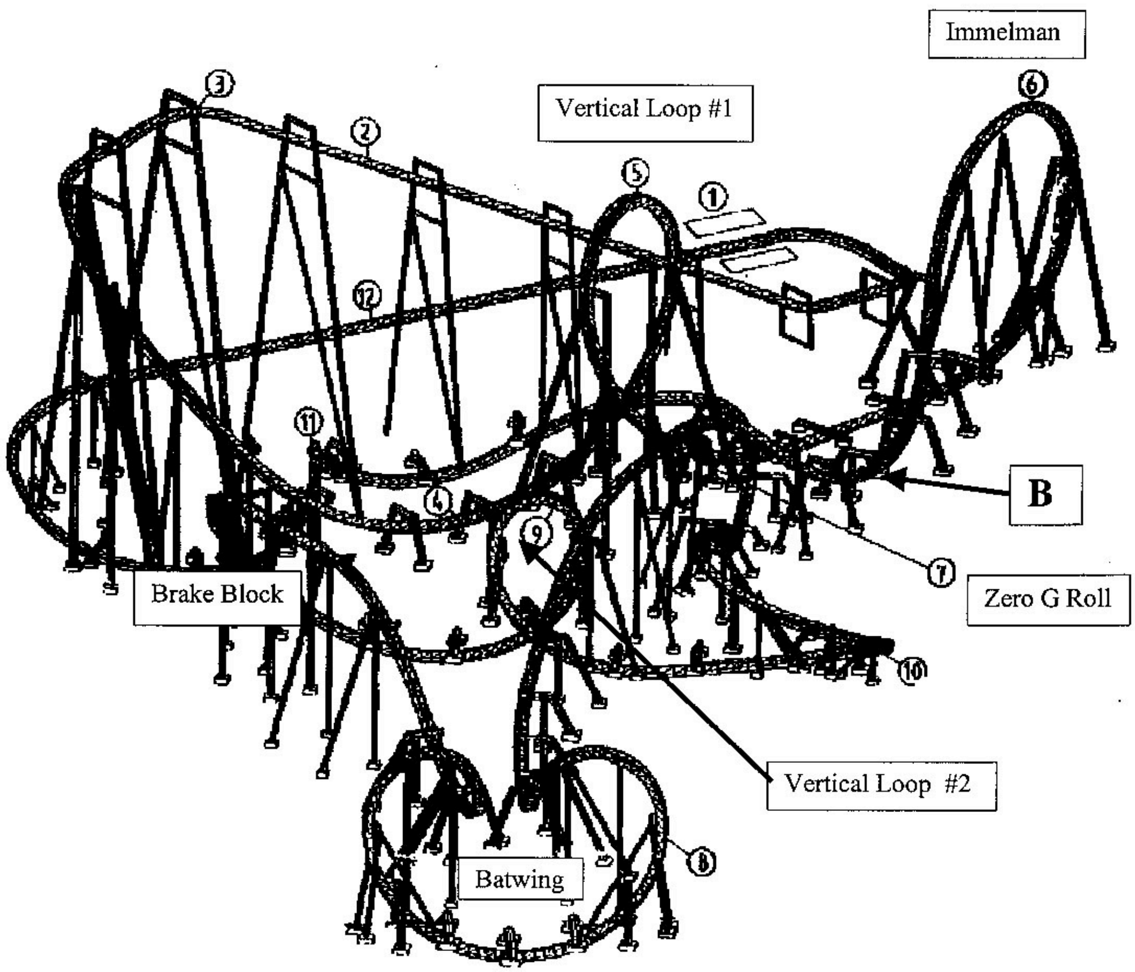
6. Find the height of the top of the first hill using your angle measurements.

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?

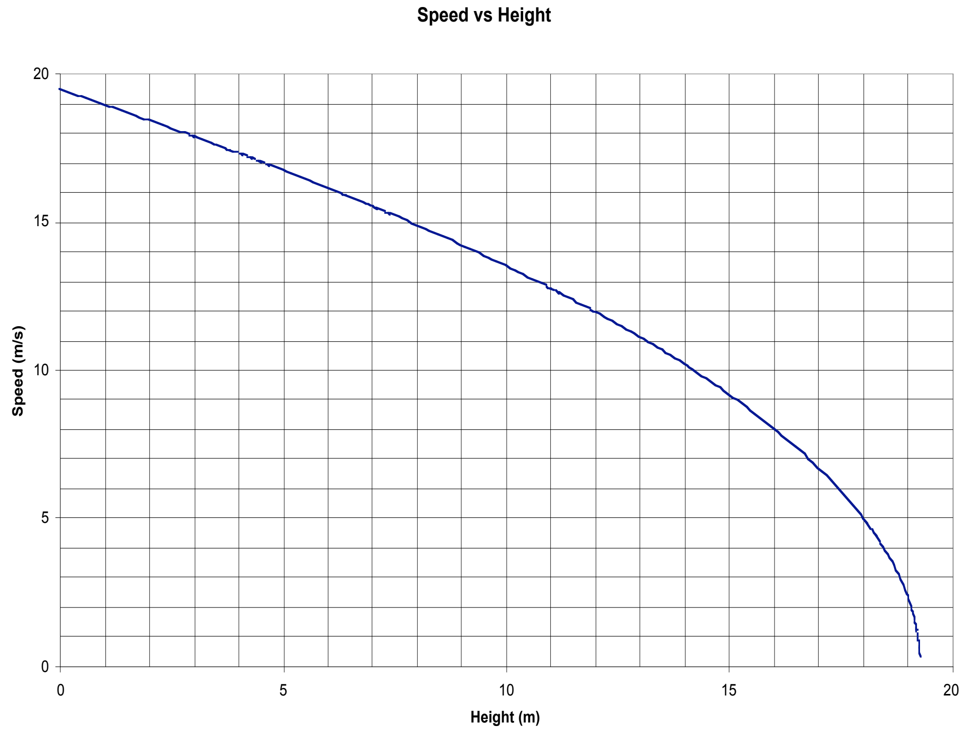
4. Why is the second vertical loop much smaller than the first vertical loop?

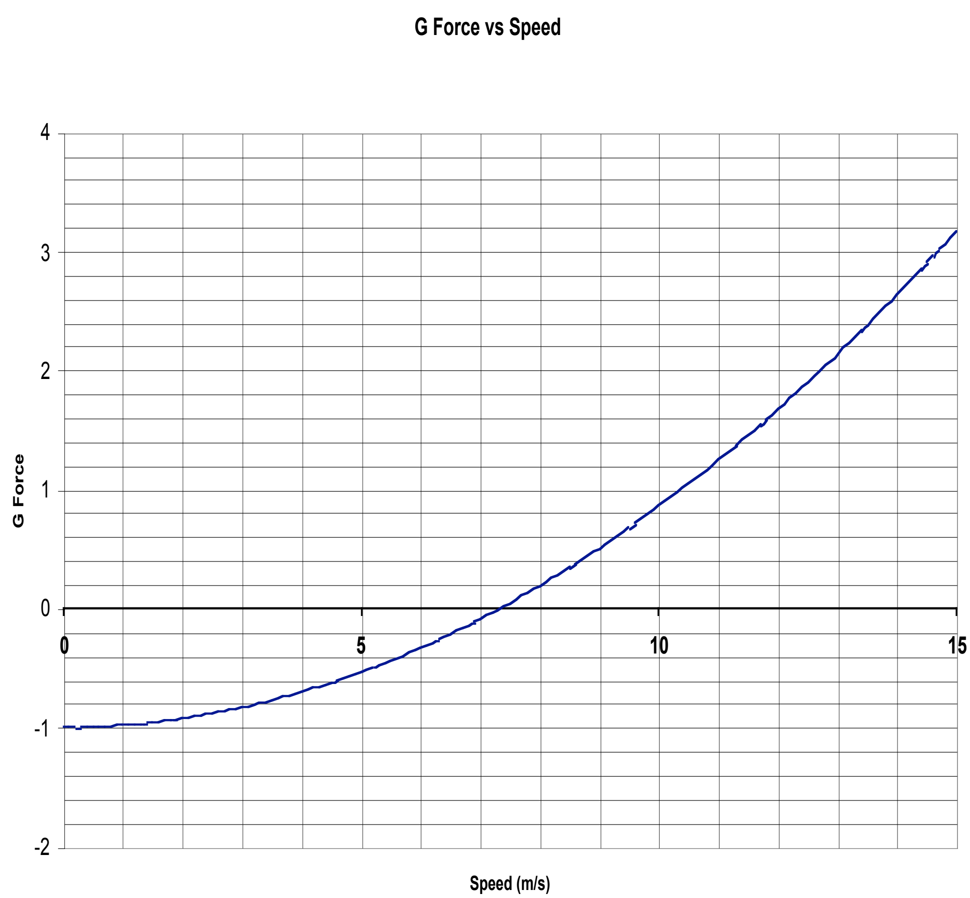
5. How is riding in the front car different from riding in the last?

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
Speed (m/s)
Height (m)
0
5
10
15
20


G Force vs Speed
G Force
Speed (m/s)
4
3
2
1
0
-1
-2
5
10
15

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?

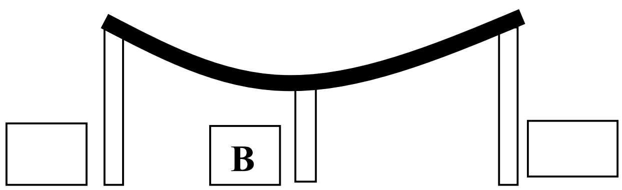
e. How do these graphical readings compare to your experiences

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).

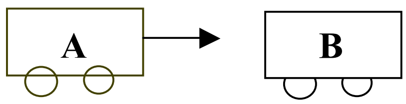
Computed value of G Force	Value from graph	Average G Force reading (if measured)

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).

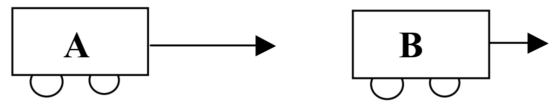
Computed value of G Force	Value from graph	Average G Force reading

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?

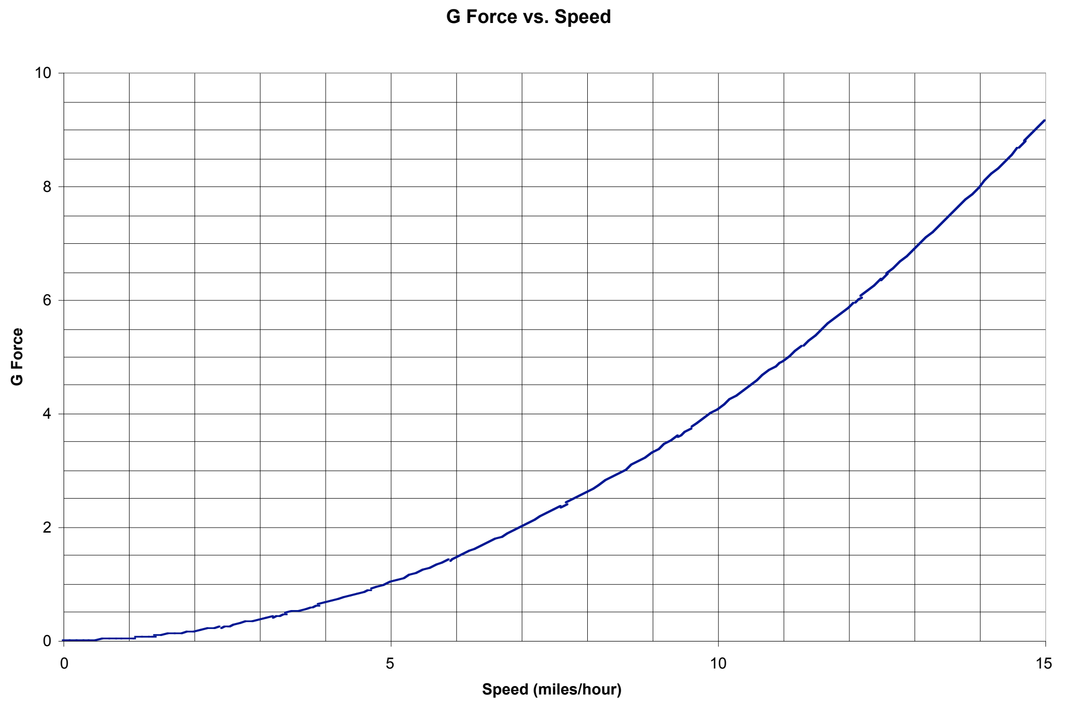
3. Answer the following:
a. When you strike a car from the rear, you feel pushed: forward backward left right
b. When you are struck from the rear, you feel pushed: forward backward left right
c. When you are struck on the left side, you feel pushed: forward backward left right
d. When you strike a car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

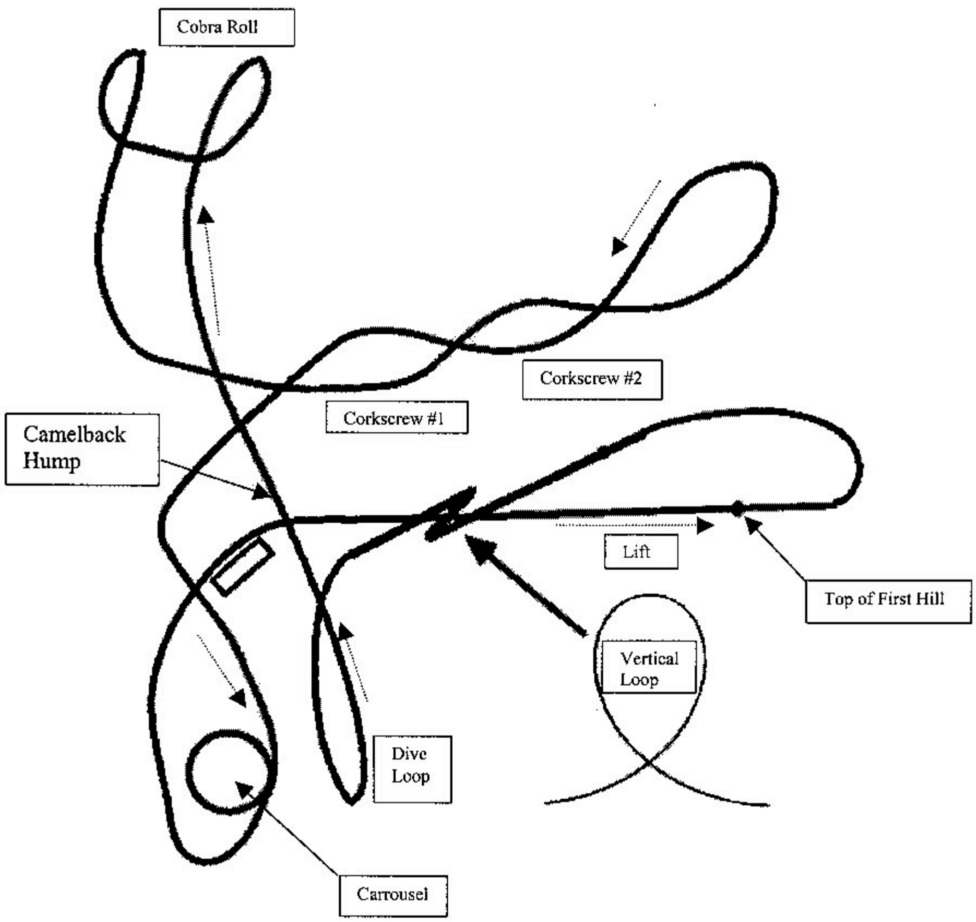


a. What happens to the force of the collision when the speed is doubled?

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?

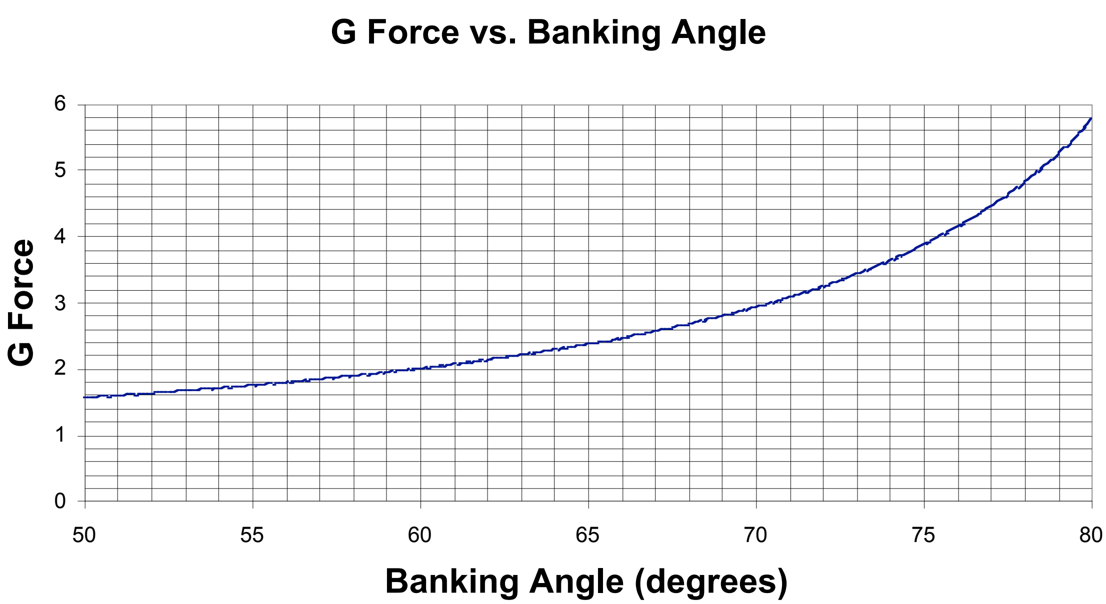
3. The Kumba has so many twists and turns that it can be disorienting. It is hard to tell where you are or whether you are upside down or not. This is especially true because your eyes will tell you that you are upside down, but you may not feel upside down. You also go from being light to being heavy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

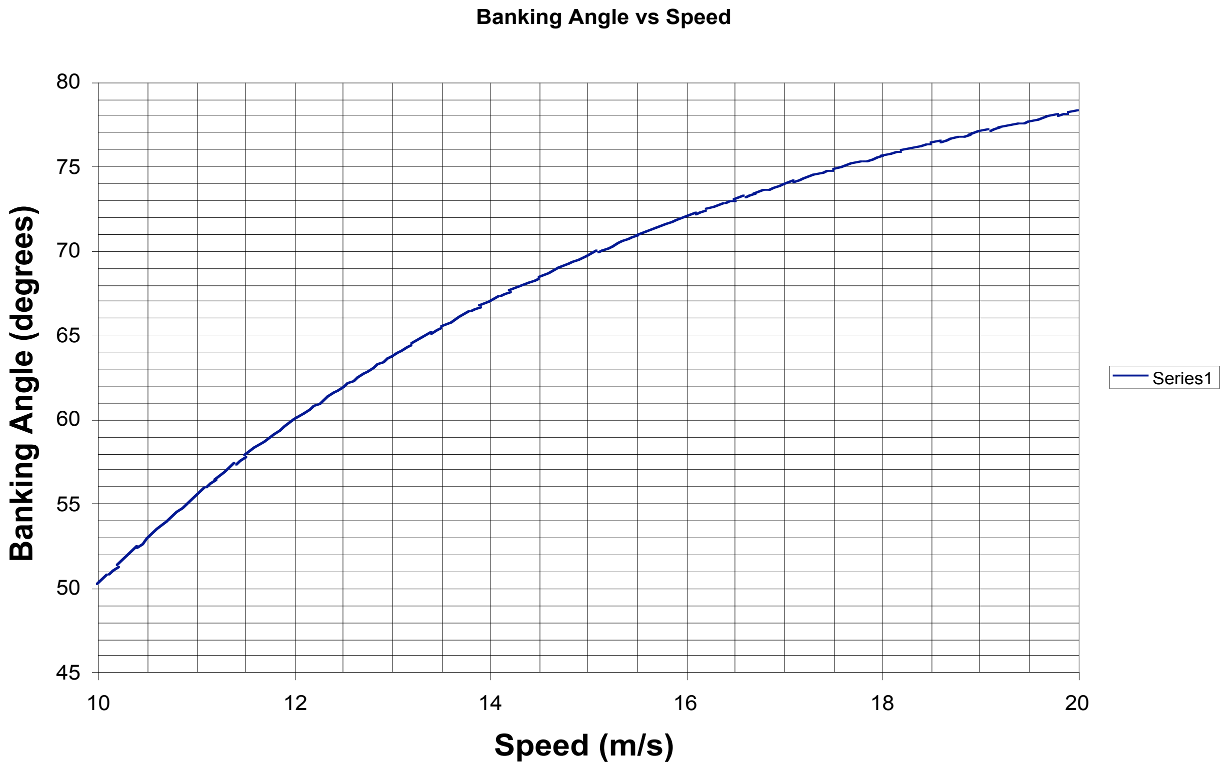
4. Give a general explanation for where on the ride you go fast and where slow.

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

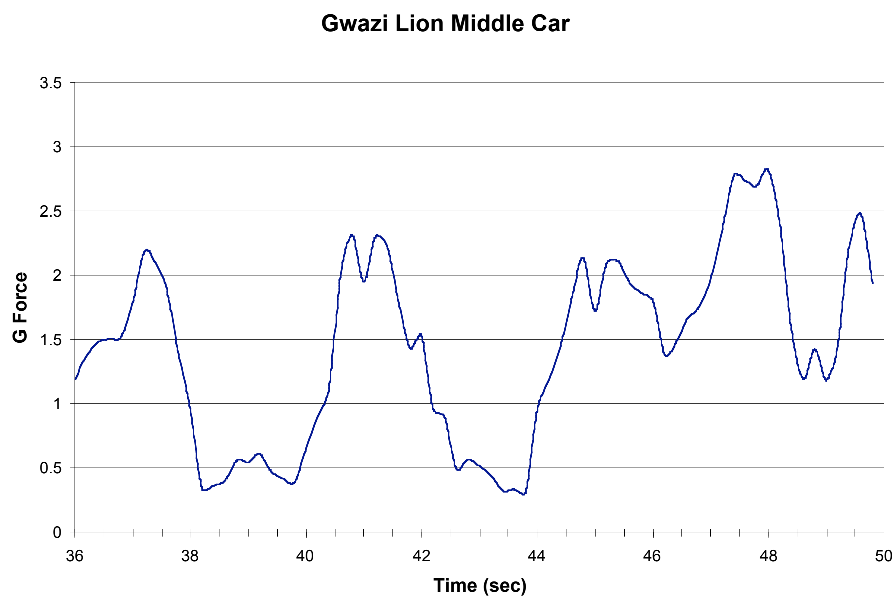
1. As you exit the ride, you will pass by the Photo Shop, which is indicated by a "P" on the diagram. Both the Tiger (further away and going to the right) and the Lion (closer and going to the left) pass by you at this point. Find the time for the Lion coaster to pass by one of the posts at the lowest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

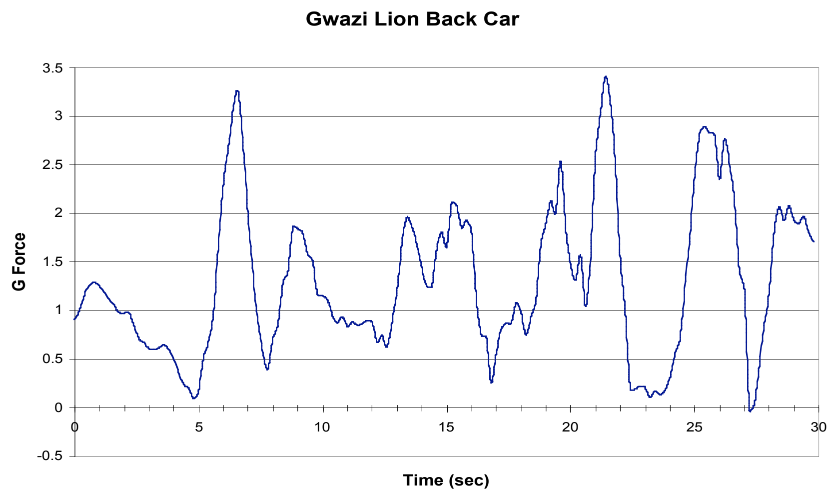
Problems

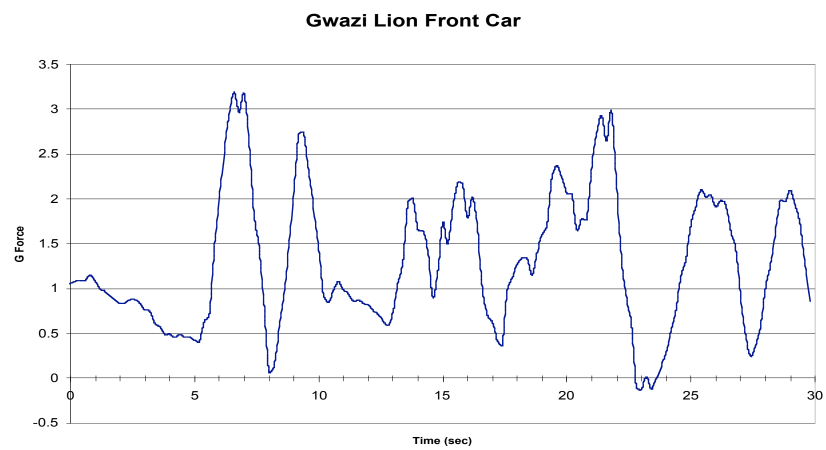
1. Compute the speed of the Gwazi Lion (by the Photo Shop) in meters/second. (Note: The length of the coaster train is 12.9 m.)

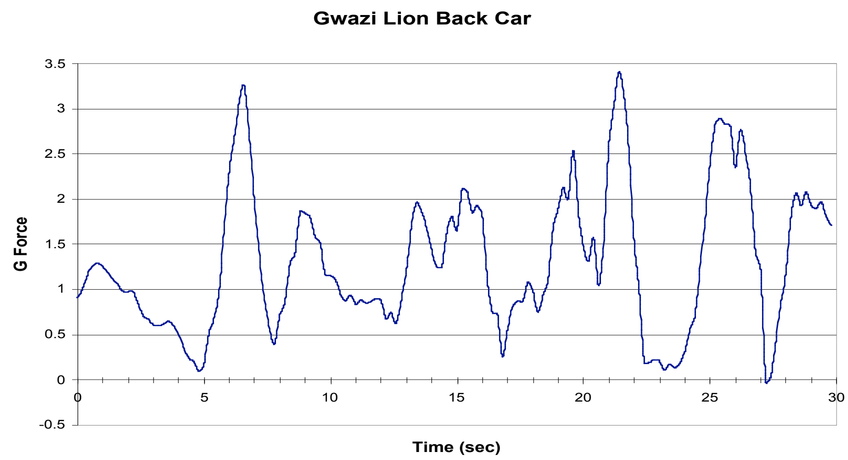
2. Answer the following questions based upon the graphs below, which were produced with a CBL, TI-83 and Low G Accelerometer. All of the graphs below start with the drop down the first hill. They show the first 30 seconds of an approximately 50-second long journey to the brakes at the end.
   a. According 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.

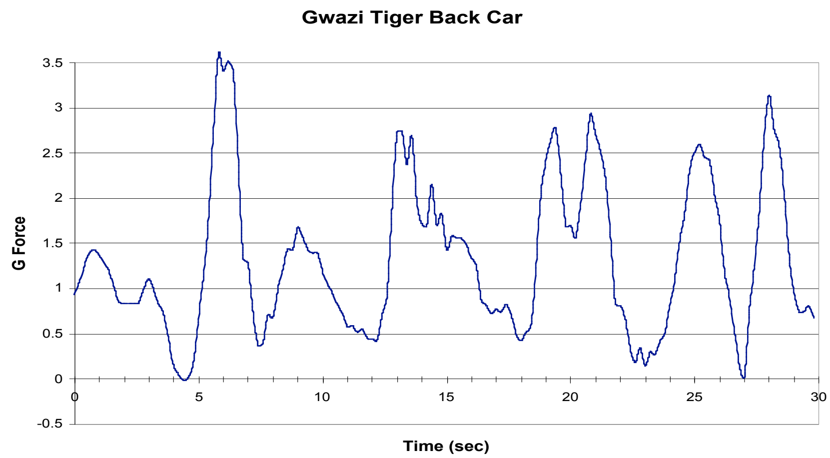
   b. Which ride would you consider more exciting? Which had the greatest G Forces?

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





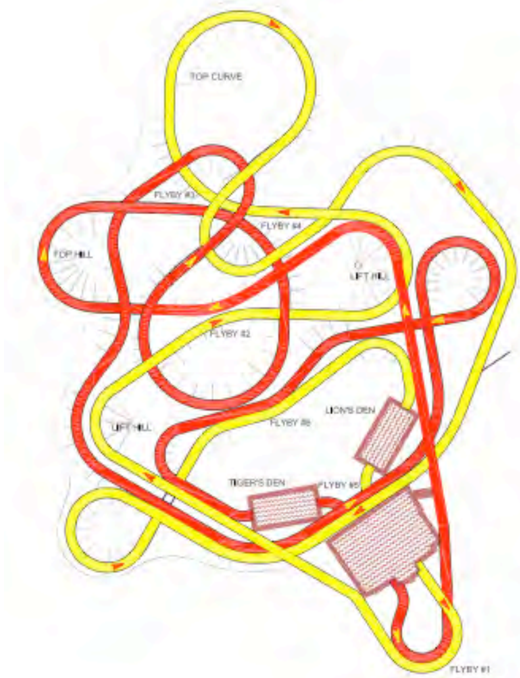




3. Using the Speed vs. Height graph, find what height is required to produce a speed equal to the speed you computed near the Photo Shop.

(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				

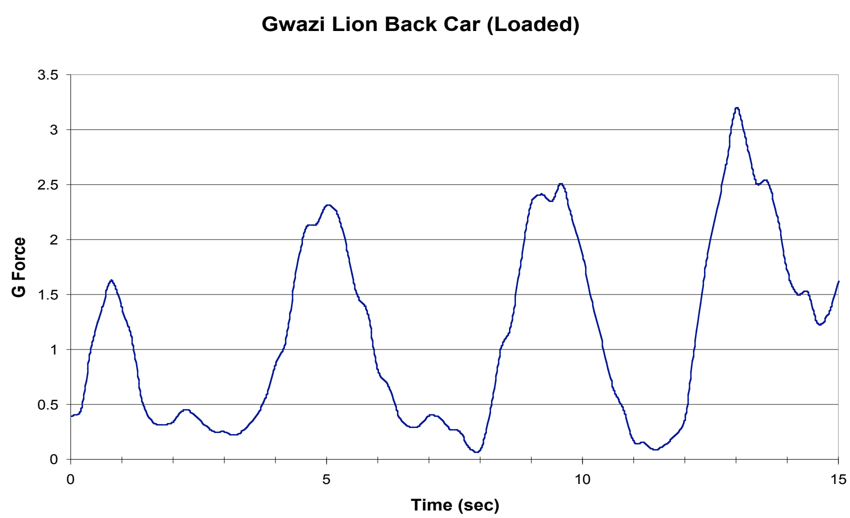
Questions

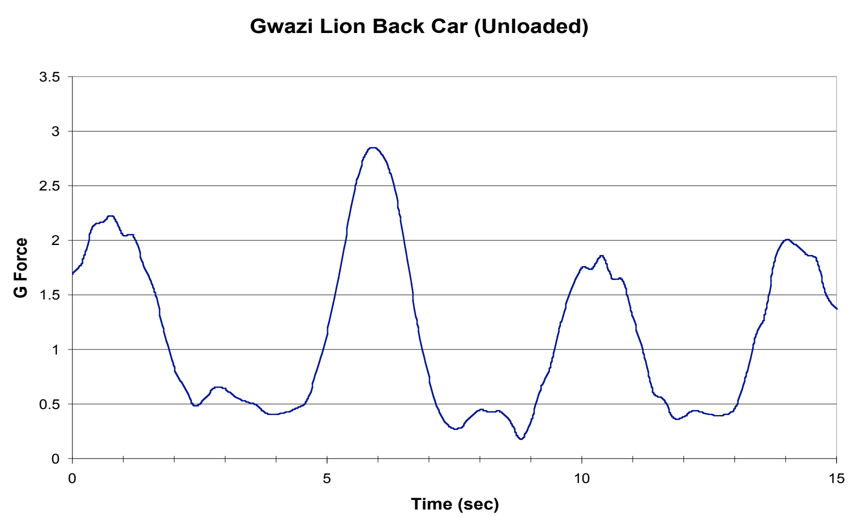
1. The two CBL graphs below, obtained with a TI-83 Calculator and Low G accelerometer, are of a 15-second portion of the ride that involves three Camelback humps, or parabolic hills. The middle of these three humps is right on top of the station. The spike at about 10 seconds is the valley (low point) 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.





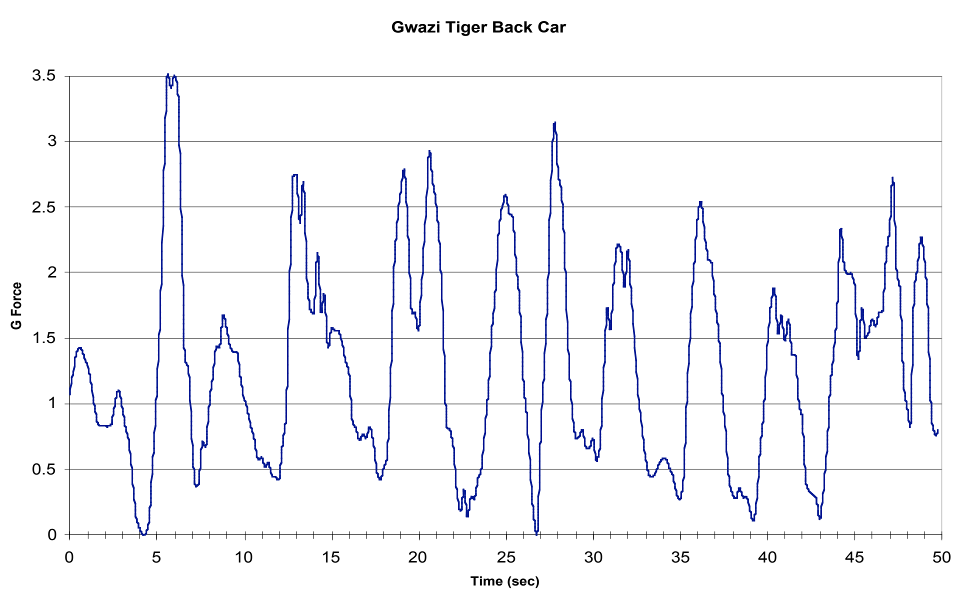
2. Using the Gwazi Lion Middle Car CBL graphs at the end of the workbook, answer the following questions:
   a. At what point on the ride do you experience the longest "low G" time? ("Low G" refers to less than 1 G) How many seconds?

   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?

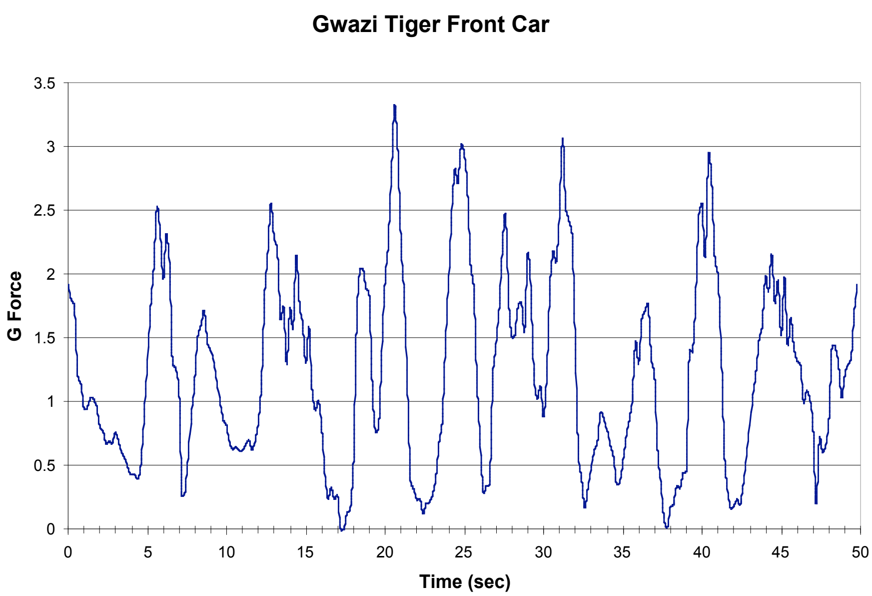


   f. Why do some of the hill bottoms, or valleys, have two peaks on the graph? (See the bottoms of the first and second hill on the Lion Middle Car graph.)

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.)

CHEETAH CHASE: 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?

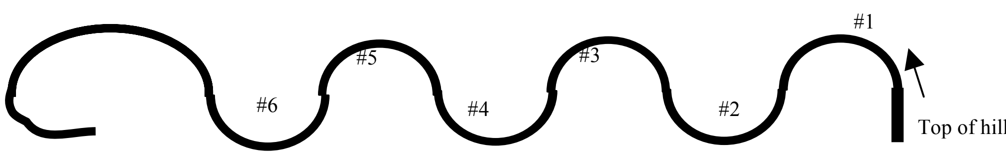
G Force Graph Turn #3 _________ Turn #4 ____________

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?

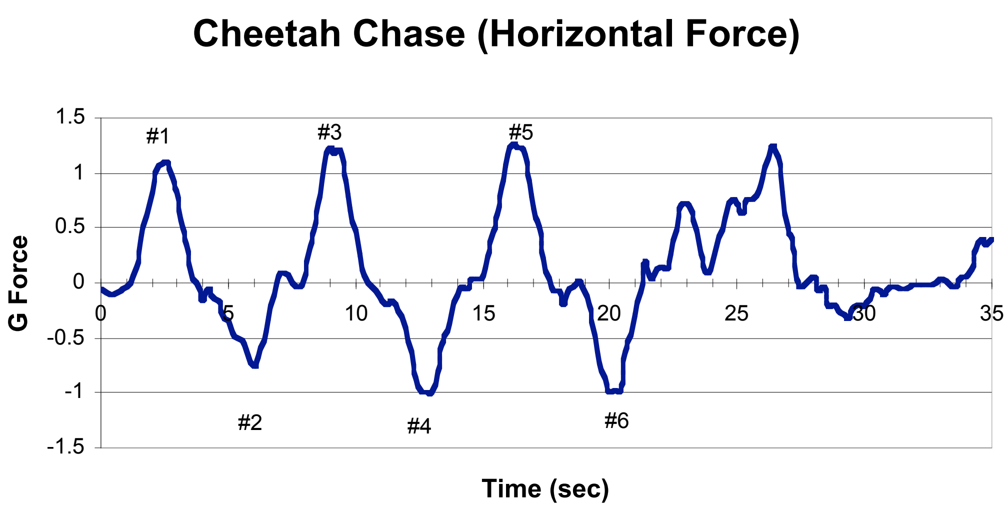


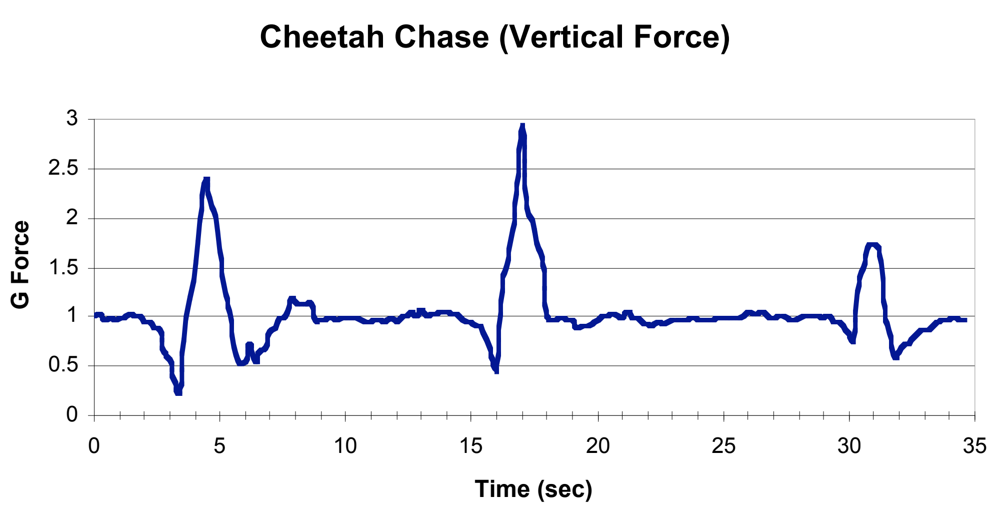
6 (Advanced)*. The radius of each of the turns is the same. R = 2.36 m. Taking the average Horizontal G Force in each of the turns from the G Force graph, compute the speed of the coaster car. $F=mv^2/r$, where F = (G Force) * mg

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

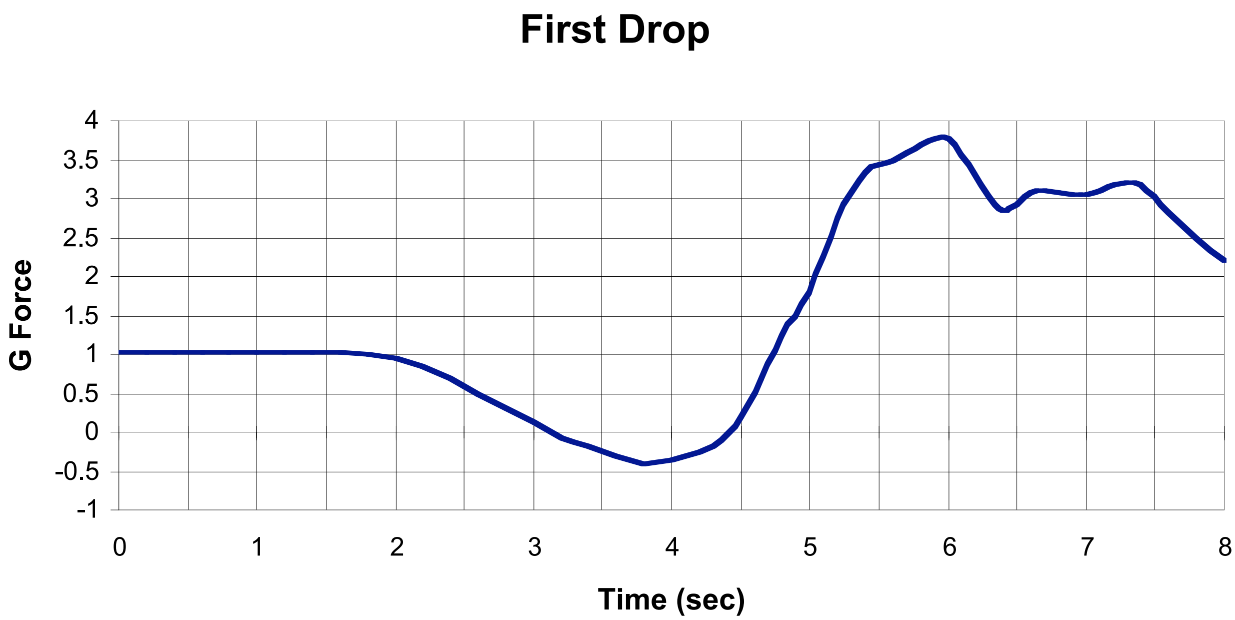
	#1	**#2**	**#3**	**Average time**
Time of fall				

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?



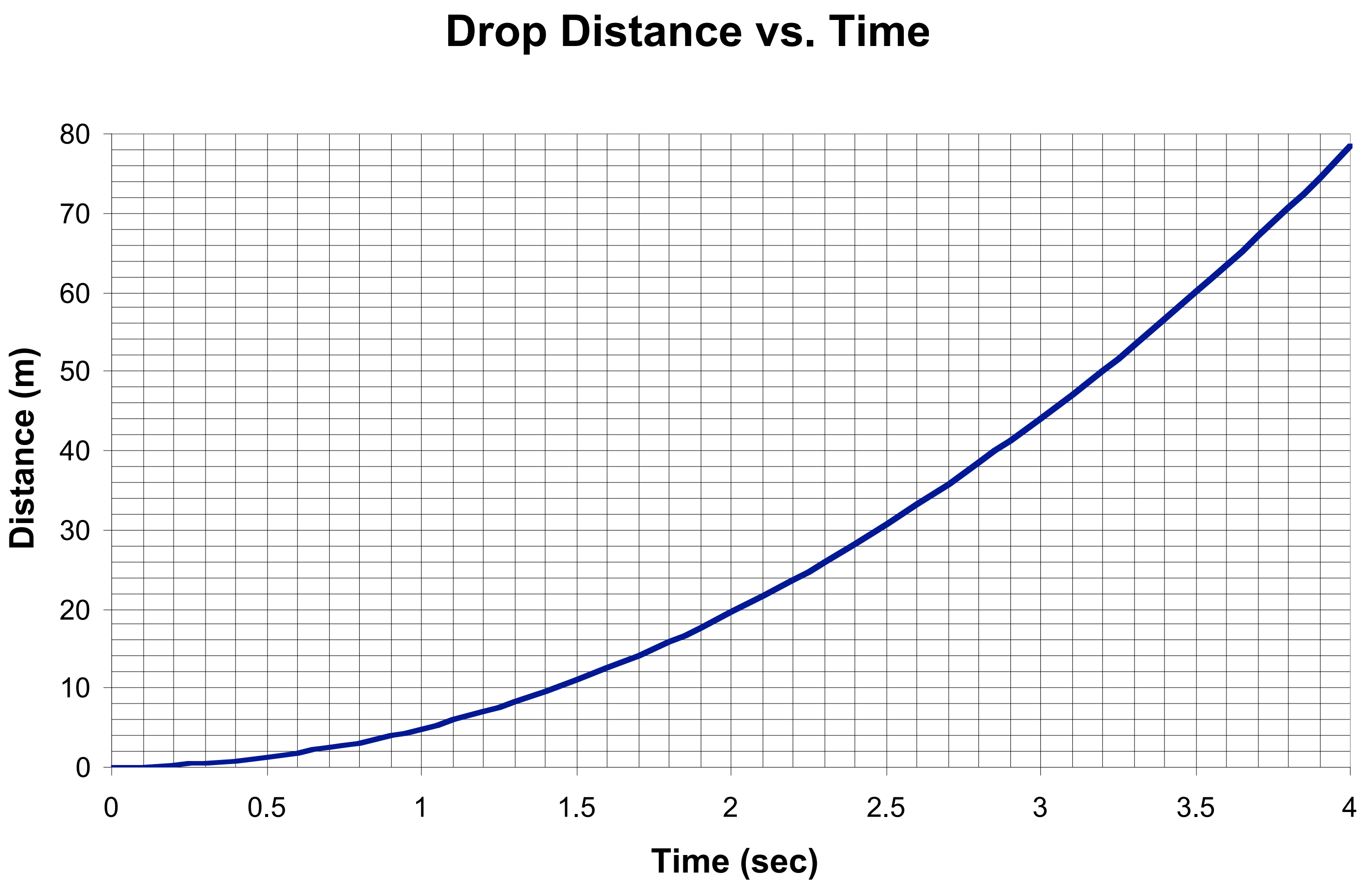
4a. From the Drop Distance vs. Time graph on the next page, determine how far the coaster dropped in the time measured with the stopwatch.

.

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

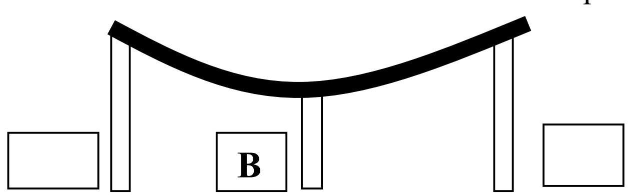
INSTRUMENTS REQUIRED
Stopwatch (No instruments allowed on the ride!)

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?

ANSWERS

LOG FLUME: BASIC

Predictions

a. slide forward b. a log with two in the front c. coming down the big hill

Data Table

1. Angle of the BBs = 35 degrees 2. Time from A to B = 0.84 seconds

Questions

1. You feel light and you have a definite dropping sensation, but you are not completely weightless. The maximum angle of the drop is 40 degrees.
2. You feel as though you are thrown forward at the bottom of the hill, because the splash slows down the log, but your inertia carries you forward.
3. The drop on the Log Flume feels very light, which is similar to the Python, but there is no lap bar on the Flume, so it might actually seem more intense.
4. The maximum splash on the Log Flume seems to be having two in the front, because the log then tends to plow into the water more.
5. An angle of 35 degrees corresponds to a G Force of approximately 0.7 g's.

Problems

1. Speed = distance/time = 11.6 m/0.84 s = 13.8 m/s
   The light pole is 10.0 m from the top of the 12.2 m tall hill, so the speed at the light pole is about 1.5 m/s slower than at the bottom. In order to be able to compute the log's speed, we need to make the compromise of timing the log when it is still speeding up, because otherwise the time would be too short to measure with a stopwatch.

2a. The G Force should be 0.65 for a trough length of 14.5 m. This will be different from the actual G Force, because the speed at the end of the trough is not zero.
2b. The minimum safe stopping distance would be about 5 or 6 meters, because a G Force of more than 2 would not be safe.
2c. When the distance is doubled, the G Force is cut in half.
Example: 12 m = 0.8 g's and 24 m = 0.4 g's.
2d. The G Force at 60 m would be 0.15, because that is half of the value at 30 m.
2e. It is not possible for the G Force to be zero, because that would take an infinite distance.

LOG FLUME: ADVANCED

Pre-Problems

a. $v^2 - v_o^2 = 2ax$, where $v = 3$ m/s and $v_o = 15$ m/s and $x = 20$ m. $a = -5.4$ m/s² and the G Force = a/9.8= 0.55 g's

b. $v = v_o + at$, where $v_o = 12$ m/s, $v = 2$ m/s and $t = 5$ s. $a = -2$ m/s², and the G Force = a/9.8 = 0.20 g's.

c. Energy loss = (Initial Energy – Final Energy)/Initial Energy * 100%

Initial Energy: ½ mv² + mgh= ½ (350 kg)(2 m/s)² + (350 kg) (9.8 m/s²)(10 m) = 35000 J

Final Energy: ½ mv² = ½ (350 kg)(12m/s)² = 25200 J

Energy loss: (35000 J – 25200 J)/(35000 J) * 100% = 28%

Predictions

20%

Data Table

Time from beginning to end of splash = 1.6 seconds

Time for log to pass a point at the end of the trough = 0.82 seconds

If you didn't do Log Flume: Basic:

Time to go from A to B = 0.84 s

Speed of the log= 11.6 m/0.84 s = 13.8 m/s

Problems

1. Height of hill = 12.2 m   Mass of log = 350 kg   Speed at top of hill = 1.2 m/s

Mass of people in log = 250 kg (This number will not affect the % energy conversion)

Speed of log at bottom of hill = 13.8 m/s (based on data from Log Flume: Basic)

Initial energy: ½ mv² + mgh= ½ (600 kg)(1.2 m/s)² + (600 kg) (9.8 m/s²)(12.2 m) =72200 J

Final energy: : ½ mv² = ½ (600 kg)(13.8 m/s)²=57100 J

Energy loss= (72200-57100)/(72200) * 100% = 21%

2. Speed at the end of the splash = length of log/time = 2.9 m/0.82 s = 3.5 m/s

3. Deceleration (using distance of splash) $v^2 - v_o^2 = 2ad$

A = ((3.5 m/s)² – (13.8 m/s)²) / (2*14.5 m) = -6.1 m/s²

G Force=a/9.8 = 0.62 g's

4. Deceleration (using time of splash) $v = v_o + at$

a = (3.5 m/s – 13.8 m/s)/(1.6 s) = - 6.4 m/s²

G Force = a/9.8 = 0.65 g's

5. The value obtained with the G Force Meter should be similar to these two readings, perhaps off by +/- 0.3.

PHOENIX: ADVANCED

Pre-Problems

a. At the bottom of its swing, the G Force will be given by the same equation that describes the G Force at the bottom of a roller coaster hill: $v^2/rg + 1$

$(15m/s)^2/(20m * 9.8\ m/s^2) + 1 = 2.1$ g's

b. Choose the position of the large mass at the end as the reference point for potential energy. PE + KE beginning = PE+KE end

$PE_o = (10kg)(9.8m/s^2)(10m) + (6kg)(9.8m/s^2)(2m) = 1098$ J

$PE_f = (10kg)(9.8m/s^2)(0\ m) + (6kg)(9.8m/s^2)(8m) = 470$ J

$KE_0 = 0$ J $\quad Ke_f = ½ (10kg)\ v^2 + ½ (6kg)\ (3/5\ v)^2$

Since the smaller mass is 3/5 as far from the pivot as the larger mass, it must have 3/5 the speed.

$Ke_f = v^2 (5\ kg + 27/25\ kg) = 6.08\ kg * v^2$

Solving for v, $v = Sqrt\ ((PE_o - PE_f)/6.08\ kg) = 10.2$ m/s

Predictions

a. 2.0 g's b. Yes

Data Table

Time to pass at bottom: 0.91 seconds

Drop time: 6 seconds

Mounted G Force Meter should read a maximum of 2.

Problems

1. Speed at the bottom (no counterweight):

$Mgh_{top} = KE_{bottom}$ $\quad mgh = .5mv^2$ $\quad v=Sqrt\ (2*g*h) = sqrt(2*9.8m/s^2*25.2\ m) = 22.2$ m/s

2. Speed at the bottom (with counterweight) h = 0 at lowest point of the boat

   $PE_o = (11650kg)(9.8m/s^2)(25.2m) + (12500kg)(9.8m/s^2)(6.5m) = 3673000$ J

   $PE_f = (11650kg)(9.8m/s^2)(0\ m) + (12500kg)(9.8m/s^2)(18.7m) = 2291000$ J

   $KE_0 = 0$ J $\quad Ke_f = ½ (11650kg)\ v^2 + ½ (12500kg)\ (6.1/12.6\ v)^2$

   Since the smaller mass is 6.1/12.6 as far from the pivot, it must have 6.1/12.6 the speed.

   $Ke_f = v^2 (5825\ kg + 1465\ kg) = 7290\ kg * v^2$

   Solving for v, $v = Sqrt\ ((PE_o - PE_f)/7290\ kg) = 13.8$ m/s
3. Speed = distance/time = 10.2 m/0.91 sec = 11.2 m/s
4. G Force= $v^2/rg + 1 = (11.2\ m/s)^2/(12.6\ m * 9.8\ m/s^2) + 1 = 2.0$ g

   The chart shows a maximum G Force of very close to 2 g's.
5. The period of a pendulum of length 12.6 m should be: T= 2*pi*Sqrt (L/g) =10.4 sec On the chart, the period varies from about 7 seconds up to about 13 seconds. The period will not be the "ideal" period, because this is a physical pendulum, not a simple one, and it has a counterweight and is swinging well beyond the small angle approximation. In an ideal pendulum, as the amplitude of the swing increases, the speed of the bottom also increases to compensate for the extra distance swung. This is only a good approximation for small angles. At large amplitudes on the Phoenix, the period will be much larger.

Questions

1. Hair hanging down, blood going to your head, falling out of the seat and pressed against the shoulder harness, the landscape look upside down, etc. On the Montu and the Kumba, you experience only the upside-down look.
2. You feel heaviest at the bottom. That is where the weight is opposite of the direction of acceleration and is also where the speed is the greatest. While falling, the "weightless' sensation is not really strong because you are not in free fall.
3. The acceleration of the Phoenix is much slower than expected because of the counterweight. If gravity acts on the ship to make it rotate clockwise, gravity also acts on the counterweight to try to make it go counterclockwise. The torque due to the counterweight is not as great as that due to the ship, so it does accelerate clockwise as expected, but at a slower rate than expected. The counterweight does not look very big, but it is even more massive than the ship itself. From the standpoint of energy, the counterweight is gaining potential energy as the boat is losing potential energy, so the gain of KE is not as great as expected.
4. The drop time is much larger than that of the Python and Scorpion because of the counterweight.
5. At point A the boat is at the bottom of its swing. As the speed of the boat at the bottom increases, the G Force at the bottom increases. At point B the boat is at the top of the swing. The graph crosses the zero line, when the boat is halfway to the top and the people in the boat are parallel to the ground. The seat is not holding up the people at this point, and therefore the G Force is zero.
6. Once the boat begins to rock, you only pass through 1 g but never really feel "normal." Negative g's mean one has a tendency to fall out of the seat. Of course, the safety restraints prevent this. Negative g's occur when the boat is above the halfway point to the top.
7. The energy comes from the tires underneath the boat that give it a push whenever it passes the bottom of its swing.

8a. The PE is not zero, because the counterweight is well above the center of gravity of the boat at the lowest point.

8b. The total energy at h = 0 is PE + KE = 2300000 J + 1390000 J = 369 000 J
At h= 10 m, PE + KE = 2860000 J + 830000 J = 369 000 J
At h= 25 m, PE + KE = 3680000 J + 10000 J = 369 000 J
These values should be close to each other, differing only a little because of the reading of the graph.

8c. Kinetic Energy is half the Final Kinetic energy at 12.5 m.

8d. Since KE= ½ mv^2, the speed at the bottom is 1.4 (the square root of two) times as big as the speed at the point where the KE is one-half the maximum.

TIDAL WAVE: BASIC

Predictions

Horizontal G Force reading: 1.6 g's   Biggest splash: Loaded in front

Pre-Problems

Speed = d/t = 11m/0.75 s = 14.7 m/s

Data Table

Largest angle of BBs: 60 degrees
Time from A to B: 0.75 seconds
Time of splash: 0.75 seconds

Questions

1. You feel thrown forward during the splash because the water stops the boat, but your inertia carries you forward. The backward force that stops you is the friction with the seat, your feet on the floor and the lap bar.
2. The boats that make the biggest splash are those whose front end digs deepest into the water. Having mass up front tends to do this. Empty boats make the least splash.

Problems

1. Speed = d/t = 10.9 m / 0.75 s = 14.5 m/s (This is about 33 mph. To convert from m/s to miles/hour, multiply by 2.24.)
2. An angle of 60 degrees corresponds to a G Force of about 1.7. Remember, however, that it is difficult to hold the meter still upon impact and read it while the water is coming down in buckets. The G Force on the Log Flume is much less, while that on the bumper cars is almost as large.

3a. According to the graph, the speed at the bottom should be 17.3 m/s. This is about 3 m/s faster than the measured value because of the energy losses to friction on the way down the hill.

3b. If there were no friction, it would take a hill only 10.7 m tall to produce a speed of 14.5 m/s.

4a. A splash of 0.75 seconds would give a G Force of 1.7. This should be close to the measured value.

4b. If the splash were 3 seconds, then the G Force would be 0.4 and not very exciting. The splash would not be nearly as big.

4c. If the splash were shorter than 0.5 seconds, the G Force would be well above 2 g's. The splash would be enormous, but the passengers would experience too large a Horizontal G Force.

TIDAL WAVE: ADVANCED

Pre-Problems

a. $v^2 - v_0^2 = 2ad$ $a = v^2 - v_0^2/2d$ = ((2 m/s)² – (10 m/s)²)/(2 * 15 m) = -3.2 m/s²
G Force = a/9.8 = 0.3 g's

b. mgh = Initial energy ½ mv^2 = final energy
Energy loss = (Initial – final)/Initial * 100% =
((9.8 m/s²)(12 m) – ½ (13m/s)²)/((9.8 m/s²)(12 m)) * 100% = 28%
The mass cancels out in the calculations, because there is an "m" in each term.

Predictions

Energy loss: 30%

Data Table

Distance of the splash: 6.4 m Time to pass a fixed point: 2.35 seconds

What to do if you didn't do Tidal Wave: Basic

1. Time from A to B = 0.75 seconds
2. Speed at the bottom = 10.9 m/0.75 seconds = 14.5 m/s
3. G Force reading is approximately 1.7.

Problems

1. Speed of the boat after the splash: Speed= d/t = 4.7 m/2.35 s = 2.0 m/s
2. $v^2 - v_0^2 = 2ad$ $a = v^2 - v_0^2 /2d$ = ((2 m/s)² - (14.5 m/s)²)/(2 * 6.4 m) = -16.1 m/s²
G Force = a/9.8 = 1.6 g's
3. The values are similar.
4. Energy loss = (Initial - final)/Initial * 100% (Assume a mass of 1 kg in the calculations. Since the mass cancels, it doesn't matter what mass you use.)
1 kg (9.8m/s²)(15.2m)+ ½ (1.5m/s)²) = 150.1 J Initial Energy
½ (1 kg) (14.5m/s)² = 105.1 J Final Energy
% energy loss = 30%
After the splash, the energy is ½ (2m/s)² = 2, so 99% of energy has been converted to heat after the splash.
5. If there were no energy loss, the speed at the bottom could be computed using the following equation: Initial Energy = Final Energy
Initial Energy= 150.1 J Final Energy= ½ mv^2 v= 17.3 m/s.

SCORPION: BASIC

Pre-Problems
Speed = length/time = 15 m/ 0.75 s = 20 m/s

Predictions
a. 40 mph b. 3 g's

Data Table
G Force at the bottom of the first hill: 3 g's
G Force at the top of the vertical loop: 0.5 g's
G Force in the horizontal loop: 2 g's
Time to pass a point at the bottom of the hill: .62 seconds
Banking angle: 60 degrees

Questions
1. The speed at the top of the Python is greater than the Scorpion — 6.5 m/s, compared with 1 m/s. The two rides are within 1 m/s of each other. If the speeds were reversed, and the Python was slow at the top while the Scorpion was fast, the difference would be 3 m/s. Also, even though the Scorpion's speed is only about .8 m/s faster than the Python's, this is almost 10 percent more kinetic energy.
2. Because of the banking of the turns, you don't feel pressed up against the sides, but you do feel heavy.

Problems
1. Speed = Length/time = 10.7 m/0.62 s = 17.3 m/s (39 mph)
2a. Banking angle corresponding to 8.1 m = 61 degrees
2b. G Force associated with 8.1 m = 2.0 g's. The G Force vs. Time graph indicates a G Force of between 2 and 2.4.
2c. G Force associated with 16.2 m = 1.3 g's Banking angle = 41 degrees
2d. G Force associated with 4 m= 3.6 g's Banking angle = 74 degrees
2e. G Force of 5 corresponds to r = 3 m, which means a banking angle of 78 degrees
2f. The highest G Force should typically be no more than 4 on a roller coaster. High g's are usually pulled at the bottom of a hill for periods of approximately 1 second, but in this case, the g's are sustained for about 5 seconds. It would be wise in this case to go with a much smaller number of g's, say 2.5. This would be a radius of 6.3 m.
3a. The graph indicates the following G Force readings:
Bottom of the first hill= 3.6 g's Top of the vertical loop = .5 g's
3b. Greater than 2 g's lasted for about 5 seconds.

SCORPION: ADVANCED

Pre-Problems
a. mgh = Initial Energy = $\frac{1}{2} mv^2$ = Final Energy
Energy loss = (Initial – Final)/Initial * 100% = (mgh - $\frac{1}{2} mv^2$)/mgh * 100%
$(9.8 * 15 - .5 * 8^2)/(9.8 * 15) = 78\%$ (Note the m's cancel because they are in every term)
b. A = 30 degrees B=35 degrees Baseline=20 m
H = (15 m)sin (50) * sin(30)/sin(20) = 16.5 m

Predictions
20% lost coming down the first hill

Data Table
Time to pass a point at the top of the loop = 1.15 seconds
Time to pass a point on the top horizontal loop = 0.9 seconds
Initial angle and Final angle depend upon initial distance to the hill and the baseline.

What to do if you didn't do Scorpion: Basic
1. Time to pass a point at the bottom of the hill: 0.62 seconds
2. Speed of the coaster at the bottom of the hill: 10.7 m/0.62 s = 17.3 m/s

Problems
1. G Force = $v^2/rg + 1$ = $(17.3 m/s)^2/(14.1 m * 9.8 m/s^2) + 1 = 3.2$ g's
The measurement on the Scorpion probably will be in the vicinity of 3 g's. The graph indicates a G Force of 3.6.

2. Velocity = 10.7 m/1.15 s = 9.3 m/s
G Force= $v^2/rg - 1 = (9.3 m/s)^2/(5.4 m * 9.8 m/s^2) = 0.6$ g's
The measurement on the Scorpion probably will be hard to read but will be less than 1. The graph indicates about 0.4 g's.
3. Velocity = 10.7 m/0.9 s = 11.9 m/s
tan (angle) = $v^2/rg = (11.9 m/s)^2/(8.1 m * 9.8 m/s^2) = 1.78$ Angle = 61 degrees
G Force = 1/cos (angle) = 2.1 g's — on the graph it ranges from 2 to 2.4
4. Energy loss = (Initial Energy - Final Energy)/Initial Energy * 100%
Initial Energy: $\frac{1}{2} mv^2 + mgh$ Final Energy: : $\frac{1}{2}$ mv^2
$(\frac{1}{2} mv^2 + mgh - \frac{1}{2} mv^2)/(\frac{1}{2} mv^2 + mgh) =$
$(.5 * (1 m/s)^2 + (9.8 m/s^2 * 19 m) - (.5 * (17.3 m/s)^2)/((.5*(1 m/s)^2 + (9.8 m/s^2 * 19 m)) = 20\%$
Mass cancels because it is in each term, and the reference point for potential energy can be the bottom of the track, hence 19 m and 0 meters, instead of 19.8 m and .8 m.
5. See setup for problem 4. Everything is the same except the final speed, which is now 11.8 m/s. % energy loss = 63 %
6. The height of the coaster is about 19.8 m above the ground level. You must take into account that the ground level of the coaster is lower than the paved ground where the measurements are taken. Also, the height of the observer must be added to the computed height. (See the solution in the pre-problem for an example.)

7. The speed at the bottom of the vertical loop is 17.3 m/s. If the radius were 5.4 meters (the same that it is at the top), the force would be: $(17.3 \text{ m/s})^2/(5.4 \text{ m} * 9.8 \text{ m/s}^2) + 1 = 6.7$ g's.This is, of course, way too high. If you made the entire coaster loop 14.1 m in radius, the coaster would never make it to the top, because the diameter of the loop (28.2 m) is higher than the height of the first hill. The compromise is to give the bottom of the loop a large radius and the top of the loop a small radius.

MONTU: BASIC

Predictions

a) No
b) Middle of the Batwing

Pre-Problems

1. Speed = Length/time = 11.6 m/0.75 s = 15.5 m/s

Data Table

Time for the coaster to pass the top of the loop: 1.04 seconds
Heaviest feeling: Middle of Batwing or second vertical loop bottom at about 4 g's

Questions

1. Following the first vertical loop and also following the Batwing, there is a straight section of track. These sections give approximately 1 g. The heaviest points are in the middle of the Batwing and just before the second vertical loop. The lightest feelings will be at the top of the Immelman and in the Zero-G roll.
2. You never achieve negative g's, thus you never leave your seat. According to the plans, the G Force on the inversions is:

First loop	1.0	
Immelman	0.2	
Zero G-roll	0.1	
Batwing	1.5	(first inversion)
Batwing	0.8	(second inversion)
Second loop	1.2	
Flat spin	1.5	

3. The radius of curvature is made smaller at the end of the ride to give a large force with a smaller velocity.
4. The second vertical loop is smaller, because the speed is decreased due to friction along the ride.
5. In the front car, you have the feeling of being pushed through the elements, while in the last car, it is like being pulled through. This is especially noticeable in the last cars at the tops of the elements. In the front cars it is most noticeable at the bottoms

of the elements. This is because the location of the center of mass of the coaster train determines the speed of the train. When the first car gets to the bottom of the hills, the center of mass is not yet there, so when the first car begins to go up, the train is still speeding up instead of slowing down.

Problems

1. Speed = length/time = 11.6 m/1.04 s = 11.1 m/s

2a. A light feeling (< 1 g) would result from speeds ranging from 7.3 to 10.4 m/s.

2b. 7.3 m/s produces a G Force of zero g's. Anything less than this will produce negative g's.

2c. 7.3 m/s occurs with a loop height of 16.5 m.

2d. If the coaster hill were 19.2 m tall, the velocity would be zero at the top. Anything taller would be impossible.

2e. The velocity would be 14.8 m/s, and the G Force would be 3.1.

3a. The brake block is the only place where you experience zero g's for any time interval.

3b. Large G Forces occur at the vertical loop bottom (3.8), the Immelman bottom (4.0), the Cobra Roll middle (4.2), vertical loop #2's bottom (4.3), and the Flat Spin (3.6). According to the CBL graph, the vertical loop #2 bottom is the greatest.

3c. Smallest G Force is a virtual tie between the Immelman top and the Zero-G roll, with about 0.2 g's.

3d. You feel heavier than normal at the vertical loop #1 top (1.3), Cobra Roll's first inversion (1.5), vertical loop #2 top (1.9), and Flat Spin top (2.1).

3e. Answers will vary.

MONTU: ADVANCED

Pre-problems

a. G Force = $v^2/rg - 1 = (10\ m/s)^2/(6\ m * 9.8\ m/s^2) - 1 = 0.7$ g's

b. G Force = $v^2/rg + 1 = (25\ m/s)^2/(30.0\ m * 9.8\ m/s^2) + 1 = 3.1$ g's

c. Energy Loss= $(\frac{1}{2}v_0^2 + gh_0 - \frac{1}{2}v^2)/(\frac{1}{2}v_0^2 + gh_0) * 100\%$ where vo = 0. $(9.8\ m/s^2 * 30\ m - 0.5 * (22\ m/s)^2/(9.8\ m/s^2 * 30\ m) * 100\% = 18\%$

Predictions

70%

Data Table — Off the Ride

Time to pass between A and C = 0.94 seconds

What to do if you didn't do Montu: Basic

1. Time to pass the top of the vertical loop: 1.04 seconds
2. Speed = 11.6 m/1.04 s = 11.1 m/s

Data Table — On the Ride

1. G Force at the bottom of the hill following Immelman: 3
2. G Force at the top of the second loop: 2

Problems

1. Speed= 22.0 m/0.94 s = 23.4 m/s or 52 mph
2. G Force = $v^2/rg + 1 = (23.4\ m/s)^2/(30\ m * 9.8\ m/s^2) + 1 = 2.9$ g's
   The graph gives a value of 2.9 g's. G Force Meter should be similar.
3. G Force = $v^2/rg - 1 = (11.1\ m/s)^2/(5.5\ m * 9.8\ m/s^2) - 1 = 1.3$ g's
   The graph gives a value of 1.9 g's
4. Energy Loss = $(\frac{1}{2}v_0^2 + gh_0 - \frac{1}{2} v^2)/((\frac{1}{2}v_0^2 + gh_0) * 100\%$, where v_0 = zero
   $(9.8\ m/s^2 * 39.9\ m - .5 * (16 m/s)^2)/(9.8\ m/s^2 * 39.9\ m) * 100\% = 67\%$

UBANGA BANGA BUMPER CARS: BASIC

Predictions

a. Forward
b. Backward
c. Left
d. Forward
e. Larger
f. 5 mph

Data Table

Stationary collision angle: 50 degrees
Moving collision angle: 30 degrees
Time between posts: 3.5 seconds

Questions

1. Stationary collision: 1.2 g's Moving collision: .6 g's
   The Tidal Wave is about 1.6 g's, and the Log Flume is about 0.7 g's.
2. The force of hitting is the same as the force of being hit. The difference is that the hitter may feel pushed forward, while the person being hit may feel pushed backward.

3a. forward 3b. backward 3c. left 3d. forward

4. Greater forces produced with higher speeds and harder bumpers

Problems

1. Speed = distance/time = 7.6 m/ 3.5 sec = 2.2 m/s, or about 5 mph

2a. When the speed is doubled, the G Force is quadrupled.
2b. When the speed is quadrupled, the G Force is 16 times as great.
2c. The maximum safe speed would be less than 7 mph, because you would want to avoid a Horizontal G Force of greater than 2.

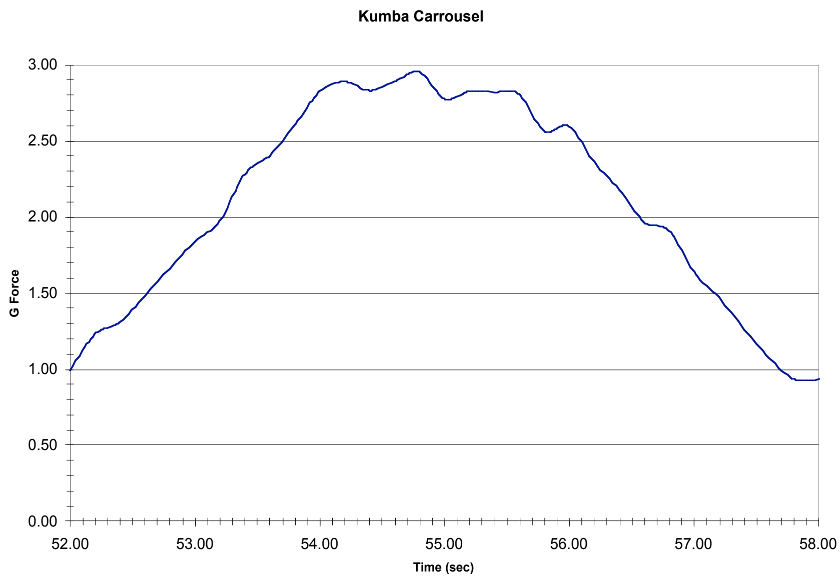
KUMBA: BASIC

Pre-Problems
Speed = length/time = 20 m/ 0.75 s = 26.6 m/s

Predictions
a. Not pushed to the left or the right
b. Heavy
c. Sometimes heavy and sometimes light
d. 35-40 mph
e. 3.8 g's
f. 7

Data Table
Time for the coaster to go from the top of the first hill to the top of the second corkscrew: approximately 45 seconds
Time for the coaster to pass the top of the first corkscrew: 1.09 seconds
The strongest G Force: Going into the Cobra Roll with a force of about 4 g's
The G Force in the carrousel: Slightly less than 3 g's

Questions
1. You never quite leave your seat when upside down. The upside down times vary:
   Vertical loop top: 0.6 g's
   Top of the Dive Loop: 0.4 g's
   Top of the Camelback: close to zero g's
   Cobra Roll inversions: 1.4 g's and 1.2 g's
   Corkscrew inversions: 1.3 g's and 0.8 g's
   Four of the seven are less than 1 g, or light, and the other three are heavy.
2. The heaviest time was going into the Cobra Roll, with about 3.9 g's.
   There are seven times as a whole where you pull more than 3 g's. The other are:
   Vertical loop bottom: 3.4 g's
   Going into the Dive Loop : 3.8 g's
   Going into the Camelback: 3.8 g's
   Middle of the Cobra Roll: 3.1 g
   Coming out of the Cobra Roll: 3.4 g's
   First Corkscrew bottom: 3.3 g's
   You pull just under 3 g's in the carrousel. The remarkable part is that you pull over 2 g's for about 3.5 seconds. This gives you a chance to really experience being heavy for a period of time. It is very difficult to get your feet off the floor, for instance. The graph on the next page shows the G Forces in the carrousel.



Because of the steep banking angle, you don't feel pushed to the right or the left. A turn at this speed with this radius of curvature wouldn't be safe without banking.

3. The Cobra Roll is very confusing. The rapid succession of first drop, then vertical loop, then Dive Loop and Camelback Hump also tends to be disorienting. It is very difficult to tell on the first time through where you are.
4. Generally speaking, the higher you are, the slower you go, and the lower you are, the slower you go.
5. Generally you feel heavy at the bottoms of the hills, corkscrews, and loops, and you feel light at the tops of those features.

Problems

1a. The banking angle is 69 degrees.

1b. The G Force that corresponds to this is 2.8 g's. This is similar to measurement.

1c. To experience 2 g's you would need a banking angle of 60 degrees and therefore a speed of 12 m/s.

1d. Because you are pulling g's for a period of 3 or 4 seconds, it is probably wise not to exceed 3 g's. This would correspond to an angle of about 71 degrees.

2. Speed at the top of the corkscrew = length/time = 13.1 m/ 1.09 s = 12.0 m/s
3. Average speed = total distance/time= 770 m / 45 s = 17.1 m/s or 38 mph
4. Upside down times

Top of Vertical Loop	Top of Immelman	Camelback Hump	Cobra Roll Inversion #1	Cobra Roll Inversion #2	First Corkscrew	Second Corkscrew
0.6 g's	0.4 g's	0 g's	1.4 g's	1.2 g's	1.3 g's	0.8 g's

5. Heavy times

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
3.4 g's	3.8 g's	3.8 g's	3.9 g's	3.1 g's	3.4 g's	3.3 g's	2.8 g's	2.9 g's

KUMBA: ADVANCED

Pre-Problems

a. G Force at top of a loop = $v^2/rg - 1 = (12 m/s)^2 /(10 m * 9.8 m/s^2) - 1 = 0.5$ g's

b. G Force at hill bottom = $v^2/rg + 1 = (30 m/s)^2 / (40 m * 9.8 m/s^2) + 1 = 3.3$ g's

Data Table

Time of descent of first car: 2.4 seconds
Time of descent of last car: 1.9 seconds
Time to pass the top of the vertical loop: 1.31 seconds

G Forces:	Bottom of first hill	3.4	Top of vertical loop	.6
	Top of first corkscrew	1.3	carrousel	2.9

What to do if you didn't do Kumba: Basic

1. Time to pass the top of the corkscrew: 1.09 seconds
2. Speed at the top of the corkscrew: 13.1 m/1.09 s = 12.0 m/s
3. Banking angle = 69 degrees G Force = 2.8 g's

Questions

1. At the top of the first hill, passengers in the first car will slide forward a little, while passengers in the last car will be pressed back into their seats. After the top of the dive loop, the first car reaches a high G Force quickly and maintains it much longer than the last car. The middle car maintains a lower force factor than either the front or the back car in the Camelback Hump. Going into the Cobra Roll, the last car maintains a high G Force much longer than the first car. Coming out of the Cobra Roll, this is reversed. The front car is more visual; the back car tends to be a much more exciting ride.
2. The descent times are different because when the first car is at the top, the center of mass has not yet reached the top, and so the coaster is still in the process of slowing down. It isn't until the center of mass reaches the top that the coaster begins to speed up. Of course, the last car reaches the top after the center of mass, so it is moving at a higher speed at the top. The last car has a faster average velocity than the first car. The people in the last car feel as though they are pulled over the top. The people in the first car seem to just glide over the top. On the other hills, a similar situation occurs.

Problems

1. Banking Angle: tan (angle)= v^2/rg
   angle= inv tan ($(15 m/s)^2 / 8.5 m * 9.8 m/s^2$)=69.6 degrees
   G Force=1 / cos (69.6 degrees) = 2.9 g's
   All sources give approximately the same result.
2. Speed at the top of the loop = length / time = 13.1 m / 1.31 s = 10.0 m/s
3. G Force at top of a loop = v^2/rg -1 = $(10 m/s)^2 /(7.2 m * 9.8 m/s^2) - 1 = 0.4$ g's
4. G Force at top of a crkscrw = v^2/rg -1 = $(12 m/s)^2 /(7.6 m * 9.8 m/s^2) - 1 = .9$ g's

5. G Force at hill bottom = $v^2/rg + 1 = (27.0\ m/s)^2 / (29\ m * 9.8\ m/s^2) + 1 = 3.6$ g's
6. Energy Loss = $(½v_0^2 + gh_0 - gh - ½\ v^2)/((½v_0^2 + gh_0) * 100\%$, where $v_0 = 2.3$ m/s, $h_0 = 40.9$ meters, and h = 30.9 m (both h's are measured from the lowest point on the ride)

$(.5*(2.3m/s)^2 + 9.8\ m/s^2*40.9\ m - 9.8\ m/s^2*30.9\ m -.5*(10\ m/s)^2)/(5*(2.3\ m/s)^2 + 9.8\ m/s^2 *40.9\ m) = 13\%$

7. With a radius at the bottom of 15.5 m and a velocity of 27.5 m/s, the G Force would be 6 g's. At the top, with the same radius, the G Force would be -0.3, which means that the coaster would fall off the track if not for the wheels below the track. If the velocity at the bottom were cut back to allow few g's at the bottom, then the coaster would not even reach the top of the loop. If the coaster were to go faster at the top to keep it on the track, then the speed at the bottom and the G Forces would be enormous. Hence, the best idea is to have a large radius at the bottom and a small radius at the top.
8. G Force at bottom of first hill: Graph gives 3.4; calculation gives 3.6
G Force at the top of the vertical loop: Graph gives 0.6; calculation gives 0.4
G Force at the top of the first corkscrew: Graph gives 1.4; calculation gives 0.9
The readings from the G Force Meter should be similar.

GWAZI: BASIC

Pre-Problem

a. Speed = length of the coaster/time = 11 m/.63 s = 17 m/s

Predictions

a. After the bottom of the first hill, the Lion has a U-turn to the left, then a sweeping turn to the right, followed by a sharp U-turn to the left. The Tiger has a U-turn to the right, then a sweeping turn to the right (again), followed by a sharp U-turn to the left. The radii of the turns are the same for both coasters.
b. After the circles, the Tiger goes through a slalom maneuver, while the Lion goes through a sweeping turn to the right. After these two maneuvers, the end of the ride is very similar for both — three Camelback Humps and a Donut.
c. Bottoms of the valleys
d. d. Back car

Data Table

Time to pass a post at the lowest point = 0.81 seconds

Questions

1a. The mathematical shape of the hill is a parabola.
1b. The riders have a "low G" experience (<1G). They feel weightless or at least close to weightless. This occurs for almost 2 seconds.
1c. Generally you feel "weightless" going over the tops of the hills or coming down the first hill. There are eight or nine "weightless" experiences on the ride.

2. The maximum force experienced is 2.3 g's. The riders experience a heavy feeling for about 2 seconds.
3. Generally you feel heavy at the bottoms of the hills. You also may feel heavy in a tight turn, especially at a high speed. These tight turns will be banked.
4. The experiences will vary, but the students may mention such things as the Tiger is more twisty, like a bobsled, and the Lion has continuous spirals.

Problems

1. Speed = length of the coaster train/time = 12.9 m/0.81 s = 16 m/s. (This is about 36 mph, compared with the maximum speed of the coaster earlier, which is 50 mph.)

2a. The front car generally experiences lower G Forces. The back car experience is closer to weightlessness in the first drop. The front car experiences negative g's at one point — the fourth crossing, where the two coasters are steeply banked.
2b. The back car has greater extremes and therefore should be more exciting.
2c. The back car of the Tiger has greater extremes on the first drop (lower g's going down and higher g's at the bottom). The Lion's back car is more intense between 24 and 27 seconds (going into and coming out of the fourth crossing).
3. A height of 13 m would produce a speed of 16 m/s.

GWAZI: ADVANCED

Pre-problems

a. Tan (a)= $v^2/rg = 15^2/(10 * 9.8) = 2.30$
   Angle is 66 degrees.
   G force = 1/cos
   (66) = 2.5
b. Energy in beginning = mgh = 1 * 9.8 * 30m = 294
   Energy at the end = $1/mv^2 + mgh = 1 * 9.8 * 3 + ½ * 1 * 16^2 = 157$
   % lost = (294-157)/294 * 100% = 47%

Predictions

a. 50%
b. It depends on the coaster and which car you sit in. Over half the situations have the greatest G Force somewhere else.

Data Table

Time for the Lion to pass the middle of the Donut = .98 seconds
Time for the Lion to pass the lowest point near Photo Shop = .81 seconds
G Force in the Donut: between 2 and 2.5

Questions

1a .The unloaded coaster ride is smoother. The low g sensations are not as intense. The G Forces at the valleys are generally greater. This happens for the most part because the unloaded coaster is slower.

1b. The time difference is approximately 1 second. The loaded car is faster. On a frictionless track, it wouldn't make any difference. With friction, a heavier coaster goes faster. It also goes faster when it is warmer. (It's amazing how much of a difference it makes in the feel of the ride.)
1c. The ride is 1.4/50 * 100% = 3% faster when loaded and warm.
2a. The longest low G time occurs at the first drop (3.6 seconds).
2b. The next longest is the first Camelback Hump (3 seconds).
2c. The lowest G point is the fourth crossing hilltop, with approximately 0.1 g for close to a second.
2d. The highest G Force occurs at the tight turn to the left, just after the fourth crossing. It is about 3.1 g's. The second highest occurs at the bottom of the second hill (third crossing) with 2.9 g's.
2e. The Tiger back car has its highest G Force at the bottom of the first hill (3.5 g's). The Tiger back car only has 2.6 g's at the tight turn to the left.
2f. Sometimes the valley doesn't have a constant radius of curvature. It is pretty close to flat on some of the dips. This creates two separate situations: a coming down and a going up, with close to 1 g in the middle. Also, there is sometimes a turn associated with either coming down or going up that can alter the G Force.
2g. The longest sustained G Force occurs in the Donut, where it is close to 2 g's for 4 seconds.
3a. Many possible explanations. First car hangs over the hilltops coming down, while the last car is flung over the hilltops. First car is thrust up the hills, while the last car isn't. Certain elements on the ride are more intense in either the first or last car.
3b. The Tiger's back car is more intense both coming down first hill and also at the bottom. The Donut has higher g's for the back car. The front car experiences higher g's in the middle of the ride (around 22 seconds).

Problems

1a. Speed=12.9 m/.98 seconds = 13 m/s
1b. Banking angle tan (a)=$v^2/rg = 13^2/11 * 9.8 = 1.56$ Angle = 57 degrees
G Force = 1/cos(a) = 1.8 g's
The average seems to be a little more than 2 g's.
1c. The coaster train is going uphill, thus changing its speed. The banking angle of the track is probably variable as well. If the speed of the train that is measured, is not the speed for the whole time.
2a. Speed of the train at the Photo Shop = 12.9 m/0.81 sec = 16 m/s
2b. Total energy at Photo Shop = $1 * 9.8 * 2 + ½ *16^2 = 138$ (estimating 2 m)
2c. Total energy in beginning = $1 * 9.8 * 27.4$ m + $½ * 1 * 2.2^2 = 272$
(271-138)/271 * 100% = 49% 49% lost to heat because of friction

CHEETAH CHASE: BASIC

Predictions

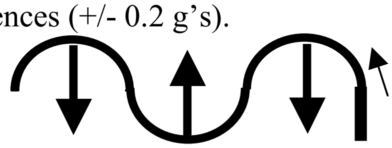
a. Stay the same
b. Vertical
c. You can't avoid being pushed

Data Table

The angle should be approximately 45 degrees each time.
The maximum G Force in the dips will be approximately 3 g's.

Questions

1. The G Force in each of the two turns will be approximately 1 g.
2. The graph indicates that the G Force is 1.2 in turn #3, and 1.0 in turn #4.
3. The largest vertical G Force should be close to 3.0, which is just a little less than many of the hill bottoms with Kumba or Montu. The force is large even though the speeds are small, because the radius of the dips is so small.
4. The forces in the six turns are all about the same. The graph indicates minor differences (+/- 0.2 g's).
5.



You can't avoid being pushed by a seatmate, because the force alternates being to the left and then to the right.
6.* If we use 1.0 for the G Force, then the speed will be 4.8 m/s, or about 11 mph.
7. The speed stayed about the same. The track sloped downward gently to keep the same speed in spite of friction.
8.* Based on a speed of 4.8 m/s and a radius of 2.36 m, the banking angle would be 45 degrees and the passengers would experience a downward force of 1.4 G's.
9.* The person on the outside of the turns experiences a slightly greater force. (The outside person would be on the right side of the car for the counterclockwise turns — 1,3 and 5. The acceleration graph shows that all of the counterclockwise turns — 1,3, and 5 — have a greater G Force than the clockwise turns of 2,4, and 6). This is because the accelerometer was worn by a passenger on the right side of the car. Thus the passenger would be on the outside of the counterclockwise turns and on the inside of the clockwise turns. Since all of the passengers in the car have the same angular velocity (radians/sec) on the turns, the centripetal acceleration experienced by the rider on the outside will be greater. ($a=r\omega^2$). It might be interesting to have a person on the left side and a person on the right side compare their numbers. As you can see from the graph, the G Force can differ by as much as .2 g's. The radius used in question #6 is the radius of the turn, as measured in the middle of the car.

SHEIKRA: BASIC

Predictions
a. 2.5 seconds
b. Yes

Pre-problem
Speed = distance/time = 20 m/0.75 s = 26.7 m/s

Data Table
1. Estimated time of big drop= 2.5 seconds
2. Stopwatch measurement of the falling time: 2.5 seconds

Questions
1. They should be within a half second of each other.
2. From the graph, the time works out to be about 2 ¾ seconds. Of course, this is assuming that anything less than 1 g feels weightless, and that is not necessarily what was measured with the stopwatch or with the estimation on the ride.
3. It increases from 1 g to almost 4 g's in about 1 ¼ seconds.
4a. According to the chart, it would fall 31 meters in 2.5 seconds.
4b. It would take 3.5 seconds to fall 61 meters.
4c. According to the graph, the drop time to the blue post should be 2.6 seconds.
5. The graph indicates that the Immelman, and the second drop after the brake block are also weightless. There are also weightless periods just after the water brake and just before the brake block. The greatest weightless period after the initial drop would be the second big drop, just after the brake block. It is approximately 2.5 seconds.

SHEIKRA: ADVANCED

Predictions
a. 4
b. 70 mph

Pre-problems
a. G Force = $v^2/rg + 1 = (20m/s)^2/(10m)(9.8\ m/s^2) = 4.1$
b. $(½\ mv_0^2 - ½mv^2/(½\ mv_0^2)\ * 100 = (30^2-15^2)/30^2 * 100 = 75\%$

Data
1. Time for the coaster to pass between posts A and C at the bottom of the hill: 0.65 sec
2. Time between the two blue posts at its highest point: 1.20 seconds
3. Splash of the water brake: 1.4 seconds

Questions
1. The base of the Immelman hill is not at ground level.

2. The graph is a measure of vertical G Force. The slowing down would be measured as horizontal G Force. The vertical G Force is zero, because its motion at this point is strictly horizontal.
3. According to the graph, the two hill bottoms are almost identical. The maximum G Force is close to the same thing, and then both are at 2 g's or above for the same time (about 4 seconds). The hill bottom following the Immelman remains at high g's (above 3.8 slightly longer) and is a little longer in the total time above 1 g.

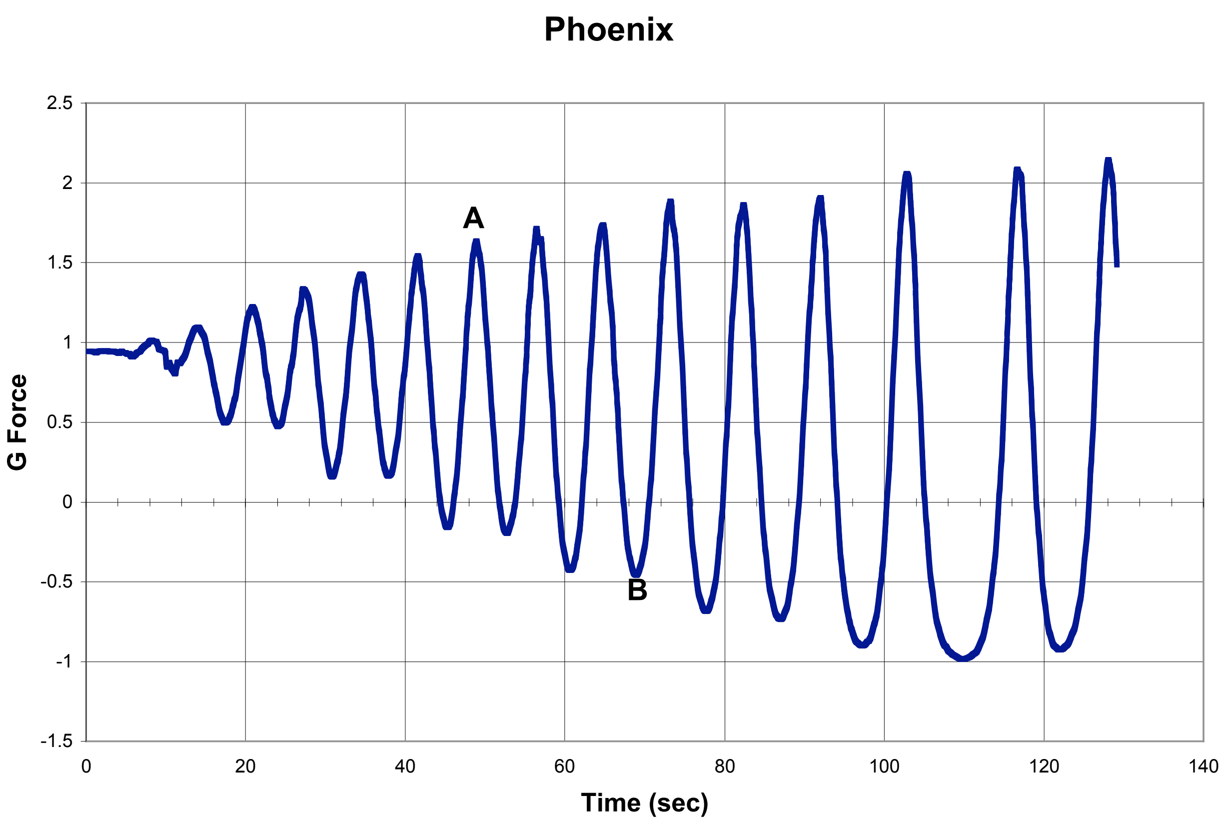
Problems:

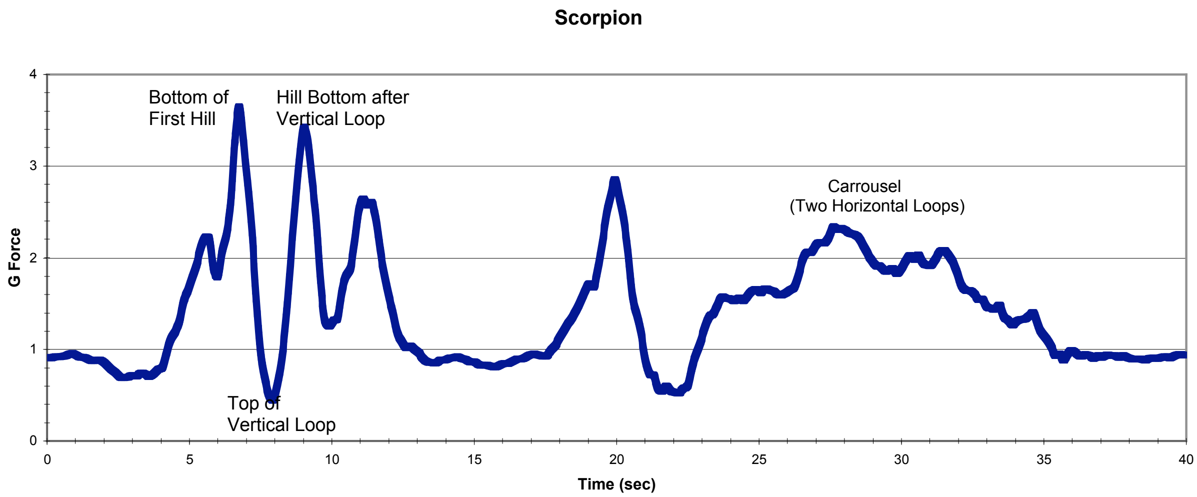
1. Velocity = 20.7 meters/.65 sec = 31.8 m/s or 71 mph (The actual speed is 72 mph.)
2. G Force = v2/rg + 1 = $(31.8 \text{ m/s})^2/(38.1\text{m})(9.8 \text{ m/s}^2)$ = 3.7 g's

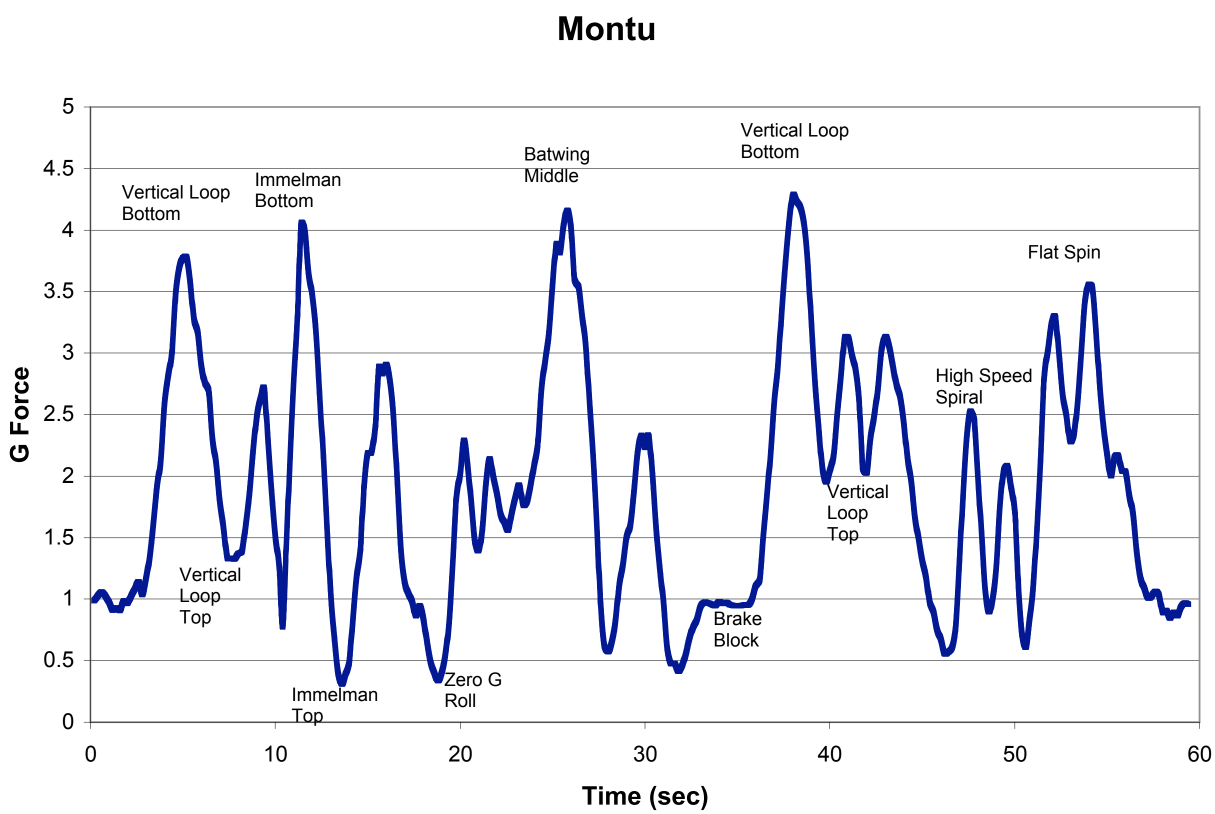
The G Force graph indicates 4 g's. The actual G force should be 3.8.

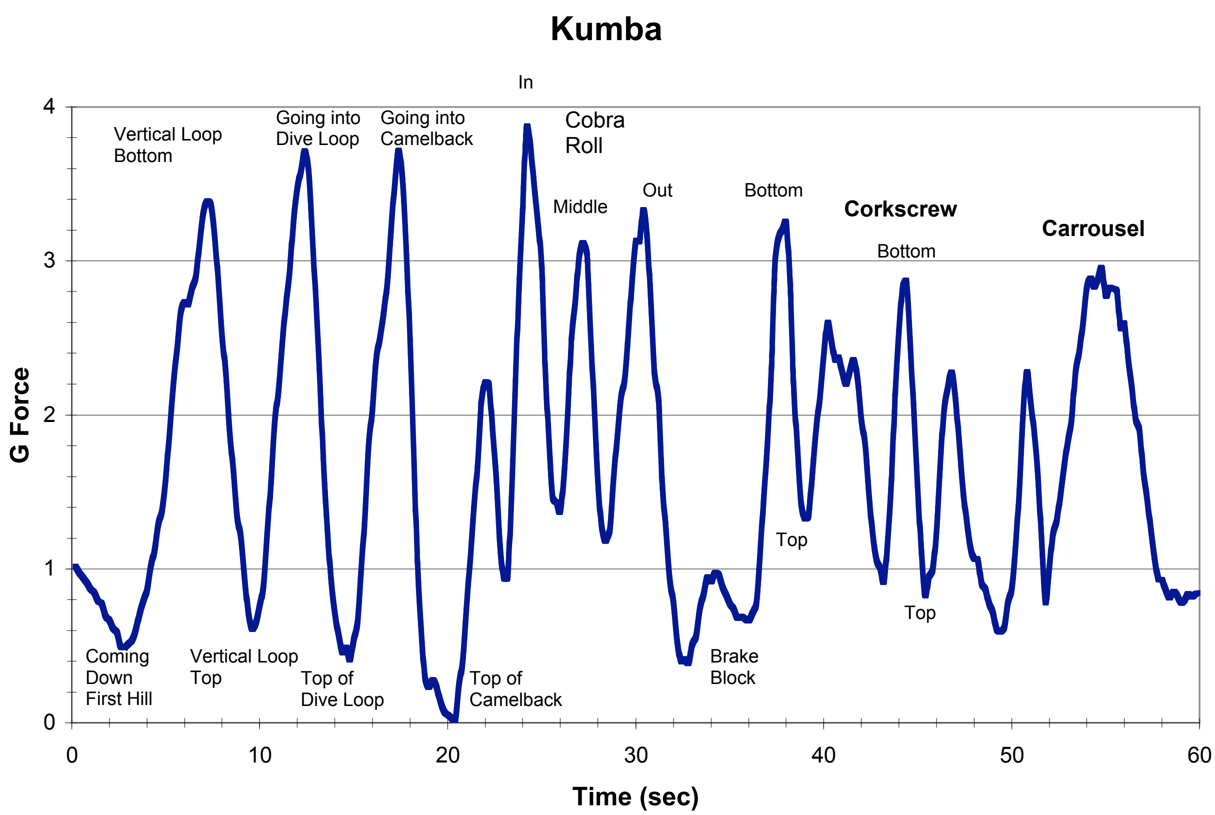
3. Velocity = 15 m/1.25 sec = 12.0 m/s or 27 mph.
4. Initial Energy = mgh = $m(9.8\text{m/s}^2)(61\text{m})$ = 598 m
   Final Energy = $m(9.8 \text{ m/s}^2)(23.1\text{m}) + 1/2\, m(12\text{m/s})^2$ = 298 m
   Energy Loss = (Initial-Final)/Initial = (598 m - 298 m)/(598 m) = 50% (The m's cancel)
5. Water Brake energy loss:
   Initial = ½m (24m/s)2 = 288 m Final = ½ m (22m/s)2 = 242 m
   Energy Loss = (Initial-Final)/Initial = (288m-242m)/(288m) = 16%
6. Time of splash: 1.4 seconds $v=v_0+at$ a=(24m/s –22 m/s)/1.4 sec = 1.4 m/s^2

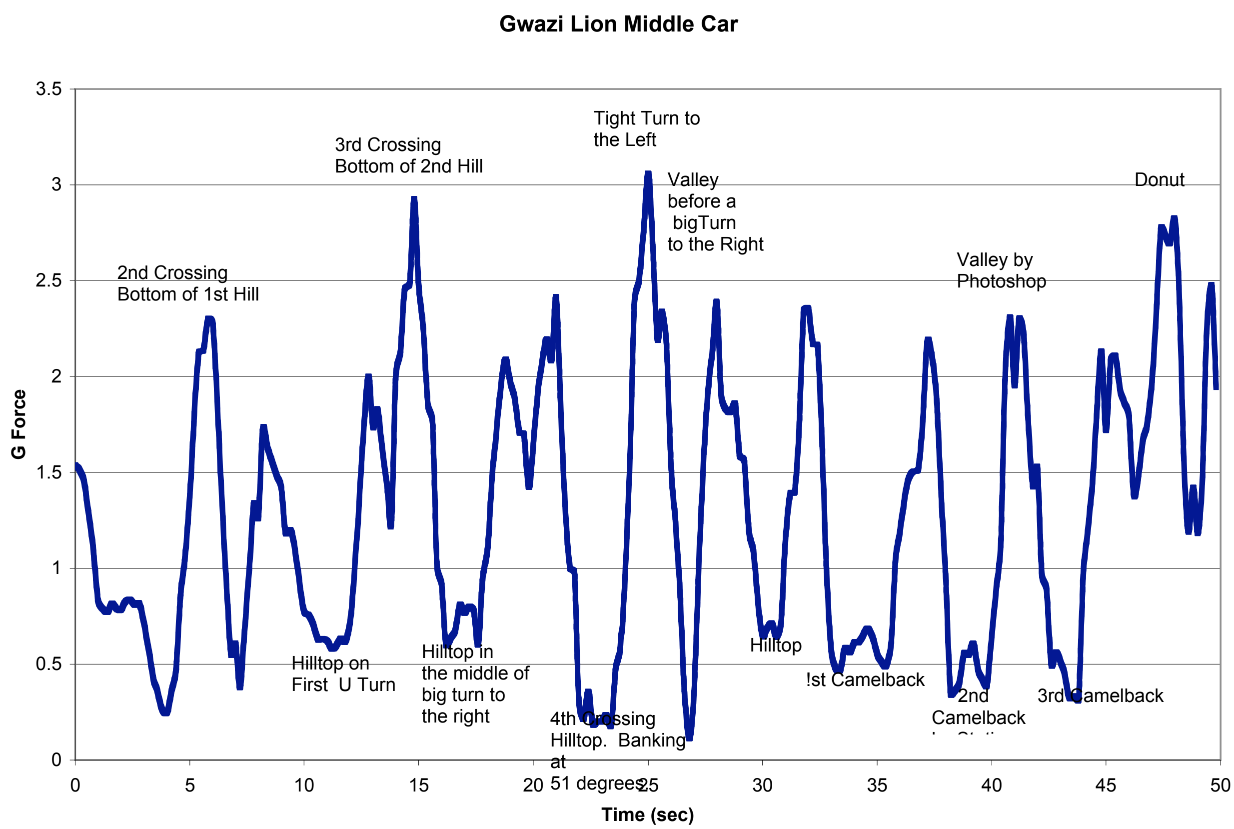
or a G Force = $m(1.4 \text{ m/s}^2)/m(9.8\text{m/s}^2)$ = 0.1. This is very small compared with a horizontal G Force of 0.7 on the Log Flume or 1.7 on the Tidal Wave. It is barely noticeable on the SheiKra.

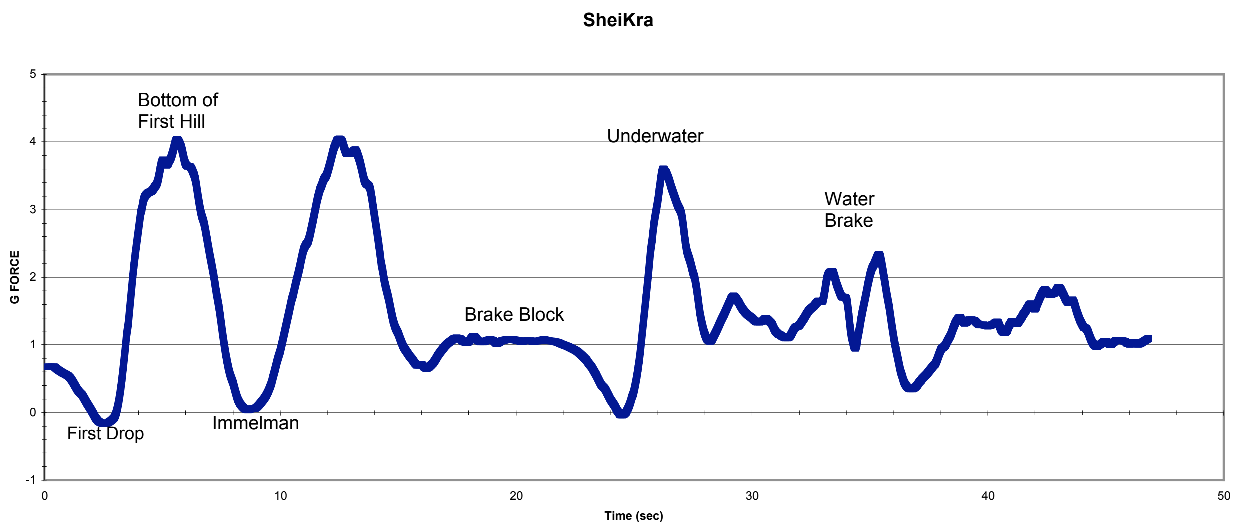

Phoenix
G Force
Time (sec)
A
B
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
0
20
40
60
80
100
120
140

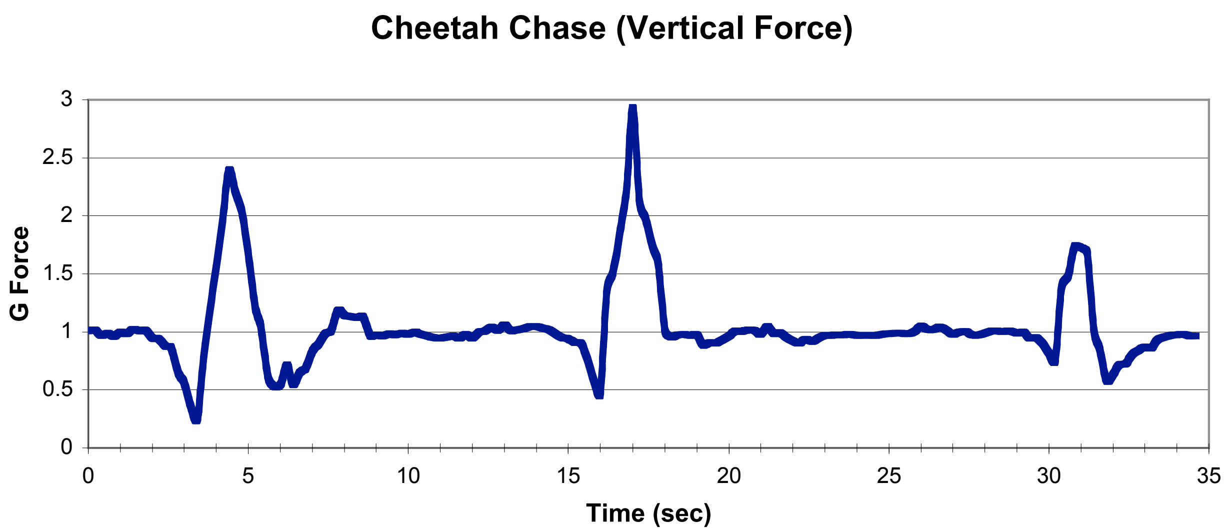

Scorpion
G Force
Time (sec)
Bottom of
First Hill
Hill Bottom after
Vertical Loop
Top of
Vertical Loop
Carrousel
(Two Horizontal Loops)
0
1
2
3
4
0
5
10
15
20
25
30
35
40

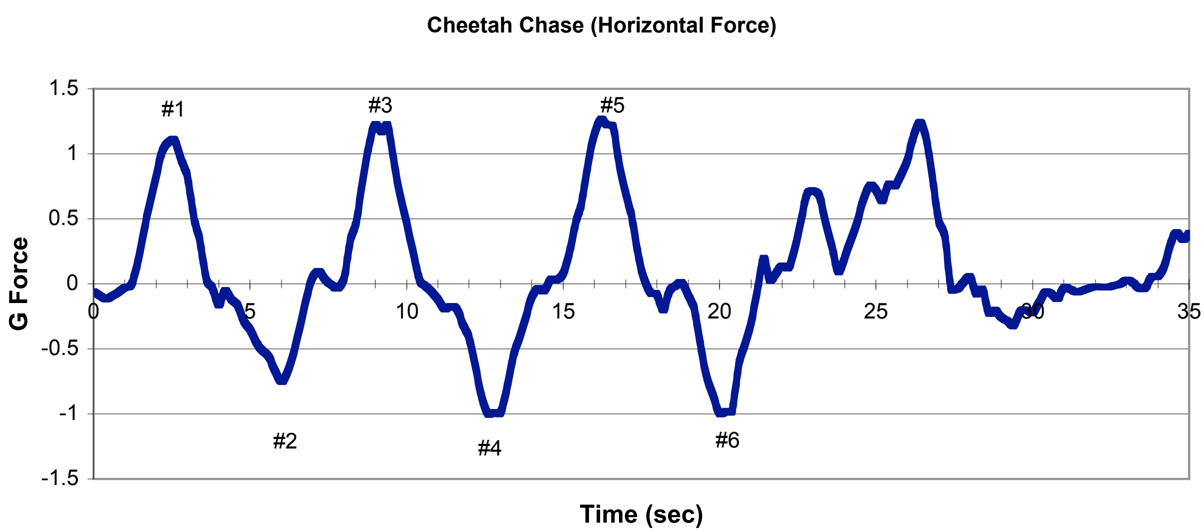

Montu
G Force
Time (sec)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
Vertical Loop Bottom
Immelman Bottom
Batwing Middle
Vertical Loop Bottom
Flat Spin
High Speed Spiral
Vertical Loop Top
Vertical Loop Top
Brake Block
Immelman Top
Zero G Roll


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


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


Cheetah Chase (Vertical Force)
G Force
Time (sec)
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35


Cheetah Chase (Horizontal Force)
G Force
Time (sec)
1.5
1
0.5
0
-0.5
-1
-1.5
0
5
10
15
20
25
30
35
#1
#2
#3
#4
#5
#6

The Worlds of

Busch

GARDENS.

TAMPA BAY, FL