SIX FLAGS GREAT ADVENTURE

PHYSICS DAY

WORKBOOK 2011

Six Flags
ACADEMIC ADVENTURES

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SIX FLAGS GREAT ADVENTURE PHYSICS DAY WORKBOOK
TABLE OF CONTENTS

INTRODUCTION

Physics Day at Six Flags Great Adventure is an outstanding resource for educators to share with their students. It provides students with the unique opportunity to provide first-hand experience for many of the concepts that are taught in the typical Physics I course. Students will experience aspects of acceleration, rotational motion, conservation of energy, and forces – big and small – that are simply impossible to demonstrate in the classroom environment. While the day at the park will be a 'fun' activity, it is also a day of hands-on learning and practical application of the topics they have worked throughout the year to master.

LEARNING GOALS

This workbook was designed to meet the needs of the average Physics I curriculum. It focuses primarily on the concepts of:
- Newton's Laws of Motion
- Force & Acceleration
- Kinematics
- Rotational and Circular Motion
- Work, Power, and Energy
- Conservation of Energy and Momentum

Students will:
- Use tools to collect physical data for analysis
- Predict and calculate forces acting on a rider at different points during a ride
- Calculate the work and power necessary to move riders through a ride
- Calculate centripetal acceleration and normal forces acting on riders in circular motion
- Use the conservation of energy to approximate velocities and altitudes of riders at different points in the ride
- Use rotational motion equations to determine linear speed of riders in circular motion

INSTRUCTIONAL PREPARATION

It is important to review the main topics that the students will be using to complete this workbook prior to your day at the park. There are additional resources on the Six Flags website that can be very useful in your review, specifically the *"Great Adventure Physics Day Review & Samples"* and *"Great Adventure Assignment for Students not at the Park"* workbooks. These were created using rides that were removed / replaced.

Familiarize yourself with the terminology of the workbook. Teachers use different variables and terms to describe forces and situations. This workbook tries to use variables and terms that are generally universal, but they may be different than what you use with your students. Examples:

- The Acceleration Meter (Accelerometer) measures the net acceleration acting on you at any given time. Some teachers refer to this with terms such as *"g-force", "force factor", "acceleration rate",* or *"g-reading".* This workbook uses the term "Acceleration Factor" to describe this acceleration. It is important that students understand how to read the meter and that the meter is providing an acceleration reading in multiples of the acceleration due to gravity.

- The use of the term "Normal Force" describes the contact force between a rider and their chair or the force between a roller coaster car and the track.

- Many of the problems can be solved independent of the mass of the rider. However, some questions (particularly those involving energy calculations) are dependent on rider mass. For simplicity this workbook will assume a common mass of 60 kg for all theoretical riders.

Please feel free to make additions and amendments to this workbook as you feel necessary to better facilitate its use for your individual group of students. I hope that you find this workbook useful and valuable to your experience at Six Flags Great Adventure.

Regards,

Tom Paterson, Physics Instructor
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I would like to acknowledge and give special thanks to my Physics Colleague Roy Sarcona for all his assistance and contributions to the development of this workbook.

I would also like give thanks and appreciation to Dory Oswald, from Six Flags Great Adventure, for all of her assistance and support in providing the resources necessary to construct this workbook. Without her vision, perseverance and dedication this workbook would not have been possible.

MAKING MEASUREMENTS AND CALCULATING ANSWERS

Most measurements can be made while waiting in line for the ride, such as timing specific events. Acceleration Meter readings must be made during the course of the ride. Be sure that the Acceleration Meter is securely attached to your wrist using the rubber band or safety strap while using it during the ride.

The workbook is designed for you to answer each question using your knowledge of Physics to find an exact answer. There are also multiple choice answers that are provided to help you determine if your calculated answer is appropriate. **Realize that the answer you calculate may not / should not exactly match a potential multiple choice answer.** These potential answers have been created using actual measurements from previous years. Therefore, you should choose the multiple choice answer **that most closely matches** what you have calculated using your measurements. **Provide your exact solutions in the box provided** and show the accompanying work and calculations in the space provided for that question.

Instructor note: students will have to use specific given mass assumptions so that the multiple choice answers will work. Also, the assumption is that the Acceleration Meter readings that the students record will give comparable to established values.

ACCELERATION FACTORS

Acceleration Factor (AF): An acceleration factor enables you to express the magnitude of an acceleration that you are experiencing as a multiple of the acceleration due to gravity. This is also referred to as the g-force (even though we are not actually measuring force) or simply how many "g's." This acceleration is usually the result of the ride's seat pushing on you to hold you up or change the direction that you are moving.

Acceleration Factors are very useful in making our measurements because while all riders will experience different forces while riding (because the force is dependent on rider mass, which varies person to person) each rider will experience the exact same acceleration.

If a rider needs to determine the individual force that they feel while riding they simply need to multiply their mass by their measured acceleration factor. For example, while standing still everyone experiences an acceleration factor of 1g (the acceleration due to gravity) and therefore the force acting on any person in this scenario is: $F_g = mg$ where g = the acceleration factor and m is the mass of the person.

To measure an Acceleration Factor: The Acceleration Meter **must be held in the direction of acceleration**. If you are moving in a circle, the Acceleration Meter should be pointed so that it is pointed towards the center of the circle. (This is considered the positive direction for circular motion.) **For most rides you will simply need to hold the acceleration meter perpendicular to the floor of the car/ride.**

EXAMPLES OF HOW TO USE AN ACCELERATION FACTOR

When you measure an Acceleration Factor:

EQUAL to 1, you feel **NORMAL. RIGHT NOW** you feel a force on your seat exactly equal to your weight as the seat supports you.

GREATER than 1, you **FEEL HEAVIER** than normal and feel pressed into the chair. In reality, the chair is pressing up on you which you interpret as being pushed down.

LESS than 1, you **FEEL LIGHTER** than usual and can feel as if you are almost lifting out of the chair. For example, this is how you feel when an elevator starts down suddenly. It is possible to have acceleration factors that are less than zero (negative) where you would feel like you are being thrown upwards (you would lose contact with your seat), however the acceleration meters are not capable of measuring this quantitatively.

For example: On a certain ride a 50 kg girl uses the acceleration meter to record an Acceleration Factor of 3. This corresponds to an acceleration of 3 g's – three times the acceleration of gravity.

- What is acceleration that she is feeling as measured in m/s^2?

    - $3 \times 9.8 \ m/s^2 = 29.4 \ m/s^2$

- How heavy does this rider feel while experiencing this acceleration factor?

    - $F = ma = (50 \ kg)(29.4 \ m/s^2) = 1,470 \ N$

# USING THE ACCELEROMETER AND OTHER MEASURING TOOLS

There are three main tools you will need to make your measurements required to complete the questions in this workbook. You will need (at a minimum):

- Acceleration Meter
- Angle Meter
- Stopwatch / Timer

The Acceleration Meter (Accelerometer) and Angle Meter can be purchased from www.Pasco.com or they can also be homemade with a little ingenuity. If a stopwatch is not available, most cell phones have this functionality built in – just make sure it is capable of timing to the tenth of a second.

Acceleration Meter
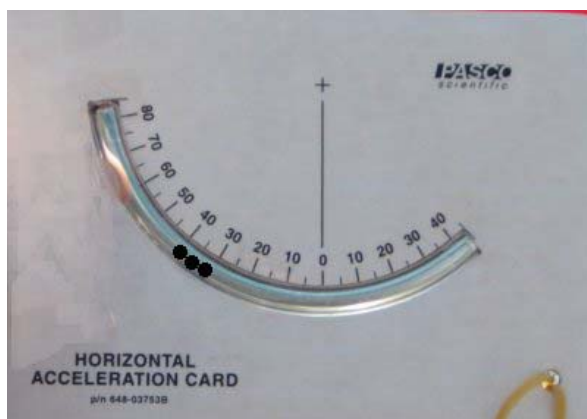
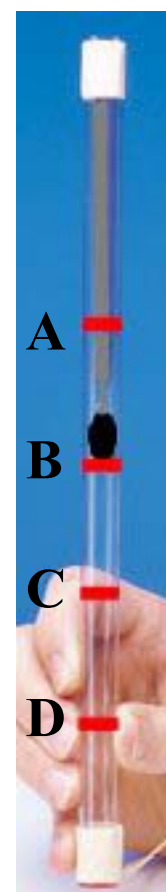Angle Meter / Horizontal Acceleration Card

Stopwatch

To use the Acceleration Meter hold it in the direction you are trying to measure. Most of the accelerations that you will measure are the result of going in a circle, so you would hold the meter with the top end pointed towards the center of the circle you are moving in. In most cases this will be perpendicular to the floor of the ride/roller coaster car.

The Acceleration Meter is usually a plastic tube with a mass suspended from a spring. There should be markings on the side of the tube in order to determine the acceleration reading. In the figure to the right the mass is the oval shaped dot in the tube. The person holding this tube is at rest, so the mass is at (B) and the net acceleration they feel is 1g – 9.8 m/s^2 – the acceleration due to gravity.

When on a ride, if the mass falls down to the second mark (C) that indicates that the rider is feeling an acceleration of 2g – 19.6 m/s^2. At the third mark (D) the acceleration would be 3g – 29.4 m/s^2. Most acceleration meters should have markings down to at 4g.

When riders feel lighter than they normally would (such as in freefall, or going over the top of a 'camel hump' on a roller coaster) the mass will move upwards to record an acceleration less than that of gravity. At point (A) on the meter the rider would feel 0g – 0 m/s^2 – weightlessness. It is also possible that the riders can experience negative g's while riding (the feeling of being thrown upwards and out of the seat), however these acceleration meters are not capable of measuring negative g's and will simply show 0g.

MAKING MEASUREMENTS

Angle Meter / Horizontal Acceleration Card:

Hold the Angle Meter so that its top or bottom side is parallel to the angle you are trying to measure.

There are three ball bearings inside the plastic tube that will move to indicate the angle. Record the angle value for the MIDDLE ball bearing.

On roller coasters you should be able to place the angle meter on the side armrest of the car to measure the angle.
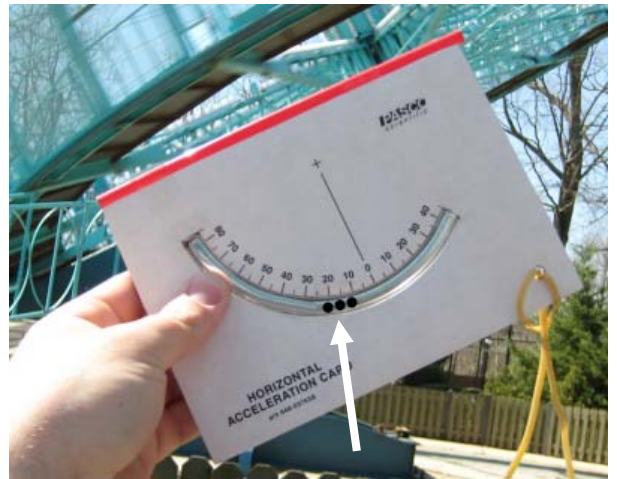
Measuring the time for a car to go over the top of a hill:

You will need to make a time measurement using your stopwatch to determine how long it takes a roller coaster car to pass a particular point.

Choose a fixed point on the hill – it should be the highest point. (See arrow in figure on left)

Start the stopwatch when the front of the car reaches your chosen point.

Stop the stopwatch when the rear of the car passes your chosen point.

You can calculate the car's velocity using your measured time and the length of the car. $v = d / t$

Measuring the time to go up a lift hill:

Begin the stopwatch when the car reaches the base of the lift hill, and stop it when it reaches the top. (See arrows in figure on right)

You can either make your measurement using the front of the car or the rear of the car as your reference point – but choose one and stick with it.

Do not start the measurement when the front of the car begins up the hill and stop it when the rear of the car reaches the top!
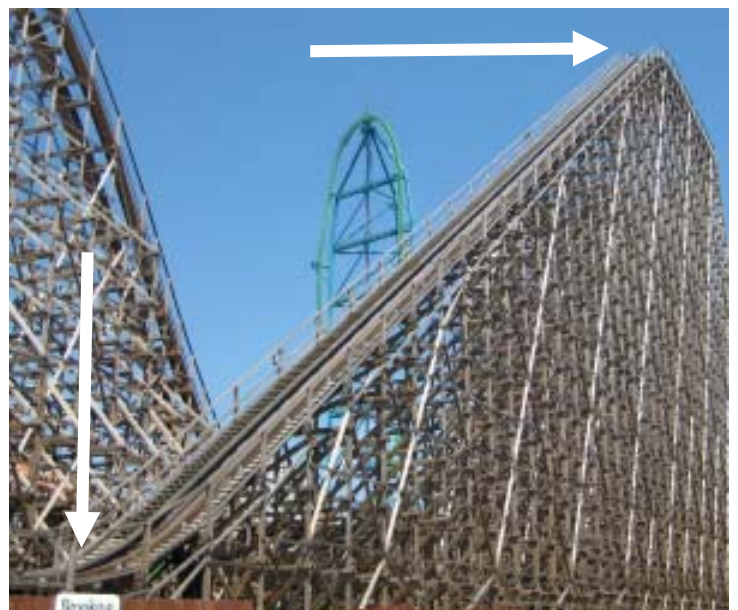
FREE BODY DIAGRAMS AND NEWTON'S 2ND LAW IN CIRCULAR MOTION

In order for an object to move in a circle, there must be some force acting on it that is pointed towards the center of the circle (the radial direction). The purpose of this force is to change the direction of the motion the object. In order to determine how large this unbalanced radial force must be, Newton's second law is applied.

$$\Sigma F_R = \frac{mv^2}{r}$$

- F$_R$ is the radial force; the positive direction for this force is towards the center of the object's circular motion.
- m is the mass of the object moving in circular motion
- v is the linear velocity of the object
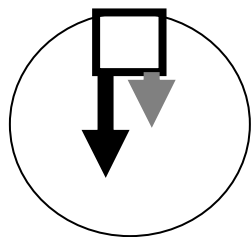- r is the radius of the object's motion as it travels in circular motion

When a person on a ride experiences circular motion (as on a roller coaster) the major forces acting on them are their weight and the contact force between the person and their seat. Summing these forces allows for the radial force to be determined, from which other information (such as velocity or radius of motion) can be determined.

The key to correctly analyzing forces for riders in circular motion is drawing the proper free body diagram. Some sample free body diagrams for riders at different points are shown below:
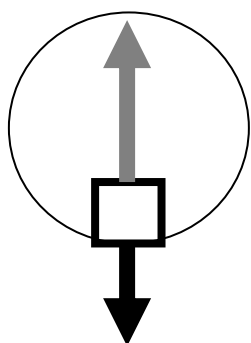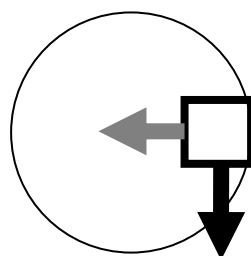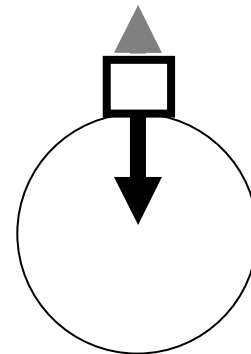
RIDER AT THE BOTTOM   RIDER AT THE TOP   RIDER AT THE SIDE   RIDER OVER A HILL

Weight Vector   Normal Force

The Acceleration Meter readings that you will take while riding tell you the amount of "g-force" that is acting on your body. One "g" is equal to the acceleration due to gravity. Two "g's" is twice the acceleration due to gravity, and so on. When you are at rest or moving at constant velocity the net acceleration acting on you is 1g acting on you (this is the regular force you feel due to the Earth's gravity). When your body is accelerated by a ride the force on you is increased due to this acceleration. Since every rider on a ride is accelerated at the same rate, but do not feel the same force (because each rider has a different mass, and F=ma) it is very convenient to use "g-force" to analyze forces when solving problems.

The reading you take with the Acceleration Meter tells you what force you feel acting on your body. If the meter reads 2 g's, then you feel a net acceleration double that of gravity and therefore you feel twice as heavy. Let's illustrate with an example:

A rider going through a circular loop on a roller coaster records a g-force reading of 0.5 when they are at the top of the loop (see picture above – 2nd from left). The rider is moving at 15 m/s and the radius of the loop is 15 meters. What is the magnitude of the force that they feel?

$$\Sigma F_R = \frac{mv^2}{r} = F_N + mg \qquad F_N = \frac{mv^2}{r} - mg \qquad F_N = \frac{(60kg)(15\frac{m}{s})^2}{15m} - 60kg(10\frac{m}{s^2}) = 300N$$

USEFUL PHYSICS FORMULAS

Kinematic Equations

$$\Delta d = d_f - d_i \qquad v = \frac{d_f - d_i}{t} \qquad a = \frac{v_f - v_i}{t} \qquad v = v_i + at$$

$$d = v_i t + \frac{1}{2}at^2 \qquad d = \frac{1}{2}t(v_f + v_i) \qquad v_f^2 = v_i^2 + 2ad$$

Translational (Straight Line) Motion

Newton's Second Law: $F_{NET} = \Sigma F = ma$ Force of Friction: $F_f = \mu F_N$

Work = Fd = ΔKE   Kinetic Energy = KE = ½ mv^2 Power = P = E / Δt

Gravitational Potential Energy = PE = mgh

Total Energy of a System = PE + KE = ½ mv^2 + mgh

Linear Momentum of an object = p = mv   Impulse = I = FΔt = Δp = mΔv

Rotational (Circular) Motion

Circumference = C = 2πr   Diameter = D = 2r

Period = T   Frequency = f $T = \dfrac{1}{f}$

Velocity = $v = \dfrac{2\pi r}{T}$ Centripetal Acceleration = $a_C = \dfrac{v^2}{r}$ Centripetal Force = $F_C = ma_C = m\dfrac{v^2}{r}$

Newton's 2nd Law for Rotational Motion: $F_{NET} = \Sigma F_R = \dfrac{mv^2}{r}$

Right Angle Trigonometry

$$\sin\theta = \frac{O}{H} \qquad \cos\theta = \frac{A}{H} \qquad \tan\theta = \frac{O}{A} \qquad a^2 + b^2 = c^2$$
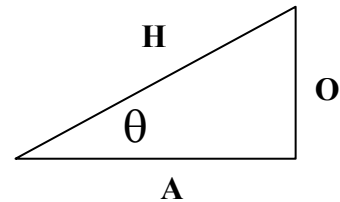
Conversion Factors

1 meter (m) = 3.28 feet (ft)   746 Watts (W) = 1 horsepower (hp)

9.8 Newtons (N) = 2.2 Pounds (lbs)

1 kilogram (kg) is equivalent to 2.2 pounds (lbs)

Measurements to make:

While observing: Go to the area behind El Toro (near the bridge that crosses the pond). Watch the car as it goes up the lift hill and record the time it takes for the front of the car to go from the bottom to the top of the hill.

Time for the front of the car to reach the top of the lift hill (Points A to B):

Time 1	Time 2	Time 3	Time 4	Time 5
Average:				

Time for the train to pass over the top of the second hill (Point C):

Time 1	Time 2	Time 3	Time 4	Time 5
Average:				

While riding:

Angle of the lift hill: _____

Acceleration Meter reading at the bottom of the first drop hill: _____

Acceleration Meter reading going over the top of the next hill: _____

1) El Toro's car goes up the lift hill much more quickly than other roller coasters usually do, however it is still moving at nearly constant velocity. What would you expect the Acceleration Meter reading to be while going up this hill if you were asked to measure it? Why?

    a) 0   b) 1   c) 2   d) 3   e) 4
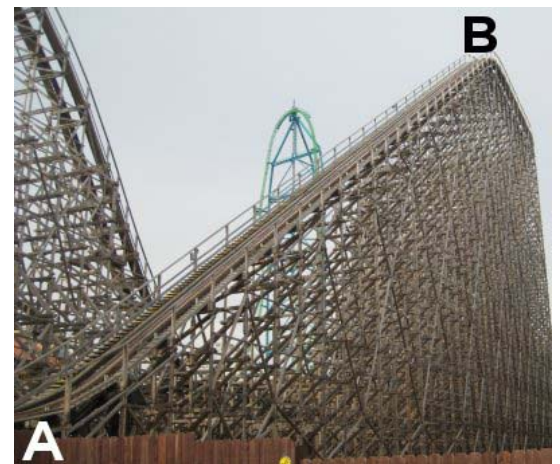
2) To get to the top of the lift hill El Toro's car is vertically lifted by 53.3 meters. The average mass of a loaded (car with passengers) El Toro car is 9750 kg. What is the work done by the motor to lift the car and passengers to the top of the hill?

   a) 100 kJ   b) 1000 kJ   c) 5000 kJ   d) 10,000 kJ   e) 100,000 kJ

3) If El Toro's lift hill was steeper (greater angle) but just as high (same height), then would the work required to bring the car from the bottom to the top be:

   a) More   b) Less   c) The Same

   Why?

4) Given the angle that you measured for the lift hill and its height of 53.3 meters, what is the average amount of force is required to push the car to the top?

   a) 500 N   b) 5,000 N   c) 50,000 N   d) 500,000 N   e) 5,000,000 N

5) Using the time you measured for the car to reach the top of the hill, what is the minimum output power of the motor that is used to pull the car up the hill?

   a) 300 W   b) 3 kW   c) 30 kW   d) 300 kW   e) 3 MW

6) If El Toro's lift hill was steeper (greater angle) but just as high (same height) and the amount of time it took to get the car from the bottom to the top was the same, would the minimum power output of the motor be:

   a) More   b) Less   c) The Same

   Why?

7) Using the Acceleration Meter reading that you measured when you reached the bottom of the first drop hill, what was your approximate speed when you were at this point? The radius of the curve at the bottom of the hill was 29 meters.

   a) 10 m/s   b) 20 m/s   c) 30 m/s   d) 40 m/s   e) 50 m/s

8) If you assume that El Toro's velocity before the first hill's drop was very small (assume zero) in comparison to its speed at the bottom of the drop hill, what was the approximate height of the drop hill?

   a) 5 m   b) 25 m   c) 45 m   d) 75 m   e) 125 m

9) The length of El Toro's car is 18.8 meters. Using your measurement for the amount of time it took El Toro to go over the top of the next hill, calculate the speed that the car was moving.

   a) 10 m/s   b) 20 m/s   c) 30 m/s   d) 40 m/s   e) 50 m/s

10) When you go over the next hill you experience the feeling of being thrown out of your seat (good thing you have a seat belt). This means that you are subjected to negative g's. The value of this acceleration is approximately 1g (9.8 m/s^2) in a direction away from the center of the curve (up). How does this compare to the Acceleration Meter value you measured? Using the speed you calculated in the previous question and an acceleration value of -1g (-9.8 m/s^2), what is the approximate radius of the curve for this hill?

   a) 10 m   b) 20 m   c) 30 m   d) 40 m   e) 50 m

OPEN ENDED QUESTIONS:

LEVEL I:
Below is a graph of Car Height vs. Time for El Toro. The section labeled A indicates the car going up the lift hill, at section B the car was turning and getting ready to drop, at section C the car is going down its first drop, at section D it is at the bottom of the first drop hill and so on. Given this graph, indicate how the rider feels (normal, heavier, lighter) at each point (A – I).

POINT	FEELING
A	
B	
C	
D	
E	
F	
G	
H	
I	

LEVEL II:
Ues the graph above to create a plot of Acceleration Meter reading vs. Time.

All measurements for this ride can be made while observing the ride. Please do not bring instruments on the ride as there is no need to take any readings while riding.

Record the time it takes the car to reach the top of the hill (from Point A to B):

Time 1	Time 2	Time 3	Time 4	Time 5
Average:				

Record the time it takes for the length of the car to pass over the top most point (Point B):

Time 1	Time 2	Time 3	Time 4	Time 5
Average:				

Record the time it takes for the length of the car to pass over the camel hump (Point C):

Time 1	Time 2	Time 3	Time 4	Time 5
Average:				

The launch system of Kingda Ka is an engineering marvel. It uses a hydraulic motor to pull a cable attached to the car to speed it up from rest to an incredible speed in a very short amount of time. The system adjusts itself so that the car should always make it over the top of the hill. The reason for these adjustments is largely a result of variable car mass (due to variable weight of the riders). For these problems we are going to assume that the car is traveling its design velocity (as listed in the problems) when it reaches the base of the hill.

11) During launch the car is accelerated from rest to approximately 128 mph (57.2 m/s) in 3.5 seconds. What is the average acceleration of the car over that time period?

a) 5 m/s^2 b) 10 m/s^2 c) 15 m/s^2 d) 20 m/s^2 e) 25 m/s^2

12) Over what horizontal distance does this acceleration take place?

a) 50 m   b) 75 m   c) 100 m   d) 125 m   e) 150 m

13) Drivers accelerating in a very fast sports car (Corvette, Porsche, etc.) can accelerate from rest to 60 mph (26.8 m/s) in 4 seconds. Pilots launching off the deck of an aircraft carrier accelerate from rest to 135 mph (60.4 m/s) in 2 seconds. Rank each vehicle from slowest to fastest acceleration:

a) Sports Car – Kingda Ka – Aircraft
b) Sports Car – Aircraft – Kingda Ka
c) Kingda Ka – Sports Car – Aircraft
d) Kingda Ka – Aircraft – Sports Car
e) Aircraft – Kingda Ka – Sports Car

14) If we assume that the mass of the Kingda Ka car and riders is 8325 kg, then how much work is done to accelerate the riders from rest to the velocity they have at the base of the hill?

a) 10 kJ   b) 100 kJ   c) 1 MJ   d) 10 MJ   e) 100 MJ

15) What is the approximate amount of power that Kingda Ka's motor produce to accelerate the car from rest to its maximum velocity?

a) 4 hp   b) 40 hp   c) 400 hp   d) 4,000 hp   e) 40,000 hp

16) As the car changes direction from horizontal to vertical it goes through a curve with a radius of approximately 65 meters. What is the centripetal acceleration of the car as it goes through this point? Provide your answer in "g's" (multiples of 9.8 m/s^2).

a) 1 g   b) 3 g   c) 5 g   d) 7 g   e) 9 g

17) Kingda Ka's hill is 137 meters tall. Using the values you recorded for the amount of time for the car to reach the top of the hill and the car's velocity of 57.2 m/s, calculate the magnitude of the average acceleration that the car has on the way up the hill.

    a) 0 m/s^2 b) 4 m/s^2 c) 8 m/s^2 d) 12 m/s^2 e) 16m/s^2

18) When the car reaches the top of the hill what should the car's theoretical velocity be using the conservation of energy?

    a) 0 m/s   b) 5 m/s   c) 10 m/s   d) 20 m/s   e) 40 m/s

19) What was the car's actual velocity as it went over the top of the hill? (To determine velocity use the length of the car – 11.5 m – and the time you measured it took to go over the peak). Calculate what this value should be using the conservation of energy (initial velocity of 57.2 m/s and height of 137 meters). Explain why this value is less than what you calculated by using the conservation of energy. What is causing this reduced speed?

    a) 0 m/s   b) 10 m/s   c) 20 m/s   d) 30 m/s   e) 40 m/s

20) At the end of the ride the car goes over a camel hump to give the riders an additional feeling of weightlessness. Using your time that you recorded for the car to go over the peak of this hump and the length of the car to determine the velocity of the car at that point. The radius of this camel hump is approximately 130 meters. What is the net acceleration that the rider feels as a result of going over this camel hump?

    a) 12 m/s^2 b) 6 m/s^2 c) 0 m/s^2 d) -6 m/s^2 e) -12 m/s^2

OPEN ENDED QUESTIONS:

Level I: Kingda Ka does not operate in the rain for the safety of the riders. To understand why this is, calculate the change in the horizontal momentum a falling raindrop would have as it strikes your body. Assume that the raindrop has a radius of 5 mm and a density of 1000 kg/m^3; the horizontal velocity of the raindrop is zero; your horizontal velocity is 57 m/s; and the collision between you and the raindrop is inelastic.

A U.S. quarter has a mass of approximately 6 grams. How fast would a quarter have to be moving to provide an equivalent change in momentum as the raindrop (assuming the quarter's collision is also inelastic).

Level II: The change in momentum of one raindrop may not seem like much, but over the course of the ride you would get hit by hundreds to thousands of drops! Assume that you would get hit by about 1000 drops during the course of the ride. How much total force would the raindrops exert on you if the time period over which the drop changes its momentum as a result of hitting you is approximately one-tenth of a second.

Measurements to Make:

About 1 minute into the ride you will go through a braking platform followed by a series of three "camel humps" immediately before returning to the station.
(See pictures on right and on the top of next page.)
It is during these camel humps that you will make Acceleration Meter readings.

"Camel Hump" section

Acceleration Meter at the top of the hump: _____

Acceleration Meter at the bottom of the hump: _____

Radius of curvature at camel humps: 35 m
Mass of the train: 2100 kg
Rider mass: 60 kg

21) Nitro's initial vertical drop is 65.6 meters. What is the potential energy of the train just before it falls?

    a) 500,000 J   b) 750,000 J   c) 1,000,000 J   d) 1,300,000 J   e) 1,600,000 J

22) The length that the train is pulled up the lift hill is 120 meters (in order to reach the 65.6 m vertical drop height). How much force did the lift chain apply to the train to pull it up the hill?

    a) 500 N   b) 1500 N   c) 7500 N   d) 12,000 N   e) 18,000 N

23) If we assume that the velocity of the train is nearly zero right before it falls, then what is the velocity of the train at the bottom of this initial drop?

    a) 5 m/s   b) 15 m/s   c) 25 m/s   d) 35 m/s   e) 45 m/s

"Camel Humps"

24) Calculate the work done by gravity <u>on you</u> during the initial drop.

    a) 5,000 J   b) 10,000 J   c) 20,000 J   d) 30,000 J   e) 40,000 J

25) At the bottom of the first drop you experience approximately 4 g's (39.2 m/s^2). What is the approximate radius of curvature at the bottom of the initial drop?

   a) 11 m   b) 22 m   c) 33 m   d) 44 m   e) 55 m

26) The train rises back up to 148 feet (45 meters) to get to the top of the next hill. According to the conservation of energy the velocity of the car at the top of this hill should be 20 m/s, but instead it is measured to be 15 m/s. An engineer inspects the track and finds that 10 meters of a flat section have been damaged and is no longer frictionless. What is the coefficient of friction over these 10 meters of track?

    a) 0.5   b) 0.6   c) 0.7   d) 0.8   e) 0.9

27) In the camel hump section of the ride, based on your Acceleration Meter reading and radius of curvature for the hump, what is your velocity <u>at the top</u> of the camel hump?

    a) 5   b) 15   c) 25   d) 35   e) 55

28) Draw a free body diagram for a rider going over the top of a camel hump, and another diagram for a rider at the bottom of a camel hump (the box is the rider, the half-circle represents the radius of curvature for the hump). What is the difference between these two scenarios when applying Newton's 2nd Law for circular motion?
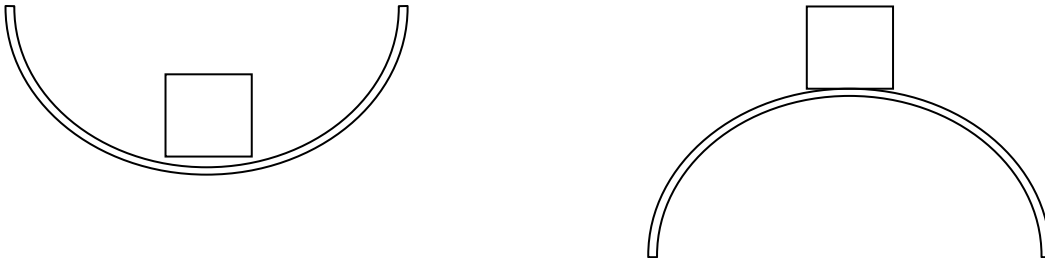
a)   There is no difference
b)   When going over the top of the camel hump, the force of gravity vector is pointed up
c)   The normal force is in the positive direction at the bottom of the hump and in the negative direction at the top
d)   There is no normal force when going through the bottom of the camel hump
e)   The force of gravity and the normal force are not in the radial direction

29) In the camel hump section of the ride, based on your Acceleration Meter reading and radius of curvature for the hump, what is your velocity <u>at the bottom</u> of the camel hump?

a) 5   b) 15   c) 25   d) 35   e) 55

30) What is the main reason for incorporating "camel humps" into the ride?

a)   To slow down the car right before it returns to the station
b)   To give the rider the alternating low-g and high-g acceleration in a short time period
c)   To give the car enough momentum to make it back to the station
d)   To keep the cost of manufacturing the ride low
e)   It makes the ride look pretty

OPEN ENDED QUESTIONS:

The graph below shows Altitude (top solid line) and Acceleration (bottom dashed line) vs. time.
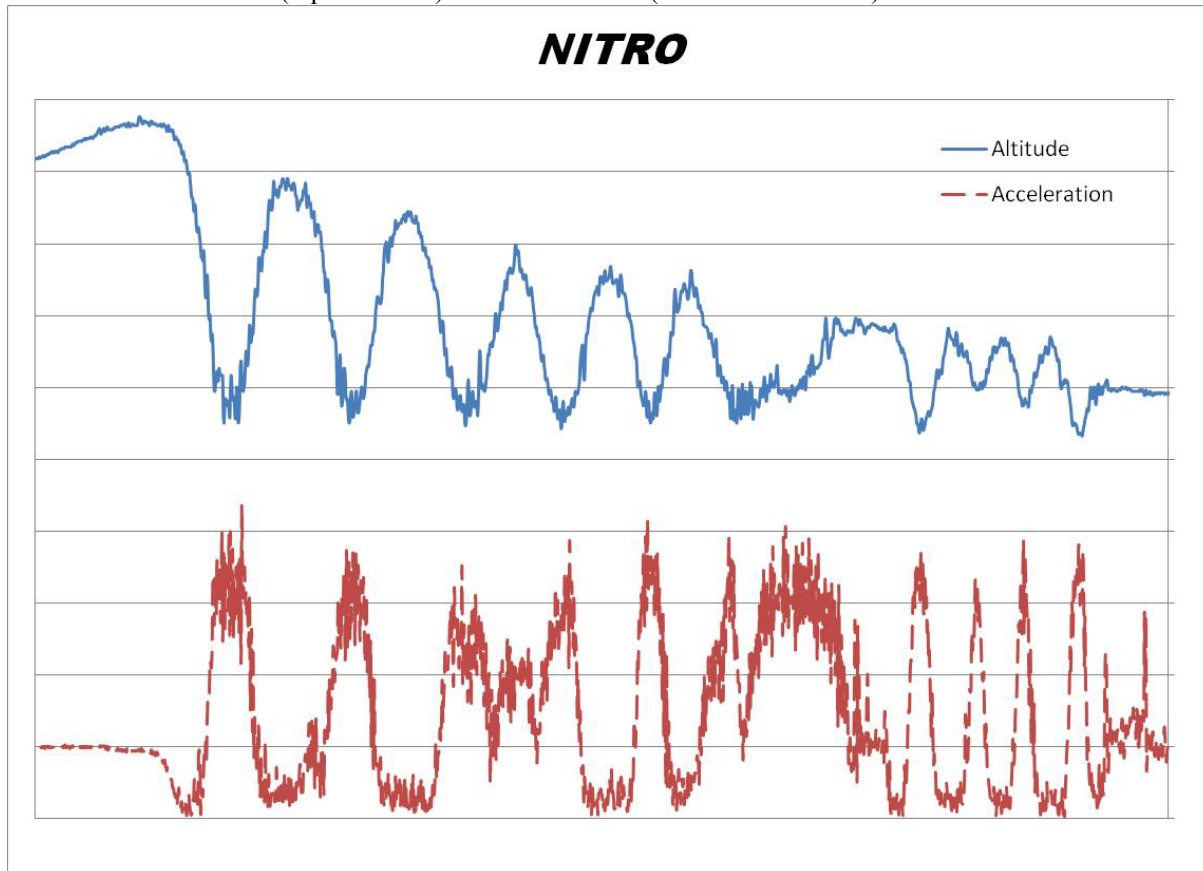
LEVEL I: On the Altitude section of the graph the last three 'bumps' represent the camel hump section that was the subject of the previous questions. What do you notice about both the Altitude and Acceleration graphs for this section? How are they similar and different when compared to themselves and each other?

LEVEL II: The Altitude graph shows that as the ride progresses each successive hill is lower than the previous one. Is this what you see in the Acceleration graph also? Describe the acceleration graph and explain why engineers designed the ride to achieve these results. If the ride does slow down the farther that it goes, how does the ride still achieve the acceleration results you see in the graph?

THE TORNADO

Measurements to Make:

Time for 5 revolutions at top speed: _____

Period of Rotation: _____

Angle of ride to vertical at full tilt, β*: _____

Radius of ride: 6.0 meters
Rider mass: 60 kg

31) What angle (in degrees) does a rider have relative to the horizontal
when the ride is at full tilt?

a) 5   b) 15   c) 25   d) 35   e) 55

32) What is your linear velocity, in m/s, as you are rotating at the
ride's top speed?

a) 2 m/s   b) 5 m/s   c) 9 m/s   d) 14 m/s   e) 17 m/s

33) What is the net radial (centripetal) force, in Newtons, needed
to keep you moving in a circle at this velocity?

a) 25 N   b) 250 N   c) 750 N   d) 1000 N   e) 1250 N

Weight Force   Perpendicular Component of Weight   Radial Component of Weight
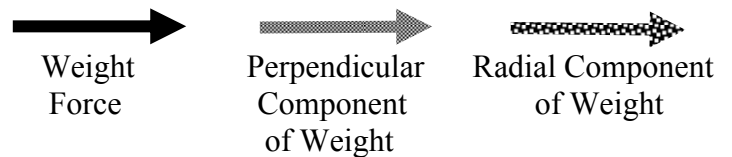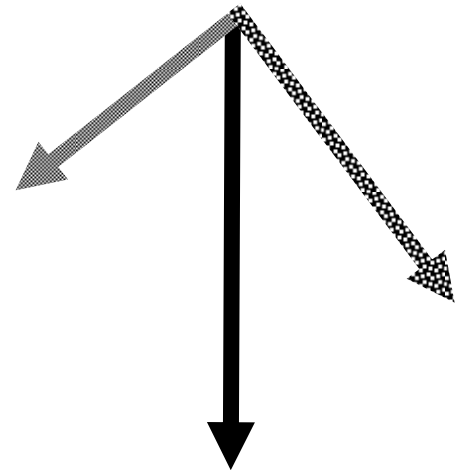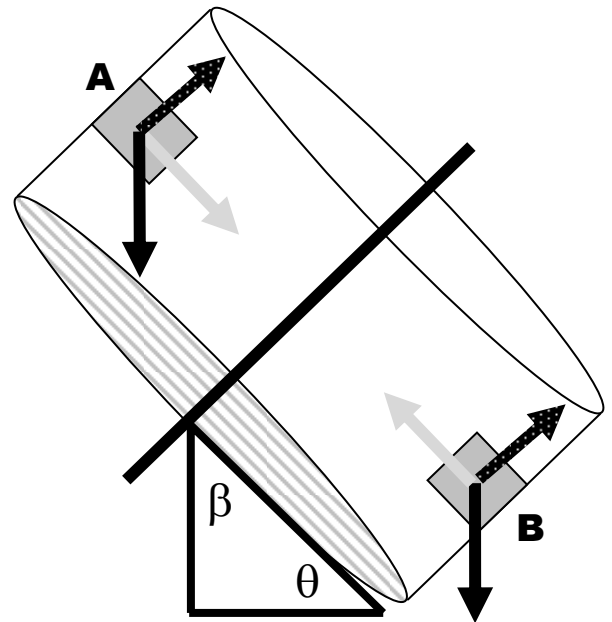
* Using your horizontal acceleration card measure the angle the
ride makes with the horizontal (θ) as shown in the picture, then
subtract that from 90° to find β

34) When the ride is horizontal (no tilt), the entire radial force is exerted by the wall on your back. What would be the Acceleration Meter reading when the ride is horizontal and moving at top speed (this is calculated, not measured)?

a) 0.25   b) 0.50   c) 0.75   d) 1.00   e) 1.25

For the next two questions the ride is tilted to its maximum angle, β (your measurement), and the rider is at position A (see the figure on the previous page). Your weight vector now has a component that is in the radial direction – here it is pointed towards the axis of rotation. Remember to assume that your mass is 60 kg.

35) What is the component of your weight, in Newtons, in the radial direction?

a) 25 N   b) 75 N   c) 150 N   d) 350 N   e) 500 N

36) What is the force, in Newtons, that the wall must contribute to keep you moving in a circle? (Remember that your weight now contributes to the radial force as calculated in the previous question.)

a) 50 N   b) 100 N   c) 250 N   d) 400 N   e) 550 N

For the next two questions we will examine what happens when you are at the lowest point with maximum tilt (position B in the figure on the previous page - 180° from your maximum height position). Your weight vector now has a component that is in the radial direction – but pointed away from the axis of rotation. Remember to assume that your mass is 60 kg.

37) When you are at the lowest point, what is the component of your weight, in Newtons, in the radial direction?

a) 25 N   b) 75 N   c) 150 N   d) 350 N   e) 500 N

38) When you are at the lowest point, what is the force (N) that the wall must contribute to keep you moving in a circle?

    a) 500 N   b) 1000 N   c) 1500 N   d) 2000 N   e) 2500 N

39) What would the ride's minimum speed need to be, in m/s, so that you are not in danger of falling towards the ride's center when you are at position A and the ride is tilted at its maximum angle?

    a) 2 m/s   b) 6 m/s   c) 10 m/s   d) 15 m/s   e) 19 m/s

40) This ride would become very uncomfortable if it was rotating fast enough so that you experienced a force of about 4 g's. When the ride is horizontal (not tilted), at what velocity, in m/s, would you experience this force?

    a) 2 m/s   b) 6 m/s   c) 10 m/s   d) 15 m/s   e) 19 m/s

OPEN ENDED QUESTIONS:

LEVEL I: The ride operator thinks that the ride would be safer if he reduces the velocity at which the ride rotates. Why is this not a good idea?

LEVEL II: Show mathematically that the rider will not fall towards the center of the ride (with sufficient velocity) at a given angle θ, regardless of the mass of the rider.

The CAROUSEL RIDE
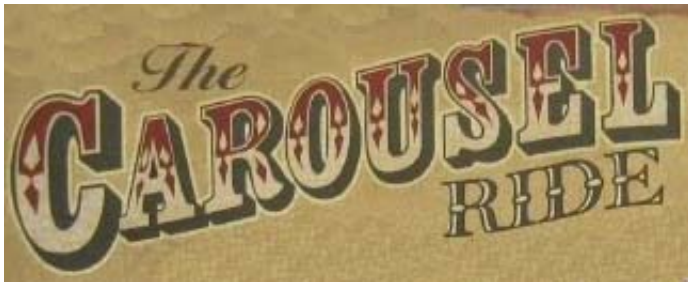
Measurements to Make:

Time for 5 revolutions at top speed: _____

Number of horses in the outer ring: _____

Spacing between horses in the outer ring: 2.62 m
Distance from center to outer horses: 5.0 m

Number of horses in the inner ring: _____

Spacing between horses in the inner ring: 1.83 m
Distance from center to inner horses: 3.5 m

Mass of rider: 60 kilograms

41) What is the period of the merry go round in seconds?

    a) 1 s   b) 3 s   c) 6 s   d) 15 s   e) 23 s

42) What is the frequency of the merry go round in cycles per second?

    a) 0.05 Hz   b) 0.07 Hz   c) 0.17 Hz   d) 0.33 Hz   e) 1.00 Hz

43) What is the circumference of the outer ring of horses?

    a) 10 m   b) 15 m   c) 20 m   d) 25 m   e) 30 m

44) What is your linear speed if you are standing next to one of the horses in the <u>outer ring</u>?

    a) 1.0 m/s   b) 2.0 m/s   c) 3.0 m/s   d) 4.0 m/s   e) 5.0 m/s

45) What is the centripetal force acting on you if you are standing next to one of the horses in the outside ring?

    a) 50 N   b) 100 N   c) 150 N   d) 200 N   e) 600 N

46) What is your linear speed if you are standing next to one of the horses in the <u>inner ring</u>?

    a) 0.5 m/s   b) 1.5 m/s   c) 2.5 m/s   d) 3.5 m/s   e) 4.5 m/s

47) What is the centripetal force acting on you if you are standing next to one of the horses in the inner ring?

    a) 10 N   b) 40 N   c) 70 N   d) 110 N   e) 600 N

48) What is the normal force that the floor is exerting on you?

    a) 0 N   b) 30 N   c) 60 N   d) 300 N   e) 600 N

49) What must be the minimum coefficient of friction (μ) to prevent you from slipping off the ride when you are standing next to one of the outer ring horses?

    a) 0.01   b) 0.10   c) 0.25   d) 0.50   e) 0.75

50) If you move so that you are now standing next to one of the inner ring horses, what will happen to the minimum coefficient of friction so that you do not slip off the ride? Explain why.

    a) It remains the same   b) It increases   c) It decreases

OPEN ENDED QUESTIONS:

LEVEL I: For safety purposes the ride's floor is coated with a non-stick surface that has a coefficient of friction with the average pair of sneakers equal to 0.7. With this coefficient of friction, how fast would the rider have to be moving while standing next to one of the outer ring horses to be thrown off the ride?

LEVEL II: Prove mathematically that μ is independent of the mass of a rider who is located at a fixed location from the ride's axis of rotation.

The Buccaneer

Measurements to Make:

Time for one complete swing: _____

Maximum angle with the vertical: _____

Acceleration Meter Readings		
Position A	Position C	Position E

While in line record the period of the ride's motion and maximum angle with the vertical – do this when the ride is at its maximum amplitude using the ship's mast to measure against. While riding record g-force (Acceleration Meter) readings – you should sit as close to either end of the ship as possible for best results.
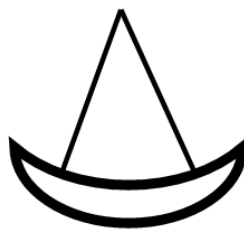
For the questions below answer as if you were sitting on the **RIGHT SIDE** of the ship (as you are looking at it as in the picture above). If you sat on the left side during the ride your answers will simply be opposite of what you experienced.

| Position A | Position B | Position C | Position D | Position E |

51) According to your Acceleration Meter, when the ride is in motion at what point in the ride do you feel the lightest?

   a) A   b) B   c) C   d) D   e) E

52) According to your Acceleration Meter, when the ride is in motion at what point in the ride do you feel the heaviest?

   a) A   b) B   c) C   d) D   e) E

For the next six questions you will need to make calculations that require how high the rider is above their minimum height. To do this, use the conservation of energy and the fact that the radius of the ships motion is approximately 12 meters. Assume that very little energy is lost to friction. Consult the figure below that shows how to determine the rider's height above the minimum point. Theta is the angle that the ship made with the vertical as measured against the ship's mast.

53) Using your reading for the maximum angle you have made with the ground, calculate the height of the rider.

    a) 3 m   b) 6 m   c) 9 m   d) 15 m   e) 20 m
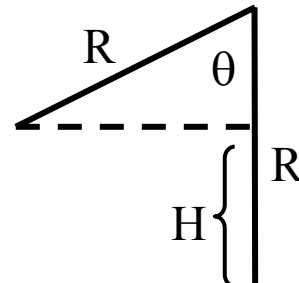
54) Calculate the maximum potential energy (Position E) that a 60 kg rider has during the ship's swing.

    a) 3,500 J   b) 5,500 J   c) 6,000 J   d) 12,000 J   e) 15,500 J

55) Calculate the maximum velocity that a 60 kg rider has during the ship's swing.

    a) 2 m/s   b) 10 m/s   c) 18 m/s   d) 26 m/s   e) 34 m/s

56) The previous questions assumed that the rider was sitting at the center of the ship. If the rider was instead sitting on the far right or left end of the ship how would their maximum potential energy compare to a rider in the center? Explain why you made your choice.

    a) It would be less   b) It would be the same   c) It would be more

57) If we assume that Position D is when the ship is at ½ the angle it makes with the vertical at Position E, then what fraction of the maximum potential energy will the rider have at Position D?

    a) 10%   b) 30%   c) 50%   d) 70%   e) 90%

58) If we assume that Position D is when the ship is at ½ the angle it makes with the vertical at Position E, then what fraction of the maximum velocity will the rider have at Position D?

    a) 10%   b) 30%   c) 50%   d) 70%   e) 90%

59) The Buccaneer has the appearance of a large pendulum. Calculate the theoretical period that the Buccaneer would have based on its length of 12 meters. Is this close to your recorded period?

    a) 2.0 s   b) 3.5 s   c) 7.0 s   d) 10.5 s   e) 14.0 s

60) Assuming that the Buccaneer does behave like a large theoretical pendulum, how by how much does the period of its swing increase by when it is fully loaded (total mass of 12,000 kg with passengers) vs. when it is empty (7000 kg)?
   a) 0%   b) 25%   c) 50%   d) 75%   e) 100%

OPEN ENDED QUESTIONS:

LEVEL I: Below is a graph actual data collected by a Buccaneer rider sitting in the middle of the ship using a computerized accelerometer and altimeter. The acceleration data (g-force) is represented with the solid line, and the altimeter (height) data is represented with the dashed line. A time data point and the 1-g data point have been added to their axis as reference values. Based on your measurements, fill in the empty boxes with the corresponding time and g-force values.

BUCCANEER
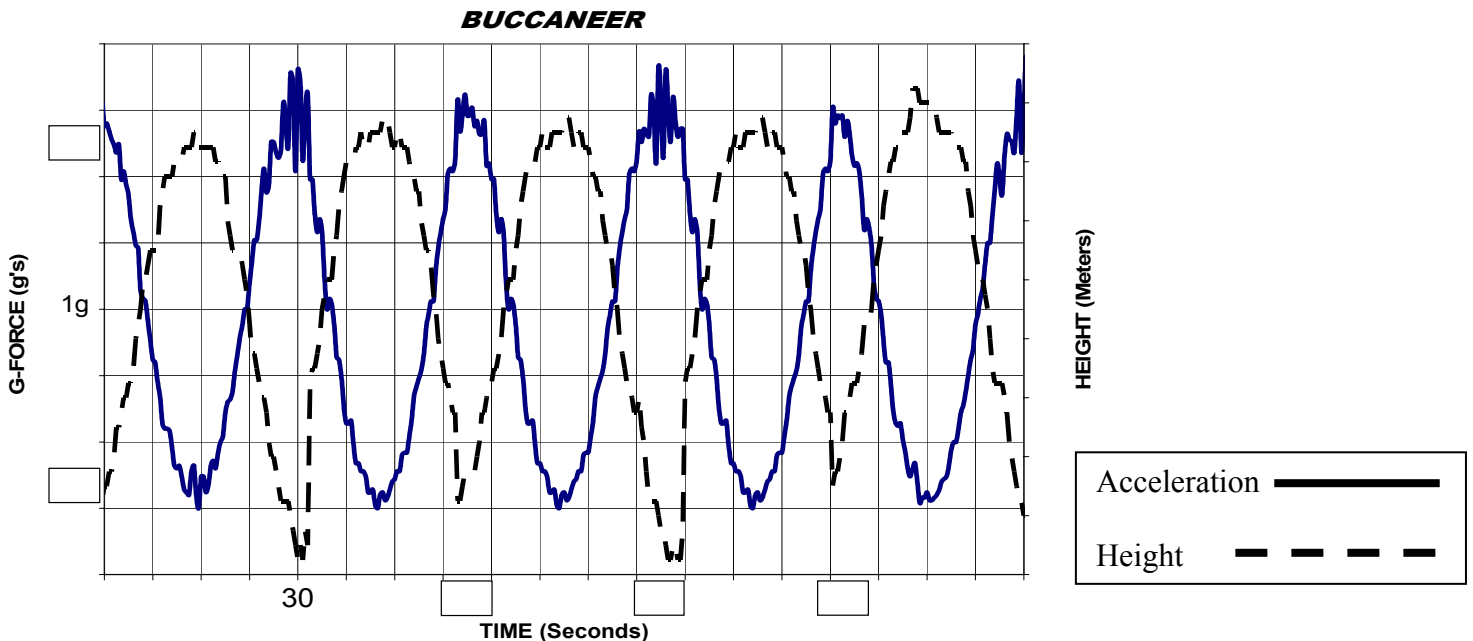
LEVEL II: Compare the graph from the previous question (where the rider was sitting in the middle of the ship) to the one below. The acceleration data (g-force) is represented with the solid line, and the altimeter (height) data is represented with the dashed line. Where in the ship was the person who collected that data sitting? How can you tell? (Answer below)

BUCCANEER

Acceleration ——————
Height — — — —
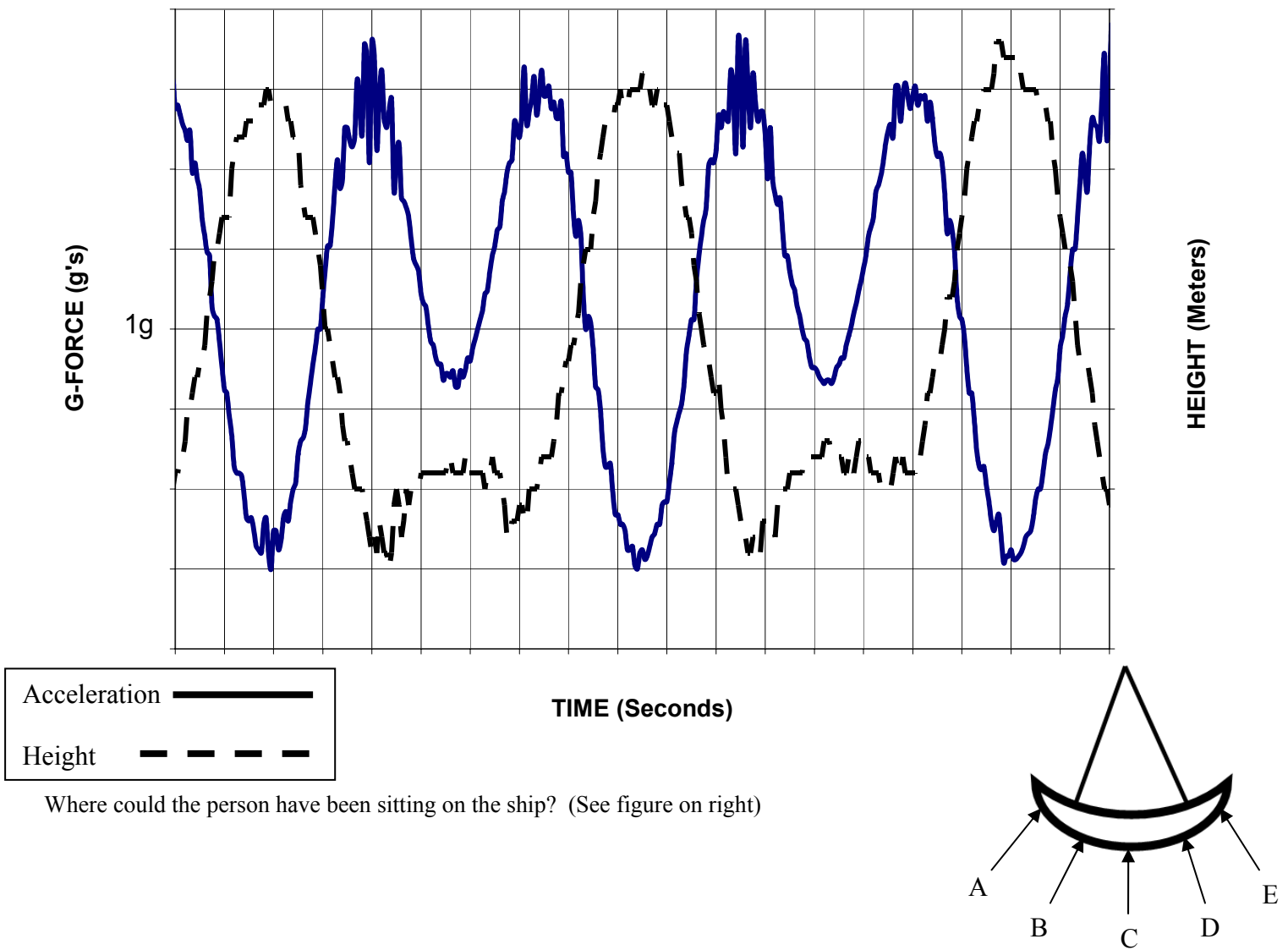
Where could the person have been sitting on the ship? (See figure on right)

What did you notice in the graph about the g-forces acting on that person that led you to believe this?

What did you notice about that person's altitude (height above the ground) that influenced your decision?

THE BIG WHEEL

Measurements to Make:

Count the number of:		
Colored Sections	Cars Per Colored Section	Total Cars

Time for 5 revolutions (at top speed): _____

Number of lights between cars: _____
(see photo below – at the park count the lights between the two arrows on the ride)

61) In 2009 the Big Wheel's 7,824 incandescent lights were replaced with more energy-efficient LED lights. Each old (incandescent) light consumed 7 watts of power. The new LED lights only consume 2 watts of power each. How much power is saved due to this light conversion? (Include all the lights for your calculation.)

   a) 5 kW   b) 50 kW   c) 500 kW   d) 5 MW   50 MW

62) The lights on the Big Wheel are turned on for an average of three hours per day during the 180 day operating season. How much energy, in kilowatt hours, does the Big Wheel's light conversion save during the course of a year?

   a) 1,000 kWhr   b) 10,000 kWhr   c) 20,000 kWhr   d) 40,000 kWhr   e) 80,000 kWhr

63) If the park is charged 18 cents per kilowatt hour, what is the yearly cost savings as a result of replacing these lights?

   a) $1000   b) $5000   c) $10,000   d) $25,000   e) $100,000

64) What is the period of rotation for the Big Wheel when it is operating at full speed?

   a) 10 s   b) 20 s   c) 40 s   d) 80 s   e) 160 s

65) The distance in between each light along the perimeter of the Big Wheel is 7.5 inches (19.05 cm). What is the circumference of the Big Wheel?

   a) 50 m   b) 75 m   c) 100 m   d) 125 m   e) 150 m

66) What is the linear velocity of a car when the Big Wheel is at top speed?

   a) 0.5 m/s   b) 1.0 m/s   c) 1.5 m/s   d) 2.5 m/s   e) 3.0 m/s

67) What is the radius of the Big Wheel?

   a) 5 m   b) 10 m   c) 15 m   d) 20 m   e) 30 m

68) What is the centripetal acceleration on a Big Wheel rider at top speed? What is the direction of this acceleration?

    a) 0.5 m/s^2 b) 1.5 m/s^2 c) 2.5 m/s^2 d) 3.5 m/s^2 e) 4.5 m/s^2

69) How much work does the Big Wheel do on a group of riders to raise them from the lowest point to the highest point on the wheel? The riders are in the same car and they have a combined mass of 300 kg.

    a) 3000 J   b) 30,000 J   c) 75,000 J   d) 125,000 J   e) 225,000 J

70) How much power is required to lift this group of riders when the Big Wheel is operating at its top speed?

    a) 3 kW   b) 7.5 kW   c) 15 kW   d) 22.5 kW   e) 30 kW

OPEN ENDED QUESTIONS:

LEVEL I: Notice the manner in which the ride operator loads the cars. The operator will not load too many consecutive cars (usually only two or three) with passengers; instead they try to space riders out evenly around the wheel. Why is this important to do in order to maintain safe and efficient operation of the Big Wheel?

LEVEL II: Imagine that you are the Big Wheel ride operator. You begin the day with 25 people waiting to be loaded onto the ride, 4 groups of 4 people, and 3 groups of 3 people (assume each person has approximately the same mass). There are 36 total cars. How would you space these groups out on the Big Wheel? Explain why you chose to space them this way. (Answer by drawing a picture or describing the angular separation between groups.)

While riding, use the horizontal acceleration card to measure the angle of the lift hill. (Hold the card on the side of the car so that it is parallel to the track) Time how long it takes the car to travel up the lift hill. You can also estimate these measurements by watching near the photo booth for El Toro.

While riding you need to make two measurements using your Acceleration Meter: take a reading at the bottom of the first drop (Point A) and another reading when you are going over the top of the next largest hill (Point B). Since Rolling Thunder is a racing coaster with two trains, Point B may be either the hill immediately after the drop, or the second hill after the drop (this is the case for the data plot shown below, but this should not affect your answers).

Measurements to Make:

Lift Hill Angle: _____   Lift Time: _____   Point A Reading: _____   Point B Reading: _____
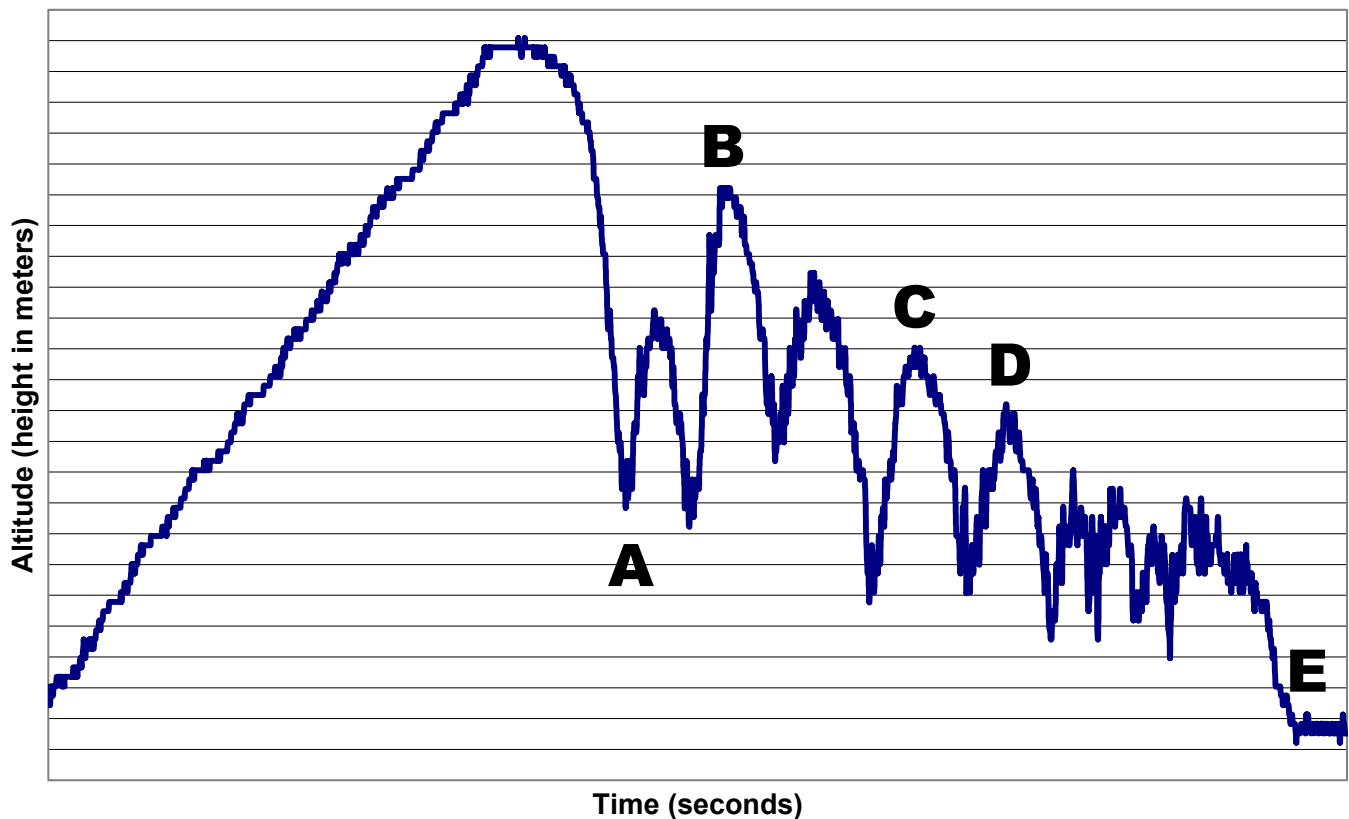
Note: Figure is not to scale. Do not use to make direct altitude measurements.

71) The lift hill raises the rider a vertical height of 23 meters using a motor and chain. If the average rider's mass is 60 kg, then how much work does the motor do on the rider?

    a) 5,000 J   b) 15,000 J   c) 30,000 J   d) 45,000 J   e) 60,000 J

72) Using the lift hill height and the angle you measured for the hill, calculate the force that is exerted on the 60 kg rider to move them up the lift hill.

    a) 50 N   b) 250 N   c) 750 N   d) 1250 N   e) 1500 N

73) What is the minimum amount of power that the motor can put out and still deliver the 60 kg rider to the top of the lift hill? (This is for a single rider only, not the whole car.)

    a) 75 W   b) 450 W   c) 950 W   d) 1400 W   e) 2000 W

74) If the lift hill was steeper how would the minimum power output required for the motor change? Assume that the hill is still the same height, and it takes the same time to reach the top. Explain why this is.

    a) Less
    b) Same
    c) More

75) Using your g-force reading at the bottom of the first drop (Point A), calculate the speed of the car using your knowledge of circular motion. Assume that the radius of curvature at the first drop is 23.5 meters. (Hint: draw a free body diagram and sum the forces on the rider to apply Newton's 2nd Law for circular motion.)

    a) 5 m/s   b) 20 m/s   c) 35 m/s   d) 50 m/s   e) 75 m/s

76) Calculate the first hill drop height using the conservation of energy and your answers from previous problems. (Note from the Altitude graph that the drop height and lift height of 23 meters are not the same.)

a) 3 m   b) 7 m   c) 11 m   d) 17 m   e) 26 m

77) The second major hill (Point B) after the drop hill is approximately 10.5 meters above the bottom of the first drop. Calculate the velocity of the car at this point using the conservation of energy and your previous answers.

a) 3 m/s   b) 12 m/s   c) 19 m/s   d) 26 m/s   e) 32 m/s

78) Refer to the graph of altitude vs. time. The difference in height between points C and D is 2 meters, but the car goes over each hill with the same velocity. Calculate the non-conservative work (work done by friction) done for a car that has a total mass (car + riders) of 5000 kg between points C and D.

a) 25,000 J   b) 50,000 J   c) 75,000 J   d) 100,000 J   e) 125,000 J

79) If an unloaded car (mass of 2500 kg) goes between points C and D what would you expect its velocity and energy lost to non-conservative work (work done by friction) to be compared to the fully loaded (mass of 5000 kg) car in the previous question? Explain why you chose your answer.

a)   The velocity would be less; the energy lost would be more
b)   The velocity would be less; the energy lost would be the same
c)   The velocity would be the same; the energy lost would be less
d)   The velocity would be the same; the energy lost would be more
e)   The velocity would be greater; the energy lost would be less

80) If there was no energy lost to non-conservative forces (friction) during the course of the entire ride, then according to the Altitude graph when the train returned to the station (Point E) it would have a velocity:

a)   Similar to its velocity at Point A
b)   Less than its velocity at Point A
c)   Greater than its velocity at Point A
d)   The car would not make it back to the station

OPEN ENDED QUESTIONS:

LEVEL I: We know that a traditional roller coaster like Rolling Thunder can never go over a hill that is higher than its initial drop hill. Referring to the graph of altitude data vs. time, we see that after point B each hill that the roller coaster goes over is not even as high as the previous one. Why do you think this is? What are some reasons the roller coaster was designed in this way?

LEVEL II: Refer to the graph of altitude data vs. time – a section of this is shown below right (not to scale). Point C is 2 meters higher than Point D, but the speed that the car goes over each hill is approximately equal. This means that some of the potential energy that should have been turned into kinetic energy was used for something else. Surprisingly, the majority of this lost energy is <u>not</u> due to friction between the wheels and the track. Explain other possibilities where the "missing" could have energy gone.
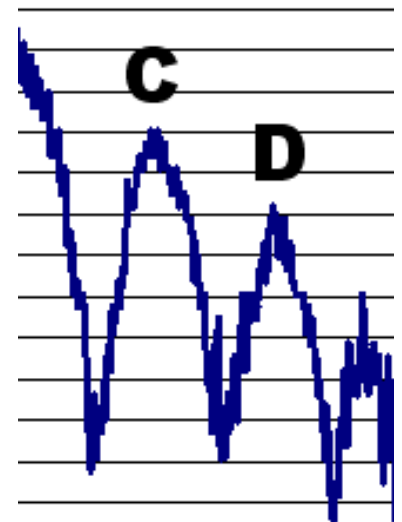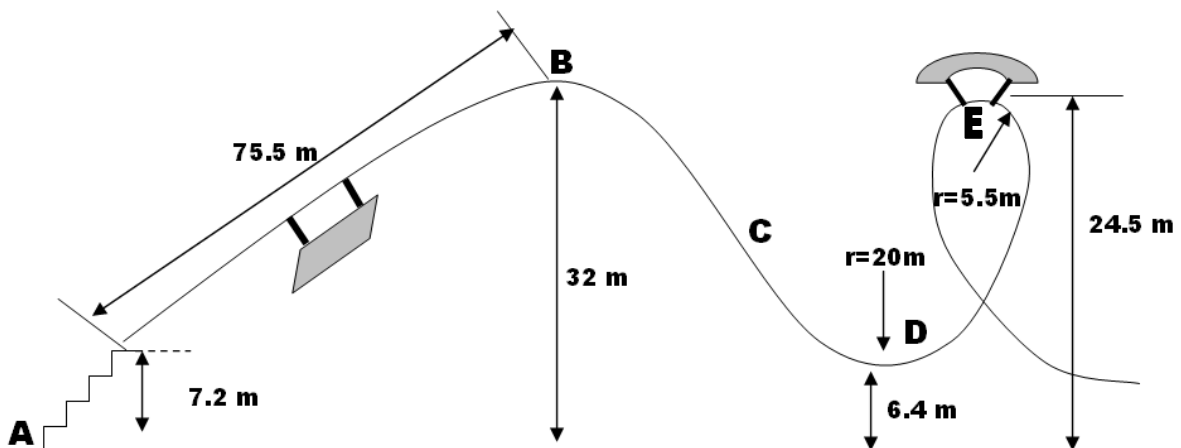
BATMAN

THE RIDE

Measurements to make from the ground:

Time it takes for the first car to reach the top of the first hill (Point B): _____

Measurements to make while on the ride:

Reading of Acceleration Meter at point B: _____   Reading of Acceleration Meter at point D: _____

Rider mass: 60 kg

81) Using the ground as your reference level, what is your potential energy at Point B?

    a) 6,000 J   b) 12,000 J   c) 18,000 J   d) 24,000 J   e) 30,000 J

Your potential energy at point B is a combination of the work you did to get from ground level to a height of 7.2 meters (by walking up steps) and the work the car did to bring you to point B by riding the coaster.

82) Find the work you did by climbing the stairs to the point where you entered the coaster car.

    a) 100 J   b) 600 J   c) 1,000 J   d) 2,000 J   e) 4,000 J

83) What is the work the coaster did on you to get you from the end of the stairs to point B?

    a) 500 J   b) 5,000 J   c) 15,000 J   d) 20,000 J   e) 25,000 J

84) What is the power that the ride used to get you to point B?

    a) 50 W   b) 200 W   c) 500 W   d) 1,000 W   e) 2,000 W

85) Assuming no energy losses due to friction, what is your total energy at point D?

    a) 6,000 J   b) 12,000 J   c) 18,000 J   d) 24,000 J   e) 30,000 J

86) What is your potential energy at Point D?

    a) 4,000 J   b) 10,000 J   c) 16,000 J   d) 22,000 J   e) 28,000 J

87) Determine the kinetic energy at point D and use it to calculate your speed at point D.

    a) 5 m/s   b) 15 m/s   c) 25 m/s   d) 35 m/s   e) 40 m/s

88) What is the centripetal force on the rider at point D?

    a) 500 N   b) 1,500 N   c) 2,500 N   d) 3,500 N   e) 5,500 N

89) Calculate the force the seat exerts on the rider (normal force) at Point D.

    a) 600 N   b) 1,200 N   c) 2,000 N   d) 2,600 N   e) 3,400 N

90) Based on your answer for the normal force, what is the calculated Acceleration Meter reading at Point D? How does this compare to your measured Acceleration Meter reading at Point D?

    a) 0.5g   b) 1.5g   c) 2.5g   d) 3.5g   e) 4.5g

OPEN ENDED QUESTIONS:

LEVEL I: What is the advantage for Great Adventure in having you walk up the first 7.2 meters of the ride in order to get on as opposed to having the train do it?

LEVEL II: What is the minimum velocity of the car at point D so that it can make it all the way through next loop?