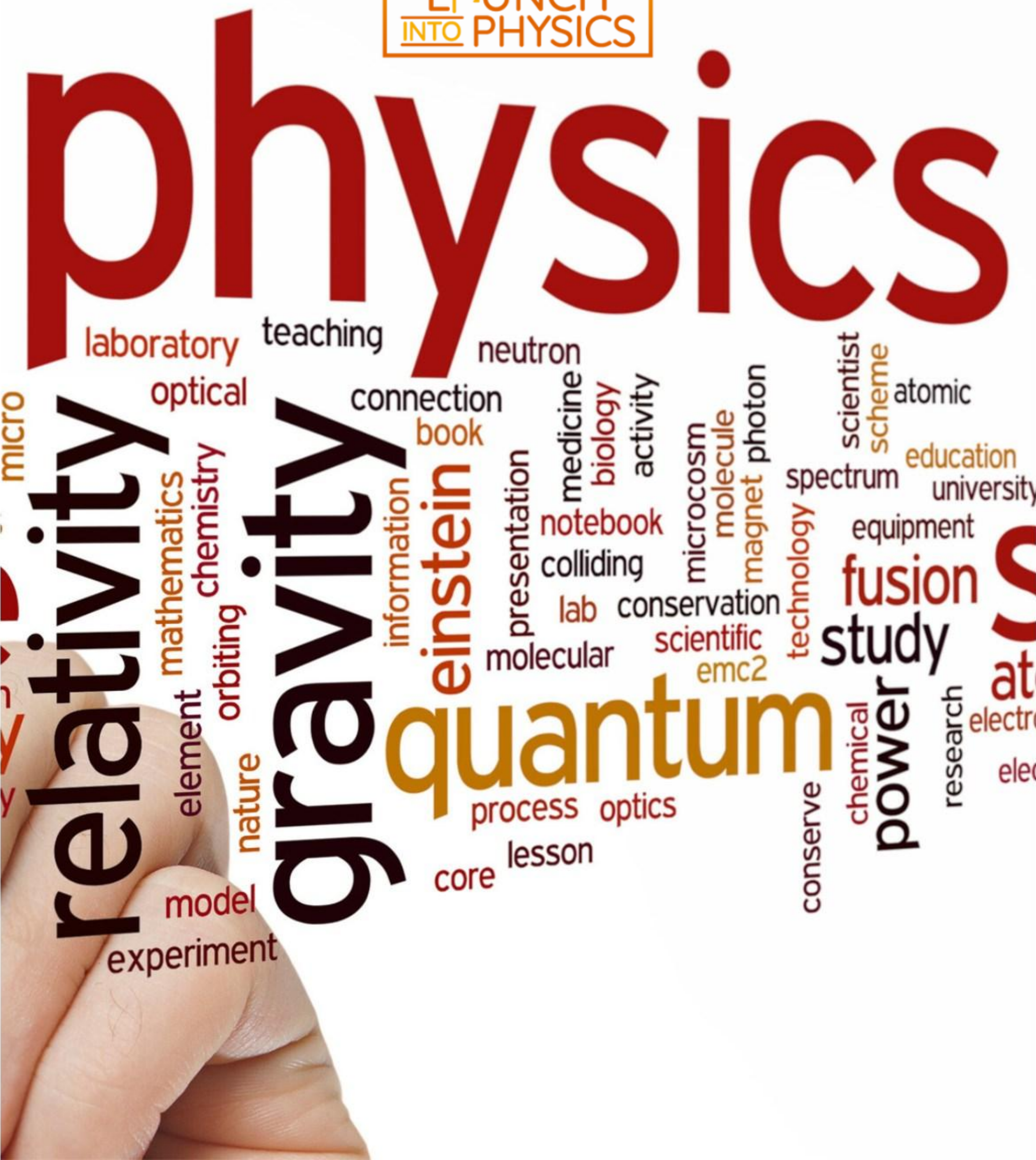
Busch Gardens. LAUNCH INTO PHYSICS



INSTRUCTOR

DR. DAVID WRIGHT

Along with Griffin, Alpengeist and Apollo's Chariot, spring at Busch Gardens showcases the physics shenanigans of Tidewater community college professor David Wright in his highly interactive shows that began in April. Wright rides a hovercraft, jumps on a pogo stick and removes a tablecloth from a table, leaving the dishes intact.

His shows are presented to middle & high school physical science & physics students along with some college students. The idea is to show off how relevant and fun studying physics can be.

He has taught physics at Tidewater Community College since 1974, took part in the debut of the Travel channel series "Insane Coaster Wars.", was Dr D in the NASA Sci Files TV series, and is also the author of this workbook.

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BENCHMARKS FOR SCIENCE LITERACY PROJECT 2061

"The terms and circumstances of human existence can be expected to change radically during the next human lifespan. Science, mathematics and technology will be at the center of that change—causing it, shaping it, responding to it. They will therefore be essential to the education of today's children for tomorrow's world. What should the substance and character of such education be? Project 2061—which began in 1985, the year Halley's Comet was last here—is a long-term effort of scientists and educators on behalf of all children. Its purpose is to help transform the nation's school system so that all students become well educated in science, mathematics and technology. Today's young people will, as adults, greatly influence what life on earth will be like in 2061,the year Halley's Comet next returns. Being literate in science is condition for doing so responsibly, as well as or living a full and interesting life. Benchmarks for Science Literacy and its companion publication Science for All Americans, contribute to that end."

Benchmarks are different from a curriculum, a curriculum framework, a curriculum design or a plan for a curriculum. It is a tool to be used by educators in designing a curriculum that makes sense to them and meets the standards for science literacy recommended in Science for All Americans.1

Doing physics at Busch Gardens is an excellent way to work on advancing these standards for Science Literacy. Relevant Benchmarks, from the book Benchmarks for Science Literacy, are listed below with activities from the Launch Into Physics Workbook listed after each Benchmark that can contribute to its achievement.

4E Energy Transformation

GRADES 6TH - 8TH

- Whenever energy appears in one place, it must have disappeared from another.
  - Level 1: Finnegan's Flyer
  - Level 2: Pantheon, Escape from Pompeii, Lock Ness Monster, Battering Ram, Griffon

GRADES 9TH - 12TH

- Whenever the amount of energy in one place or form diminishes, the amount in other places other forms increase's by the same amount.
  - Level 1: Finnegan's Flyer
  - Level 2: Pantheon, Escape from Pompeii, Lock Ness Monster, Bettering Ram, Griffon

4F Motion

GRADES 6TH - 8TH

- An unbalanced force acting on an object changes its speed or direction of motion or both. Whenever an object is seen to speed up, slow down or change direction, it can be assumed that an unbalanced force is acting on it.
  - Level 1 and Level 2: All Ridess

GRADES 9TH - 12TH

- The change in motion of an object is proportional to the applied force and inversely proportional to the mass. (Newton's Second Law)
  - Level 1 and Level 2: All Rides
- Whenever one thing exerts a force on another, an equal amount of force is exerted back on it. (Newton's Third Law)
  - Level 1: Der Autobahn, The Trade Wind

8C Energy Sources and Use

GRADES 6TH - 8TH

- Transformations and transfers of energy with a system usually result in some energy escaping into its surrounding environment (heat).
    - Level 2: Escape from Pompeii, Loch Ness Monster (Power)

9B Symbolic Relationships

GRADES 6TH - 8TH

- Graphs can show a variety of possible relationships between two variables. As one variable increases uniformly, the other may do one of the following: always keep the same proportion to the first, increases or decreases steadily, increase or decrease faster and faster, get closer and closer to some limiting value, reach some intermediate maximum or minimum, alternately increases and decreases indefinitely, increase or decrease in steps or do something different from any of these.
    - Level 1: Le Scoot Log Flume, Griffon
    - Level 2: Alpengeist, Apollo's Chariot

GRADES 9TH - 12TH

- Any mathematical model, graphic or algebraic, is limited in how well it can represent how the world works. The usefulness of a mathematical model for predicting may be limited by uncertain-ties in measurements, by neglect of some important influences, or by requiring too much computation.
    - Level 1: Apollo's Chariot
    - Level 2: Apollo's Chariot, Alpengeist
- Tables, graphs and symbols are alternative ways of representing data and relationships that can be translated form one to another.
    - Level 1: Loch Ness Monster
    - Level 2: Alpengeist, Griffon

9C Shapes

GRADES 6TH - 8TH

- The graphic display of numbers may help to show patterns such as trends, varying rates of change, gaps or clusters. Such patterns sometimes can be used to make predictions about the phenomena being graphed.
  - Level 1: Le Scoot Log Flume, Alpengeist
  - Level 2: Alpengeist, Apollo's Chariot

GRADES 9TH - 12TH

- Distances and angles that are inconvenient to measure directly can be found from measurable distances and angles using scale drawings or formulas.
  - Level 2: Apollo's Chariot

12B MANIPULATION AND OBSERVATION

GRADES 6TH - 8TH

- Insert instructions in a computer spreadsheet to program arithmetic calculations.
  - Introduction: Spreadsheet Simulations of a Roller Coaster

12C Manipulation and Observation

GRADES 6TH - 8TH

- Use calculators to compare amounts proportionally.
  - Level 2: Loch Ness Monster (both sections), Der Wirblewind, Escape from Pompeii, Battering Ram, Alpengeist, Griffin

GRADES 9TH - 12TH

- Use computers for producing tables and graphs and for making spreadsheet calculations.
  - Pre-Activities: Spreadsheet Simulation of a Roller Coaster

12D Communications Skills

GRADES 6TH - 8TH

- Read simple tables and graphs produced by others and describe in words what they show.
  - Level 1 and Level 2: All Rides

VIRGINIA STANDARDS OF LEARNING

The workbook provides opportunities to work on Virginia Standards of Learning for both Physical Science and Physics. Following each SOL is a list of those rides that are relevant. Teachers also can add additional questions to the workbook to address a particular SOL need.

All rides involve research skills and investigation of real world problems.

PHYSICAL SCIENCE

PS. 1

The student will plan and conduct investigations in which;

- independent and dependent variables, constants, controls, and repeated trials, are identified.
- valid conclusions are made after analyzing data
- research methods are used to investigate practical problems and questions; and
- experimental results are presented in appropriate written form.

The following utilize interpretation of graphs:

- Level 1: Le Scoot log flume, Alpengeist, Apollo's Chariot, Loch Ness Monster, Griffon, Invadr, Finnegan's Flyer, Pantheon
- Level 2: Loch Ness Monster, Alpengeist, Apollo's Chariot, Battering Ram, Griffon, Tempesto, Verbolten, Pantheon

PS. 6

The student will understand states and forms of energy and how energy is transferred and transformed. Key concepts include:

- potential and kinetic energy
- mechanical, chemical and electrical energy
  - Level 1: Finnegan's Flyer
  - Level 2: Escape from Pompeii, Loch Ness Monster (energy), Battering Ram, Apollo's Chariot

PS. 7

The student will investigate and understand temperature scales, heat and heat transfer. Key concepts include:

- absolute zero, phase change, freezing point, melting point, boiling point, conduction, convection, vaporization and condensation
  - Level 2: Escape from Pompeii, Loch Ness Monster (power)

PS. 10

The student will investigate and understand scientific principles and technological applications of work, force and motion. Key concepts include:

- Work, Force, Mechanical Advantage, Efficiency, Power, Horsepower, Gravitational Force, Speed/Velocity, Mass/Weight, Newton's three laws of motion acceleration:
    - Level 1: Loch Ness Monster, Der Autobahn (bumper cars), Le Scoot Log Flume, The Trade Wind, ALpengeist, Apollo's Chariot, Griffon, Invadr, Finnegan's Flyer
    - Level 2: Loch Ness Monster (both sections), Der Wirblewind (swings), Escape from Pompeii, Battering Ram, Alpengeist, Apollo's Chariot, Griffon, Tempesto, Verbolten, Pantheon

PS. 11

The student will investigate and understand basic principles of electricity and magnetism. Key concepts include:

- Static Electricity, Current Electricity, and Circuits
- Magnetic Fields and Electromagnets
- Motors and Generators
    - Level 2: Verbolten, Pantheon, Tempesto

01 Physics

PH. 1

The student will investigate and understand how to plan and conduct investigations in which the components of a system are defined

- Instruments are selected and used to extend observations and measurements of mass, volume, temperature, heat exchange, energy transformations, motion, fields, and electric charges
- Information is recorded and presented in an organized format
- Metric units are used in all m measurements and calculations
- The limitations of the experimental apparatus and design are recognized
- The limitations of measured quantities through the appropriate use of significant figures or error ranges are recognized.

Almost all of the ride sections satisfy this SOL.

PH. 2

The student will investigate and understand how analyze and interpret data. Key concepts include:

- A description of a physical problem is translated into a mathematical statement in order to find a solution
- Relationship between physical quantities are determined using the shape of a curve passing through experimentally obtained dates
- The slope of a linear relationship is calculated and includes appropriate units
- Interpolated, extrapolated, and analyzed trends are used to make predictions
- Situations with vector quantities are analyzed using trigonometric or graphical methods

All of the Level 2 sections involve mathematical interpretation of a physical situation, and all except for Escape from Pompeii and Der Wirblewind involve graphical interpretation, analysis and prediction. Many of the Level 1 rides also satisfy this SOL.

Physics

PH. 5

The student will investigate and understand the inter-relationships among mass, distance, force and time through mathematical and experimental processes. Key concepts include:

- Linear motion
- Uniform circular motion
- Newton's laws of motion
- Gravitation
- Work, Power, Energy
  - Level 1: Loch Ness Monster, Der Autobahn, Le Scoot Log Flume, The Trade Wind, Alpengeist, Apollo's Chariot, Griffon, Ivadr, Finnegan's Flyer, Pantheon
  - Level 2: Loch Ness Monster (both sections), Der Wirblewind, Escape from Pompeii, Battering Ram, ALpengeist, Apollo's Chariot, Griffon, Tempesto, Verbolten, Pantheon

PH. 6

The student will investigate and understand that quantities including mass, energy, momentum and charge are conserved. Key concepts include:

- Kinetic and potential energy
- Elastic and inelastic collisions
  - Level 1: Der Autobahn, Verbolten, Pantheon
  - Level 2: Escape from Pompeii, Loch Ness Monster (energy), Battering Ram, Apollo's Chariot

PH. 7

The student will investigate and understand the energy can be transferred and transformed to provide usable work. Key concepts include:

- Transformation of energy among forms, including mechanical, thermal, electrical, gravitational, chemical and nuclear
- Efficiency of systems
  - Level 1: Finnegan's Flyer
  - Level 2: Escape from Pompeii, Loch Ness Monster (Energy), Battering Ram, Griffon, Pantheon

A note from Busch Gardens Williamsburg

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

Students will not be able to take any measurement devices on the rides.

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

INTRODUCTION

Busch Gardens is one of the world's largest physics labs. Here you can investigate forces and accelerations, energy, weightlessness and inertia. Instead of just watching forces act on objects, you will be the object on which the forces are acting. You can experience forces similar to the space shuttle astronauts on the Loch Ness Monster, feel the effects of inertia as you rapidly decelerate on Escape from Pompeii, feel close to weightless as the log plunges down the incline on the Le Scoot log flume or confuse your senses as you go upside down on Alpengeist. Physics at Busch Gardens is definitely X-treme physics. Why do people love roller coasters and other thrill rides? Speed alone is not the answer. An airplane trip at 500 mph is not very exciting, unless the plane is taking off, landing, turning or experiencing turbulence. It is accelerations that provide the excitement. The rides are in many ways very similar to experiences in cars or airplanes, but everything is very much exaggerated.

Launch into Physic Show

The Launch Into Physics workbook may be used at Busch Gardens on any day that the park is open. There also will be a number of special days each year in which there will be a "Launch into Physics Show" in the Abbey Stone theatre. Busch Gardens Williamsburg, presents this high-energy physics show where hip-hop jams collide with the physics of motion. Inspired by the perplexing twists and turns of the park's world famous roller coasters, this dynamic show encompasses interactive demonstrations and energetic experiments. Don't miss the extraordinary David Wright, Ph.D., Professor of Physics at Tidewater Community College, as he explains the physics behind Busch Gardens Williamsburg's thrills. For more information, email: BGW.GroupSales@BuschGardens.com

Preparation for Your Visit

Each set of exercises in the workbook is designated as Level 1 or Level 2 and generally focuses upon a particular physical principle such as Acceleration or Energy. Most roller coasters have both Level 1 and Level 2 exercises. (The Loch Ness Monster has two sets of Level 2 exercises: one covering Vertical Accelerations and the other concerned with Power, Energy and Acceleration.) There are nine sets of Level 1 exercises and eleven sets of Level 2 exercises. To allow for maximum flexibility, there are many more exercises in the workbook than can be done by the students in one day. You should make copies of those sections of the workbook that you want your students to do. You may assign all of the students to do the same rides, let them choose from a list or arrange for different groups to do different rides and then share with each other later. You can also choose to allow students to just do parts of some rides (i.e Apollo's Chariot Level 2 Questions 1,2,4,7,9) Your students will get more out of their experience if you prepare them for it. This workbook contains a number of pre-activities, and also a review of Principles of Physics applicable to a park visit. This Principles of Physics section also includes the relevant equations that are needed to complete some of the questions in the workbook. Plan a recap day after your return from the park to discuss the activity, compare notes and reinforce the concepts learned.

Middle school teachers will want to assign Level 1 exercises. If you have an advanced middle school class, you also may pick some of the Level 2 exercises. High school teachers may want to mix some Level 1 experiences in with a Level 2 core. Level 1 questions are less mathematical than Level 2. Level 1 exercises do not require the use of any equipment. Stopwatches are needed to gather data in all of the Level 2 exercises, except Apollo's Chariot. Angle measuring devices are needed for some Level 2 rides (Der Wirblewind, Loch Ness Monster, and Battering Ram). The instrument requirements are mentioned at the beginning of each set of exercises.

Student will not be able to take any measuring equipment on the rides

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

Graphs

1. Theoretical graphs: These graphs in the workbook were produced using a computer program. They include the following relationships: Force Factor vs. Distance, Force Factor vs. Speed, Force Factor vs. Banking Angle, Speed vs. Height and Force Factor vs. Radius. They can be used in the place of equations to determine values or simply used to get a visual representation of the relationships
.

2. CBL Force Factor graphs: These graphs were produced with the use of a TI-83 calculator, a CBL and a low g accelerometer. Data for the Loch Ness Monster, Alpengeist, Da Vinci's Cradle, Apollo's Chariot, Griffon and the Battering Ram is included in the workbook.

These Force Factor graphs are not based on any scientifically accurate accelerometer testing of the ride. In fact, the testing was done solely for the purpose of providing information necessary to complete the experiments in this workbook and does not reflect the actual ride conditions.

3. Coaster Profile Graphs: These graphs represent only an approximate representation of the coaster. They are not intended to provide an accurate scale drawing of the coaster.

Suggestions

1. Have the students work in groups of three to five. They will be able to share ideas as well as equipment. Arrange to have them check in with you in the middle of the day to monitor their progress.

2. Have the students make three measurements for each time measurement required. You may decide to have one person make three measurements or three people make one measurement each. This may depend on how many rides you want them to investigate.

3. Have students read the section entitled WHAT TO DO ON THE RIDE before they get on the ride. Have them circle their answers to the PREDICTIONS before riding the rides or making any measurements.

4. Those who do not wish to ride can make those observations and measurements that can be done OFF THE RIDE while they are waiting.

5. Please be courteous and obey all of the park rules.

6. If you visit on a "Funky Physics Show" day, plan to have your students attend the show at the Abbey Stone Theatre.

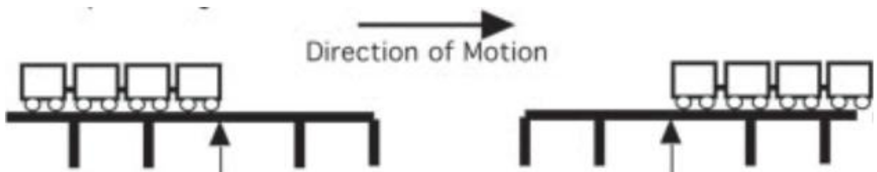
Measurements

Time

Time measurements are used to find speeds. In equations, the speed will be indicated by the letter "v" for velocity. The terms velocity and speed are often used interchangeably in ordinary language. Strictly speaking, a velocity has both a magnitude and a direction, and the magnitude of the instantaneous velocity is called the speed.

a. **Front to Back times** are used to find the speed of coaster trains such as the Loch Ness Monster. They also can be used with slow moving boats, like Escape from Pompeii after the splash.

Speed = length of coaster train/front to back time



Start stopwatch as the front of the coaster train arrives at reference post.

Stop stopwatch as the rear of the last car passes the same point.

b. **Total time** is used to find the average speed for an entire ride, such as on Apollo's Chariot.

Average speed = total distance/beginning to end time

c. **Point to Point time** is a technique that is useful when a front to back time is just too small. The boat in Escape from Pompeii is timed between a post and the splash at the bottom of the hill. It is also used to measure the speed of Alpengeist as it passes between two columns at the bottom of its first hill. The stopwatch is started when the front of the boat or coaster passes point A and then stopped when the front arrives at point B.

Average speed = (distance between A & B)/time to go between A & B)

Force

Vertical Forces

Forces that are experienced while on the rides are measured using something called the Force factor (FF).

$$\textbf{Force Factor(FF)} = \frac{\textbf{Seat force on rider}}{\textbf{Weight of the rider}} = \frac{\textbf{Force}}{\textbf{mg}}$$

If riders are not accelerating, they will be experiencing a vertical force factor of 1. This is because the chair (or seat) must exert an upward force equal to their weight to keep them from falling. A force factor of 1 is normal.

In order for the rider to accelerate upward, such as the bottom of a coaster hill or at the bottom of the swing of Da Vinci's Cradle, the chair must push up on the rider with a force that is greater than the rider's own weight (mg). If the rider experiences a force factor of 2, this signifies that the force is twice normal body weight and the rider will feel twice as heavy as normal. On hilltops, the rider may experience a force factor of 0.5. This would indicate that the seat is pushing up with a force that is half the normal weight of the rider and he will feel light.
Astronauts and test pilots talk about "pulling g's." Pulling 3 g's means the same thing as a force factor of 3. When discussing forces, force factor and "g's" are often used interchangeably. Typically, theme park rides do not exceed a force factor of about 4.

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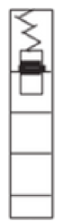
If we were to use the "force" instead of the "force factor," each person will have to report a different number, based upon his own weight.

The following rides have mounted accelerometers: Battering Ram (as seen from the ride queue: left most seat, and first seat right of center), Da Vinci's Cradle (rows 5 and 6), Alpengeist (row 6), Apollo's Chariot (row 6), Griffon (row 3).

The normal position of the hanging weight is a force factor of 1. One line below that is 2. The lowest line is a force factor of 4. When the spring is totally compressed that represents a force factor of 0. The middle of the hanging weight is used to indicate the force factor.

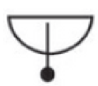


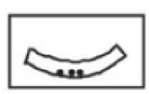
Horizontal Forces

If a rider is stationary or moving at a constant speed in a straight line, he or she experience a horizontal force factor of zero. A horizontal force factor of 0 is normal. If the rider is accelerating and the horizontal force factor is 1, then this would indicate a horizontal force equal to the weight of the rider. A rider that weighs 100 lbs and experiences a horizontal force factor of .5 would be experiencing a horizontal force of 50 lbs. These horizontal forces are produced by the back of the chair (or seat), friction between the pants and seat and the side of the car or the lap bar. The horizontal force factor is seldom greater than 1.

Horizontal forces can be forward, backward or sideways. If the horizontal force is forward, the person will feel pushed back into their seat. If the force is backward, then the person will feel pushed forward. A person experiencing a force to the left will feel thrown to the right. A force to the right will feel like being thrown to the left.

An angle measuring device may be constructed for off-the-ride measurements. They will be used on the following Level 2 Rides: Der Wirblewind, Loch Ness Monster, and Battering Ram. A protractor with a hanging weight on a string works well. There also are commercially available cardboard devices that consist of metal balls in a plastic tube.





To measure an angle, line up the straight edge of the protractor, or the top of the cardboard with the incline of the Loch Ness Monster, or the hanging swing of the Der Wirblewind. In the case of the Battering Ram, you will line up the top of the protractor between the rotational point at the top, and the middle point of the Battering Ram boat at its highest position. With the Battering Ram and Der Wirblewind, you will be measuring the angle with respect to the vertical. This can be read directly off the protractor. With the incline of the Loch Ness Monster,
you will need to subtract the protractor reading from 90 degrees to find the angle with respect to the horizontal. The cardboard angle measuring device works just the opposite, with a subtraction from 90 required for the Der Wirblewind and the Battering Ram.

1. Practice with the Stopwatch

a. Front to Back Measurements

On the Loch Ness Monster the speed can be determined by timing how long it takes the coaster train to pass a fixed point. Several of these front to back time measurements that need to be made at Busch Gardens are less than one second, and therefore it is a good idea to have the students practice. Have them measure the length of the car, then make front to back time measurements as it drives by.

They start the stopwatch as the front of the car passes some point, such as a light pole or tree, and then stop the stopwatch when the back bumper of the vehicle passes the same point. Speed then is equal to the length of the car divided by the front to back time. This is a great opportunity to discuss measurement errors. Since each student is measuring the same event, they all should have the same time. This also will give them a chance to practice taking measurements of small times. A typical car is about 15 feet long. Thus, if it drives by at 10 miles/hour, the front to back time will be close to 1 second. If it drives by at 15 miles/hour the front to back time will be about .7 seconds. Many of the times that the students will measure at the theme park will be in the neighborhood of .7 seconds. The coasters will be going about 60 miles/hour, which is four times faster than 15 mph, but they also will be about four times as long.

If you are unable to go outside to use a car, then try using one of the following:

1. Have a person walk by with a board or a pole. Chose a board length, and speed of walking so that the front to back measurement will be between .5 and 1 second.
2. Have a chain of people holding hands run by. This will simulate the coaster train, which is made of several cars.

b. Point to Point Measurements

If a vehicle is very small (such as the boat on Escape from Pompeii) it is difficult to make a Front to Back time measurement to determine its speed. Times less than a half a second are almost impossible to take accurately. With Escape from Pompeii, it is possible to take a front to back measurement at the top of the hill where the speed is slow, but not at the bottom of the hill where it is going much faster. With these smaller vehicles, timing the vehicle between two different points can be used to determine the speed. As long as the distance between these two different points (posts, light poles, rocks, etc.) is known and the points are far enough apart such that the time will be longer than 0.5 seconds, the speed can be determined.

Measure the distance between two points (desks, standing students, cones, etc.) in the classroom or hallway and have a student run by. Have the class time this student between these two points and determine the speed. Have several students time the runner, and compare their results. This should help indicate the need for multiple measurements and practice.

2. Pre-Activities Involving the Physics Principles

a. Which Way is Up?

Upside down - Ask the class to imagine that someone is grasping their ankles and holding them upside down. Have them name as many ways as possible that they are hanging upside down.

Possible answers might include: hair fell down, blood rushed to the head (they will look red, and feel warm and "heavy headed"), everyone looked upside down, they felt the force of the hands holding them up. The students can then be asked to remember these things when they are upside down on the coasters and see how many of these things they experience on the coaster.

Weightless - Drop a milk carton full of water with a hole punched in the bottom. No water will leave the carton on the way down. While it is in a state of free fall, the water and carton are weightless.

Chair Force determines "weight." Sit in a chair and take your feet off the floor. Describe what you feel. Only the force of the chair.) Now put your hands underneath your chair and pull up fairly hard. Describe how you feel. Would your bottom feel any different if you were to put on a lot of weight? (No. The force with which the chair pushes on you determines your "weight" or how heavy you feel.)

b. Centripetal Acceleration

Bucket of Water - Take a bucket of water and spin it around your head. The water doesn't fall out. 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

Spinning Hanging Weight - Hold a string with an object tied onto it at arms length and spin around. The angle at which the weight hangs is the banking angle for that speed and radius of turn.

Spinning Book - Take a book and place an object such as a pencil or eraser on it. Then hold the book at arms 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 the student pay attention to how the banking angle depends on how fast you spin and how far out you hold the book.

Bicycle - Ride a bicycle around in a circle. Note how the banking angle depends upon the speed and radius of the turn.

d. Energy

Basketball and Tennis Ball - If a basketball and tennis ball are dropped separately, they will both bounce up to a position that is below where they were dropped. This is because some of the original gravitational potential energy is changed into heat energy in the collision. If the tennis ball is placed on top of the basketball and then dropped, the tennis ball will bounce much higher than the position from which it was dropped. It appears that it got the energy from nowhere. However, you also should notice that the basketball bounced somewhat lower than before. Some of the original energy of the basketball was transferred to the tennis ball.

Pendulum - Tie a string to the ceiling and attach a metal ball. Once the ball is released, it will not gain new energy but will simply change gravitational potential energy into kinetic energy, and then back to gravitational potential energy. Therefore, it can't swing any higher than its release point. Hold the ball up to your nose and release it. Friction will assure that it will not quite come back to the nose.

e. Oscillations

Period - Measure the period of a ball on a string. Keep the angle small. Compare the theory to the actual measurement. Now time the period again, but this time use a very large swing angle. Does this create much of a difference?

3. Spreadsheet Simulation of a Roller Coaster

This activity can be either a pre- or post-trip activity.

Equipment Required: Computer with spreadsheet program (Lotus 1-2-3, Quattro Pro, Excel, Appleworks, etc.) A great way to understand the physics of roller coasters is to "play" with a model of a coaster on a spread- sheet. Even if students don't have an understanding of the equations that produce the results, they can still alter the initial conditions and see what the effects are (i.e. What if the initial hill were twice as high, how much would the speed at the bottom increase? How can I produce a force of 4 g's at the bottom of the first hill? What if the second hill were higher than the first?). The students can see at a glance how the magnitude of the Velocity (speed),
Potential Energy (PE), Kinetic Energy (KE), Total Energy (TE), Banking Angle (BNK ANGL), and Force Factor(FF) vary as the Height (H), Radius of the turns and loops (R) are changed.

The spreadsheet model presented on the page entitled Spreadsheet Formulas was written in Excel, but other spreadsheet programs are very similar. The initial coaster has a first hill 25 meters high, followed by a clothoid loop that is 15 meters high, a second hill 15 meters high and a horizontal loop that is 10 meters above the ground. The first hill bottom (C) has a radius of curvature of 35 meters, the radius of the top of the clothoid loop is 10 meters, and the radius of curvature of the second hilltop is 60 meters. The back curve has an initial horizontal radius of 70 meters and the big horizontal loop has a radius of 30 meters.

The equations that are used to find the force factors, banking angle and energy are listed below. In all of these calculations the value of mass is taken to be "1."

Force Factor Equations

Bottom of Hill	Top of Loop	Hilltops	Banked Turns
v2/rg + 1	v2/rg – 1	1-v2/rg	1/cos (angle)

Banking Angle: tan (angle) = v2/rg

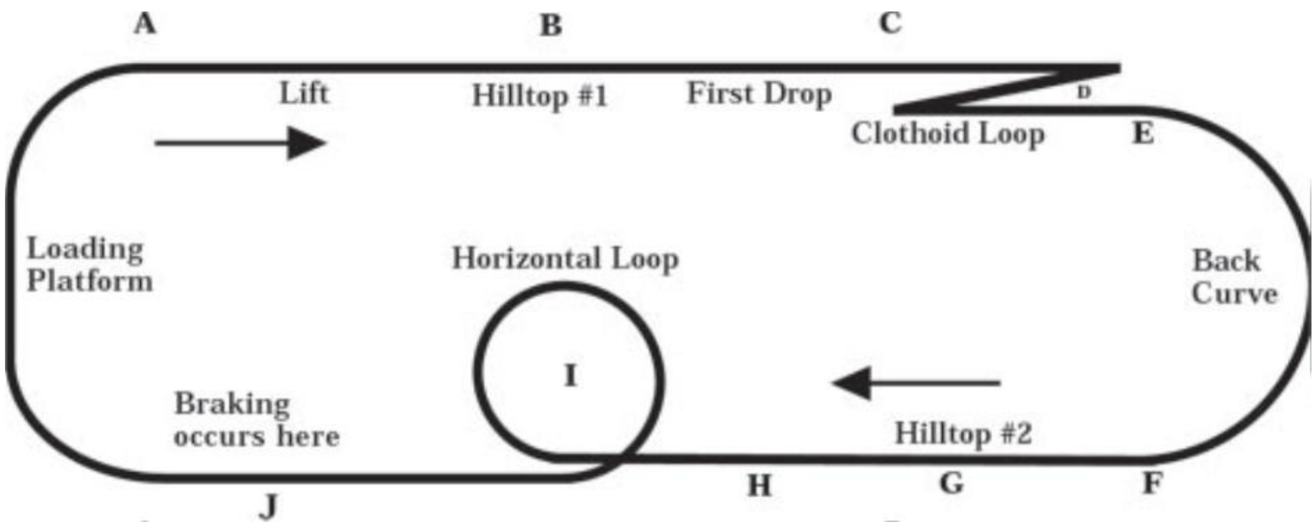
Kinetic Energy .5mv2 Potential Energy mgh Total Energy PE+KE

The students should only make changes in heights (H) and radius (R) of the turns and loops. The new values of energy, force factor and banking angle will then be computed by the spreadsheet. The students will need a copy of the sheet with the top and side views of the roller coaster.

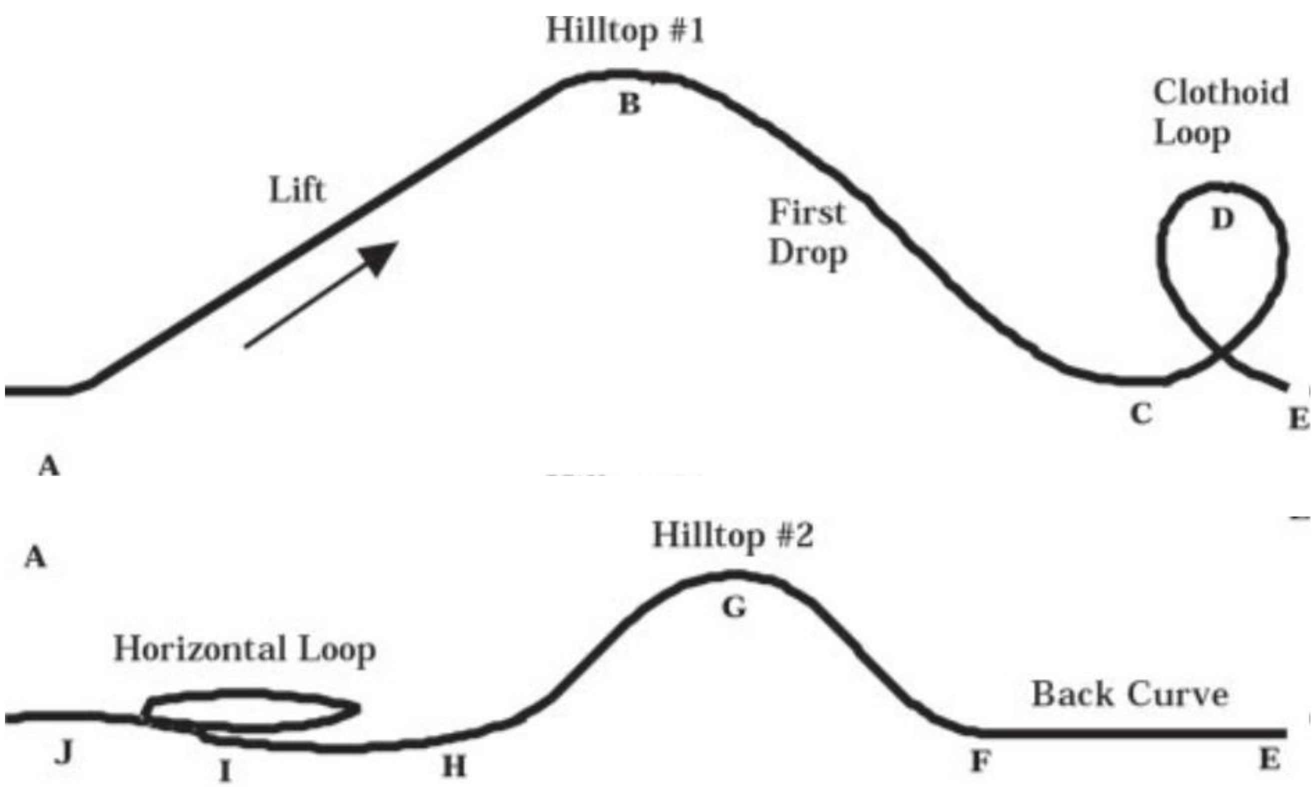
The sheet entitled **What If** (Spreadsheet) demonstrates some of the possible changes that can be made to the coaster, and illustrates some of the investigations that can be made.

Miscellaneous Notes: A negative force factor indicates the coaster will leave the track unless it has a second set of wheels underneath the track. An imaginary answer indicates that the result is not possible. Friction is not taken into account in this model, so the sum of Kinetic + Potential energy is always equal to the total energy.

BASIC ROLLER COASTER
TOP VIEW



SIDE VIEW



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SPREADSHEET FORMULAS

	A	B	C	D	E	F	G	H	I
1	LOCATION	H	VELOCITY	PE	KE	TE	R	BNK ANGL	F
2	B	25	=SQRT(2*9.8*(B2-B2))	=9.8*B2	=0.5*C2^2	=D2+E2			
3	C	0	=SQRT(2*9.8*(B2-B3))	=9.8*B3	=0.5*C3^2	=D3+E3	35		=+C3^2/G3/9.8+1
4	D	15	=SQRT(2*9.8*(B2-B4))	=9.8*B4	=0.5*C4^2	=D4+E4	10		=+C4^2/G4/9.8-1
5	BCK CRV*	0	=SQRT(2*9.8*(B2-B5))	=9.8*B5	=0.5*C5^2	=D5+E5	70	=ATAN(C5^2/G5/9.8)*180/PI()	=1/COS(H5*PI()/180)
6	G	15	=SQRT(2*9.8*(B2-B6))	=9.8*B6	=0.5*C6^2	=D6+E6	60		=1-C6^2/G6/9.8
7	I*	10	=SQRT(2*9.8*(B2-B7))	=9.8*B7	=0.5*C7^2	=D7+E7	30	=ATAN(C7^2/G7/9.8)*180/PI()	=1/COS(H7*PI()/180)
8									
9			Mass is assumed to be					180/PI converts radians	Here, degrees must be
10			equal to 1 in all equations					to degrees	converted to radians
11									before the cosine of th
12									angle is taken

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SPREADSHEET

Original Specifications of the Roller Coaster with m=1

Location	Height	Velcoity	PE	KE	TE	Radius	BnkAngle	FF
B (Hilltop #1	25	0.00	245	0	245			
C (Bottom of Drop	0	22.14	0	245	245	35		2.43
D(Top of Loop)	15	14.00	147	98	245	10		1.00
Back Curve	0	22.14	0	245	245	70	35.54	1.23
G(Hilltop #2)	15	14.00	147	98	245	60		0.67
I (Horizontal Loop)	10	17.15	98	147	245	30	45.00	1.41

Increase the height of the first hill to 50 meters.
Notice the changes in the velocity, banking angle and force factors.

Location	Height	Velocity	PE	KE	TE	Radius	BnkAngle	FF
B(Hilltop #1)	50	0.00	490	0	490			
C(Bottom of Drop)	0	31.30	0	490	490	35		3.86
D(Top of Loop)	15	26.19	147	343	490	10		6.00
Back Curve	0	31.30	0	490	490	70	55.01	1.74
G(Hilltop #2)	15	26.19	147	343	490	60		-0.17
I (Horizontal Loop)	10	28.00	98	392	490	30	69.44	2.85

Adjust two of the turn radii to avoid force factors that are either too high or negative.

Location	Height	Velocity	PE	KE	TE	Radius	BnkAngle	FF
B(Hilltop #1)	50	0.00	490	0	490			
C(Bottom of Drop)	0	31.30	0	490	490	35		3.86
D(Top of Loop)	15	26.19	147	343	490	20		2.50
Back Curve	0	31.30	0	490	490	70	55.01	1.74
G(Hilltop #2)	15	26.19	147	343	490	80		0.13
I (Horizontal Loop)	10	28.00	98	392	490	30	69.44	2.85

Make the second hill higher than the first (#NUM! is an imaginary number)

Location	Height	Velocity	PE	KE	TE	Radius	BnkAngle	FF
B(Hilltop #1)	25	0.00	245	0	245			
C(Bottom of Drop)	0	22.14	0	245	245	35		2.43
D(Top of Loop)	30	Err:502	294	Err:502	Err:502	10		#NUM!
Back Curve	0	22.14	0	245	245	70	35.54	1.23
G(Hilltop #2)	15	14.00	147	98	245	60		0.67
I (Horizontal Loop)	10	17.15	98	147	245	30	45.00	1.41

By changing only the radii of the turns, design an exciting coaster with a heavy bottom, a very light hilltop, and a horizontal loop that is steep and forceful.

Location	Height	Velocity	PE	KE	TE	Radius	BnkAngle	FF
B(Hilltop #1)	25	0.00	245	0	245			
C(Bottom of Drop)	0	22.14	0	245	245	20		3.50
D(Top of Loop)	15	14.00	147	98	245	10		1.00
Back Curve	0	22.14	0	245	245	70	35.54	1.23
G(Hilltop #2)	15	14.00	147	98	245	20		0.00
I (Horizontal Loop)	10	17.15	98	147	245	10	71.57	3.16

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WHICH WAY IS UP?

As the students ride the roller coasters, 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, they 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 they 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. The 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. Your weight, is really a measure of the strength of the "chair force" or support force.

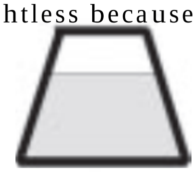
Top of the Loops on the Loch Ness Monster

In a steeply Banked Turn

Weightlessness

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

If only the force of gravity acts on an object, it is in a state of free fall. Diving off a high dive or bungee cord jumping produces 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.



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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 also can 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, like the Loch Ness Monster also produces near weightless sensations.

Horizontal 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.

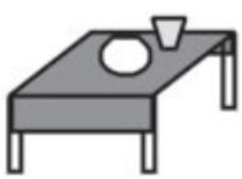
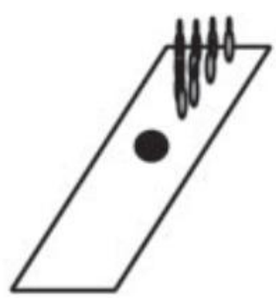


Table Cloth and Dishes

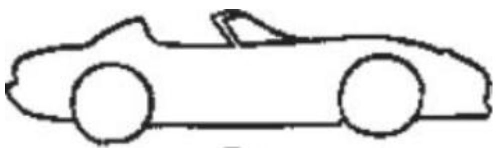


Bowling Ball Rolls

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. The bowling ball on the other hand, once 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 (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.

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



Dodge Viper 0 to 60 mph in 4.1 seconds. Acceleration=6.43 m/s or 2/3 g. The car must produce a force that is 2/3 the weight of the car to cause this change in speed. The passengers also experience a horizontal force of 2/3 their weight pushing them forward.

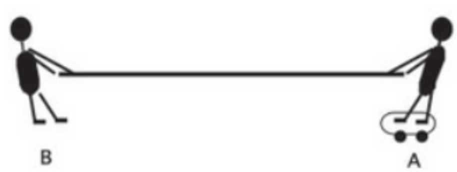
Space Shuttle Takeoff **3.0 g's**

Apollo Moonshot **7.5 g's**

Dragster **3.5 g's**

Commercial Airliner taking off **1/5 g's**

Newton's Third Law: For every action, there is an equal and opposite reaction.



Person A on the skateboard will always lose the tug o' war. Person A can't pull on the rope without being pulled.

To accelerate the person in the elevator upward, the floor of the elevator must push up on the feet with a force greater than the weight of the person, and the feet push back on the floor with the same force. The person will feel heavy.

(If the upward force was 3 g's, they would feel 3 times heavier than normal.)

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Applications

On a roller coaster, it is the acceleration that produces the thrills. Accelerations can be changes in either speed or 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.

Force < 1 g

Change in Speed: BRAKING

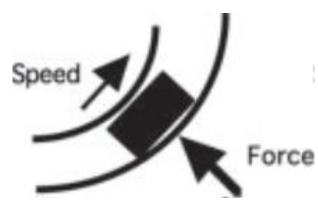
A force is required to make the passengers slow down. If the change in speed occurs quickly, the seat of the coaster car can't produce enough force and the passengers feel as if they are thrown forward. Actually, the coaster car stopped and they didn't. These forces are generally less than 1g.

Initial Speed

Force < 1 g

Increase in Speed: HORIZONTALLY

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 the hills.



Changing Direction: TURNING A CORNER

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 they were thrown to the right.) The greater the speed or smaller the radius of the turn, the greater the force required. When g forces are high, the turns are banked to keep passengers from being thrown to the left and right. (See section on Centripetal Force).

Force Factor

Every acceleration requires a force to cause it. The force factor (FF) indicates how much larger or smaller than the weight of an object a force acting on that object is. Thus, if an object "weighs" 100 lbs, and it experiences a horizontal force of 150 lbs, that would be called a force factor of 1.5. If the horizontal force were 50 lbs, that would then be a force factor of 0.5. To compute the force factor, take the force acting on the object and divide by the weight of the object.

Force Factor = Force/mg

Newton's Second Law states F=ma

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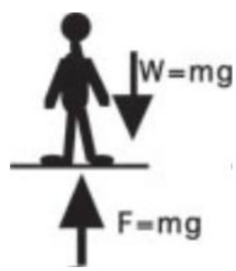
Substituting this into the force factor equation produces

Force Factor=ma/mg or FF=a/g

So, an acceleration of 1.2 g in the horizontal direction corresponds to a force factor of 1.2. Sometimes, the force factor is expressed in g's with 1 g corresponds to a force equal to the weight.

Vertical Accelerations

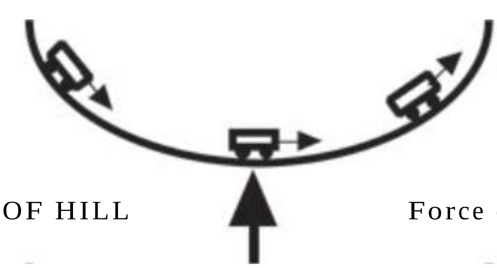
A vertical acceleration may be either a change in speed or change in direction. In both cases a vertical force is required to cause this acceleration. When the vertical force acting on a person is equal to their weight, then the person will have no vertical acceleration. This force could be the ground pushing up or the force of the chair that the person is sitting in.



The person feels normal. We say that they are experiencing a force factor of 1, which is sometimes also expressed as 1g. (If a force other than gravity acts on a person, the force factor tells how many times their weight (mg) the force is.)

If the upward force is greater than their weight, say twice as much, then the force factor is 2, or they are experiencing 2g's.

If there is no upward force, then the person feels weightlessness as they free fall.



Change in Direction: BOTTOM OF HILL

Force experienced is 2.5-3.5 g's

An upward force is required to make the coaster change its 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 Apollo's Chariot and Loch Ness Monster this force exceeds 3 g's on many of the hill bottoms. The maximum force experienced is between 3.5 and 4 g's.

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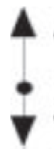
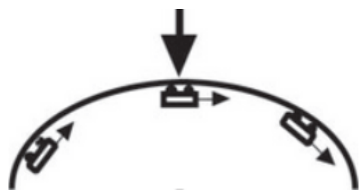
The resultant of these two forces must equal the centripetal force.


Chair Force

mg

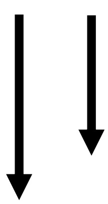
Chair Force - mg = mv^2/r
Chair Force= mv^2/r + mg
Force Factor=Chair Force/mg=v^2/rg + 1



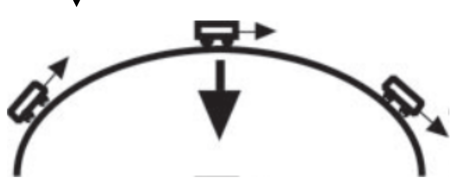
Change in Direction: TOP OF A LOOP **Force experienced is 0 to 2 g's**

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. Alpengeist riders experience six inversions.

Chair Force + mg = mv^2/r Chair Force = mv^2/r –mg produce the centripetal force.



Chair Force + mg = mv^2/r Chair Force = mv^2/r –mg produce the centripetal force.



Change in Direction: TOP OF THE HILL Force experienced is less than 1

At the top of a hill, a downward force is needed to cause the change in direction. If the coaster is moving slowly enough, gravity can provide sufficient force to cause this 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 and the passengers experience a "tummy lifter." The Camelback Hump on Apollo's Chariot is designed so that the force experienced is very close to zero for more than 3 seconds. (If a force greater than that of gravity is required because of the speed of the coaster, then the passengers must have shoulder harnesses and the coaster must have two sets of wheels, one above as well as below the tracks.)

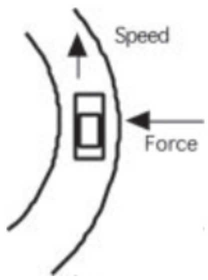
Here the Chair Force is up and the Weight is down, so these two forces subtract Toward the center of the circle is considered positive.

mg-Chair Force= mv^2/r
Chair Force=mg- mv^2/r
Force Factor=1- v^2/rg

CENTRIPETAL ACCELERATIONS

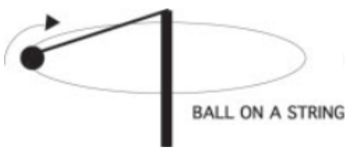
An acceleration is either a change in speed or a change in direction. An object traveling in circular motion is constantly changing direction and therefore accelerating. This kind of acceleration (circular motion) is called Centripetal Acceleration. Newton's Laws indicate that all accelerations are created by forces acting on an object. Centripetal accelerations are created by forces acting in toward the center of the circle, which are called Centripetal Forces.

The magnitude of the centripetal acceleration of an object traveling at velocity v and in a circle of radius r is given by a= v^2/r. The direction of this acceleration is in toward the center of the circle. According to Newton's Second Law, the force required to create this acceleration is given by mv^2/r and is called the Centripetal Force.

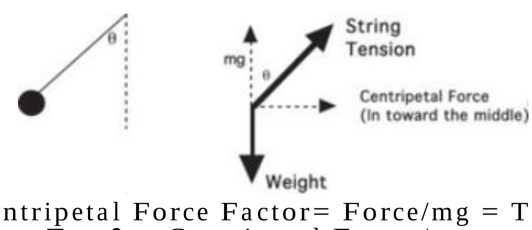


In order for a car to turn a corner to the left, there must be a force to the left. Friction between the tires and the road provides the force for the car to turn the corner. The car in turn must apply a force to the people inside to make them turn the corner.

The centripetal force factor is given by the centripetal force divided by the weight of the object. It indicates what fraction of the object's weight is required to make it go in a circle. In the case of the car, it is given by (mv^2/r)/mg = v^2/rg



In the example illustrated above, the tension in the string provides not only the force required to make the ball go in a circle but also the force to support the weight of the ball.



Centripetal Force Factor= Force/mg = Tan θ
Tan θ = Centripetal Force /mg or
Centripetal Force= mg (Tan θ)

The centripetal force factor on any object traveling in a circle is simply equal to the tangent of the angle at which the swinging object hangs. This is true whether the angle is formed by the hanging weight of a horizontal accelerometer, or the swing on Der Wirblewind. The angle of swing can be measured with a protractor and then the centripetal force factor can be computed as the tangent of this angle.

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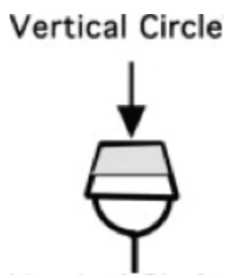
As indicated on the previous page, the centripetal force factor also can be determined if the velocity and radius of the turn are known (v^2/rg). The angle that such an object will hang as it swings around can then be determined by using the inverse tangent.



If a bucket of water is swung in a vertical circle, a centripetal force is required. When the bucket is upside down, the bucket must push the water in toward the center of the circle, or in this case downward. According to Newton's Third Law, the water then pushes up on the bucket. The water doesn't fall out if the bucket is spun fast enough.

The Loch Ness Monster has two large vertical loops. When a coaster car is upside down in the loop the track must push down on the car to keep it going in a circle. The car then pushes up on the track. The seat of the car pushes down on the passengers and they in turn push up on the seat. They think that down is up.

At the top of loops, passengers do not feel upside down, because the force of the seat is pushing them down.

The loops on the Loch Ness Monster are called Clothoid Loops. The curvature of these loops is shallow near the bottom and very tight near the top. Because the loop is so high, the coaster cars have slowed down to under half their bottom speed by the time they reach the top. The shape of the loop is critical. If the loop had the same shape at the bottom where the speed is very high as it does at the top, the passengers would experience over 10 g's at the bottom. If the curve were as shallow at the top as it is at the bottom, the passenger would really need the "safety" harness to keep you from falling out of the coaster.

At the top of the loop, the track pushes down on the coaster car, and the seat in turn pushes down on the passengers. Gravity also pulls down on the car and the passengers.

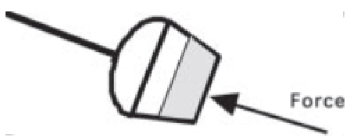
The sum of these two forces on the passengers, the seat force and gravity must equal the centripetal force.

Seat Force + mg = mv^2/r
Seat Force = mv^2/r – mg
Since the Force Factor is Seat Force divided by mg,
Force Factor = (mv^2/r – mg)/mg = v^2/rg – 1

Thus, if the first term is less than one, the coaster car would fall off the track. As the velocity increases, the force factor gets larger.

BANKING ANGLE

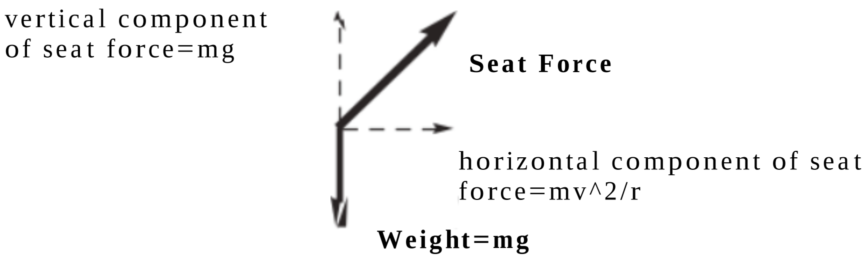
A bobsled can't turn a flat corner because there is very little friction with the ice. The turn must be banked. When a turn is banked properly, there is no sideways force required, only a force perpendicular to the track. If the bobsled pushes with a force of 3 times the weight of the riders (force factor of 3), they push back with a force factor of 3 and feel three times heavier than normal (Newton's Third Law). The angle of banking depends on the speed of the bobsled and the sharpness of the turn.



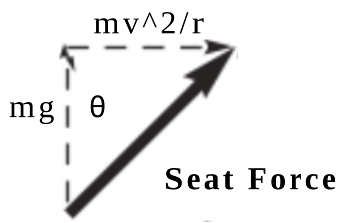
A bucket of water twirled around will naturally hang at the appropriate angle so that there is no sideways force. Therefore, the water does not spill out. The water level remains parallel to the bottom of the bucket. Hanging coasters don't have banked turns, but the coaster cars swing out as they turn the corners. The angle of swing for a hanging coaster is mathematically the same as the banking angle for a standard coaster that is turning a corner with the same speed and radius of curvature.

Because of the banked turns of a roller coaster, especially in tight turns as illustrated below, the passengers experience a force parallel to their spine, instead of "feeling" a sideways force. The riders will feel heavy, but even at high banking angles, which are as high as 70 degrees on some coasters, they will not be thrown against the side of the car.

To compute the banking angle: As a coaster rounds a corner or the swings go around in a circle, two forces act on the passengers: the seat force and their weight. The seat force has a vertical and a horizontal component. The vertical component must equal the weight of the object so that it can balance gravity. The horizontal component must be equal to the centripetal force (mv^2/r) so that it can create circular motion.



Using trigonometry, the tangent is equal to the opposite divided by the adjacent:



$\tan \theta = (mv^2/r)/ mg = v^2/rg$

To compute the force factor: By trigonometry, cos θ = mg/Seat Force or Seat Force/mg = 1/cos θ. Since Seat Force /mg = force factor,

Force Factor = 1/cos θ

The banking angle can be computed using the radius and velocity or measured with a protractor. Once the banking angle is known, the force factor can be computed.

Example: Find the banking angle and the force factor when
r = 8 m v = 14 m/s
$\theta = \text{invtan}\ (14\ m/s)^2/(8m)(9.8\ m/s^2) = 68.1$ degrees.
Force Factor = 1/cos (68.1 deg) = 2.69

(Note: The centripetal force factor (v^2/rg), which was derived in the Centripetal Acceleration section of this booklet, is the force required to make the rider go in a circle of radius r. In this example, its value of 2.5 is only slightly less than the total force factor experienced by the rider. These two values are different, because of the banking angle. The seat must supply a force to both causing the rider to go in a circle, and also to support the weight of the rider.)

The force factor could also be computed by using the force triangle above, applying the Pythagorean theorem to find the Seat Force, and then dividing by mg.

$(\text{Seat Force})^2 = (mg)^2 + (mv^2/r)^2$ thus,
Seat Force/mg = Force Factor = $\text{Sqrt}(1 + (v^2/rg)^2)$

Energy

Energy can be changed from one form to another, but it can never be lost
.
Roller coaster cars do not have a motor. 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. They have the greatest Gravitational Potential Energy when they are the 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 Gravitational Potential Energy as gravity pulls them down the hill and gain Kinetic Energy or energy of motion. The total amount of energy remains the same. As they go up the next hill, they slow down and lose Kinetic Energy while gaining Gravitational Potential Energy.

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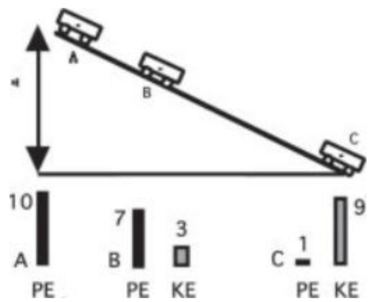
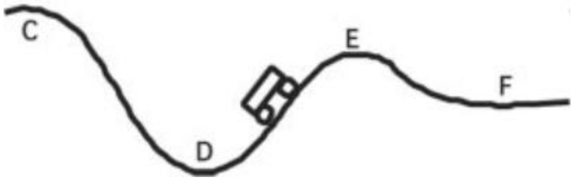


The coaster had 10 units of energy at the top of the hill and 10 units of energy at the bottom of the hill. This is called Conservation of Energy. The sum of the Potential and Kinetic Energy always adds to the same number. The less Potential Energy the coaster has the more Kinetic Energy it will have and the faster it will go.

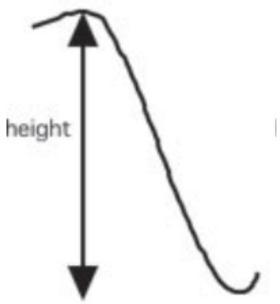


Kinetic energy (Highest to Lowest): D, F, E, C

In actual operation the coaster may lose nine units of potential energy and only gain seven units of Kinetic Energy. 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. Apollo's Chariot loses almost 60% of its initial energy due to friction before it is braked 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 though 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.

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

Examples of Energy Conservation



The height of the first hill (original gravitational potential energy) determines the maximum speed of a roller coaster ride. A steeper first hill will get you to the bottom quicker, but not change the speed at the bottom. The height of the first hill on the Loch Ness Monster is 34.8 m (114 ft). 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 26.1 m/s (59 mph).

In order to have a speed that is twice this value (52.2 m/s or 118 mph) would require a hill that is four times as high (139.2 m or 457 t). A speed of 40 m/s, which is about 30 mph faster than the original would require a hill that was 81.6 m or 268 ft. The cost of producing hills this high explains why coasters general- ly have maximum speeds of no greater than 60 to 70 mph.

If the speed at the top of the hill is small, then the speed a the bottom will be given by the square root of 2*g*h.

Listed below are other rides in the park with their hill heights, and theoretical speeds.

Apollo's Chariot	64 m	35.4 m/s
Escape from Pompeii	15.2 m	17.2 m/s

If the speed at the top of the hill is not small, or you wish to compute a more accurate speed at the bottom, use the following equation (conservation of energy) and solve for v at the bottom.

(.5 mv^2 + mgh) at top = (.5 mv^2 + mgh) at bottom

In order to compute energy losses (conversions to heat) the following equation could be used:

(Energy at top - Energy at bottom)/(Energy at top) x 100%= % of energy lost

The third hill can be higher than the second, as long as it is not higher than the first. Since kinetic and potential energy are converted to heat throughout the ride, the hills must in general be getting smaller near the end of the ride.

It takes work to change the energy of an object. When the Le Scoot log flume or Escape from Pompeii makes the big splash at the bottom of the hill, the water does work on the boat to slow it down. Since this happens when the boat is moving horizontally, there is no change in the gravitational potential energy. The work done is therefore equal to the change in kinetic energy of the boat.

Work = Force * distance= Initial Kinetic Energy - Final Kinetic Energy

OSCILLATIONS

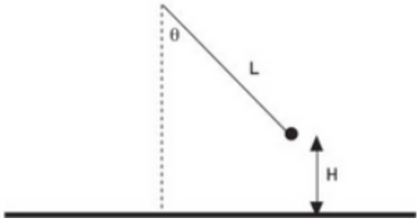
A simple pendulum oscillates about a pivot with a period described by

$$T = 2\pi\sqrt{L/g}$$

The period describes the time that it takes to go from an extreme position, back to that position again.

If a hanging object is oscillating back and forth, then at the bottom of the swing, the cord is tight, whereas it is almost slack at the top.

The kinetic energy is maximum at the bottom and the potential energy is a minimum.



To find the velocity at the bottom:

1/2 mv^2 = mgh

where H = L - L cos θ

Therefore 1/2 mv^2 = mg(L - L cos θ)

and v = sqrt (2g(L-Lcos θ))

Loch Ness Monster

Predictions:

1. coming down the first hill
2. feel pressed into your seat
3. feel heavy, but upright in car

Questions:

1a. Only the eyes gave away the fact that you were upside down. You do not leave your seat, blood does not rush to your head, and your hair does not fall "down."

1b. No, and you do not feel upside down. In fact, the riders will feel a little heavier than normal, and will feel pushed up into their seats.

1c. There were no other sensations of being upside down.

1d. Approximately 1.2. This indicates that you will feel normal, definitely not upside down.

2a. Because of the banking and the turns, there was not a sensation of being pushed to the sides.

2b. You feel pressed into your seat. Down, however, is now almost sideways.

3a. It feels like weightlessness. These hills are parabolic, hence the coaster follows its natural path in a state of free fall, or close to it.

3b. The CBL graph indicates a force factor very near zero. The duration of the "lightness" is about 3 seconds.

4. The front car is much more a visual shock than the rest of the coaster train. You feel as if you are pushed up the hills, and you feel as if you fall forward at the tops of the hills. In the rear car, you are literally whipped over the first hill. You descend the hills in a much shorter time than the first car. You experience a much wilder ride than the first car. The speed of the train is determined by the location of the center of gravity of the train, so front and rear cars have different speeds at the same point on the track. This creates a much different ride for the front and rear cars.

Der Autobahn Bumper Cars

Predictions:

1. feel pushed backward
2. pushed to the left
3. lean forward
4. both the same

Data Table:

1. When you strike a car from the rear, you feel pushed FORWARD
2. When you are struck from the rear, you feel pushed BACKWARD
3. When you are struck on the left side, you feel pushed LEFT
4. When you strike a car on its side, you feel pushed FORWARD

LEVEL 1 ANSWERS

Questions:

1. Striking a stationary car or hitting the side wall. This produces the greatest acceleration or change in speed.
2. The forces are similar to Escape from Pompeii and a little larger than the Le Scoot log flume.
3. Direction of Forces: A: to the left B: to the right C: to the left D: to the right
4. The forces are both the same, according to Newton's Third Law. Le Scoot log flume

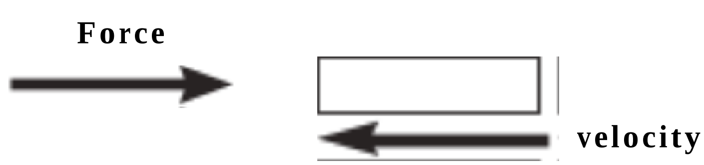
Le Scoot Log Flume

Predictions:

1. slide forward
2. a log with two in the front

Questions:

1. The Loch Ness Monster is steeper (55 degrees versus 40 degrees for the log flume) and higher and faster, but the log flume, with its absence of a lap bar, still feels scary and very weightless. Opinions will vary as far as which is scarier.
2. At the bottom of the hill, the water slows down the log, but the inertia of your body makes it continue forward, so you slide forward.
3. If the boat has big people in the front, it will tend to "plow into" the water, make a bigger splash and stop more quickly. An empty log tends to glide further.
4. The direction of the force is opposite to the direction of motion.



5a. The actual force factor, which is close to .7 would be a stopping distance of about 16.5 m. Anything much larger than this would cause you to slide forward too much. Escape from Pompeii that has a larger force factor of 1, also has a lap bar.

5b. If the stopping distance is doubled, then the force factor is cut in half. 11 m corresponds to a force factor of 1, and 22 meters is a force factor of 0.5.

5c. A 60-meter stopping distance would correspond to a force factor of a little under 0.2, which is half of the force factor of 30 meters.

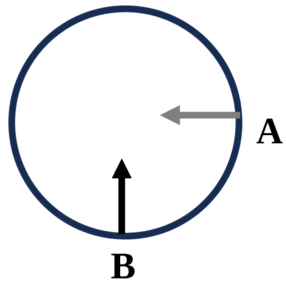
The Trade Wind

Predictions:

1. pushes you in toward the center 2. inside

Questions

1. Direction of Force



2. Even though there appears to be a force pulling you outward, there is actually a force pushing you in toward the center. This is the centripetal force. The cart pushes you inward, and you in turn push outward on the cart. Actually your inertia is trying to get you to go in a straight line and the car pushes you in a circle.
3a. The side of the car pushes on you.
3b. The person on the outside exerts a push on you, and you in turn appear to "crush" them.
3c. The outside person feels like they are being sandwiched between the inner person and the cart. The outside person will feel a greater force pushing them in a circle, but the difference is not too great.
3d. On the inside.

Alpengeist (Vertical Acceleration)

Predictions:

1. Vertical Loop (5)
2. Answers will vary

Questions:

1. The Loch Ness Monster (60 mph) has a smaller first hill. Loch Ness = 34.8 m and compared to Alpengeist, which has a first hill that is 56.4 m above the lowest point of the coaster, and 49.4 m above the bottom of the first hill.

2a. 67 mph = 29.9 m/s. The chart indicates a force factor of 3.1.

2b. The Force factor should not exceed 4, so the maximum speed should be 36 m/s (81 mph).

2c. 15 m/s will produce a force factor of 1.5. You could also increase the radius of curvature.

3. In order to increase the speed at the bottom, you must increase the height of the first hill.

4a. The greatest force factor is about 4, measured at the bottom of the second hill, just before the vertical loop.

4b. The CBL measurement just before the vertical loop is the greatest force factor. It is very close to 4.

4c. The CBL graph indicates that the force factor at the bottom of the first hill is 3.0. The Chart indicates about 3.1.

5a. Answers here will vary, but the Cobra Roll and the Vertical Loop will probably be favorites.

5b. The Cobra Roll has two inversions close together with three events with a force factor of 3.0 or higher. This is probably the most intense experience.

Apollo's Chariot

Predictions:
1. Approaching, Coming Down, At the Hilltop
2. Both
3. 25 seconds

Data:
"Air time" = 25-28 seconds

Questions:

1a. Parabola

1b. Both

1c. Answers will vary, but most will probably go with the first drop or first camelback.

1d. 4.5 seconds. It occurs on the first camelback hill.

1e. Hilltops and first drop.

2a. 26 seconds.

2b. The flight path is remarkably close to the camelback hills of Apollo's Chariot.

3a. The track is essentially parabolic for about 35 meters, and then is approximately close for an additional 5 meters.

3b. Passengers experience a force factor (g's) between 3 and 4.

3c. Passengers experience a force factor of less than 1 for about 3.5 seconds.

3d. A fall of 60 meters would correspond to 3.5 seconds.

3e. A 40-meter drop would correspond to 2.9 seconds. This is within a 1/2 second of the expected "air time." The time in 3c. is for a force factor of less than 1, and not for "weightless." It makes since that this time would be a little longer than true free fall.

4a. 4.2 seconds (Based upon 2.1 seconds up and 2.1 seconds down)

4b. The CBL graph shows approximately 4.5 seconds.

4c. Free Fall (near weightlessness) occurs both going up and coming down.

5a. The recorded air time should probably fall between 25 and 30 seconds. This is a bit subjective, and also dependent upon the ability to count "seconds."

5b. An air time of 26 seconds, would correspond to 40% "airtime."

5c. According to the CBL graph the coaster was below a force factor of 1 for 29 seconds.

5d. Being less than a force factor of 1, is only an approximation for the weightless feeling.

6. Averages of accelerometer readings should be fairly close (+/- 0.5) to the CBL graph readings. The bottom of the first hill is close to 3.5. The others are approximately 3.0.

Griffon

Predictions:
1. 2.5 seconds
2. Yes. Both Immelmans
3. More than four (probably 7 times)

What to do and notice on the ride:
1. First Drop: 2.5 sec
2. Weightless approximately 7 times
3. Second Drop: 2 sec

What to do and notice off the ride:
1. 2.5 seconds

Questions:
1. Similar

2a. 31 meters

2b. 3.6 seconds

2c. 2.6 seconds

3a. 1st drop, top of Immelman #1, going into brake block, 2nd drop, top of Immelman #2, Camel back hump, little Camel back hump.

3b. Longest weightless period is the 1st drop. Top of First Immelman is similar to first drop. Next longest weightless period is the 2nd drop.

4a. Same as 3a.

4b. Using the chart, the weightless periods for 1st and 2nd drop are 2.3 sec and 1.7 sec. Times should be close to within a half second of the estimations.

4c. 1st drop is almost the same weightless time as the 1st Immelman.

4d. Both are out of your seat "weightless", but the the 1st drop probably seems more intense.

5a. Dropping straight down, upside down on the Immelman, camel-back hump.

5b. Various answers.

6. Using the same criteria (Force factor , 0.5), Apollo's Chariott has two camelback humps that are about 4 seconds each, which is much longer than any weightless period on Griffon. The total time with a Force Factor of less than 0.5 is about 20 seconds. There are 10 instances of Apollo's Chariott when the Force Factor is less than 0.5, compared to 7 on Griffon. The total time on Griffon at less than 0.5 is about 9 seconds.

Estimation Questions:
1. 10 months
2. 92 sections
3. 111,800 lbs
4. 3108 ft
5. 12 hours

Invadr

Predictions:

1. b
2. a
3. d

Questions:

1. The first drop 1.7 seconds

2. a=l.0 sec C=l.1 sec E=l.2 sec

3. about 1.5 g's or more=12 times Over 2 g's=? times Loch Ness=3.4 Alpengeist=3.0

4. a. It is going form hill to valley to hill to valley to big turns so quickly, it is non-stop excitement.
   b. the next lowest coaster if Verbolton (53 MPH)
   c. The coaster is built on a hillside and the low point on the Helix is at the lowest point of the coaster.

5. Banked turns.

6. Always banked. The banking angle increases with a higher speed or a smaller radius of turn (sharper turn) If it weren't banked you would feel a substantial lateral force. Yes you do feel heavy in the turns. The first banked turn, for example was a pretty steady 1.4 g's.

7. There are about 13 different elements in 36 seconds, so it averages just less than 3 seconds between events.

8. The Steel coasters are taller, many of them go upside down, some of them have higher Force Factors and they all have a higher maximum speeds. They both have air time hills, high Force Factors at the bottom of the hills, and banked turns

Finnegan's Flyer

Predictions:

1. c
2. b
3. d
4. c

What to do and notice off the Ride: Time for two oscillations=19.4 sec. Period=9.7 sec.

Questions:

1.Period from the graph=9.7 seconds

2. a. You feel heavy at the bottom of the swing. Yes, it is the bottom of the hills on roller coasters. It is essentially the same force going forward and backward, as long as the angle remains the same.
   b. Force Factor=3.3 This is similar to the 3.5 that many coasters have on their first hill bottom (i.e. Lock Ness, Apollo's Chariot)
   c. 8 times above a force factor of 2.

3. a. You have a weightless feel at the top of the swing, especially at the higher angles. Weightless feeling: floating, hair flying, out of your seat.
   b. "Weightless" = 8 times
   c. Weightless on Tempesto 8 times, Battering Ram 8 times, Apollo's chariot 10 times
   d. Time at less than a Force Factor of 0.5 = 1.8 seconds

4.The computed speed for Finnegan's Flyer is 21 m/s (47 mph).

5. a. On the Battering ram you are closer to vertical going one way rather than the other, because you are sitting in the extreme seat.
   b. The velocity is much smaller, 25 mph compared to 45 on Finnegan's Flyer.

Pantheon

Predictions:

1. e
2. d
3. b

Questions:

1. Row 1 and Row 10 both have about 16 airtime hills. This is not a hard and fast number, because some of the airtime hills are short and just below 1, Hill B2 stays below one, so I just called that 1airtime hill land not 2, etc.

2a. Negative g's at the hilltops, either approaching or leaving the top or both

2b. Hill Chas a very constant zero g reading, because it is totally vertical. The other hilltops are parabolas.

2c. The high force factors (g force) are found at the base of the hills.

3a. Longest airtime (leas than 0.5 g's) is Hill B2. It's about 5.5 seconds below 0.5 g.

3b. Griffon is about 2.5 seconds. Apollo's Chariot has an airtime hill, its first full parabola, of a 4.2 seconds.

3c. Generally, except for Hill C, the airtime hills are parabolas.

4a. The Force factor on Hill Bottom 8 has a maximum of 3.7 and it is above 3.5 for about 2 seconds.

4b. Here are a couple of other Hill Bottoms of high g's

Hill Bottom 11	FF=3.4	It is above 3 g's for 1.4 seconds
Hill Bottom 10	FF=3.4	It is above 3 g's for 1.2 seconds
Hill Bottom 7	FF=36	It is above 3 g's for 1.0 seconds

4c. These are indeed some of the most intense places on the ride, along with the launches.

5a. The launches feel pretty much the same both forwards and backwards. The difference is when you, are accelerating forward, you feel pressed back into y our seat, but when you are speeding up, backwards, you feel like you are being pushed out of the seat.

5b. The first launch appears to be the most intense, with the greatest change in velocity.

6. Row 1- of the coaster is going the fastest at the top of the hill. Row 1 eases over the top of the hill, but Row 10 is thrust over the top. The coaster is still slowing down when Row 1 crests the hill, but the coaster starts to speed up once the middle of the coaster (its center of mass) moves over the top. Row 10 is a better ride at the top of the hills.

7. Hill tops D and E feel about the same, seven though one is upside down. They both go to about -0.5 g's, but D has a low Force Factor for about 4.5 seconds, whereas its only for about 3 seconds on E.

Loch Ness Monster (Vertical Acceleration)

Predictions:

1. 3.5 g
2. No
3. Going down the hills

Data:

Front to Back Time at B = 0.70 sec
Front to Back Time at D = 1.00 sec
Front to Back Time at E = 1.50 sec

Questions:

1. You feel the heaviest at the bottoms of the hills (B and D), and in the banked turns in the Dragon's Lair. You are heavy because of a large acceleration (change in direction).
2. You feel the lightest coming down those parabolic shaped hills (A and C). Here you are in a state of free fall, or very close to it and therefore will feel very close to weightless.
3. You never actually lose contact with you seat. In fact you will feel heavy when upside down.
4. Velocity at bottom of Hill (B) = 26.0 m/s = 58 mph Velocity at bottom of Hill (D) = 18.2 m/s = 41 mph Velocity at top of loop (E) = 12.1 m/s = 27 mph
5. Force factor at B = 1+ (26.0^2/(9.8*30)) = 3.3
Force factor at D = 1+ (18.2^2/(9.8*16)) = 3.1
Force factor at E = (12.1^2/9.8*4.6)-1 = 2.2
6. Locations B and D are two places where you feel heavy. You also feel heavy approaching the second loop.
7a. The minimum speed to get through is that which produces 0 g's. That speed is about 6.5 m/s. Between 6.5 and 9.6 m/s would produce a force factor between 0 and 1. The force factor should not exceed 4.0, so the maximum speed at the top should be 15 m/s.
7b. Answers will vary, but should be close to the actual value, which is close to 2.
8. FF=v^2/rg + 1 = (18.2^2 (4.6*9.8)) + 1 = 8.3. This is obviously way too large and would be dangerous. If the radius at the top were the same as the bottom, then the coaster would fall off the track. FF = (12.1^2/(16*9.8) - 1 = -.07
9. The force factors are 3.4 for B, 2.8 for D, and 1.2 for E. These are close for B and D, but off by 1 for the reading at E.
10a. The light times are coming down the hills. The maximum time is about 3 seconds.
10b. You might lose contact with your seat, if the force factor becomes less than 1. This occurs coming down the first hill, and going up and down the second hill. It doesn't happen anywhere on the loop.
11. The heavy feeling lasts about 2 seconds.

Der Wirblewind Swings (Banking Angle)

Predictions:

1. same angle
2. naturally aligns with chains
3. heavier

Data:

Angle of Swing = 45 degrees
Time for Three Revolutions = 16.5 sec Revolutionary Period = 5.5 seconds

Questions:

1. Velocity = Circumference/period = 2 (3.14) (9.0 m)/ 5.5 seconds = 10.3 m/s
2. Angle of swing = invtan (v^2/rg) = invtan (10.3 m/s^2/(9.0 m*9.8 m/s^2))= 50 deg
Measured angle of swing will be about 45 degrees. Percent Error will vary.
3. Force factor = 1/cos (θ) = 1/cos (50) = 1.6 This compares to a feeling of being slightly heavy.
4. Banking angle = invtan (v^2/rg) = invtan (12.3 m/s^2/(8 m * 9.8 m/s^2) = 63 degrees
Force factor = 1/cos (θ) = 2.2
5. Empty swings hang at the same angle as those with people in them. The mass does not enter into the calculations, since the mass in the centripetal force relationship and the mass in the weight relationship cancel out. The inner swings will, however, hang at a slightly smaller angle than the outer swings.
6. The body naturally hangs at the same angle as the swings. You should not feel any forces to the left or to the right on the swings, but will feel heavier.
7. The tilt of the top will cause the force factor to vary as you go uphill and downhill. The angle of swing will also vary because of this tilt.

Escape from Pompeii (Energy)

Predictions:
1. 30 mph
2. About the same
3. Fully Loaded Boat
4. A Water Ride like Pompeii
5. 1/3

Data:
Time from P to S = 0.95 seconds
Distance of Deceleration = about 10 meters
Front to Back Time after the Splash = approximately 3 seconds

Questions:

1. Speed = 12.5 m/ (0.95 seconds) = 13.2 m/s (30 mph)

2. Predicted speed = Square root of (2*9.8 m/s^2 * 15.0 m) = 17.1 m

3. mgh - .5mv^2/mgh x 100% = 40 % of initial energy is not converted to kinetic energy

4. It was transformed to heat energy. The water, boat and slide become a little warmer.

5. The Alpengeist loses 7% of its energy coming down the first hill.

6. A fully loaded boat seems to make a bigger splash than an empty boat. If the boat is loaded heavily in the front, it will make an especially large splash and slow down more quickly.

7a. vafter = 5.4 m/ 3.0 s = 1.8 m/s.

Force factor=F/mg = ((13.2 m/s)^2-(1.8 m/s)^2)/(2*10 m*9.8 m/s^2) = .9

The actual force factor will probably be different, because we assumed that the splash produced the same force for the whole distance.

7b. This force is much less than that of the roller coasters, but this is a horizontal force as opposed to a vertical force. Being pressed into your seat is much different than being stopped by the lap bar. The force is a bit more than on the Le Scoot log flume.

8. All of the boats have approximately the same speed at the bottom. In theory they should be exactly the same, just like in Galileo's experiment with the balls dropped from the Leaning Tower of Pisa. In reality, the heavier boat may have a larger speed at the bottom, because friction will affect the lighter boat more.

9. You slide forward in your seat, because your inertia carries you forward while the water stops the boat.

10. The energy is transferred by radiation. The fires are above or to the sides of the riders, thus convection could not be an effective agent. Air is a poor conductor, so there is not nearly enough time for heat to be conducted to the riders from the flames.

Loch Ness Monster (Power, Energy and Acceleration)

Predictions:

1. 125 horsepower (93 kw)
2. 5%
3. Last car

Data

Front to Back time at the Bottom of the Hill = 0.70 seconds
Angle of descent = 55 degrees
Top to Bottom of hill: First Car = 4.3 seconds Top to Bottom of Hill: Last Car = 2.6 seconds
Time of Ascent = approximately 30 seconds

Questions:

1a. Using the chart, the velocity at the bottom should be 26.1 m/s.

1b. Velocity at bottom of hill = 18.2 m/ 0.70 sec = 26.0 m/s (58 mph)

1c. Percent error will vary. (Computed-Graph)/(Graph) *100%

1d. If the timing of the coaster train is correct, these two should be very close. The chart value does not take into account the speed of the coaster at the top or the frictional losses coming down. These two factors basically cancel each other out.

2. 40 miles/hr = 16 m 60 miles/hr = 36 m 80 miles/hr = 64 m

3. 144 m. This is more than twice as high as Apollo's Chariot.

4. Estimated mass of people = 2100 kg (potential + kinetic)top - (potential + kinetic)bottom = energy lost to heat Energy at top = (8500 kg)(9.8 m/s^2)(34.8m) + .5(8500 kg)(5.7 m/s^2)^2 =3.04 x 106 J Energy at bottom = .5 (8500 kg) (26.0 m/s)^2 =2.87 x 106 J Energy loss = .17 x 108 J % energy loss = .17 x 106 J /3.04 x 106 J x 100% = 6%

5. Average acceleration = (v-v0)/t = (26.0 m/s - 5.7 m/s)/ 4.3 seconds= 4.7 m/s^2
The theoretical acceleration should be g sin(θ). With θ = 55 degrees, then a= 8.0 m/s. The angle of the hill is not 55 degrees for the whole way. If the time of the last car is taken then the average acceleration would come to 7.8 m/s^2. This value is not correct, however, because by the time the last car gets to the descent point its speed is well above the 5.7 m/s that was the velocity of the first car at the top.

6. Work = ΔPE/time = (8500 kg)(9.8 m/s^2)(75 m*sin(25))=2.64 x 106 J
Power= Work/time = 2.64 x 106 J / 30 seconds = 88.0 kw = 118 horsepower.
This is the power required for a fully loaded train. The motor is rated at 125 horsepower and runs on 480 V.

7. The top to bottom time for the first car was approximately 1.7 seconds longer than for the last car. This is because the first car begins its descent before the center of mass of the train has arrived at the descent point. The train does not really begin to accelerate appreciably until the center car passes over the drop point. The last car has significantly higher velocity by the time it arrives at the drop point.

Battering Ram (Oscillations)

Predictions:
1. On the extreme edges
2. Center of the ship is at the lowest point

Data:
Period of Oscillation = 7.3 seconds Maximum Angle with Vertical = 60 degrees

Questions:

1. v= square root of (2*g* h) where h = L- L cos q = 12.8 m - 12.8 cos (60) = 6.4 m v= 11.2 m/s
2a. Force factor = v^2/rg +1 = (11.2 m/s)^2/ (12.8 m * 9.8 m/s^2)+1 = 2.0
These values should be close, as long as the angle measurement is correct.
2b. Force factor from the CBL graph is about 1.8 at maximum.
2c. Both force factors should be close to 2.0
2d. The force factors on the CBL graphs are both close to 1.8, which is similar to the 2.0 measurements.
2e. There is not much difference in the maximum readings for the two seat positions. Theory indicates that the middle position should have a slightly larger maximum force since the middle seat is going faster at the bottom.

2f. Da Vinci's Cradle also had its maximum force factor at the bottom, but the force factor is much greater than on the Battering Ram.
3a. Period of Oscillation = 7.2 seconds
3b. This comes extremely close considering the angle is well beyond the small angle approximation and the fact that this is a physical pendulum and not just a simply ball on a string.
3c. The CBL graph gives a period of approximately 7.6 seconds.
4. The maximum speed of the boat occurs as the middle of the boat passes through the lowest point of the swing. This is the point of minimum potential energy. Maximum force is also experienced at this point.
5a. Weightlessness is experienced at the extreme of the oscillation, when you are facing backward. At this point the back of the seat is horizontal and the seat itself is vertical. You have no support force at all, and are momentarily in a state of free fall.
5b. Extreme weightlessness occurs in the extreme edge seating at this point. In the middle seating position, the body is never close to being horizontal.
5c. The minimum force factor in the middle seat is 0.5, but it is 0.1 in the extreme seats.
5d. The middle seat experiences essentially the same thing going forward and backward, but for the extreme seats, going backward at the top is 0.1 and going forward at the top is 0.8.
6. Opinion may vary on this point, but the eyes do certainly affect how we experience things.
7. People scream or yell when they are weightless. This is a very unusual feeling.

Alpengeist (Miscellaneous)

Predictions:
1. Neither
2. Camelback Hump (7)
3. High Speed Spiral (9)

Data:
Time between Posts A and C = 0.80 sec
Front to Back Time at Top of the Loop = approximately 0.94 sec

Questions:
1. Speed = 24 m/ 0.8 sec = 30 m/s = 67 mph

2. Speed=11.6 m/ 0.94 sec = 12.4 m/s = 28 mph

3a. Force factor at the bottom = (30 m/s) ^2/(9.8 m/s^2*44 m) + 1 = 3.1

Force factor at top of the loop = (12.4 m/s) ^2/ (9.8 m/s^2 * 7 m) - 1= 1.2

3b. Force factors from CBL graph: Bottom of Hill = 3.0. Top of loop = 1.6

3c. All of the values should be close to 3.0 for the bottom of the first hill and 1.5 for the top of the first loop.

3d. The values for the bottom of the second hill should be close to 4.0.

4a. A vertical force meter reading of 3.1 will correspond to a radius of 44 m.

4b. No it doesn't double. (Example: 20 m= 5.6 and 40 m = 3.3) It is because you add 1 to the ratio.

4c. The force factor approaches 1. However, even when r = 1000 m, the force factor is still 1.09. In order to be
equal to 1, the radius would need to be infinite.

4d. To avoid force factors of greater than 4, the minimum radius should be about 31 m.

5. The banking angle in the high-speed spiral is the largest on the ride, because it has a radius of only about 8.0 m. All of the turns are banked. There is also a sweeping turn just after the high-speed spiral.

6a. The students should never leave their seats or feel upside down except for perhaps the zero-g roll. Here they will experience close to weightlessness. According to theory, the Immelman has a force factor of about .5, so they will feel light. The vertical loop and both inversions on the Cobra Roll are between 1 and 2. The Flat spin is close to 1.0.

6b. The CBL graph gives the following values for the inversions: Immelman 0.6, Top of Vertical Loop 1.6, Cobra Roll Inversion 2.6 and 1.9, Flat Spin 1.3. Zero-g roll 0.5 Answers will vary in the comparisons.

7a. The speed at the bottom of the Loch Ness Monster second hill is less than that of Alpengeist. (41 mph versus 67 mph.)

7b. The radius of curvature is greater for Alpengeist (44 m compared to 30 m).

7c. If the Loch Ness Loop was on Alpengeist, it would be a rough ride. The velocity at the bottom of Alpengeist is 28 m/s. So instead of a force factor of 3.6 that results from Alpengeist's 30.5 m radius at the bottom, the 16 m radius would produce a force factor of about 6. At the top of the 17.4 m loop, the velocity would be approximately 20 m/s providing a force factor of 8. In reverse, the Loch Ness only has a speed of 18 m/s at the bottom of its loop, so it would never make it to the top of Alpengeist's loop. (Minimum speed required to get to the top is 25 m/s.)

Apollo's Chariot

Predictions:

1. 40 mph
2. 60%
3. Last Row

1a. Since the track is flat at the bottom, the force factor will be 1. A flat straight track indicates no acceleration (change in speed or direction), and hence a force factor of 1.

1b. The track is flat for about 8 meters, but when you are traveling at about 32 m/s, this last only about 1/4 second.

1c. Passengers experience "normal" weight at this point. They feel neither heavy nor light. (The wind is blowing in their faces at over 70 mph, but there is not apparent weight difference). The other places on the ride are the Brake Block, the top of the first hill, and the end of the ride.

2. 2nd Row CBL Graph: Less than 1=30 seconds Greater than 2= 17 seconds 8th Row CBL Graph: Less than 1=30 seconds Greater than 2= 15 seconds

3a. The graphs with squares are designed for a largest velocity at the top.

3b. Less than

3c. Greater Than

3d. As the energy is lost to friction, the height of the hills must decrease.

4a. As Row 2 of the coaster approaches the top of the hill, its speed is greater than the speed of the middle car. Coming down from the top, its speed will be a bit less than the middle cars speed at that point. Because the hill is designed for the speed of the middle cars, the force factor going up will be less than that of the middle car, and coming down it will be greater than the force factor of the middle car. Row 8 is just the opposite, because its speed going up is less than normal and its speed coming down is greater than normal.

4b. The middle car has the same speed approaching the top and receding from the top. 5a. The force factor and banking angle appeared to stay the same.

5b. The curve decreases to maintain a fairly constant force as the speed decreases.

5c. The banking angle is tan-1 (v2/rg) and the force factor is 1/ cosine. Banking angle is therefore 63.4 degrees, and the force factor is 2.2.

5d. At the top of the spiral, the speed decreases according to the conservation of energy PE+KE=PE+KE. 1/2mv2 + mgh = 1/2mv2 + mgh. The "m" cancels. Solving for the final velocity yields 16 m/s. The banking angle at the top will therefore be 58.5 degrees and the force factor 1.9.

6a. As the radius becomes very large, the force factor approaches 1, regardless of the velocity. 6b. A maximum force factor of 3, would correspond to a radius of about 28 m.

6c. R(28m/s)= 41 m R(25)= 33 m R(22) = 25 m R(19)= 19 m R(16)= 13 m

6d. FF(28m/s)=3.4 FF(25)=2.8 FF(22)=2.2 FF(19)=1.8 FF(16)=1.4

7. The last car is more intense. Last car has more negative force factors. The first drop has a lower force factor for a longer time in the last car. The first car has much more wind. The first car creeps over the hilltops, while the last car seems to be pulled over.
8. The average speed of the ride is 1220 m/ 66 seconds= 18.5 m/s or 41 mph.
9a. Calculations: First Hill Bottom 3.4 Second Hill bottom 3.2 Last Dip 3.3 9b. CBL Data: First Hill bottom 3.6 Second Hill bottom 3.5 Last Dip 3.4
9c. Reading will depend upon which car the student was in, problems with reading accelerometer, approximate nature of the force factor graph, etc.
10a. Speed should be 35.5 m/s or 79 mph. The actual speed is slower because of friction. The amount of energy lost to friction is about 15%.
10b. Assuming m=1. 1/2*2^2 +9.8*64=629 J=initial energy
1/2*19.6^2+9.8*6.9 = 260 J=final energy Energy Loss = Initial-final/Initial *100%= 59%

Griffon

Predictions:
1. 4
2. Bottom of the second vertical drop
3. 73 mph

What to measure and notice on the ride:
1. Force Factor 1st drop bottom: 3.7 Force Factor 2nd drop bottom: 4.0
2. Force Factor while falling: close to 0
3. It doesn't seem to be accelerating.

What to do off the ride:
1. Time between A and B: 0.83 seconds

Questions:
1. Approximately 1.5 seconds
2. The graph indicates that both Hill bottoms 1 and 3 (following the big drops) have a force factor of about 4, whereas Hill bottoms 2 and 4 (following the Immelmans are about 3.8). Hill bottom 3 actually has the greatest force factor on the ride.
3. Hill bottom #1 has a force factor of greater than 2 for about 25% longer than the next longest time.
4. The accelerometer readings should be about the same, within plus or minus 0.5.
5. It pauses to heighten the anticipation of the drop. 6a. You feel heavy for about 3.5 seconds.
6b. On the space shuttle, you experience a Force Factor of over 2 for approximately 2 ½ minutes just before obtaining obit, with about half of that time at close to 3. The Shuttle also goes through periods of close to normal (1g) in between heavy periods. The Shuttle takes longer to increase the force factor than does the Griffon, taking 5 minutes to go from a FF of 1 to that of 3, whereas the Griffon goes from 0 to 4 in only a couple of seconds. The Griffon also has a greater FF than does the shuttle (4 as compared to 3), but the length of time with a large FF is much greater with the Shuttle.
7. The speed at the bottom of the second drop is only about 60 mph, compared to 73 mph at the bottom of the first drop, but the radius of curvature of the track at the bottom of the second drop is less. It's a sharper turn.

Problems:

1. v=d/t v=26.8 m/ 0.83 sec = 32.3 m/s = 72 mph
2. FF = v2/rg + 1 = (32.3 m/s)2/(40.0 m*9.8 m/s2) +1= 3.7. The graph shows a FF of just under 4.
3. FF= v2/rg + 1 = (26.9 m/s)2/(25.0 m *9.8 m/s2) +1= 4.0. The graph shows a FF of just under 4.
4. % Energy lost = (KEi-KEf)/ KEi * 100%, where KE= ½ mv2. Every term has a ½ and an m, so they cancel. Energy lost= (22.42-20.52)/22.42 *100= 16%

a=(vf2-vi2)/2d= ((22.4m/s)2-(20.5m/s)2)/(2*30m)=1.4 m/s2. FF=a/g= 0.14
This will probably not be very noticeable on the ride, but it looks spectacular off the ride (Rooster plume of water).

Estimations:

1. 3800 cubic yards
2. 380 dump trucks
3. 97,000 gallons
4. 2000 bathtubs
5. 8 feet

Verbolten

Predictions:

1. Maximum Force Factor in magnetic launches: 0.9
2. Big round House turn at bottom of big hill: Force Factor about 3.8
3. Speed of Verbolten at bottom of the big hill: 22 m/s (about 50 miles/hour)

Data:

The time for the coaster to go between the four supports should be close to 0.76 seconds.

Questions;

1. You feel lightest on the ride as you are coming down the big hill, and also as you arrive at the tops of hills. At the end of your inside experience, you drop straight down. In each case you are close to free fall, which occurs when gravity is the only force acting. Probably at least 6 near weightless experiences.

2. a) The greatest force factor is in on the second turn. It is about 3.8.

b) The first turn, which is right at the bottom of the hill, has a maximum force factor of 3.3, but you are over 1.5 g's for about 2.2 seconds. The second turn, which has a higher maximum, only has a heavy time of about 1.6 seconds.

c)The greatest weightless feeling is coming down the big hill. You are less than 0.5 g's for about 1.4 seconds.

3a) At "C" the coaster train is rolling to a stop along a level track. The passengers experience a Force factor of 1 and are not pressed into their seats. At "D" the coaster suddenly drops. The dip shows the drop and the spike is when the coaster stops.

b) "A' was a single turn, whereas "B" was a double loop.

c) The double loop inside the building is above a force factor of 1.5 for almost 6 seconds, which is longest heavy feeling on the ride. Its maximum value is about 3.6. The first turn, "A" has a higher force factor (about 3.8), but the time is much shorter. At the end of the ride, there is also a turn that has a force factor of 3.8. It's about the same force factor and about the same duration as curve "A".

LEVEL 2 ANSWERS

Problems:

1. An average time of 0.76 seconds, produces a velocity of 16.8 m /0.76 sec=22.1 m/s. This is about 50 miles/hour.

This is much slower than most of the other coasters which range from 60 to about 73 mph. It seems faster than 50 miles/hour because of the action at the bottom of the hill with the three big turns.

2.a) Launch 1 has approximately 240 boxes for a velocity change of 12.0 m/s. (27 mph)
Launch 2 has approximately 250 boxes for a velocity change of about 12.5 m/s (28 mph)

Our Logger Pro program, allowed us to find the integral of these two graphs. The integral is the area under the curve. It should be similar to the area you computed by counting boxes. The integral for Lunch 1 was 12.07 and the integral for launch was 12.44.

b)Launch 1 has a total time of about 2.6 seconds. Launch 2 is also about 2.6 seconds.

c)Maximum force factor for Launch 1 was 0.8 and for Launch 2 it was 0.9.

d)The Ferrari Enzo: a=26.8 m/s /3.1 sec = 8.6 m/s2. Force Factor=0.9. Very similar to the second launch.

e)Estimates will vary.

f)The two launches are very similar. The second launch has a slightly higher maximum. The second launch takes less time to reach its maximum, but then the acceleration dies down quickly, before reaching a plateau.

It turns out that both launches have very similar average accelerations L1=4.72 m/s2 and L2=4.68 m/s2, but because the second launch is about 0.12 seconds longer, the change of velocity with the second launch is about 0.5 m/s more than launch 1.

Level 2 Answers

Pantheon

Predictions:

1. a
2. b

Questions:

1. It was produced at Hill C, the vertical spike. The hump on the left is beginning the ascent, the hump on the right is leaving the spike. The flat place is the middle is going straight up and coming straight down. This is free fall, with only gravity acting and a force factor of 0. The other air time hills are parabolas, and because the coaster is not a point object, it can't be designed so that each car on the train has a perfect O g's.
2. The graph come down to 1 in the middle, because there is a flat place on the track. When a coaster is traveling along the flat ground, no matter how fast it is going, the vertical force factor is always 1. The flat part of the curve is not very long, but it is noticeable on the graph. If between two hill bottoms you have another hill, as with the lnvadr example, then you have an air time hill, as opposed to a flat region.
3. Hill Bottom 5 (going up) Row 1 3.5 g Row 10 4 g Hill bottom 7 (going down) Row 1 3.6 g Row 10 3.2 g
a. The coaster is going backward, so Row 10 arrives at the bottom of the spike first and begins to go uphill. By the time Row 1 arrives at the bottom of the hill, the center of mass of the coaster is already about 6 meters up the hill, and the coaster is considerably slower. The radius of the turn is the same for both, so a slower speeds makes for a smaller Force Factor FF=v'/rg +1.
b. When the coaster arrives at Hill bottom 7, the coaster is once again going forward, so Car 1 arrives with a higher speed and then the coaster train goes uphill, making car 10 slower at the bottom.
c. Hill Bottom 6 Car 10 (3.7)will have a higher force factor than car 1(3.3). 1 got to the bottom while the train was still speeding up. Hill Bottom 4 Car 1 (2.7) will have a higher force factor than Car 10 (2.3). The coaster is going backwards, because car 10 reaches the bottom while the train is still speeding up.
4. It is approximately 85%, but the estimates will probably vary a lot, showing that making an accurate measurement is not easy.
5. Liv=at I counted 367 boxes, so Liv= at= 367 boxes *0.0245 m/s= 9.0 m/s where each box is 05*.05s*9.8 m/s'=0.0245 m/s (They axis was the force factor with no units) The Integral (area under the curve) which Liv is found by analyzing the graph on the computer was 9.1 m/s. The change of 9.0 m/s corresponds to change of 20 mph
6. a. Speed of the Coaster at the top of Hill B: Length of coaster is 13.1 m Time=2.34 sec v=d/t =5.6 m/s or 13 mph.

b. Speed of the Coaster at the top of Hill D: Time =1.14 sec v=d/t=ll.5 m/s or 26 mph where m/s *2.24 = mph
c. h=54.9 m. vo=S.6 m/s Solve v'-vo'= 2gh for v v=Square Root (2gh + vo')

v= Square Root (2 * 9.8 m/s2*54.9 m+ (5.6 m/s)') =33.3 m/s = 75 mph. This is very close to the published value of 73 mph. You also expect the theory to be a little bit high, because we have not taken friction into account.

d. Solve v'-vo'= 2gh for h Vo=33.3 m/s (from part C) v= 11.5 m/s (from Part B)
h=(v'-vo')/2g= ((11.5 m/s)2-(33.3 m/s)2) /(2* (-9.8 m/s2))=49.8 m (once again, assuming no friction losses)

7. Row 1 8 to D 3.7 to -0.6 Difference of 4.3
Row 10 82 to 8 -1.0 to 3.8 Difference of 4.8
8. a. How many time greater than or equal to 3.5 Row 1---3 Row 10---4
b. Row 1 has a higher Force Factor on Hill Bottoms 1,2,4,7,10,11,12 (Row 10 is higher on 5,6,8,9)
Only Hill bottoms 4,5,6, and 7 have significant differences (0.4 or higher). 3 and 13 are almost the same as each other, and the others (1,2,8,9,10,11,and 12) are only difference by 0.2 at the most.
c. Hill Bottoms 5,6 are at the Spike, where Row 10 was going faster at the bottom than Row 1, both going up and going down.
Here it is obvious, with the difference in Row 1 and 10 being was at least 0.4 g's . Hill Bottoms 4 and 7 are also different by 0.4, with Row 1 having a higher Force Factor because it is going faster at the hill bottoms. The easy ones to figure out are when the coaster goes from the "level" ground to Hills Band C or vice versa.
9. a. Hill tops and the spike made you either feel light or slightly pulled out of your seat. Either way you didn't feel pressed into your seat at all. This provides a lot of the thrill of the roller coasters. These light feelings should correspond directly with the graphs being close to a Force Factor of 0.

Tempesto

Predictions:

1. c
2. d
3. c

Questions:

1. Left to right: B,C,B,A,M,K,M,A,B,D,E,F,G,H,M,A,B,C,B
2. The track is a horizontal straight line at this point. The track only needs to supply a force equal to the weight of the coaster. It doesn't matter how fast the coaster is moving, the vertical force factor will still be "1".
3. Force Factor=4.2 v= 26.9 m/s (60.2 mph) FF-v2/rg +1 v-Square Root ((FF-1l*rg l
4. The Radius of the turn is smaller than at point B.
5. In general, you feel heavy as you reach the bottom of the hills and also as you begin climbing up. This is because the coaster "wants" to continue going in a straight line, and the track must exert a force larger than the weight of the coaster to change its direction.
6. The weightless/negative g experiences were:
a. Reaching the top of a hill and also beginning a descent (similar to a camelback hill)
b. On the launches where the velocity was not sufficient to get to the top, the coaster "stopped" and then went back down the hill. You experienced close to O g's, when the coaster was in vertical free fall.
c. In the Heartline roll top, when you were upside down On Apollo's Chariot, the only weightless times were Camelback hills(parabolic), similar to "a" above. This also included the first drop.
7. The longest weightless experience was at Kand at H. The most consistent zero g event was at K, where it was very close to O for almost 0.6 seconds.
8. The acceleration needed on this short track starting in the middle of the horizontal track, would be difficult and also stressful on the people. You get two and a half launches to get up to speed on the ride. Also, it makes for a more interesting ride, with the zero g's as the coaster goes Lip the hill twice, without making itto the top.
9. Even though the coaster is small, it is mighty. No other coaster at the park approaches 4 twice, as Tempesta does
10. Launch 1. +0.4 Launch 2 -0.3 Launch 3 +0.4 Launch 4 -0.4 Launch 5 +0.4
L1 +V +A= speeding up L2 -V -A= speeding up L3 +V +A speeding up L4 +V -A =slowing down. LS= -V +A. It matches well, because if both V and A have the same sign It's speeding up, and when they have opposite signs, It's slowing down. The Verbolten accelerations, have an average Force Factor of 0.5, which is a bit bigger but definitely similar to the launches of Tempesta. You can see in the graphs of Launch 2 and 5 that the accelerations are fairly constant on Tempesto.
11. In the heartline roll of Tempesto, you really feel upside down, because you are at -1 g. On Loch Ness Monster it is actually about +1 g at the top of the loop (you feel normal), on Alpengeist it is + 1.6 at the top of the vertical loop (you actually feel heavy) and on Griffon it is about 0.2 g's (you feel very light) difference has to do with the speed at the top and the radius of curvature at the top.
12. Answers will vary

WHICH WAY IS UP? LOCH NESS MONSTER

Predictions:

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

1. When will you feel light or close to weightlessness?
   At the bottom of the first hill   Coming down the first hill   Top of the loops
2. When you are upside down will you
   Feel pressed into your seat   Lose contact with your seat
3. When the ride goes in horizontal circles inside the mountain at a steeply banked angle, you will
   Feel light   Feel heavy and pushed against the side   Feel heavy, but upright in car

WHAT TO DO AND NOTICE ON THE RIDE

1. When going around a banked turn, note whether you are thrown to the left or the right or remain upright in your seat. When you are going in circles in the darkness of the Monster's Lair, note how steeply the turns are banked and pay attention to whether you feel pressed into your seat.
2. When you are upside down, note all the ways that you can tell that you were upside down. Close your eyes on one of the two loops. Note whether you ever lose contact with the seat.
3. Pay attention to your feelings when you are coming down hills A and C. Note whether your stomach feels lighter or heavier.
4. Ride once in the front car (or near the front) and once near the rear of the coaster train. Note any differences in the two rides.

Questions:

1a. List all the ways that you could tell that you were upside down.

1b. Did you ever leave your seat when you were upside down? Did you feel upside down?

1c. When you closed your eyes, how could you tell that your were upside down?

1d. According to the CBL graph** on the next page, what was your force factor when you were upside down? Does this match your answer to question 1b?

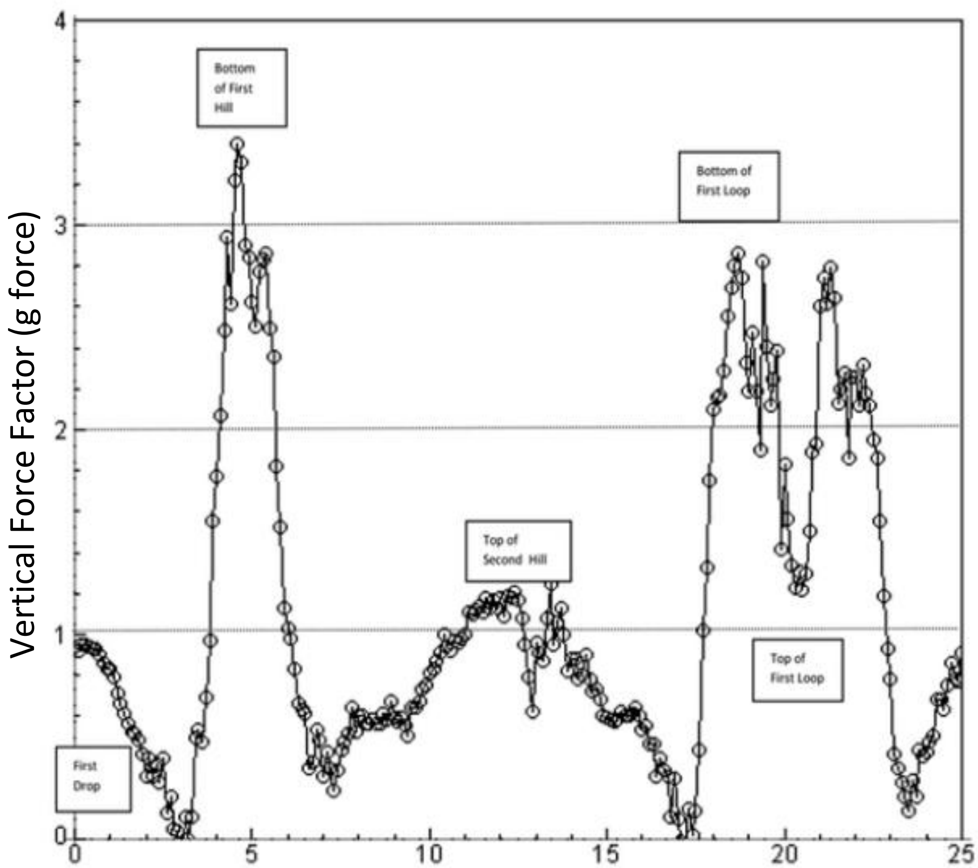
2a. While going around the steeply banked turns, did you feel pushed to the left or right or did you stay upright in the coaster car? Why?

2b. In the darkness of the Monster's Lair, as you are turning in circles at a steeply banked angle, are you pressed into your seat? Which direction appears to be down?

3a. While going down the first and second hills, did you feel weightless? Why?

3b. Does the CBL graph** on the next page match your feelings on these two hills? According to the graphs, for how long did you feel light?

4. Describe any differences between riding in the front car and the rear car of the coaster train. Explain why these were different.



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HORIZONTAL ACCELERATION
DIE AUTOBAHN BUMPER CAR

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

1. When your car is hit from the rear, your body will
   lean forward   feel pushed backward
2. When your car is hit from the left, you will feel
   pushed to the left   pushed to the right
3. When you strike a car, you will
   lean forward   feel pushed backward   it depends on how you hit them
4. Car A collides with a stationary Car B. Which passenger experiences a greater force?

The stationary passenger (B)   The moving passenger (A)   Both the Same

WHAT TO DO AND NOTICE ON THE RIDE

1. In the following collisions, note whether your body feels pushed forward, backward to the left or to the right.
a. You strike a stationary car from the rear (Like A abov e)
b. You are stationary and are struck from behind. (Like B abo ve)
c. You are struck from the left or right by another car
2. You strike a car on its side.

Data Table

When you strike a car from the rear, you feel pushed	Forward	Backward	Left	Right
When you are struck from the rear, you feel pushed	Forward	Backward	Left	Right
When you are struck on the left side, you feel pushed	Forward	Backward	Left	Right
When you strike a car on its side, you feel pushed	Forward	Backward	Left	Right

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Questions:

1. In which kind of collision did you feel the greatest force?

2. How does this force compare to what you feel on Le Scoot log flume or Escape from Pompeii?

3. The direction of force is opposite to the direction that your body moves. Indicate the direction of the force experienced by A, B, C and D in each of the collisions illustrated below.

4. Based upon your observations, who experiences a greater force in a collision? Is it the person being hit, the person hitting or are they both the same?

HORIZONTAL ACCELERATION
LE SCOOT LOG FLUME

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

1. At the bottom of the hill when the log makes a big splash, will you

   feel pressed back into your seat   slide forward neither

2. Which makes a bigger splash

   an empty log   a log with two in the front   a log with two in back   all the same

WHAT TO DO 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 slide forward.

2. Pay attention to your feelings on the last long drop.

WHAT TO DO AND NOTICE OFF THE RIDE

1. From the wooden bridge that leads to Germany, watch a number of logs come down the hill. Try to discover what determines the type of splash produced. (Big or small, long lasting or short, etc.) Also note whether empty logs or partially filled logs come down slower, faster or the same as logs with four people.

Questions:

1. How do your feelings on the drop compare to the drops on the roller coasters in the park (i.e. is it scarier, does it feel more weightless?) Does the fact that there is no lap bar make a difference?

2. Were you thrown forward or pushed back into your seat at the bottom of the hill? Why?

3. Based upon your observations, what makes a difference in the size of the splash? (What produces a maximum splash, minimum splash, etc.)

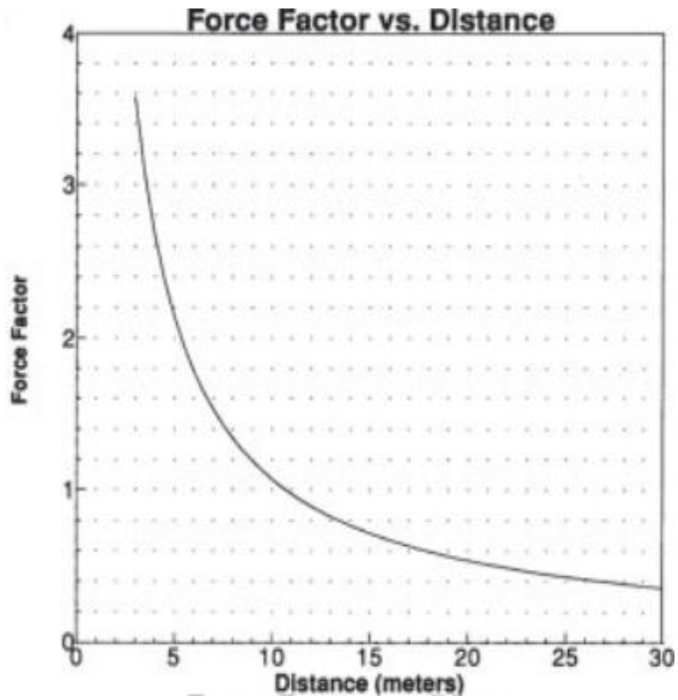
4. What is the direction of the force that you experienced? Draw a sketch of you in the log showing the movement of the log and the direction of the force and remember the force is opposite to the direction that your body moves.

5. The shorter the stopping distance, the greater the force. The chart below, based on Newton's Laws, illustrates the force factor required to stop a log at the bottom of the last drop in a given distance.

a. According to the graph, what is the minimum stopping distance that you think would be safe? What is the force factor corresponding to this distance?

b. When the Distance is doubled, the force factor is: (Hint: Compare 11m and 22 m) Doubled Stays the Same 1/2 as much 1/3 as much 1/4 as much 1/5 as much

c. What would be the force factor if the distance were 60 meters?



6. Do the partially loaded logs come down faster, slower, or the same as fully loaded logs? Why?

Centripetal Acceleration

The Trade Wind

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

1. As The Trade Wind cars spin in a circle, a force

   pushes you outward   pushes you in toward the center

2. If you are riding with a little child, they should sit on the side of the car closest to the

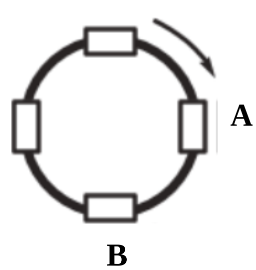
   outside   inside

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Ride The Trade Wind twice, once toward the middle and once toward the outside. Notice the differences in ride sensations.

Questions:

1. As you accelerate, your body will feel like it is pushed or flung in the direction opposite to the direction of the force acting on you. Because of the high speed and fairly small radius of rotation of this ride, the force required to cause the acceleration is very close to your own weight. Remembering your feelings on the ride, indicate on the diagram below the direction of this force on you at points A and B.



2. Using Newton's Law of Inertia, explain why you feel as if you are flung outward.

3a. What pushes on you to make you go in a circle if you are seated alone?

3b. What pushes on you if you are seated on the inside next to someone?

3c. What is the difference between riding on the inside or the outside?

3d. Where should a little child sit? inside outside

Vertical Acceleration

Alpengeist

Instrument Needed: Mounted Vertical Accelerometer. Sit in Row 6.

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

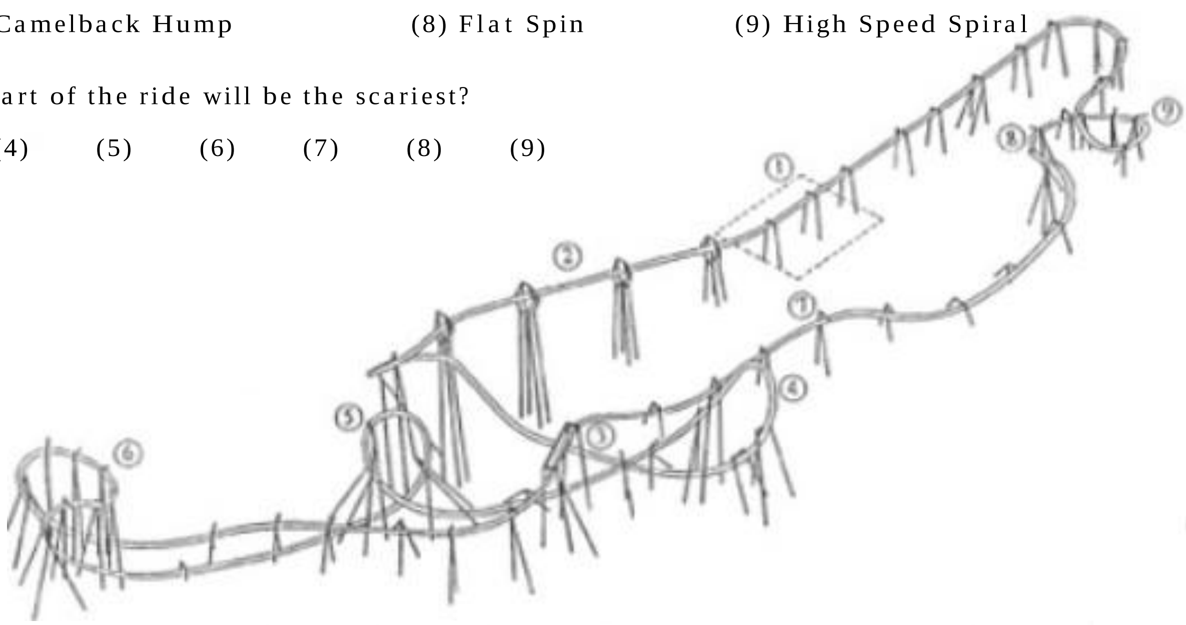
1. At what point on the ride will you experience the maximum force?

(3) Bottom of the First Hill (4) Immelman Loop (5) Vertical Loop (6) Cobra Roll

(7) Camelback Hump (8) Flat Spin (9) High Speed Spiral

2. Which part of the ride will be the scariest?

(3) (4) (5) (6) (7) (8) (9)



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WHAT TO DO AND NOTICE ON THE RIDE

1. Record the maximum force factor and note where on the ride it occurs.

	#1	#2	#3	Average
Maximum Force Factor				

If you are not in a row with the accelerometer, or the accelerometer is missing or not functioning pay attention to where you feel the heaviest on the ride

Questions:

1. The speed at the bottom of the first hill of Alpengeist is approximately 67 mph. How does this compare to the Loch Ness Monster? Why is this speed different from the Loch Ness Monster?

2a. What is the force factor at the bottom of the first hill where the speed is 67 mph (30 m/s)?

Force Factor (according to the chart):

2b. If the designer wanted to make a more intense ride, what maximum force factor should they set for the bottom of this hill? What speed would correspond to this force factor?

2c. If you were asked to redesign the coaster for those who don't like a thrilling ride and can't exceed a force factor of 1.5, what speed should you set for the bottom of this hill? Instead of changing the speed, how else could you make it "wimpy?"

3. As a roller coaster designer, what do you change in order to change the speed at the bottom of the first hill?

4a. According to your measurements, what point on the ride had the great force factor? Why was it big at that point?

4b. According to the CBL force factor graph** (following question 5) what point on the ride has the maximum force factor. How does this compare to your answer to 4a?

4c. According to the CBL force factor graph,** what is the force factor at the bottom of the first hill? How does this compare to the force factor computed in question 2b?

5a. Based on your experiences, which part of the ride was the scariest? Which was the most disorienting? Which part had the greatest thrills?

5b. According to the CBL force factor graph** on the next page, which part of the ride is the most intense? (You might define intense as being the highest force factor for the longest interval of time, or perhaps it is the greatest number of changes in force factors in a short period of time.)

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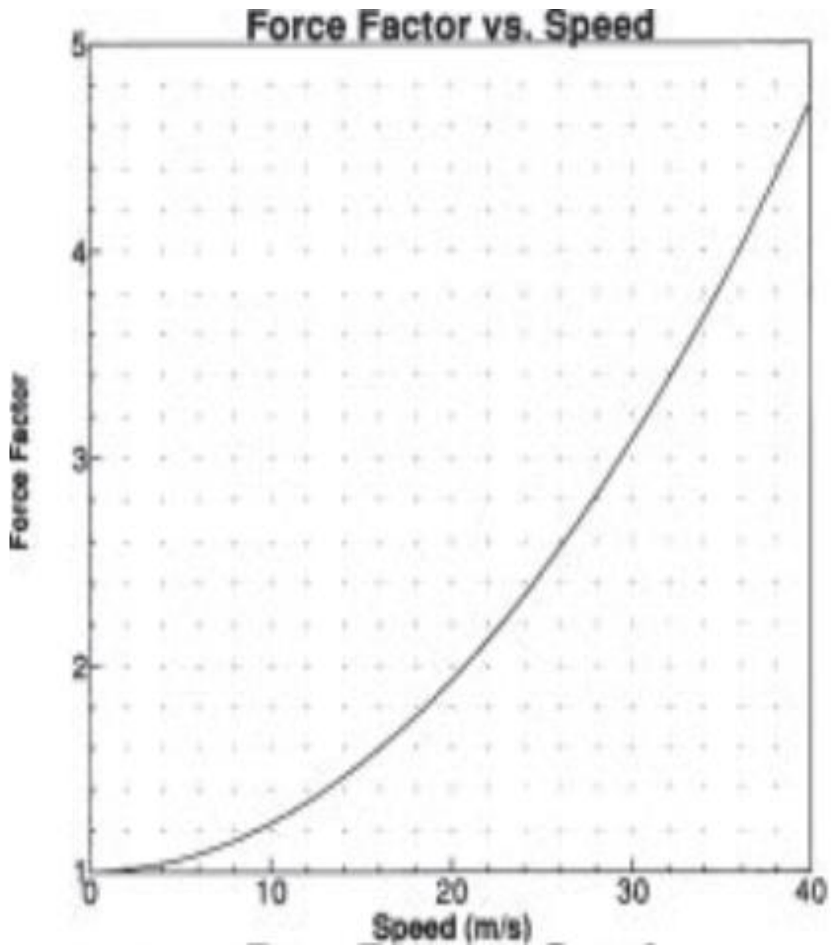
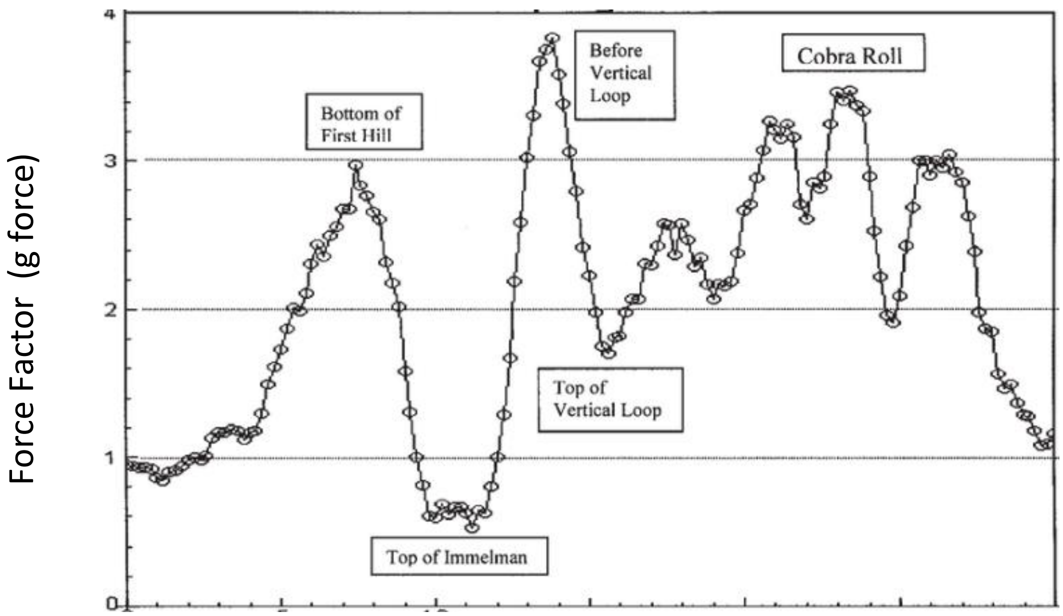
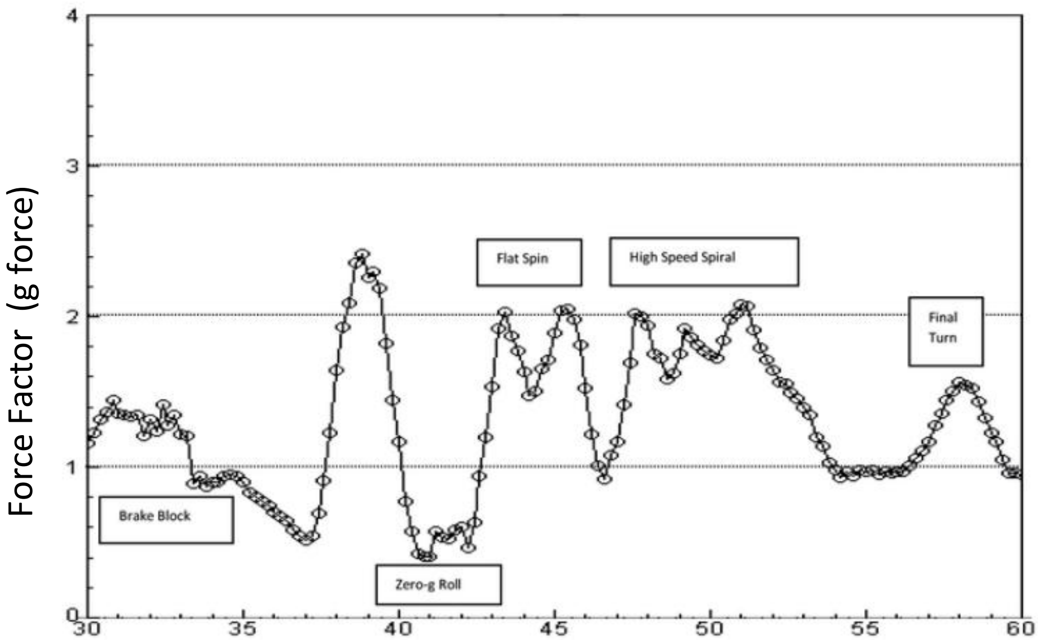

Force Factor vs. Speed
Force Factor
Speed (m/s)
1
2
3
4
5
0
10
20
30
40

Alpengeist



Alpengeist



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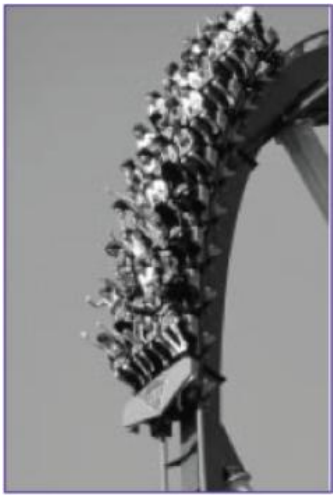
WEIGHTLESSNESS

APOLLO'S CHARIOT

Instrument Needed: Mounted Vertical Accelerometer. Sit in Row 6.



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

1. Weightlessness occurs on the Camelback hills (Circle all that apply)

 approaching the hilltop coming down from the hilltop at the hilltop

2. Which produces a weightless feeling?

 going over the hilltop coming down the hilltop both

3. From the top of the first hill to just after the last dip seconds is approximately 66 seconds. From how many of those seconds will you be "out of your seat" (close to weightlessness)?

 5 seconds 10 seconds 25 seconds 40 seconds

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Practice counting in seconds (one thousand one, one thousand two, ...or one Mississippi, two Mississippi, and then from the topof the first hill to the end of the ride, count how many seconds you experience "air time." ("Air Time" or Weightlessness refers to being very light, or out of your seat. It is a time where the force factor is less than one, approaching zero.) Record your own time and the time of two friends, or do it three times yourself.

2. Pay attention to where the longest period of weightlessness occurs.

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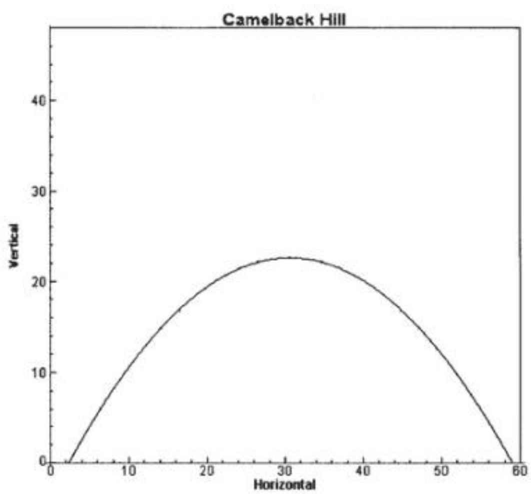
3. Note where on the ride you feel weightless (going up hills, coming down hills, tops of hills, spirals, bottom of hills, etc.).

4. Record the force factor at bottom of the first hill, the bottom of the second hill and the last dip.

	#1	#2	#3	Average
Air Time				
Force Factor at Bottom of First Hill				
Force Factor at Bottom of Second Hill				
Force Factor at Last Dip				

Questions:

1. The graph* below shows the top of the first camelback hill, with the scale in meters.



a. What mathematical shape does this hill appear to be?

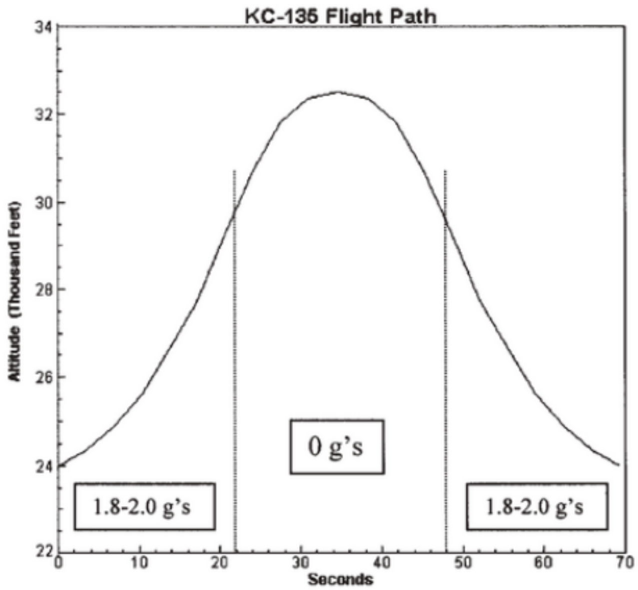
b. Is the weightless feeling experienced on the way up the hill, on the way down, or both?

c. Where on the ride did you experience that longest period of weightlessness?

d. According to the CBL Force Factor graph (Apollo's Chariot 4th Row) which is on the pages following b question 6, what is the longest period of weightlessness experienced on Apollo's Chariot (Take the time of weightlessness to be the time that the force factor is less than 1.) Where does it occur?

e. Describe in general, where on the ride you experience weightlessness.

2. When the astronauts train for space travel, they fly in an Air Force plane, KC 135, that flies in a trajectory, as illustrated below. The plane is called the "Vomit Comet."



a. According to the graph, how long a period of weightlessness is achieved in the Vomit Comet?

b. How does the shape of the Camelback hills on Apollo's Chariot compare to the flight path of the KC-135?

3. The graph* at the top of the following page shows the first coaster drop of 64 m (210 ft). The circles indicate the actual shape of the hill. The line indicates a "perfect" parabola. The natural motion of a freely falling object is a parabola. When the coaster track follows this parabolic path, the passengers experience free fall, or weightlessness.

a. For how many meters does the track "essentially" follow the parabolic shape?

b. What happens at the bottom of the hill when the track deviates from the parabola?

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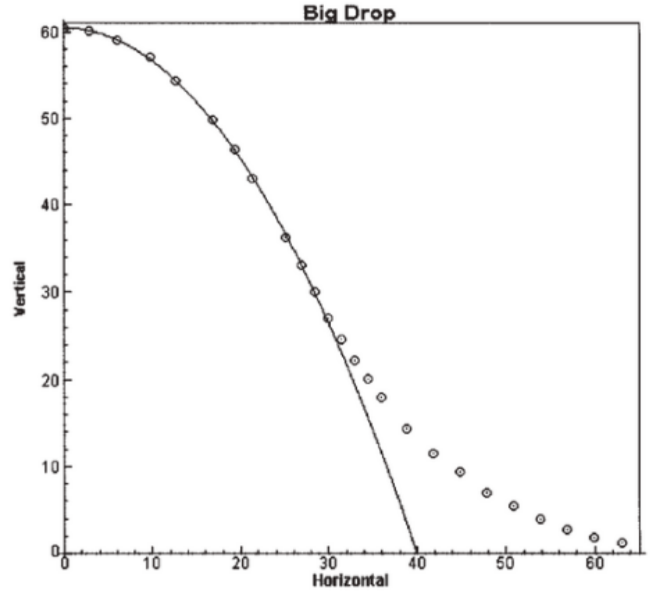
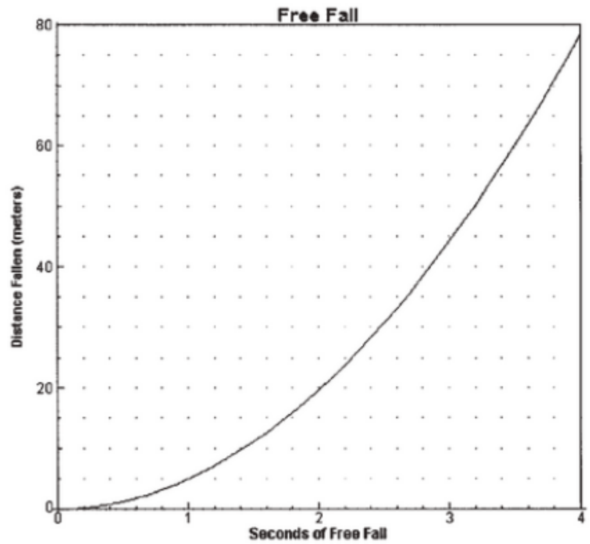


*This graph is only an approximate representation of the actual coaster.

c. According to the CBL Force Factor graph**, how many seconds of free fall does the coaster experience on the first drop? (Measure the time that the force factor is less than 1.)

d. The first hill is 64 meters tall, but there is about a 4-meter dip, before the first big drop of 60 meters. The graph on the next page indicates the distance fallen in a given time. What would be the falling time for a hill 60 meters tall?

e. What is the falling time for the portion of the curve that is "close" to the parabola? How does this compare to the actual "air time" found in 3c?



4a. Using the Free Fall graph above, developed using equations of motion, compute the "airtime" on the Camelback Hill that is illustrated for Question #1. (Assume that the portion of the hill that is shown, is that fraction of the hill that is close to parabolic.)

4b. Find the actual "airtime" from the CBL Force Factor graph**(FF<1).

4c. If your answer to 4a is off by several seconds, explain why.

5a. What is the average number of seconds of "air time" that you counted on the ride?

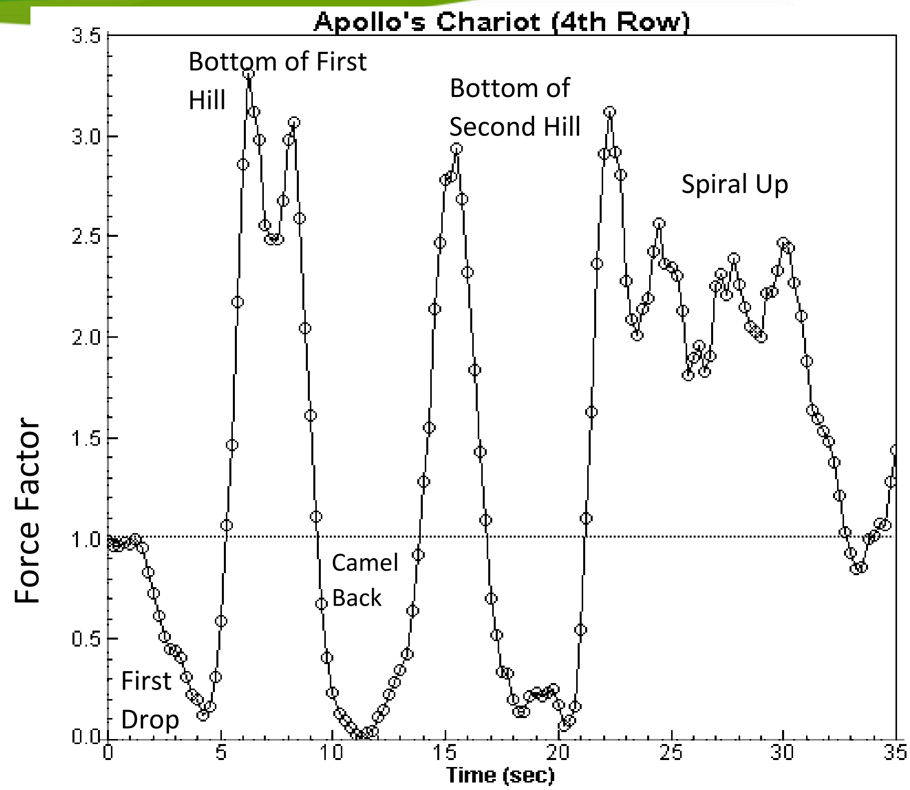
5b. What fraction of the 66-second duration of the ride are you weightless?

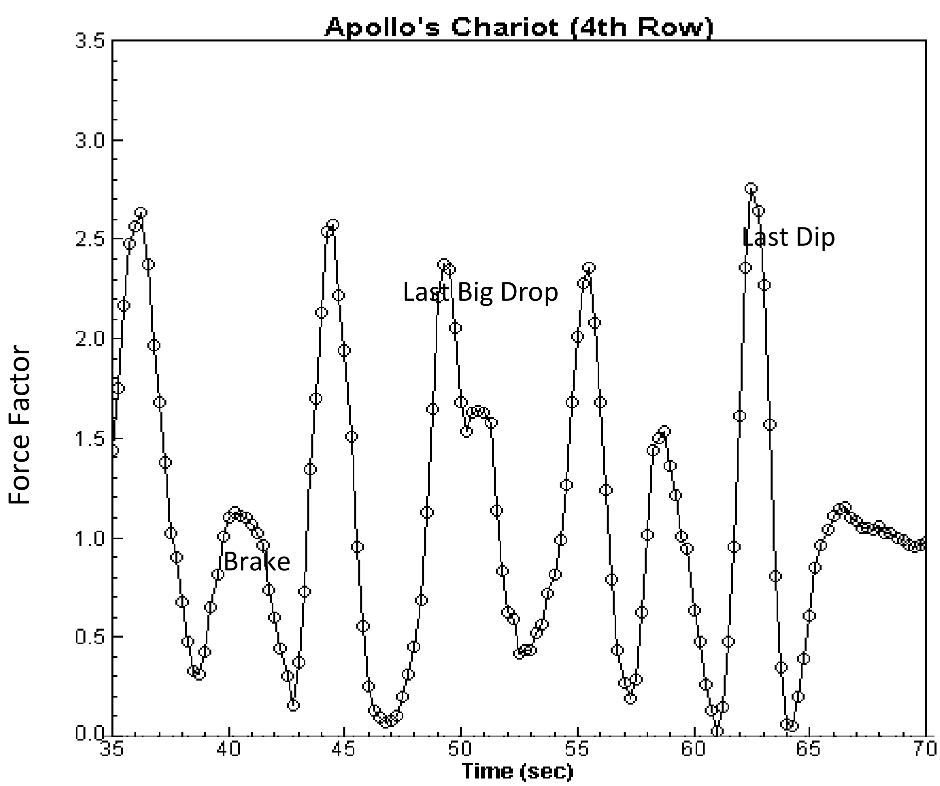
c. Using the CBL Force Factor graphs on the next page, find how many seconds the coaster had a force factor less than
1.5d. How does this number compare to your "counted" value? Why are they different?

6. Using the CBL Force Factor graph on the next page, estimate the force factor at the bottom of the first hill, the bottom of the second hill and the last dip. first Hill bottom Second Hill bottom Last Dip How do these numbers
compare with your data?

First Hill bottom ________ Second Hill bottom _______ Last Dip ________

How do these numbers compare with your data?





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WEIGHTLESSNESS

GRIFFON

Instrument Needed: Stopwatch.

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

1. How long will you feel weightless on the big drop?

   .5 seconds   1.5 seconds   2.5 seconds   3.5 seconds

2. Will you ever feel weightless when you are upside down?

   yes   no

3. How many times will you experience weightlessness?

   once   twice   three times   four times   more than four times

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Practice counting in seconds (one thousand one, one thousand two, … or one Mississippi, two Mississippi, etc.) and estimate the time that you're weightless on the big drop. Estimate to the nearest ½ second. This weightless, out of your seat time, is often referred to as "air time." If you have a stop watch you can time instead of counting out loud.

2. Note how many times you are weightless throughout the ride, and which weightless periods are the greatest.

3. Estimate how long are you weightless during the second vertical drop? If you have a stop watch you can time instead of counting out loud.

WHAT TO MEASURE AND OFF THE RIDE

1. Estimate or measure the time that it takes for the coaster to "free fall" down the first hill. Begin when the coaster begins to fall (it will hang at the edge for approximately five seconds before falling), and stop when the coaster arrives at the top of the first white post that supports the track. The track begins to curve after this point. If you have a stopwatch, you can time it instead of counting out loud.

	#1	#2	#3	Average
ON RIDE: Time of Fall-First Drop				
ON RIDE: Time of Fall-Second Drop				
OFF RIDE: Time of Fall-First Drop				

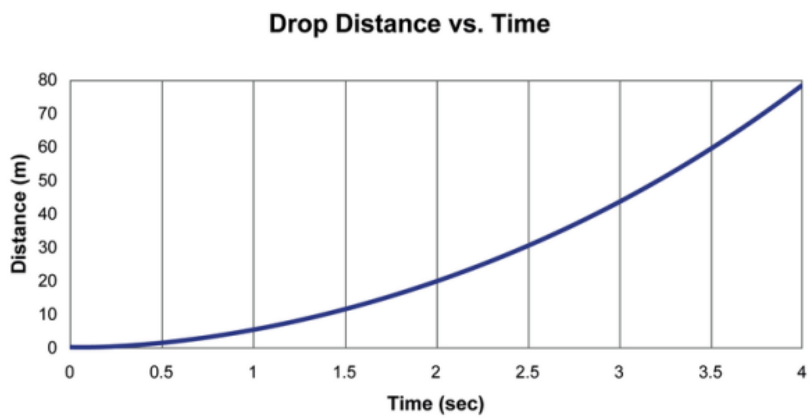
Questions:

1. How does the weightless time on the first drop estimated on the ride, compare to the time estimated while watching the coaster off the ride?

2a. From the Drop Distance versus Time graph at the bottom of this page, determine how far the coaster dropped in the time measured with the stopwatch.

2b. If the coaster dropped the entire 62.5 meters to the ground, how long would the falling time be? (Of course, this is not possible because the coaster track must begin curving before it reaches the ground.)

2c. Using the drop distance graph, what should the "free fall" time be? (It is 34.1 meters from the top of the hill to the white post.)



3a. Using your experiences on the ride, indicate where else on the ride, other than the two vertical drops, are you "weightless."

Definitions: The upside down loops are called "Immelman" or inverse dive loops.

Camelback hump refers to a parabolic hill as illustrated to the right.

Hill bottom is simply the bottom of a large drop.
The block brake is the flat section of track in the middle of the ride, the water brake is where the big plumes of water are created, 1st and 2nd drop refers to the vertical drops on the ride.

4a. Now, using the Griffon 1st Row graph at the end of this section, name all of the times when you experienced "weightlessness." Pick periods where the force factor is less than 0.5 seconds. Is this the same answer that you had in question No. 3?

4b. Using the chart, compute how long the first drop, and second drop produced weightlessness. (For an estimation, assume that a force factor of less than 0.5 is apparent weightlessness.) How do these times compare to what you estimated while riding or watching the ride.

4c. Using the chart, how does the weightless period for the first drop compare to the weightless period on the first Immelman?

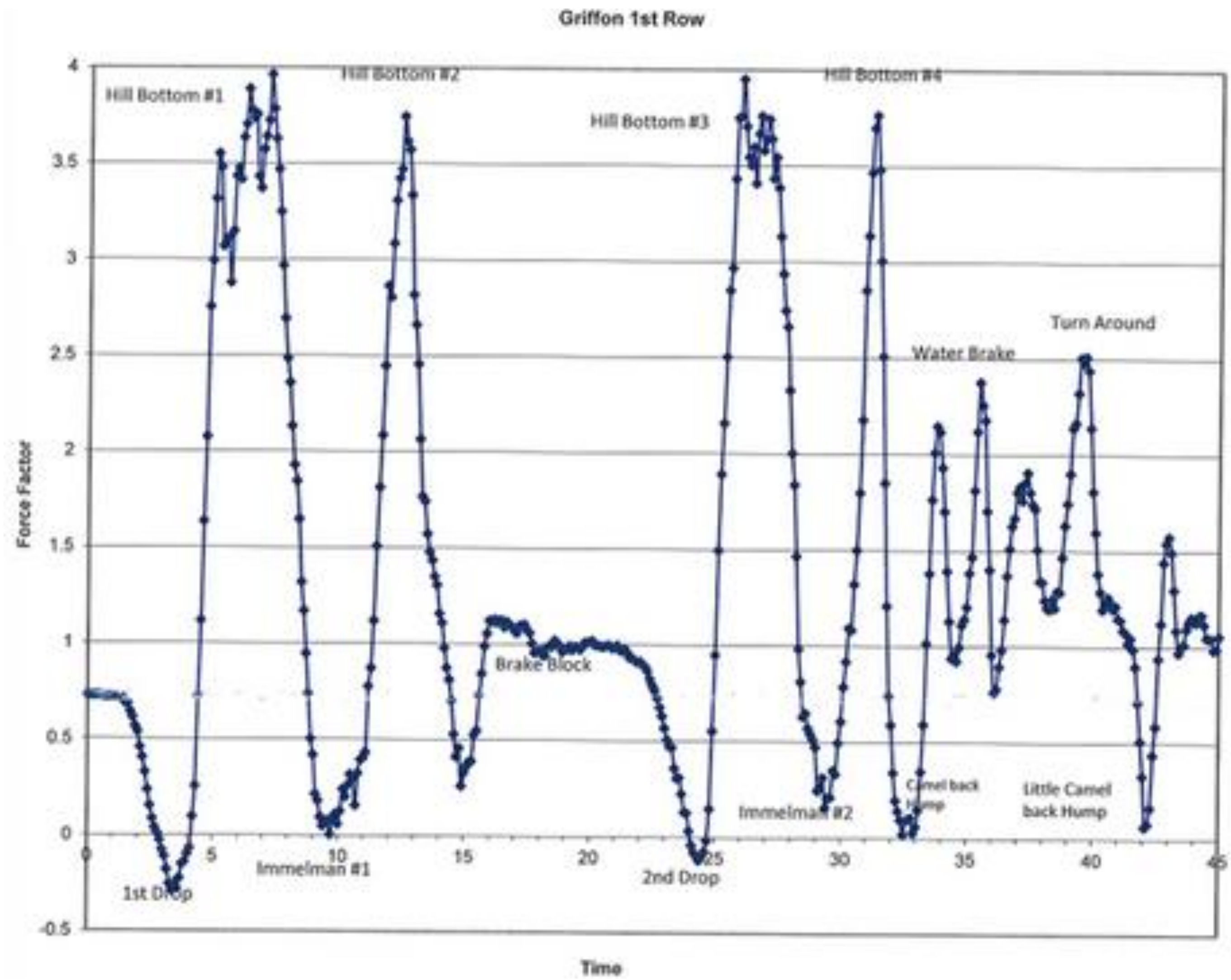
1st drop is: much greater a little bit longer almost the same time a bit shorter

4d. Dod the weightless periods on the 1st drop and Immelman feel the same or different? If different, why?

5a. There are three different situations that provide weightlessness on this ride. What are they?

5b. The vertical drops are visually very different from the other two situations. How else do the weightless periods differ from each other?

6. How do the weightless periods on Griffon compare to the weightless periods on Apollo's Chariot (Use the 8th Row graph)? (Compare number of weightless periods and length of airtime for individual instances and for the entire ride.)



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ESTIMATION QUESTIONS:

1. How long did it take to construct Griffon?

   6 months   10 months   12 months   15 months   18 months

2. How many sections of track were used to construct Griffon?

   56   92   150   183   274

3. What is the heaviest section of track?

   2,125 lbs   34,215 lbs   58, 116 lbs   111,800 lbs   223,520 lbs

4. What is the total length of track?

   560 feet   1,814 feet   3,108 feet   4,456 feet   6,321 feet

5. Once a coaster train is initially placed on the track, what is the minimum run time, fully loaded with water dummies, before it can be certified as safe?

   1 hour   2 hours   4 hours   8 hours   12 hours

Note: Busch Gardens runs the coaster trains for many more hours than the minimum.

Vertical Acceleration and Weightlessness

Invadr

nstrument Needed: None

Predictions:
1. How close together will the various elements of the track be(i.e time between weightless feelings)

   a) 1 sec b) 3 sec c) 4 sec d) 6 sec

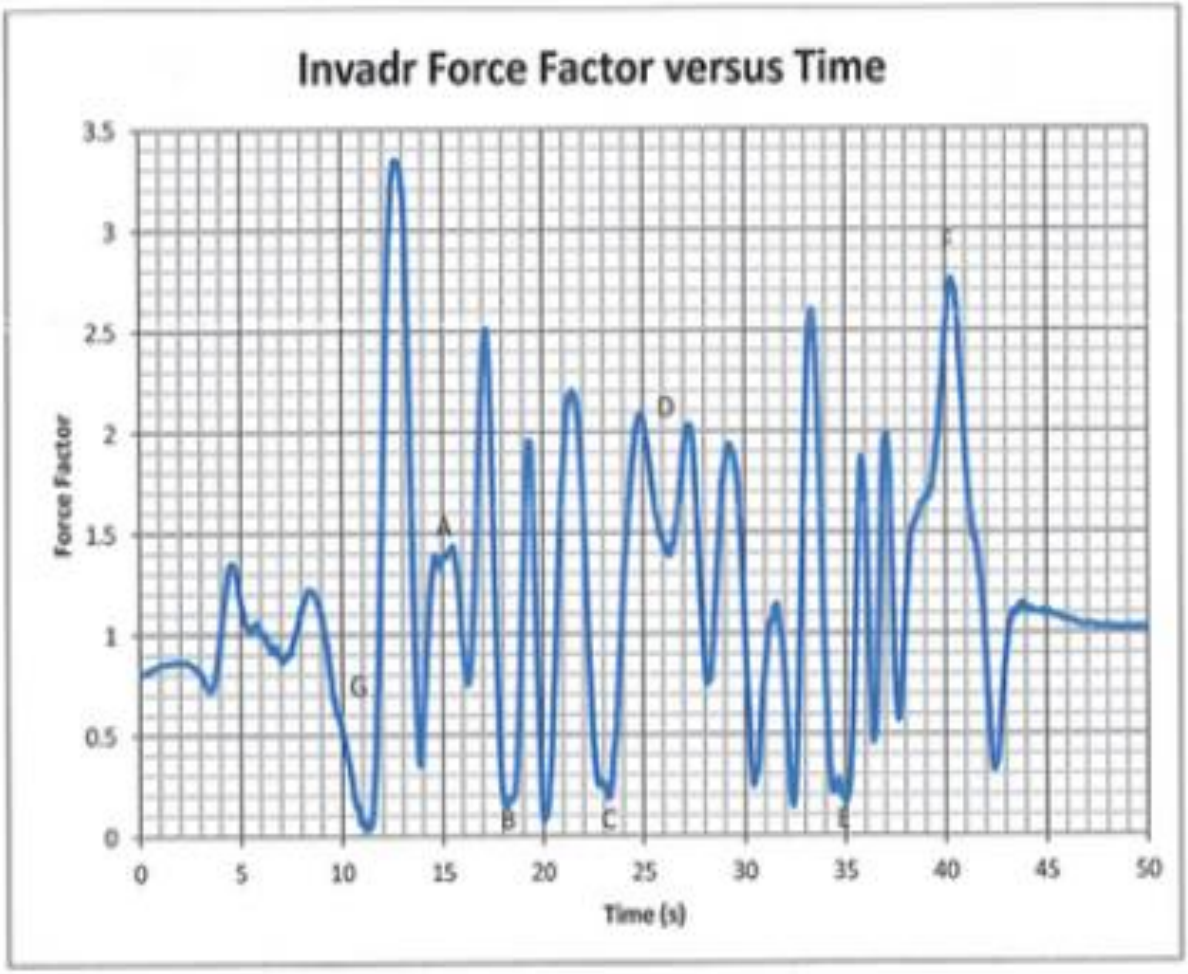
2. The longest weightless period (<.Sg) will be about

   a) 2 sec b) 4 sec c) 6 sec d) 8 sec

3. You will feel heavy on the coasters at

   a) Hill bottoms b) banked turns c) neither d) both

Questions:
The graph on the next page indicates the Force Factor (g force) for the elements of the lnvadr. Each letter corresponds to the letters on the sketch of lnvadr. A and D are banked turns. B, C and E are camelback hills, F is a Helix-a 360 degree turn at the very end of the ride, and G is the first drop of 74 ft.



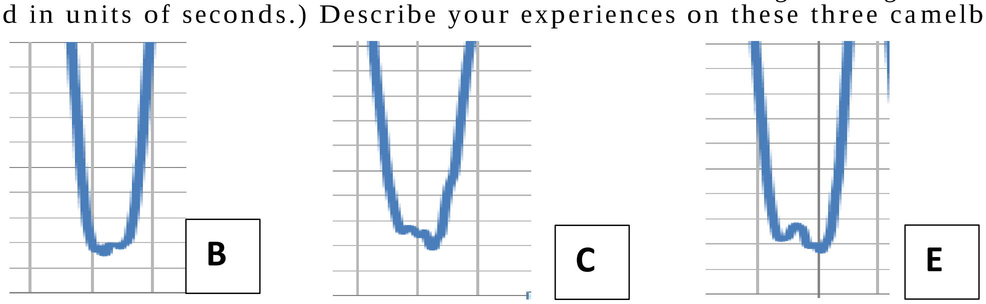
1. There are many times during the ride, where you will feel weightless. If we assume that experiencing a Force Factor of less than 0.5 (0.5 gs') feels very close to weightlessness, which weightless experience was the longest? How long was it?

2. Going over a camelback hill, produces a weightless experience. It is a parabolic hill:
You will also find a lot of these parabolic hills on Apollo's Chariot, but they are a lot bigger than those on lnvadr. The three parabolic hills on lnvadr that have the greatest "air time" are B(the first camelback after the banked turn after the first drop), C (the camelback that you approach soon after B, just after you make a turn to the right), and E(the camelback that goes over top of the first drop). You will feel weightless both going up and also coming down these camelback hills. Which of these three below have the longest weightless sensation(< 0.5 g's)?(The x axis is measured in units of seconds.) Describe your experiences on these three camelback hills.

The top line is 1 g

The middle line is 0.5 g

The bottom line is 0 g



3. There were 13 times low g elements, where the Force Factor dipped below 0. How many times did the Force Factor go come close to or go over 1.5? How many times did it go over 2.0? According to the graph, the Largest Force Factor was almost 3.4. How does this compare to the first drop of the Loch Ness Monster or Alpengeist.

4. The highest speed on the coaster is about 48 mph, at the bottom of the 74 ft drop.
   a. It is the slowest of the big coasters at the park, but it doesn't feel slow? Why?

   b. What is next slowest coaster? Apolli's Chariot, Griffon, Alpengeist, Loch Ness Monster, Verbolten.

   c. The second fastest speed on Ivadr is the bottom of the Helix near the end of the ride. Near the end of the ride, friction has robbed the coaster of a lot of its speed, so how is this possible?

5. Hill bottoms produce a high Force Factor, like just after G, and at the bottom of the helix {F). What other place on the ride has high force factors?

6. Was the track banked each time you turned a corner, or just some of the turns? Why are the turns banked, and which of the following would determine the banking angle (speed, radius of the turn, both)? Did you feel heavy in the turns?

7. One of the things that makes lnvadr so exciting is the non-stop action. From the top of the first hill to the end of the Helix is about 36 seconds. How close together are the elements on the average? (Find the average time by looking at the number of different elements in that time frame. You might counts episodes of less than lg, or great than about 1.3 g, but don't count both. So you'll either be finding the time between light point or heavy points. {For comparison sake, Apollo's Chariot has some great thrills and wonderful airtime (it's longest airtime (<0.5 g's) is 4 seconds). It has a similar, but a little bit smaller number of elements that are below 1 g, but the time span is 66 seconds.)

8. How would compare this wooden roller coaster to the steel roller coasters at the park? How are the similar, how are they different? (Note: This coaster is called a Hybrid coaster, because the ride supports are made of steel, and not wood as on a traditional wooden coaster. Steel supports are more resistant to the weather and require much less bolt tightening than wooden supports.)

Force Factor-Oscillations

Finnegan's Flyer

Instrument Needed: Wristwatch or stopwatch

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

1. What is the period of one oscillation on Finnegan's Flyer at maximum angle.

   a. 6 sec b. 8 sec c. 10 sec d. 12 sec

2. How much will the largest force factor be?

   a. 3.0 b. 3.3 c. 3.5 d. 3.7 e. 3.9

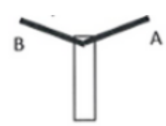
3. What is the longest that you will feel close to weightless (Force Factor <0.5)?
   a. 0.8 sec b. 1.1 sec c. 1.4 sec d. 1.8 sec

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Where do you feel weightless on the ride? How many times do you feel weightless? What seems to be the maximum time for a weightless event?

2. Where do you feel heavy? How does this heavy feeling compare to the bottom of the first hill on Loch Ness Monster or the Alpengeist?

WHAT TO MEASURE AND NOTICE OFF THE RIDE



1. Using your watch or the stopwatch on your phone, time 2 complete oscillations (periods) of Finnegan's Flyer, when it is above 90 degrees.
   (One complete period is from "A" back to "A")
   Do this twice, or use a friend's data for the second trial.
   Find the period, by taking the average time for 2 oscillations and dividing by 2.

T1(time for 2 oscillations)	T2(time for 2 oscillations)	Average T (T1+T2)/2	Period (T/2

Questions:
1. At the top of the next page is a force factor (g force) versus time graph of the pendulum's oscillation. It is not a position versus time graph, so a period is not the distance between two peaks, but between three peaks, or three zero points shown by the double arrow

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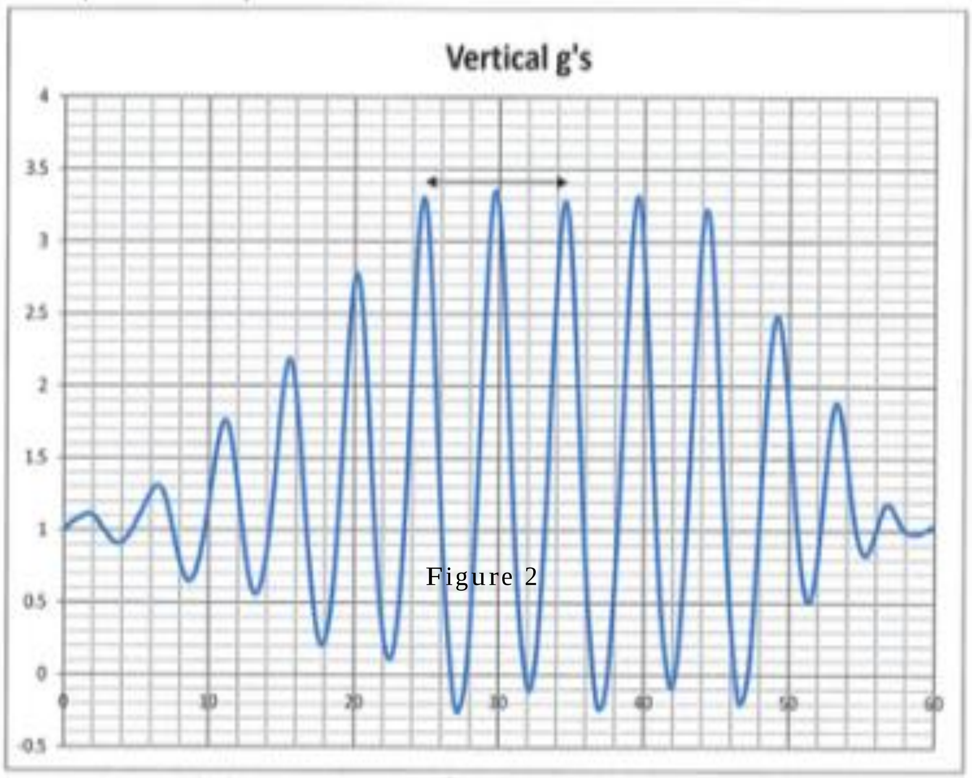


Figure 2

Use Figure 2 to find the period. (One period is indicated on the graph by the double arrow.) This should be close to the value that you measured with your watch/stopwatch. Is it? If it isn't, why not?

Period is ___________ seconds

(Note: This period can't be accurately computed using the pendulum equation $T=2\pi\sqrt{(L/g)}$. This equation is a small angle approximation, which is fairly accurate when the angle is less than 10 degrees. However, when the angle is more than 90 degrees, like it is on Finnegan's Flye, the predicted value can be off by more than 20%. In this case, using the pendulum length L=15.9m, produces an expected period of only about 8 seconds.)

2. a. Where do you feel heavy on the ride? Is this in the same location as you feel heavy on coasters? Is it the same going forward and backwards?

b. Using Figure 2 to examine the heavy times on the ride.

The largest Force Factor FF=______________________
How does this compare to the FF on the coasters at the park?

c. What is the number of times that the Force rises above 2?

3. a. Where do you feel light or close to weightless on the ride? Describe this "weightless" feeling.

b. Defining a "weightless feeling" as having a force factor of less than or equal to 0.5, according to the graph, how many times would you feel "weightless" _________

c. This weightless feeling really adds to the thrill of the ride. Many rides at Busch Gardens have several weightless periods. Are there any rides that have as many or more than Finnegan's Flyer?

d. Figure 3, shows that same thing as Figure 2, but we have zoomed in to be able to find the time that you have a force factor of less than 0.5.

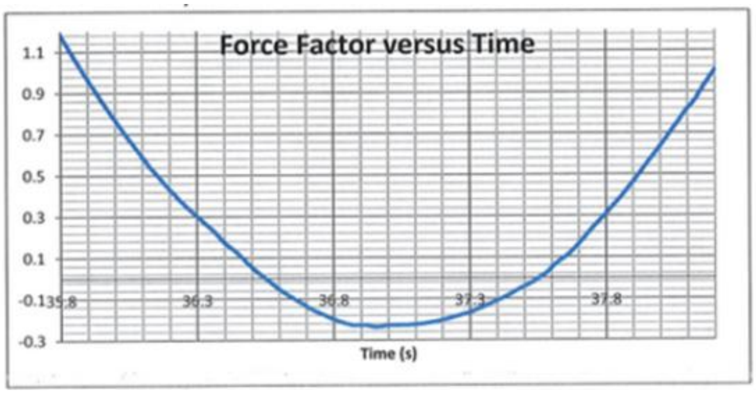


Figure 3

Time at less than a Force Factor of less than 0.5= ___________ sec

(For some comparison, at the Battering Ram, the other pendulum ride at the Park, the weightless time is about 1.2 seconds.)

e. Are the other rides at the park where you feel "weightless" for as long as on Finnegan's Flyer.

4. Compute the maximum speed of Finnegan's Flyer? We can use the conservation of energy to compute the speed (mgh=1/2 mv2). If an object is dropped from rest at height "h", and we ignore friction, it's speed at the bottom will be given by v=√(2*g*h) where g=9.8 m/s2

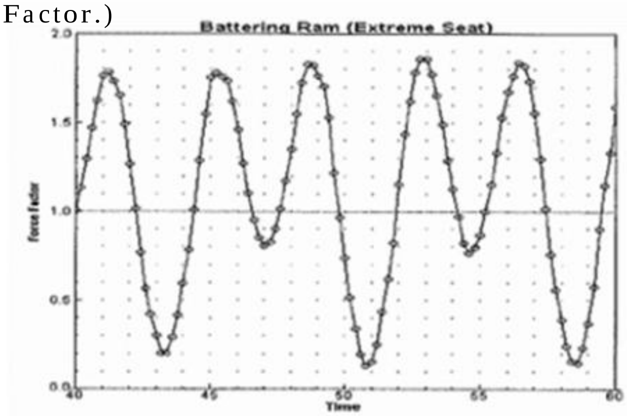
At it's highest, Finnegan's Flyer is about 22.5 m above its lowest point. (The pendulum length is 15.9 meters its biggest angle is about 115 degrees)

V =________________ m/s = _______________ mph (multiply velocity in m/s by 2.24 to produce mph)

5. Comparison of Finnegan's Flyer to Battering Ram

a. Why does the graph of the Force Factor of the extreme seat on Battering Ram look so different to the graph for Finnegan's Flyer. We have included a picture which shows the position of the accelerometer on Battering Ram with a white circle,

b. Why is the maximum Force Factor on the Battering Ram so much smaller than on Finnegan's Flyer? (Hint: It's not the length of the arm, because it everything else is the same, a smaller arm would have a larger Force Factor.)



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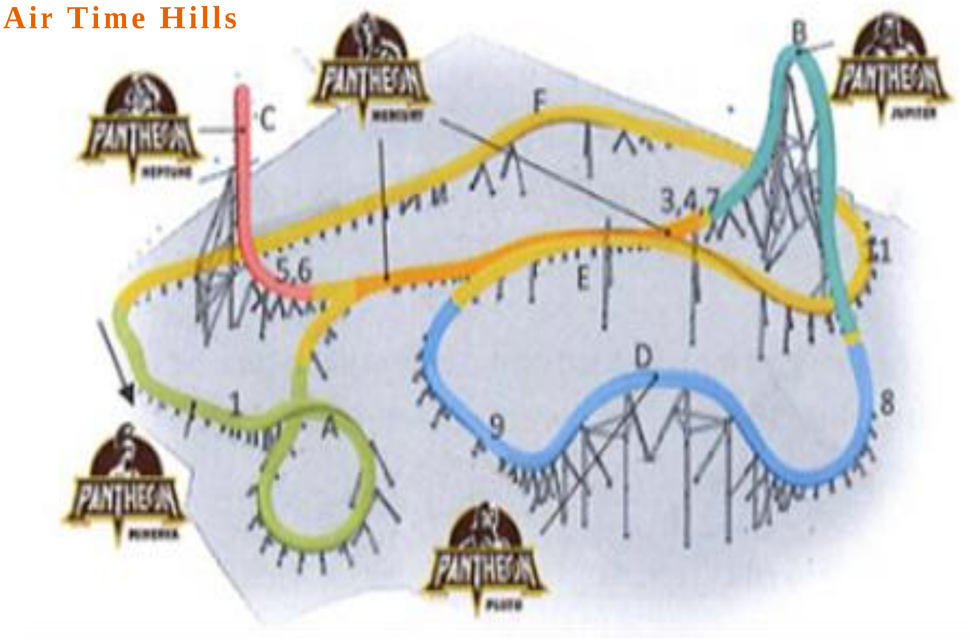
Magnetic Launch and Air Time Hills

Pantheon



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

1. Which point in the ride will have a big force factor (g') for the longest time?
(The bottoms of hills B and C have multiple numbers, because the coaster passes that point several times)

 a) 1 b) 6 c) 8 d) B e) C f) D

2. Which point in the ride will have the very close to O g's for the longest time?

 a) 1 b) 6 c) 8 d) B e) C f) D

3. Which coaster car has the more intense experience at the top of the hills?

 a) Car 1 b) Car 10

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Where do you feel the heaviest for the longest time?
2. Which magnetic launch felt the most intense?
3. How does your inversion on Hill E compare to your feelings on the top of Hill D?
4. Ride in the front and the back car (or close to the front and back) and pay attention to your experience at the tops of the hills, especially Hilltop 8 and 9.

WHAT TO MEASURE AND NOTICE OFF THE RIDE

1. Watch carefully from a distance, as the coaster goes over the top of Hill Band Hill D. Pay careful attention to the speed of car 1 and car 10 as they reach and go over the top of the hill.

Questions:

The Vertical Force Factor graphs for Pantheon, have the hill bottoms labeled with numbers and the hilltops labeled with Letters. (A force factor of 1, is the same thing as 1 g) These numbers correspond to the diagram on Pantheon on the first page of this Pantheon workbook section. Use the Row 1 graph to answer the questions, unless otherwise directed. The numbers 10, 20, 30, etc. are the times in seconds. All of the graphs have the vertical Force Factor (or g's) plotted on the y axis and time plotted on the x axis.

1. Use the Force Factor Chart for Row 1 to find out how many airtime hills there are. Now find the number on the Row 10 chart. We can define air time as being less than a force factor of 1. Is this number different on the Row 10 chart?

Row 1 Number of airtime hills_______ Row 10 Number of airtime hills _________

2. A vertical force factor of zero feels like floating. A positive force factor indicates that you are pressed into your seat and feel heavy. (A force factor of 1, is the same thing as 1 g.) A Negative force factor feels like you are being pulled out of your seat.

a. Where in general do you find the negative g's?

b. Where do you find a fairly constant zero g reading? How is this hill different from the others?

c. Where do you find the high g readings?

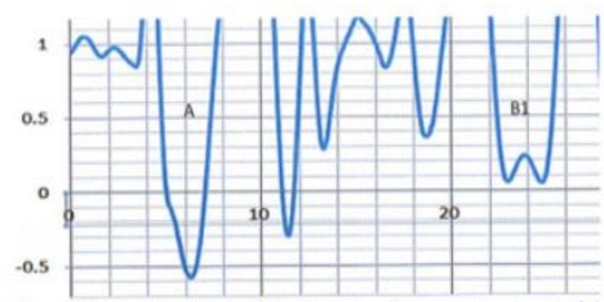
3. a. Which place has the longest airtime (less than 0.5 g) How long is it? (The AIR TIME HILL CHARTS below show 6 of the hills with the longest air time.)

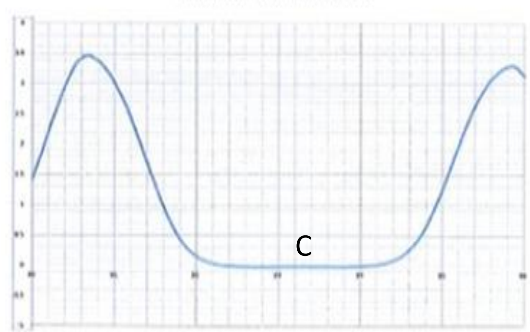
Longest Airtime _______________ (Hill Top #_____)

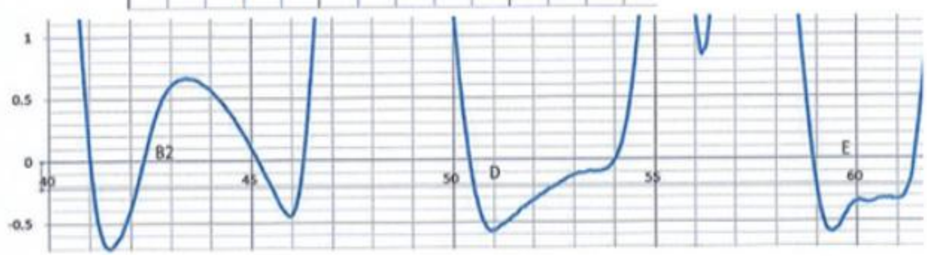
b. How does this compare to the longest air time on the other rides at Busch Gardens? Is it more less air time than Apollp's Chariot or Griffon? Which ride at Busch Gardens can come close to matching these air time
hills on Pantheon?

c. What is generally the shape of these air time hills?

AIR TIME HILL CHARTS







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4. a. Where is the g force greatest for the longest period of time?

Large force factor for the longest time: Force Factor ___________
Time at close to maximum ___________ Location ___________

b. Compare this to other places with big times at a high force factor

Force Factor _________ Location _________ Length of time above 3g’s_____
Force Factor _________ Location _________ Length of time above 3g’s

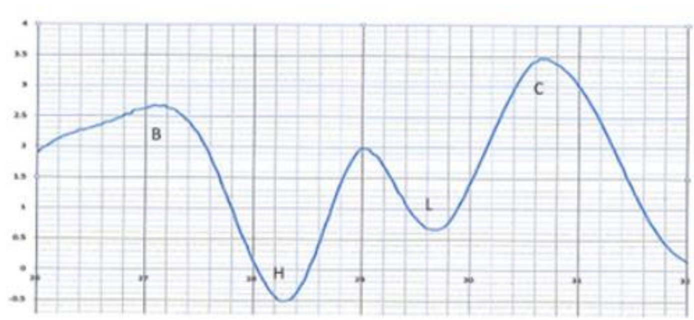
c. Did these places on the ride feel like the places of greatest intensity?

5. Launches: There are 7 launches on this roller coaster. The park publicity says that there are four launches, one at the beginning and then three between hills Band C. Between Band C there are actually two launches each way. 13 is the launch closest to Hill B, and why is the launch closest to Hill C.

γ Launch (closest to Hill C) β Launch (closest to hill B)

Between the two launches is a small camelback hump hill that produced low g's. The white strip down the middle of the track is the electromagnets that produce the launch. The arrows show the beginning and end of the launches. Notice that ln the 13 launch, the electromagnets continue up the hill a little.
Also, the guard rails (and the track) on the Hill C side of the hump are going slightly uphill between the two white circles

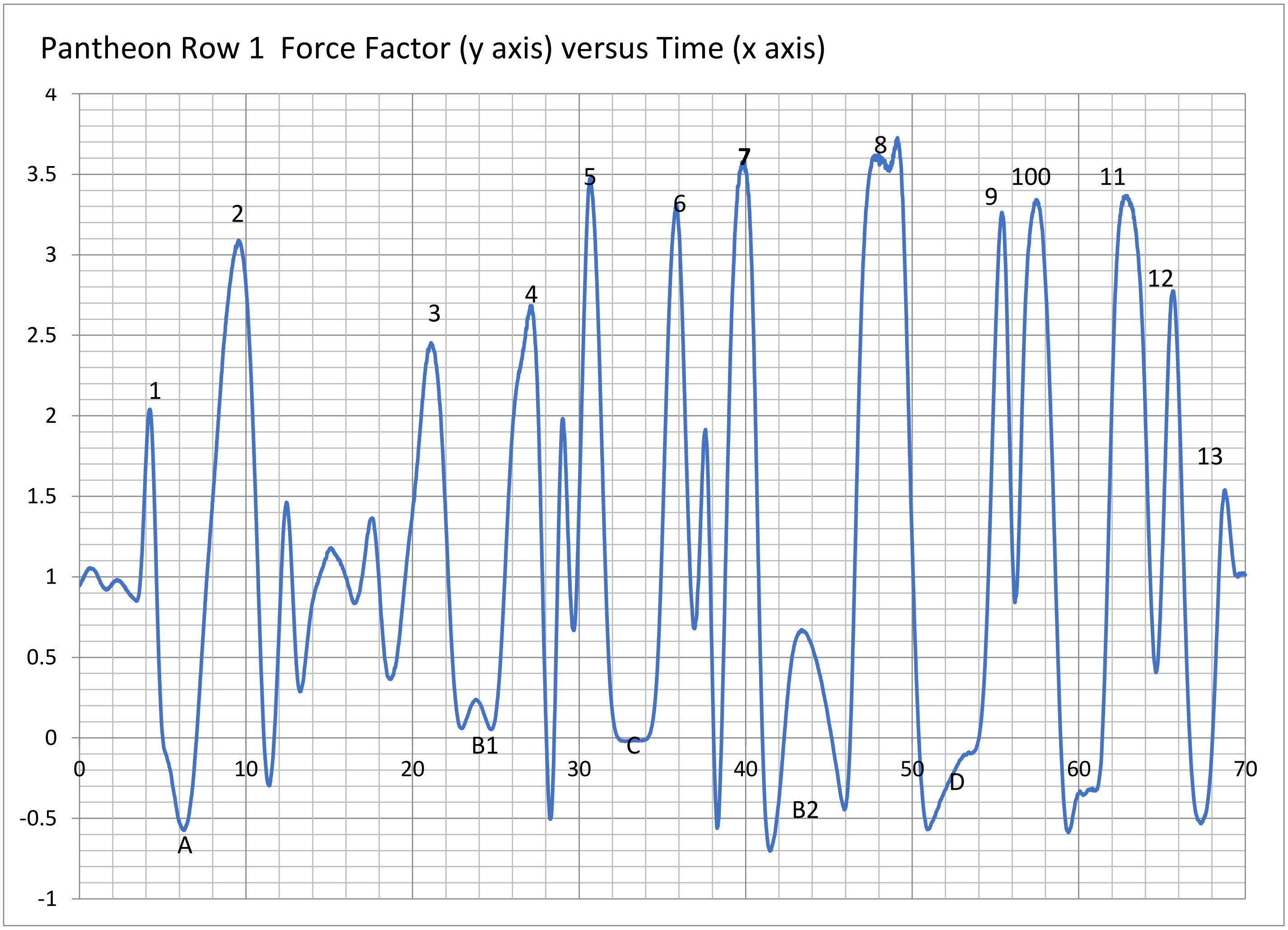
The factor factor graph below is of the coaster going backwards toward Hill C, the Pike.

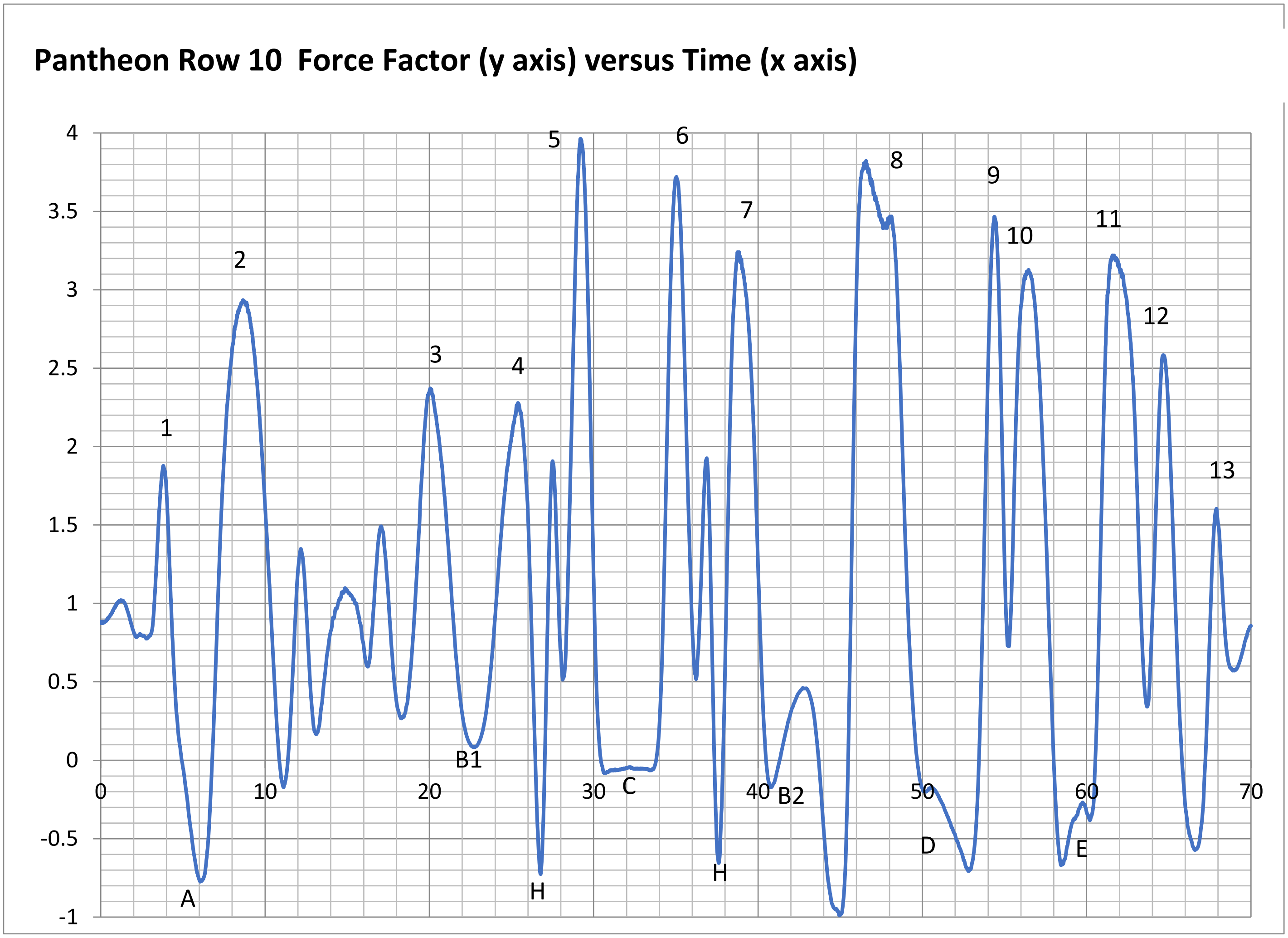


B is the bottom of hill B, C is the Bottom of hill C, and His the top of the hump between the two magnetic launches. Lis caused by the slight rise after the Hump. It's like half of a parabola. One magnetic launch occurs between Band H. The other magnetic launch occurs around the vicinity of L.

a. Do these launches feel the same when you are going backwards and when you are going forwards?
b. How do these launches compare to the first launch at the beginning of the ride. Which launches were the most intense?

6. From your observations and experiences on the coaster train at the tops of the hills, which coaster car was faster at the top and why. How does this affect the ride? Would car 10 or car 1 be a "better'' ride at the top, and why?
7. Compare your experience on Hilltop D and Hilltop E which is an inverted air time hill. Now look at both the row 1 graph and the row 10 graph. Which one has more airtime? Does the graph give you any hint that the coaster is upside down.





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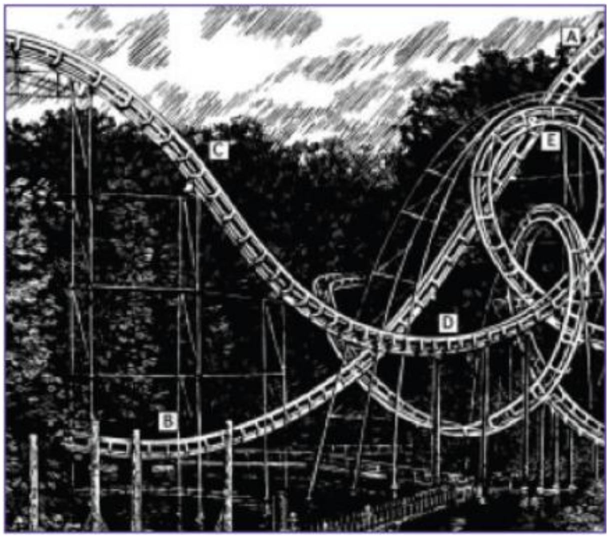
Vertical Acceleration
Loch Ness Monster



Instrument Needed: Stopwatch.

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

1. On the Loch Ness Monster you experience forces similar to those experienced by the space shuttle astronauts. What maximum force will you experience? (A force factor of 1, often called 1 g, is a force equal to your normal weight. 2 g's means twice your normal weight, etc.)

1.5 g 2.0 g 2.5 g 3.0 g 3.5 g 4.0 g 4.5 g 5.0 g 5.5 g 6.0 g

2. When you are upside down, will you ever lose contact with your seat? Yes No

3. When will you feel the lightest?

going down the hills in the valleys on the hilltops

WHAT TO DO AND NOTICE ON THE RIDE

1. Note where on the ride you feel heavy and where you feel the lightest.

2. Do you ever feel weightless?

3. Do you ever lose contact with your seat?

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WHAT TO DO AND NOTICE OFF THE RIDE

Measure the front to back time at the bottom of the first hill at point B. Also measure the front to back times at D and E. (Note: The post at point B in the middle of the lake has a green ring around it.)

DATA TABLE

Front to Back Times		#1	#1	#1	Average
	B				
	D				
	E				

Questions:

1. Where on the ride did you feel the heavy? Why were you heavy? Where did you feel the heaviest?

2. Where did you feel light on the ride? Why? Did you ever feel weightless?

3. When you were upside down, did you ever lose contact with your seat? Why?

4. Compute the velocities at points B, D, and E using the front to back times measured. The length of the coaster train (d) is 18.2 m. v= d/t. Convert to Miles/Hour using the following conversions:

1 hour=3600 seconds, 1 mile=1609 meters.

Velocity at bottom of hill (B) = __________ m/s=__________ miles/hr

Velocity at bottom of hill (D) = __________ m/s=__________ miles/hr

Velocity at top of loop (E) = ___________ m/s=__________ miles/hr

5. Given the radii of curvature at point B, D, and E, compute the force factors at these three points.

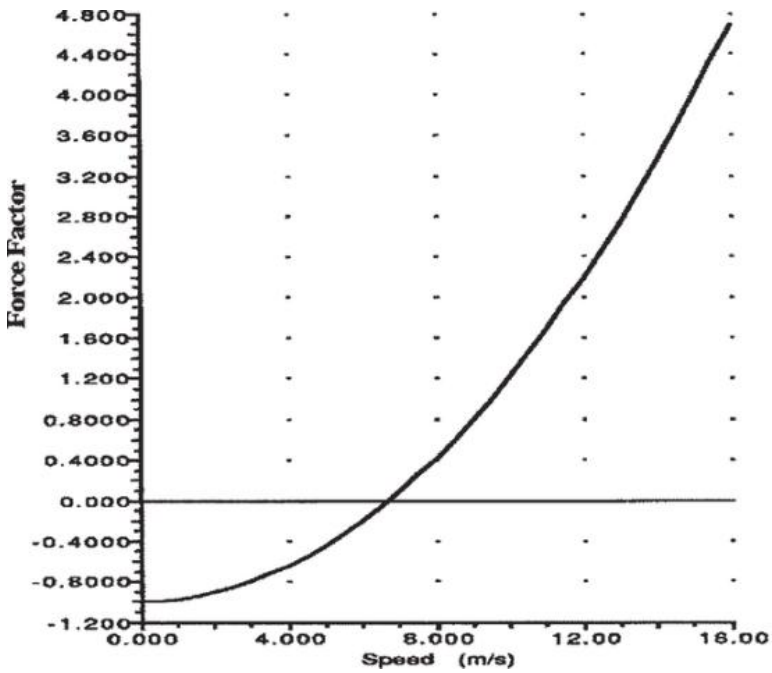
Radius at B= 30 m   Radius at D= 16 m   Radius at E= 4.6 m

Force Factors: B __________ D ___________ E __________

FF=1+(v^2/rg) Hill Bottoms   FF=(v^2/rg) -1 Tops of Loops

6. Where on the ride did you feel heavy?

7a. The graph below, based on Newton's Laws, represents the force factor as a function of velocity at the top of the loop. What is the minimum velocity required to get the coaster through the loop? What range of velocities would produce a light feeling at the top? What should the coaster designer use as the maximum velocity at the top?



Minimum Velocity __________

Range of Velocities__________

Maximum Velocity __________

7b. Using the speed at the top of the loop (E) computed in question 4, find the force factor from the graph.

8. The shape of the loop is called a Clothoid. It has a large radius of curvature at the bottom and a small radius at the top. To investigate what the loop would be like without a variable radius, first find the force factor at the bottom, if the radius at the bottom of the loop were the same as the top of the loop (4.6 m). Next find the force factor at the top of the loop, if the radius at the top were the same as the radius at the bottom (16 m). In both instances, use the velocities computed in #4.

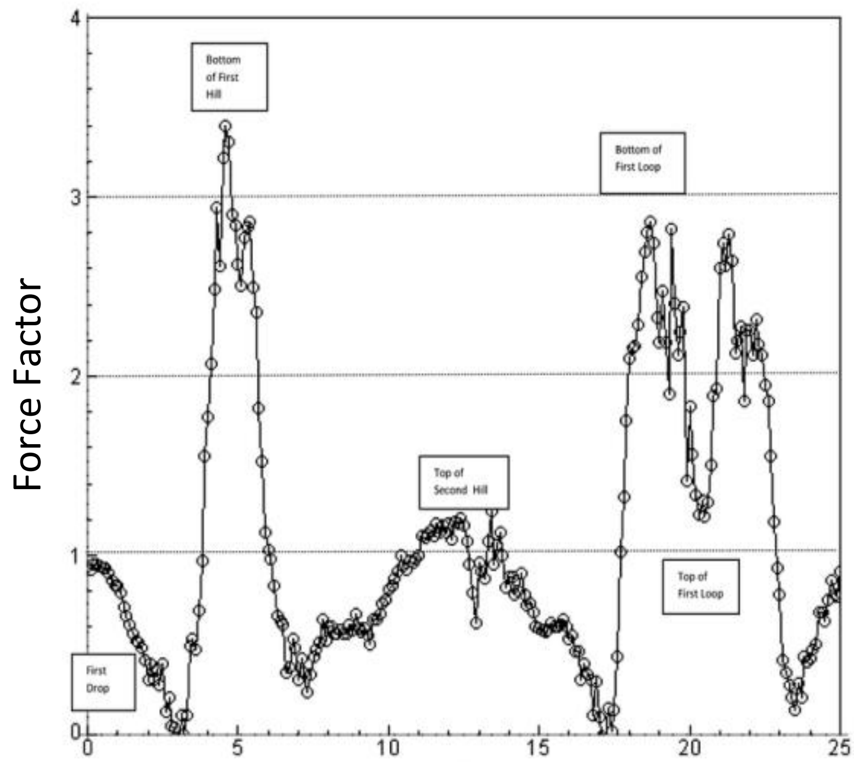
9. According to the CBL Force Factor graph** on the next page, what are the force factors at point B, D, and E? How do these compare to your calculations in question 5?

B __________ D __________ E __________

10a. According to the CBL Force Factor graph**, when do you feel light? Does this correspond to your experiences? How long does the graph indicate that you will feel light (FF<1)?

10b. What value of force factor would indicate that you would lose contact with your seat? Does the graph indicate that you will lose contact? Did you lose contact? If so, where?

11. According to the CBL Force Factor graph**, how long do you feel heavy at the bottom of the first hill? (Notes: We will define heavy as being a force factor of 1.5 or greater. The dots on the graph are 0.1 seconds apart.)



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BANKING ANGLE

DER WIRBELWIND

Instruments Needed: Stopwatch, angle measuring device.

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

1. How will the angle that an empty swing seat makes compare to that of a swing with a passenger? The empty seat will have:

same angle   smaller angle   larger angle

2 As you sit in the swing, does your body naturally align with the chains, or do you feel pulled toward the inside of the circle or pushed to the outside of the circle?

naturally aligns with chains   pulled toward center   pulled toward outside

3. As the swings go around, the top tilts so that you are going up part of the way around, and down part of the way. As you are on your way up, you feel:

heavier   lighter   normal

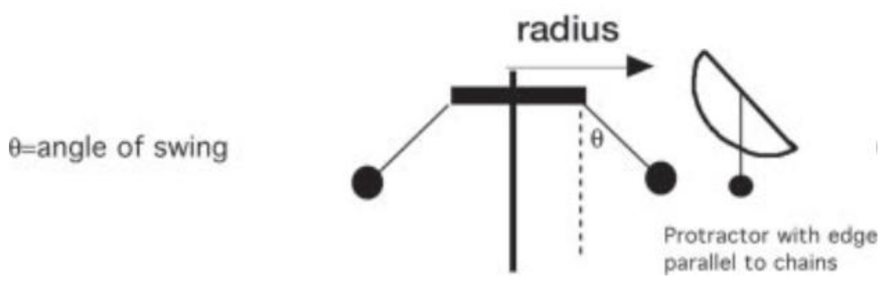
WHAT TO DO AND NOTICE ON THE RIDE

1. Do you feel heavy or light as you spin and are traveling upward?

2. Note how the angle your body naturally assumes compares to the angle of the swings. (Do you have to lean one way or the other to keep yourself parallel to the swing chains?)

WHAT TO DO AND NOTICE OFF THE RIDE

1. With an angle measuring device, find the average angle at which the swings hang relative to the vertical.



2. Find the revolutionary period of the swings, by waiting until it achieves full speed and then timing three revolutions and dividing by 3.

3. Notice the angle at which full and empty swings hang.

	#1	#2	#3	Average
Angle of Swing				
Time for Three Revolutions				

Questions:

1. Given that the radius of the outside swing is 9 meters when at maximum velocity, calculate the velocity of the swings.

velocity= circumference/period

velocity= __________

2. Determine the angle at which the swings should hang, based upon their velocity and radius, and compare this to the actual angle of swing. tan(angle)=v^2/rg

Comp Measured angle __________

% error between computed and measured values __________

3. Using this computed angle of swing, compute the force factor. How does this compare to how you felt?

Force factor= 1/cos(θ) = sqrt (1 + (v^2/rg)^2)

Force factor= __________

4. On Alpengeist roller coaster, the coaster train goes through a horizontal circle near the end of the ride called the High Speed Spiral. The radius of this spiral is 8 meters, and the velocity of the coaster train at this point is about 12.3 m/s. In order for the coaster train to successfully negotiate the turn, the track must be banked. The same force diagram and equations are used to find the banking angle of a coaster and the forces experienced, as you used for the swings. Compute the force factor and the banking angle.

Banking Angle (θ) __________

Force Factor __________

5. Do the empty swings hang at the same angle as the ones with people? Why?

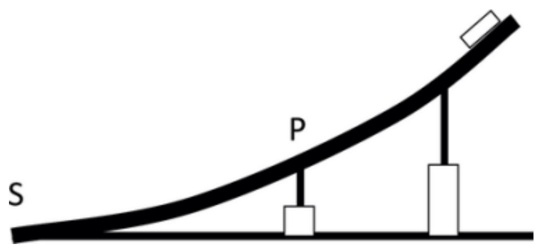
6. While Der Wirblewind was spinning, did your body naturally hang at the same angle as the swings? Did you feel any force toward the center or toward the outside of the circle of swing?

7. There are two kinds of motion in this ride: the standard rotation, and the changing tilt of the top. What difference does the tilt of the top make in ride experience?

Energy

Escape from Pompeii

Equipment needed: Stopwatch.



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

1. Estimate the speed of the boat at the bottom of the hill in mph. The hill is 15 m (5 stories) high.

5 10 15 20 25 30 35 40 45 50 55 60

2. A fully loaded boat will be faster slower about the same as partially full or empty boat

3. Which situation makes for the biggest splash?

empty boat fully loaded boat partially loaded boat all are the same

4. Which ride "loses" more of its energy going downhill?

A roller coaster A water ride like Pompeii

5. How much energy is "lost" coming down the big drop?

10% 20% 40% 60% 80%

WHAT TO DO AND NOTICE ON THE RIDE

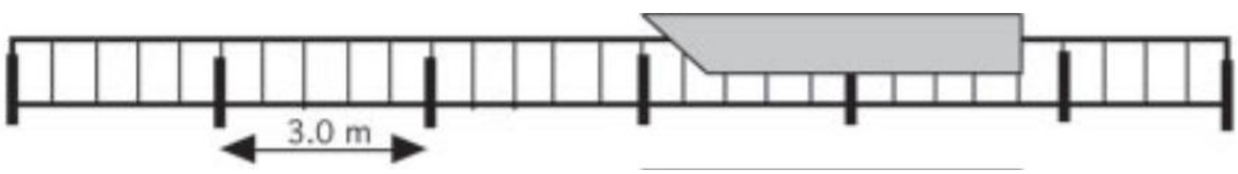
1. Note what happens to you at the bottom of the first drop. Do you feel pressed back into your seat or do you slide forward in your seat as if pushed forward? Is the force you experience greater than or less than that of the Le Scoot log flume?

WHAT TO DO AND NOTICE OFF THE RIDE

1. Time the boat from the lower steel beam (P), which is marked with a tan colored stripe, to the beginning of the splash (S). Start the stopwatch when the front of the boat reaches P, and stop it at the splash (S), at the bottom of the hill.

2. Are all the splashes the same size and duration? If not, what seems to make the difference? Is the force you experience greater than or less than that of the Le Scoot log flume?

3. Record the deceleration distance in meters. This is the distance that the boat travels during the splash, while it is slowing down to a constant speed. (Use the metal bars in the water, as illustrated below, to determine the distance. Every fifth bar has a bracket support.)



4. Pick a point some distance after the splash when the boat is moving at a constant speed, and time the boat past that point (Front to Back time).

	#1	#2	#3	Average
Time from P to S (in sec)				
Distance (d) of Deceleration (during the Splash) in meters				
Front to Back Time after the Splash				

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Questions:

1. Compute the average velocity of the boat at the bottom of the hill, by dividing the distance between P and S (12.5 meters) by the average time. Convert to miles/hour by using the following conversion factors: 1 mile=1609 meters 1hour=3600 seconds.

Velocity= 12.5 m/ (sec)= ___________ m/s = ___________ mph

2. According to the energy conservation, the potential energy at the top of the hill (mgh), should equal the kinetic energy at t __________). The hill is 15.0 meters high, and __________ . If we assume that the velocity at the top of the hill is small, and set these two energies equal to each other, you can solve for the velocity at the bottom of the hill. 1/2 mv^2 =mgh

Predicted velocity= m/s

3. Compute the percentage of the initial energy (potential energy at the top of the hill= mgh) that was not converted to Kinetic energy at the bottom of the hill (Final energy=.5mv^2) Use velocity from Q#1.

(Initial Energy-Final Energy)/Initial Energy * 100 % = __________ %

4. What happened to this energy that was "lost?"

5. The Alpengeist roller coaster is reported to have a velocity at the bottom of its first hill of 67 mph (30.0 m/s) The height of its hill is 49.4 m. Assuming a small speed at the top of the hill, what are the energy "losses" on the Alpengeist?

(Initial Energy-Final Energy)/Initial Energy * 100 % = __________ %

6. What factors seem to determine the size and duration of the splash at the bottom of the hill? Why do these factors make a difference?

7a. Compute the force factor experienced by the riders at the splash.

According to the conservation of energy, if there are no changes in potential energy, Work= Change in Kinetic Energy, where Work= F*d = Force * Distance of splash First compute the velocities before and after the splash.

v(before) was computed in question #1 __________ = Distance of splash= __________

v(after)= length of boat/front to back time= __________

Length of boat= 5.4 m

Using these velocities and the splash distance, compute the force factor.

F*d=1/2 mv(before)^2 - 1/2 mv(after)^2

If both sides are divided by mgd, then Force factor=v(before)^2 - v(after)^2)/2dg where F/mg is the definition of force factor. Force factor = __________

7b. How is this force factor different from that experienced on the roller coasters? How does it compare to your experience on the log flume?

8. From your observations, does an empty (or partially full) boat have the same speed at the bottom as a full boat? Why?

9. Did you feel pressed back into your seat, or did you slide forward at the bottom of the hill? Why?

10. Heat energy is transferred by one of three methods: convection, conduction or radiation. As your boat tours the ruins of Pompeii, which of these three methods provides the predominant means of heating you?

Convection Conduction Radiation

Power, Energy and Acceleration

Loch Ness Monster

Equipment Needed: Stopwatch, Angle measuring device.

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

1. A fully loaded coaster consists of 7 cars (914 kg/ car) and 28 people. An electric motor drives a chain that lifts the coaster up to the top of the first hill. How powerful must the motor be?

25 horsepower (19 kw) 125 horsepower (93kw) 400 horsepower (298 kw)

2. How much energy is lost to heat as the coaster plunges down the first hill?

5% 15% 25 %

3. Which of the coaster cars gets from the top of the hill to the bottom the quickest?

first car last car both the same

WHAT TO DO AND NOTICE OFF THE RIDE

1. Measure the front to back time at the bottom of the first hill. (If you have already have this data, then just copy it into the data table.) The reference post at the bottom of the hill is marked with a green stripe.

2. Measure steepest angle of descent of the first hill. This is best done on the bridge between Germany and Italy.

3. Time the first car from the top of the hill (point where the net ends) to the bottom (lowest point in the middle of the river, marked with the green stripe). Time the last car between the same two points. (Hint: These times are greater than 2 seconds.)

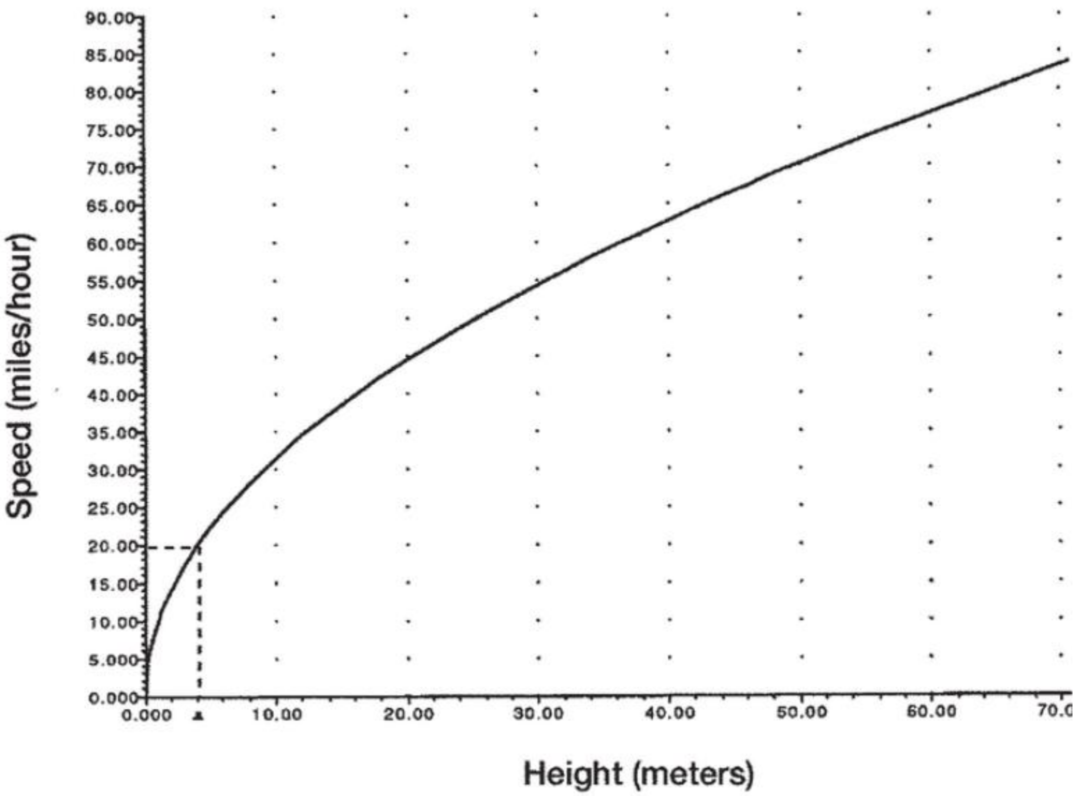
4. Time the ascent of the coaster as the chain pulls it up the lift hill.

	#1	#2	#3	Average
1. Front to Back at the Bottom of the Hill				
2. Angle of Descent				
3a. Top to Bottom of Hill: First Car				
3b. Top to Bottom of Hill: Last Car				
4. Time of Ascent				

Questions:

The graph based on kinematics below shows how the speed of a coaster depends on the height of the first hill. The dotted lines indicate how to find that 20 mph corresponds to a height of 4 meters.

The height of the first hill determines the total energy of the coaster. As it comes downhill it converts this gravitational potential energy to kinetic energy or energy of motion. The graph is based upon a negligible speed at the top.



1a. The Loch Ness Monster hill is 34.8 meters tall. According to the chart, what should be the speed at the bottom?

1b. Compute the speed at the bottom using the front to back time measurement, and then convert to mph by using 1 hour=3600 seconds and 1 mile=1609 meters.

speed at bottom of the hill = 18.2 m/ (__________ sec) = __________ m/s = __________ mph

1c. Compute % error between answers 1a and 1b above. % error Use 1a as the standard.

1d. Explain any difference between the speed computed with the graph and the speed computed with the front to back time.

2. List the hill heights required for the following speeds. List the heights to the nearest meter.

20 miles/hour h= 4 meters 40 miles/hour h= __________

40 miles/hour h= __________ 60 miles/hour h= __________

80 miles/hour h= __________

3. How high would a hill have to be to have a speed of 120 miles/hour? (Hint: Note how many times higher is a 40 mph hill compared to a 20 mph hill. Also note how many times higher is an 80 mph hill compared to a 40 mph hill.)

72 m (236 ft) 108 m (354 ft) 144 m (472 ft) Do you think that this will ever be built?

4. Given the following information in addition to the data that you gathered, find the percentage of energy that is lost to heat as the coaster comes down the first hill:

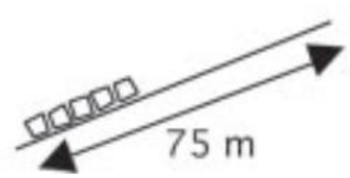
Mass of coaster= 6400 kg
Mass of 28 People (estimate) __________
Height of first hill above the river= 34.8 m
Velocity of the coaster at the top of the hill=5.7 m/s
Percentage of total energy lost = __________

5. Using the time of descent for the first car along with the initial velocity at the top of the hill (5.7 m/s) and the velocity computed at the bottom of the hill, compute the average acceleration of the first coaster car. How does this compare with the theoretical velocity based on the angle of descent? Why will the computed acceleration of the last car be different?

Acceleration (First Car)= __________ Theoretical Acceleration(first car) __________

6. Using the time of ascent, the length of the incline (75 m), the angle of ascent (25 degrees) and the mass of the coaster train and passengers, compute the power that the motor must have to lift the coaster train up the hill. (See Question 4)

Power = __________



7. Was the top to bottom time for the first car significantly different from the top to bottom time of the last car? If so, why?

Oscillations

Battering Ram

Instruments Needed: Stopwatch, Angle measurement device, Mounted accelerometer.

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

1. Where should you sit on the Battering Ram to experience weightlessness?

   in toward the middle   on the extreme edges

2. The ship is going fastest when the

   center of the ship is at the lowest point   edges of the ship are at the lowest point

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Sitting in the extreme seat on the left side, make three measurements of the maximum force factor.

2. Sitting in a middle seat (right hand side), make three measurements of the maximum force factor.

3. Notice where you are when you experience a “weightless” sensation. Ride part of the ride with your eyes closed.

	#1	#2	#3	Average
Force Factor in Extreme Seat				
Force Factor in Middle Seat				
Period of Oscillations				
Maximum Angle with Vertical				

WHAT TO MEASURE AND NOTICE OFF THE RIDE

1. Measure the period of the oscillation. (Time the boat from its highest point on one side, until it returns to this position on the same side.)

2. Notice where people scream, or their hair flies up.

3. Measure the maximum angle that the center of mass makes with the vertical.

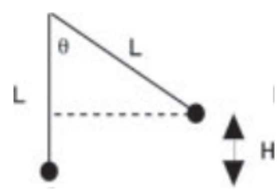
DATA TABLE

Period of Oscillation				
Maximum Angle with Vertical				

Questions:

1. Find the velocity at the bottom by using the Law of Conservation of Mechanical Energy. The radius (L) of the Ram's swing is 12.8 m. H is the maximum height of the center of mass.

H= __________ V= __________



2a. Compute the force factor at the bottom of the swing. The force factor is computed in the same way as the force factor at the bottom of a roller coaster hill. FF= v^2/rg +1

FF(computed) = __________

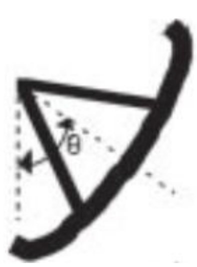
2b From the CBL graphs** at the end of this section, find the maximum force factor. Are these force factors close? Why or why not?

FF (from graph) = __________

2c. How does your force factors for the middle seat compare with the computation?

2d. How do your two maximum force factors compare with the corresponding force factors on the CBL graphs?

2e. If there is a difference between the maximum force factors for the middle and extreme seat, explain why.



3a. Compute the Period of Oscillation using the basic pendulum equation.

$$T = 2\pi\sqrt{L/g}$$

T= __________

3b How does this compare to your measured value? How would you explain the differences?

3c. What is the period obtained from the CBL Force Factor graph**? How does this compare to your measured time?

4. When does the Battering Ram experience maximum velocity? Is this the same point that the maximum force is experienced?

5a. Where on the ride do you experience weightlessness? Why are you weightless at this point?

5b. In which seating position (middle or extreme edges) will passengers experience more weightlessness? Explain.

5c. According to the CBL Force Factor graphs**, what is the minimum force factor experienced in the extreme seat? What is the minimum force factor experienced in the middle seat?

extreme seat __________ middle seat __________

5d. Why does the extreme seat graph look so different from the middle seat graph?

6. Does riding with your eyes closed make any difference in the sensations experienced?

7. Where do people scream? Why?

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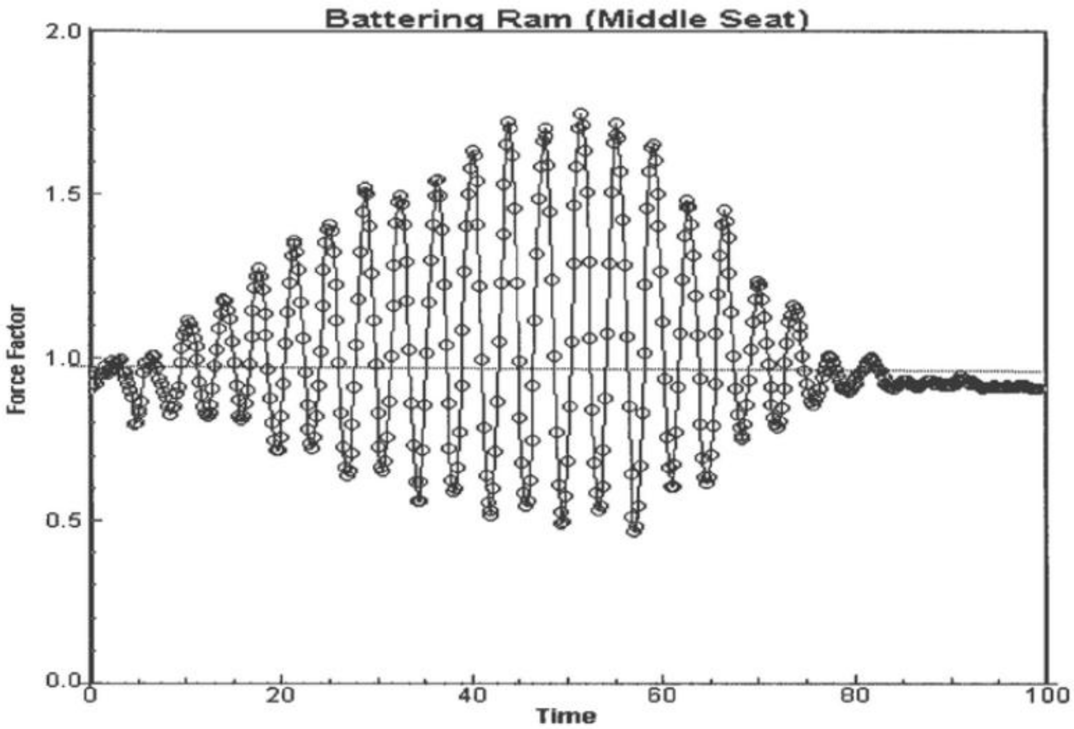

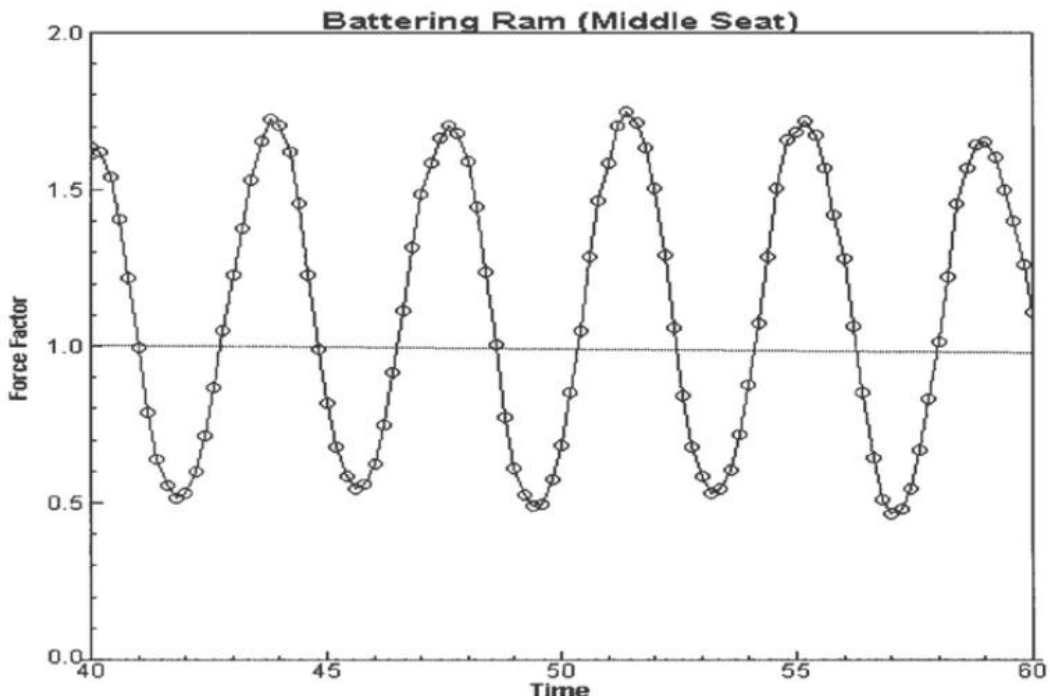

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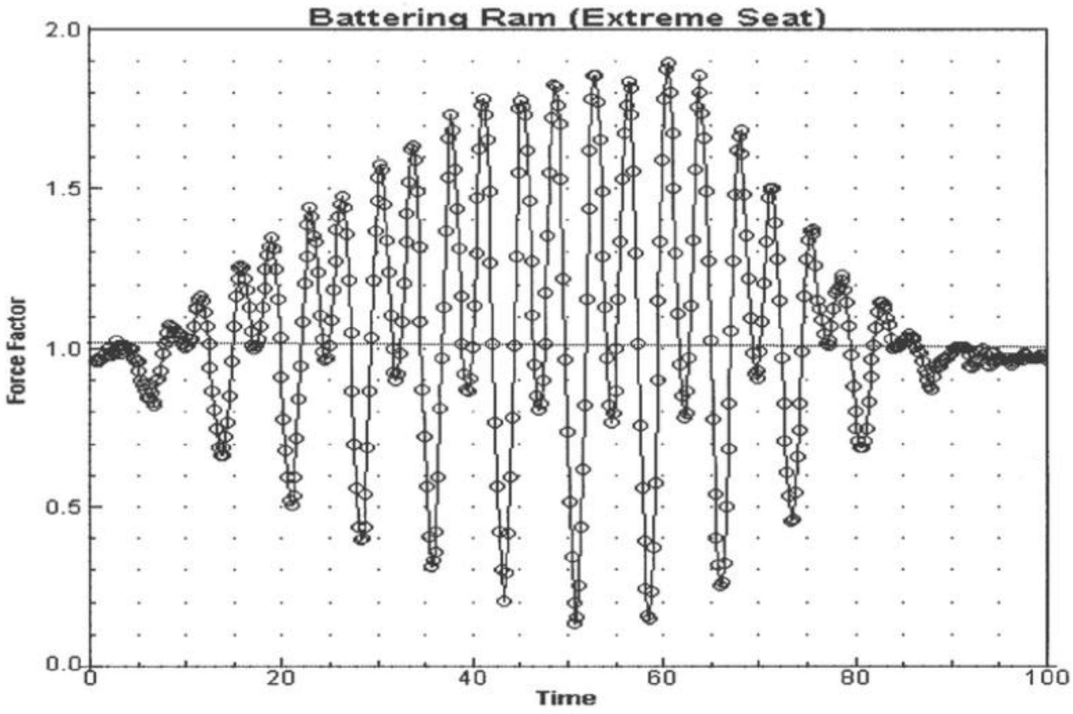

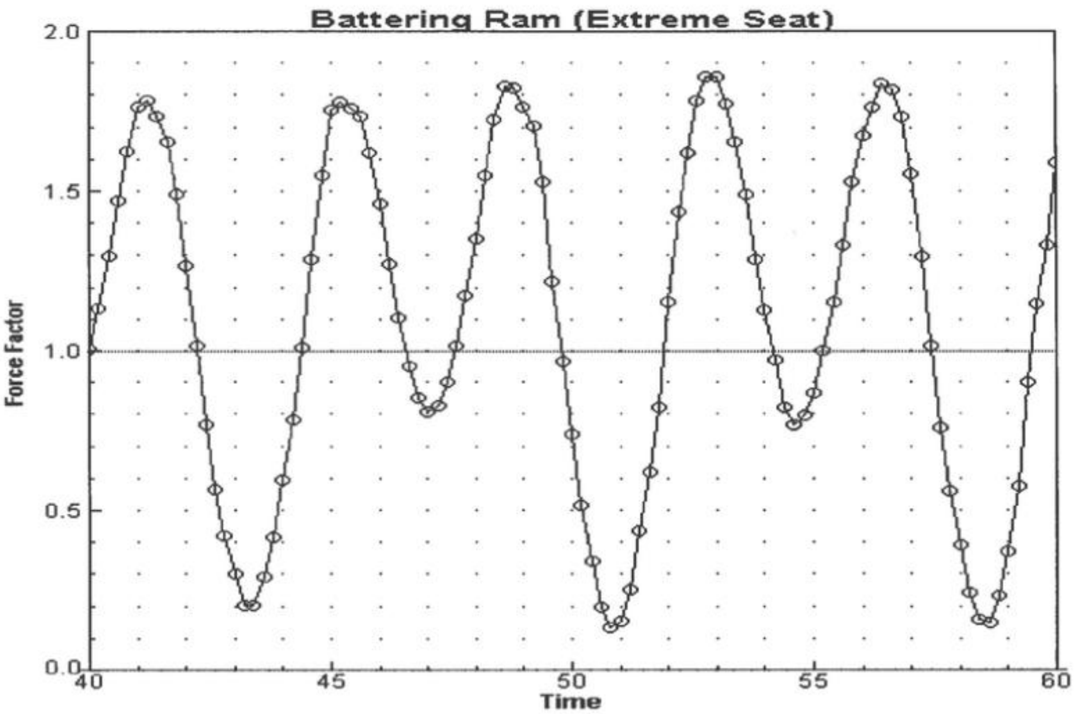

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Miscellaneous

Alpengeist

Instruments Needed: Stopwatch, Mounted vertical accelerometer. (Sit in Row 6.)

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

1. Will you leave your seat or feel upside down when you are inverted 106 ft (32 m) above the ground in the vertical loop?

leave your seat   feel upside down   neither

2. Where will the lightest feeling on the ride be experienced?

The First Hill (Between 2 and 3   The Immelman (4)

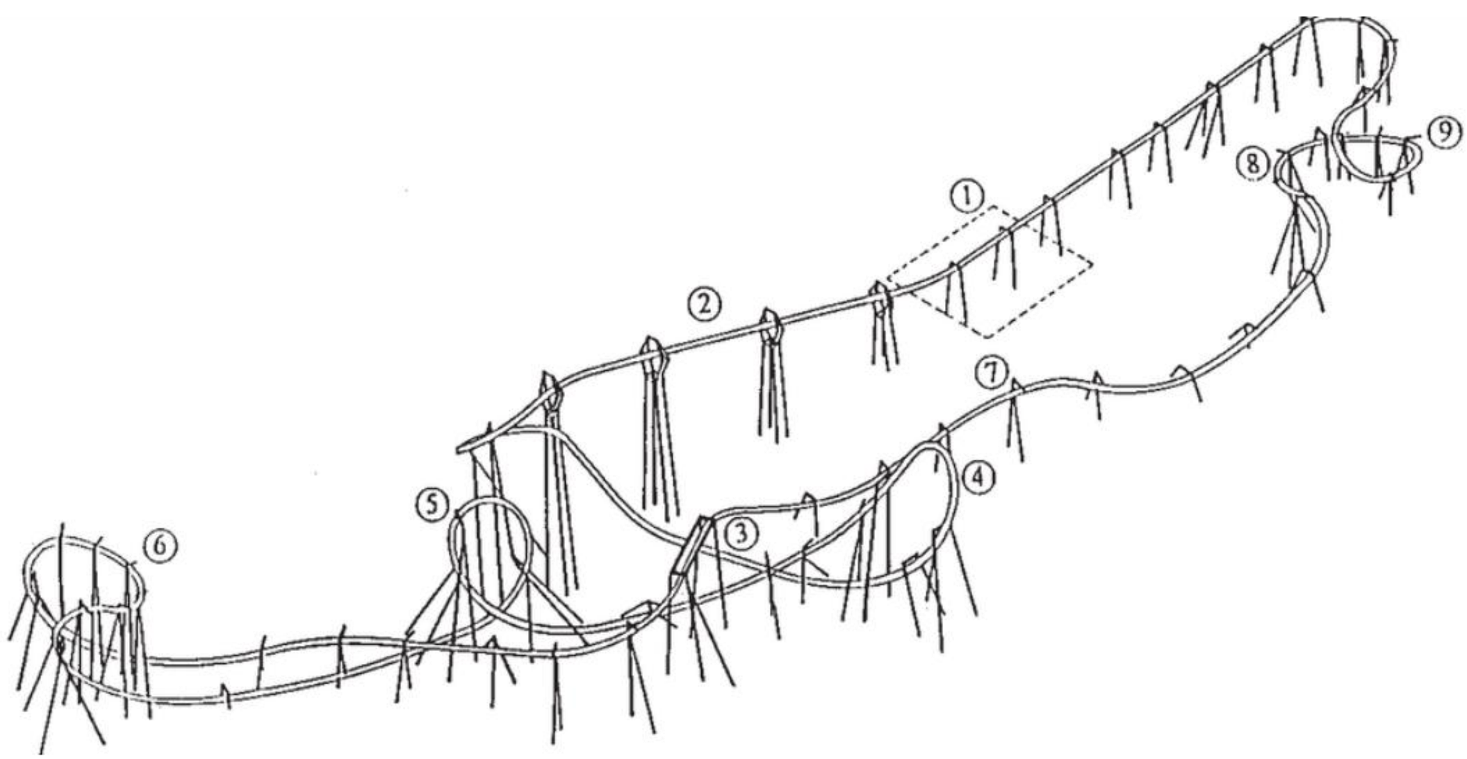
The Vertical Loop (5)   The Cobra Roll (6)

The Camelback Hump (7)   The Flat Spin (Pancake Flip) (8)

The High Speed Spiral (9)

3. Where on the ride will you experience the greatest banking angle?

(3)   (4)   (5)   (6)   (7)   (8)   (9)



WHAT TO MEASURE AND NOTICE ON THE RIDE

1. On all of the inversions, notice whether you feel light, heavy or normal.

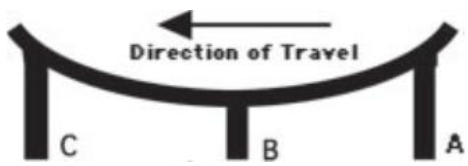
2. Do you ever leave your seat or feel upside down?

3. Record the force factor at the bottom of the first hill, at the bottom of the second hill and at the top of the vertical loop.

WHAT TO MEASURE AND NOTICE OFF THE RIDE

	#1	#2	#3	Average
Force Factor at Bottom of First Hill				
Force Factor at Bottom of Second Hill				
Force Factor at top of Vertical Loop				
Time between Posts A and C				
Front to Back Time at Top of Loop				

1. With a stopwatch, time the coaster between posts A and C at the bottom of the first hill. B is the column that is attached to the track near its lowest point, and A and C are the first columns to the left and right of the post B. Columns A and C are marked with a white stripe at their bottom. This can be best viewed from deck next to where the drinks are sold. It may also be viewed from the covered bridge.



2. In the vertical loop (5), record the time between the front car arriving at the top of the loop and the end of the back car arriving at the top of the loop. This is called a front to back time. (This may be viewed from a number of different places including the deck by the drink stand and the covered bridge.)

3. Pay attention to where on the ride the coaster cars are flung outward at an angle.

	#1	#2	#3	Average
Time between Posts A and C				
Front to Back Time at Top of Loop				

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Questions:

1. Compute the speed of the coaster at the bottom of the first hill. Convert to miles per hour by using 1mile=1609 meters and 1 hour=3600 seconds. The distance between posts A and C is 24 meters.

Velocity at hill bottom = __________ m/s = __________ mph

2. Compute the speed of the coaster at the top of the vertical loop. The length of the coaster train is 11.6 meters.

Velocity at top of loop = __________ m/s = __________ mph

3a. Given that the radius of curvature at the first hill bottom is 44 meters, and the radius of the top of the loop is 7.0 meters, compute the force factors.

Force Factor (bottom of first hill) __________ Force Factor (top of vertical loop) __________

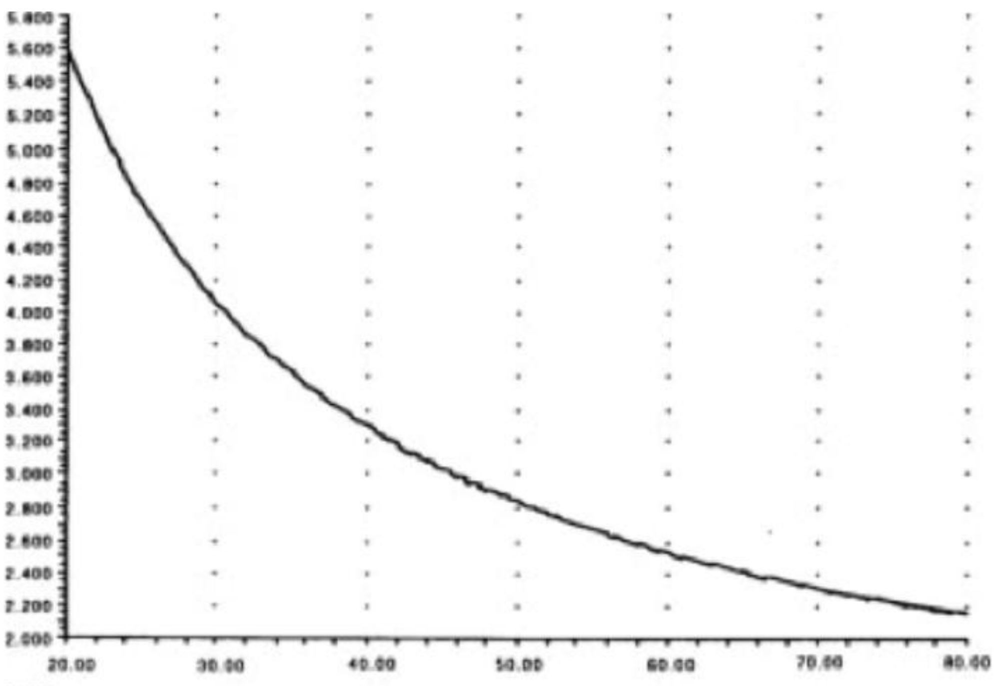
Hill bottoms FF= v^2/rg + 1 Tops of loops FF= v^2/rg -1

3b. From the CBL Force Factor graph** on the page following question 8, find the force factors at the bottom of the first hill and at the top of the loop. Are these two sets of force factors close to the computed values? Why or why not?

Force Factor (bottom of first hill) __________ Force Factor (top of vertical loop) __________

3c. Compare your measured force factors for the bottom of the first hill and the top of the vertical loop, to the CBL and your computed values.

The following graph, based on Newton's Laws, illustrates the relationship between the radius of curvature at the bottom of a hill and the force factor for a coaster with a maximum speed of 67 mph.



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3d. Also compare your measured force factor at the bottom of the second hill to the CBL value.

4a. According to the graph, what radius of curvature corresponds to the force factor that you computed in question 3 for the bottom of the first hill?

4b. Does the force factor double when the radius of curvature is cut in half? If not, why not?

4c. What number does the force factor approach when the radius becomes extremely large? (Hint: FF= 1 + v^2/rg.) How large would the radius have to be to equal that number?

4d. What do you think should be the maximum force factor at the bottom of the hill? What radius of curvature corresponds to this force factor?

5. Are there other places on the ride, other than the high-speed spiral (9), where there is a banking angle? Which place has the greatest banking angle? (Alpengeist is an inverted coaster. On a suspended coaster the cars are allowed to swing, but an inverted coaster's cars must hang at the same angle as the track.)

6a. Discuss the differences in the inversions. Did you ever feel upside down? Did you ever leave your seat? At which point on the ride did you feel the lightest?

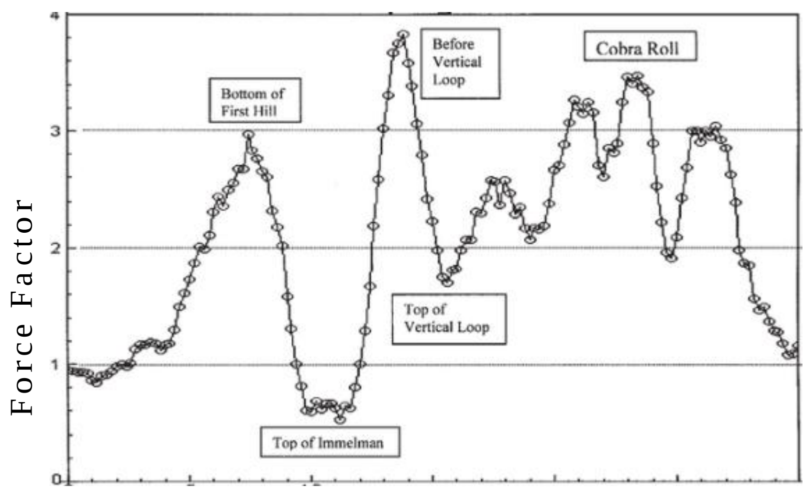
6b. According to the CBL Force Factor graph** following question 8, which of the inversions had the lowest force factor? Which inversion had the greatest force factor? Is there an inversion where you would leave your seat? How does this match your experiences?

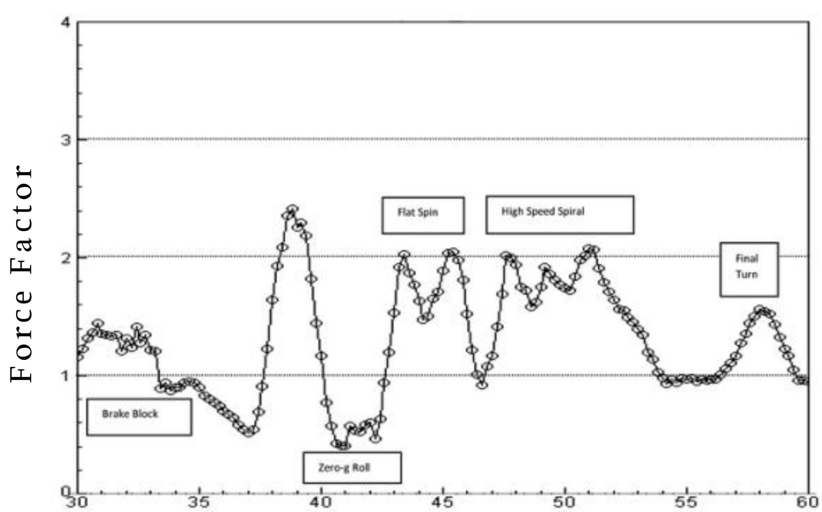
Comparisons

7a. The radius of curvature of the bottom of the second hill of the Loch Ness Monster is only 16 meters. Why isn't the force factor at this point excessively large?

7b. Why is the force factor at the bottom of the first hill on Alpengeist less than that at the bottom of the first hill of the Loch Ness Monster, even though Alpengeist is going about 7 mph faster?

7c. The vertical loop of Alpengeist (106 ft or 32.3 m) is almost twice as high as the vertical loops on the Loch Ness Monster (57 ft or 17.4 m). These are clothoid loops with a variable radius. On Alpengeist the radii are 30.5 m at the bottom and 7.0 m at the top, while the Loch Ness has a radius of 16 m at the bottom and 4.6 m at the top. What would happen if you put the Loch Ness Monster Loop on Alpengeist and vice versa?





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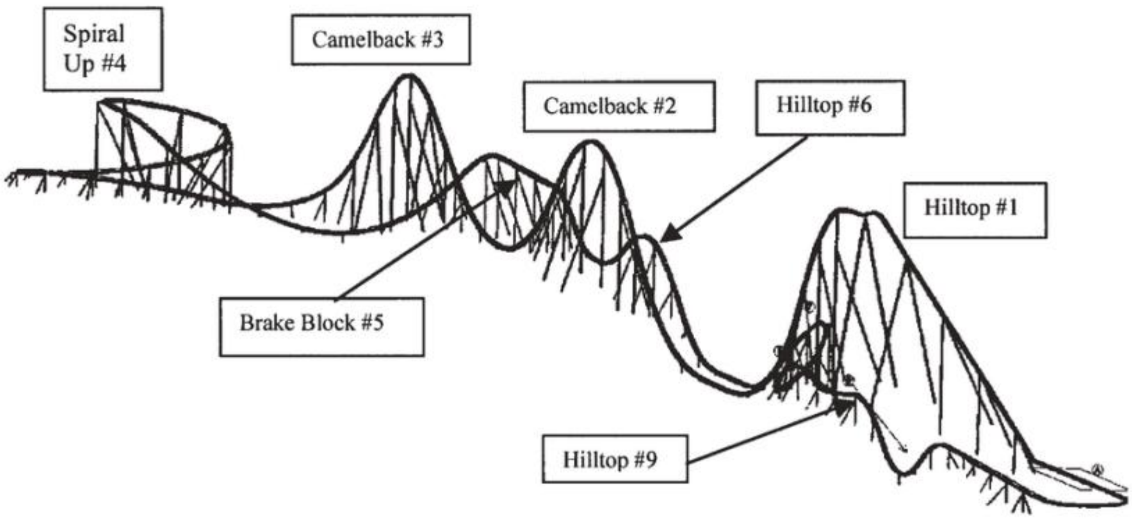
MISCELLANEOUS-
ENERGY, VERTICAL ACCELERATION, BANKING ANGLE
APOLLO'S CHARIOT

Instrument Needed: Mounted vertical accelerometer. Sit in Row 6.



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

1. What is the average speed of the ride (from the top of the first hill to just after the last dip following hilltop #9)?

   20 mph   30 mph   40 mph   50 mph   60 mph

2. How much energy is dissipated (turned into heat) before the coaster reaches the brakes at the end of the ride?

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

3. Which ride is the most "intense"?

   front row   middle   row last row

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Ride near the front and near the back and pay attention to the differences in the ride.

2. In the spiral up portion of the ride, focus on the banking angle and force factor. Do they stay the same or change dramatically?

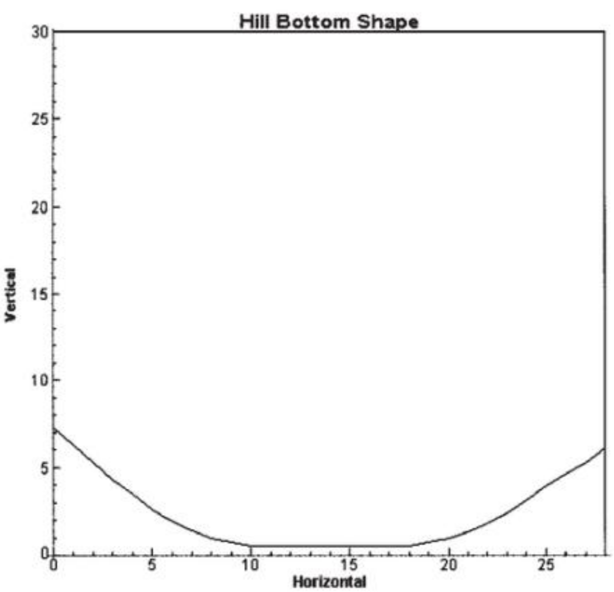
3. Record the force factor at bottom of the first hill, the bottom of the second hill and the last dip (just before the coaster gets slowed down by the brakes).

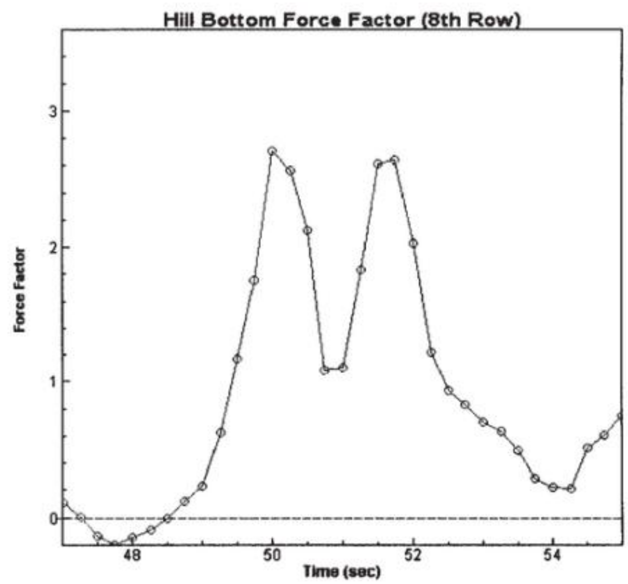
4. Notice the approximate value of the force factor in the spiral up portion of the ride (where it turns around to come back.) Also notice whether it is increasing, decreasing or staying the same.

	#1	#2	#3	Average
Force Factor at Bottom of First Hill				
Force Factor at Bottom of Second Hill				
Force Factor at Last Dip				

Questions:

1. The graph* on the left shows the coaster track at the hill bottom following hilltop #6, with the dimensions expressed in meters. The CBL graph** on the right shows the force factor experienced at that hill bottom (This force factor graph begins with the previous hilltop and concludes with the next hilltop.)





This graph is only an approximate representation of the actual coaster.

a. Why is there a dip in the force factor at 51 seconds?

b. The value of the dip is approximately one, but the force factor remains at one for only a fraction of a second. Why?

c. What does this force factor of one indicate about the experience of the passengers at this point? There are three other places on the ride where the force factor is approximately one for at least a second. Where are they? Use the CBL Force Factor graphs** on the page following question 12.

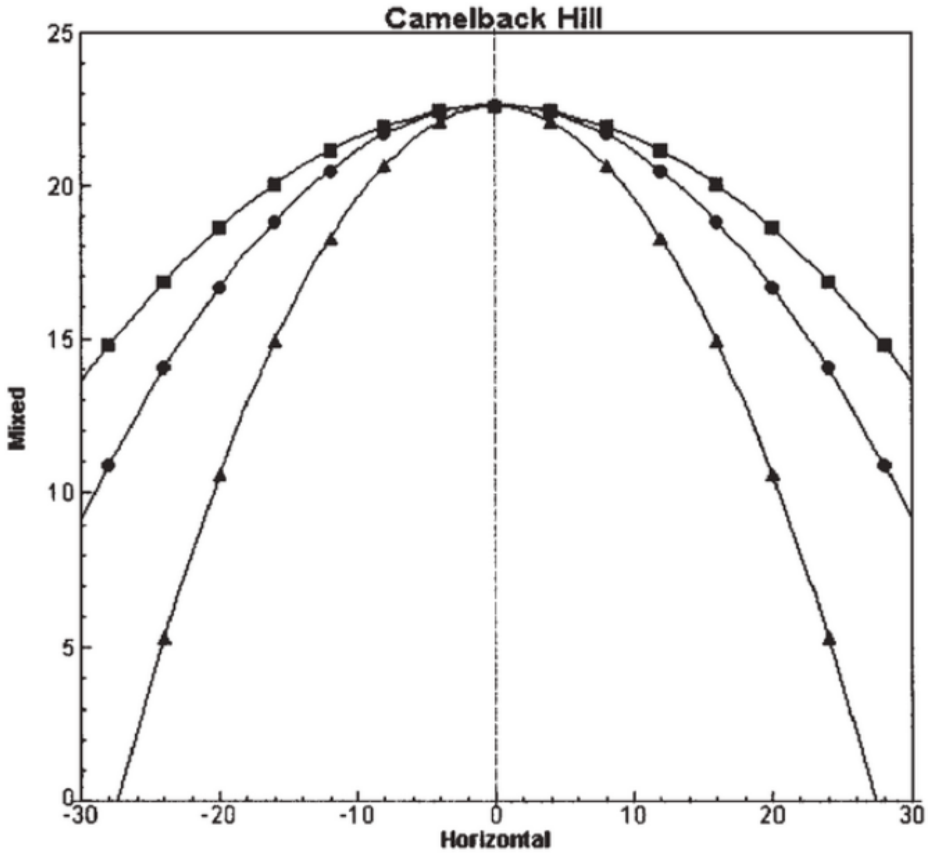
2. The thrills of a roller coaster ride come with accelerations. Being pressed into your seat (high force factor) or experiencing "air time" (low force factor) is exciting. How many seconds is the factor high (greater than 2)? How many seconds is the force factor low (less than 1)? Use either the 2nd Row or 8th Row CBL graphs** for the measurements.

Greater than 2 __________ Less than 1 __________

3a. Which one was designed for the largest speed at the top (circle, square, triangle)?

3b. If the coaster is going faster at some point on the camelback hill than the middle car would go at that point, the force factor for that car will be (less than, greater than) the force factor of the middle car at that point.

3c. If the coaster is going slower at some point on the camelback hill than the middle car would go at that point, the force factor will be (less than, greater than) the force factor of the middle car at that point.



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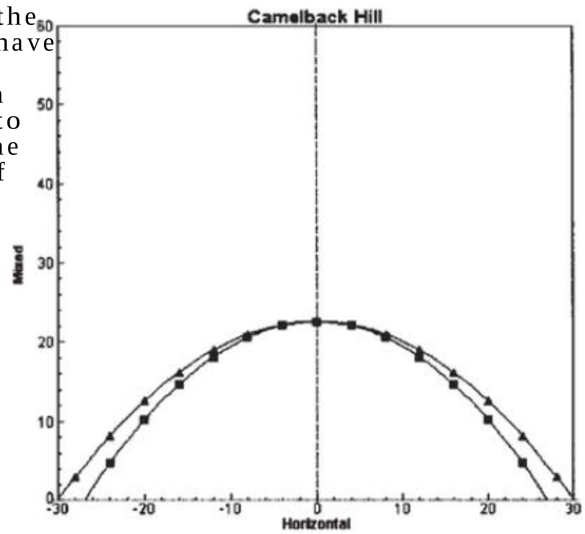
3d. The camelback hills on Apollo's Chariot are all designed to have the same approximate speed at the top (+/- 2mph of the average), and thus they all have a similar shape. The graph to the right shows the similarities in shapes between the highest and lowest speeds How is it possible to have the speeds be the same, considering all of the energy that is lost throughout the ride because of friction?



4. After coming down camelback hill #3, the coaster begins a spiral up. The coaster goes through about 540 degrees (a circle and a half), as it takes about 7 or 8 seconds to go uphill on a track of constant slope.

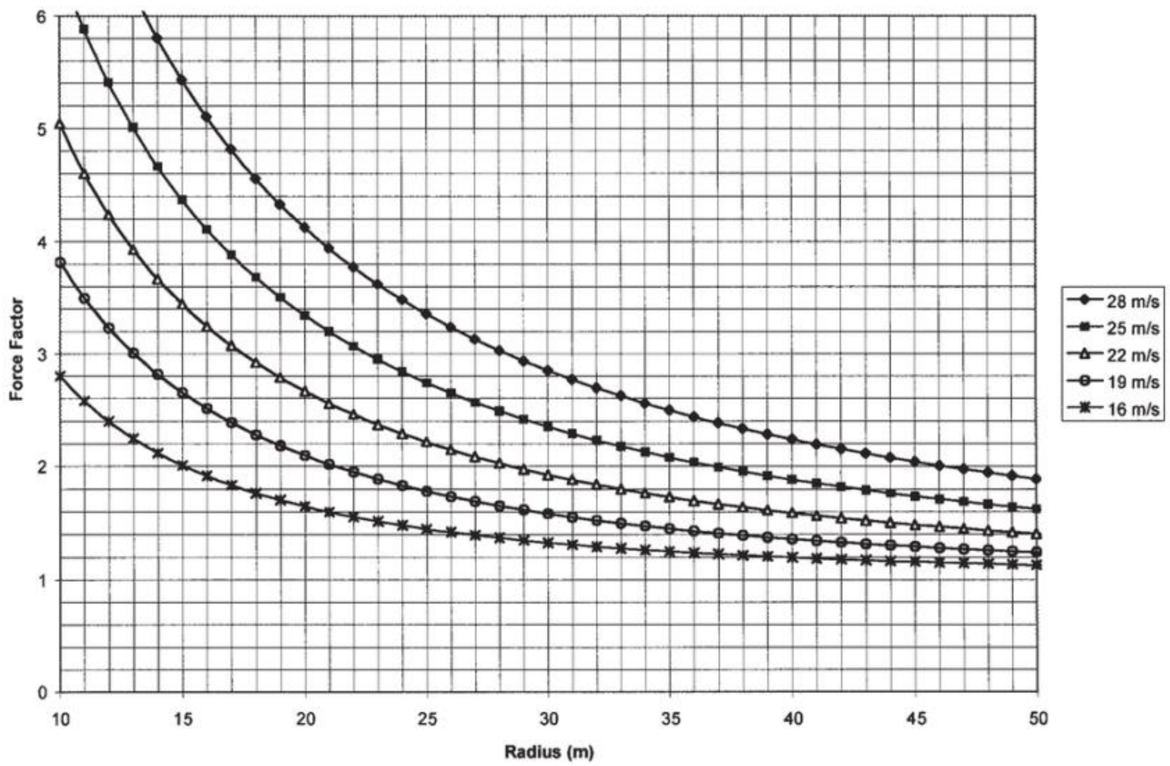
a. In your experience, did the force factor and banking angle (stay about the same, increase, decrease) as the coaster went up the hill?

b. The radius at the bottom of this spiral is 40 m and then it decreases gradually until the curve at the top of the spiral has only a radius of 16 m. Why does the curve decrease in radius?

c. Compute the force factor experienced at the bottom, if the speed is 28 m/s. What is the banking angle at this point?

d. The top of the spiral is about 27m higher than the bottom. Using energy conservation, find the speed at the top. Compute the force factor experienced at the top, and the banking angle.

6. The graph below, based on theory, indicates the force factor experienced when a coaster rounds a corner (or goes in a horizontal circle). It shows the force factor as a function of the radius, for a fixed speed. There are five curves, each representing a different fixed speed.



a. What does the force factor approach, as the radius gets very large?

b. What is the minimum radius that should be considered for spiral up at the bottom of the hill where the speed is 28 m/s?

c. In order to keep the force factor the same as a coaster goes in a circle, while going uphill, the radius must change. This is because the speed will be changing. Give the radius that would be needed at each speed to produce a force factor of 2.2.

Radius (28m/s)= __________ Radius (25 m/s)= __________ Radius (22 m/s)= __________

d. What happens to the force factor if the radius stays the same as the coaster goes uphill while the speed decreases?

Give the force factor for each speed, with a fixed radius of 25 m.

FF(28 m/s)= __________ FF (25 m/s)= __________ FF (22 m/s)= __________

FF(19 m/s)= __________ FF (16 m/s)= __________

7. How does riding in the front car differ from riding in the back car? Use the two CBL force factor graphs** and information obtained by riding in both the front and the back cars to answer this question. Which is the "more intense" ride, the front or the back?

8. What is the average speed of the ride? (The time from the top of the first hill to just after the last dip is 66 seconds. The total distance traveled in this time is about 1220 m.) Convert this to miles/hour, given that 1mile=1609 m.

9a. Given the following approximate radii of curvature and speeds, compute the force factor for the following three locations.

First Hill: radius=45.6 m speed=32.6 m/s Force Factor= _________

Second Hill: radius=37.0 m speed= 28.1 m/s Force Factor= _________

Last Dip: radius 17.0 m speed= 19.6 m/s Force Factor= _________

9b. Using the 8th row CBL data, list the force factors for the same three places.

first hill __________ second hill __________ last dip __________

Radius (19m/s) = __________ Radius (16m/s) =__________

9c. Compare your accelerometer measurements to the CBL data and the computations. Are they close? If not, why not?

10a. This ride is called a hypercoaster, because of its high speeds and thrills. The drops on Apollo's Chariot, are listed below (Drop #1 follows Hilltop #1)

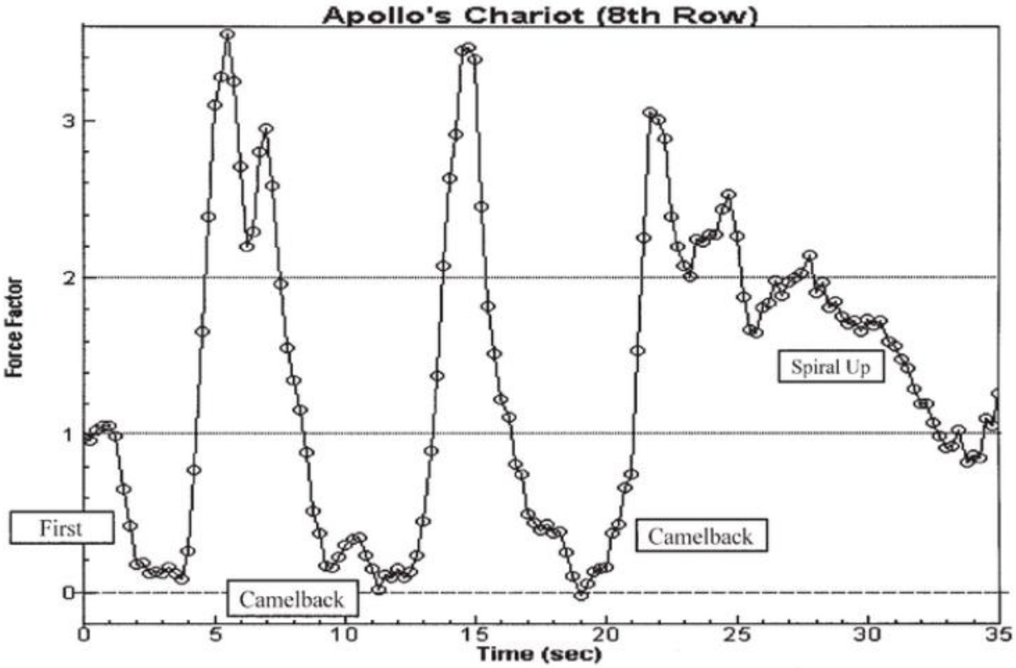
1. 64 m 2. 40 m 3. 44 m 4. 31 m 5. 15 m

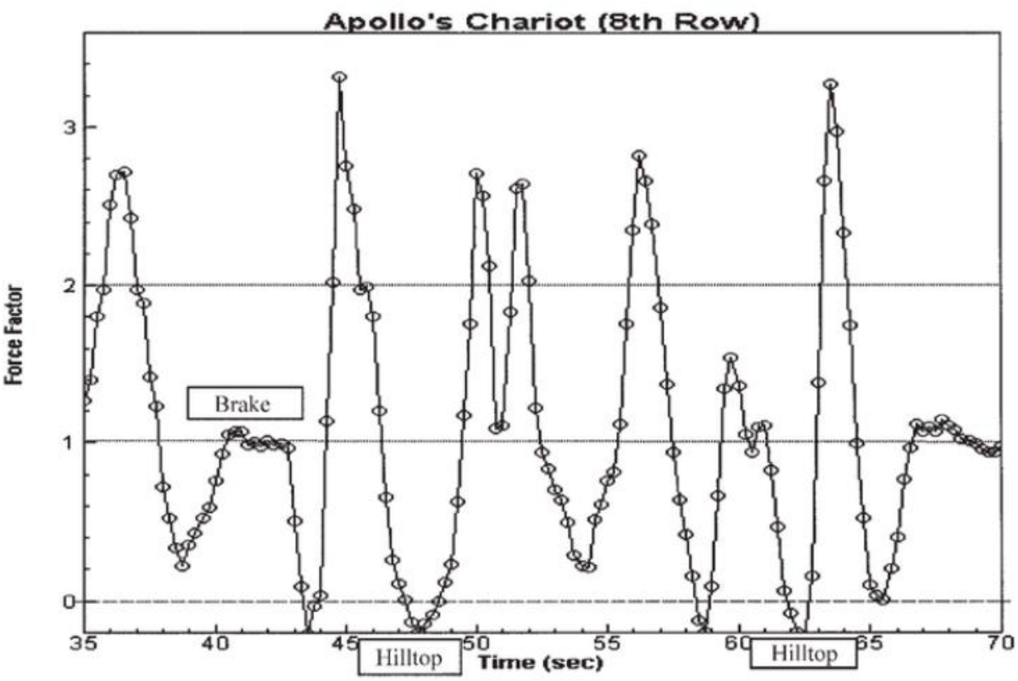
6. 27 m 7. 12 m 8. 5 m 9. 15 m

For some perspective, the first drop on the Loch Ness Monster is 35 m. Alpengeist has a first drop of 49 m and a vertical loop of 32 m.

Based upon the height of the first hill and a speed at the top of 2 m/s, what should be the speed at the bottom of first hill of Apollo's Chariot? Why is the actual speed (32.6 m/s) slower than the prediction? How much energy is lost coming down the first hill?

10b. The top of the first hill is 64.0 meters above the lowest point on the coaster and the speed of the coaster at the top is approximately 2m/s. At the bottom of the last dip, the elevation is about 6.9 meters above the lowest point on the coaster and the speed is approximately 19.6 m/s. What percentage of the energy has been lost to friction in the course of the ride?





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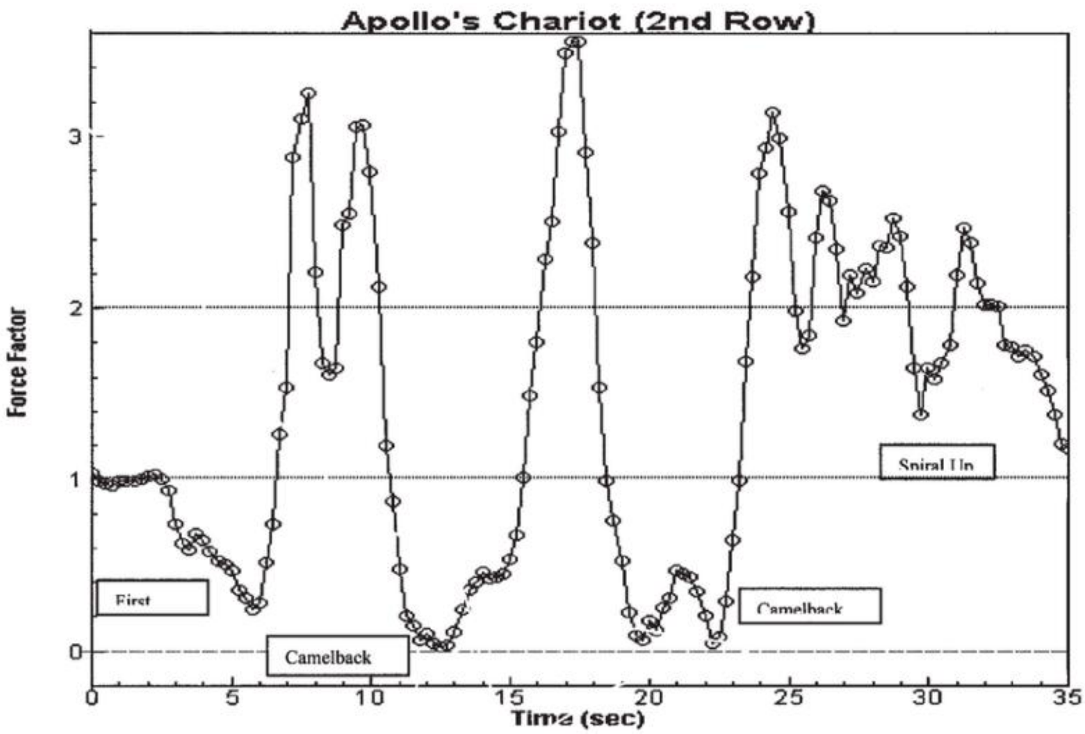

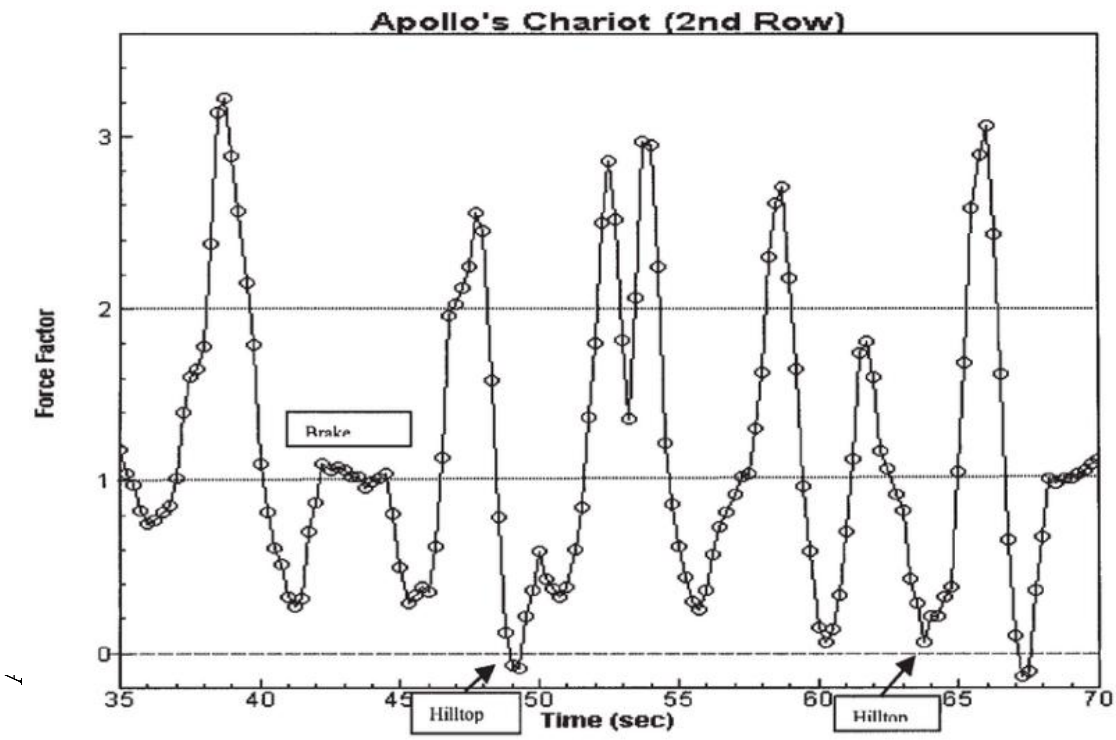

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VERTICAL ACCELERATION

GRIFFON

Instruments needed: Stopwatch, Mounted vertical accelerometer (sit in Row 3.)

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

1. What will be the maximum force factor on the ride?

   2 2.5 3 3.5 4

2. Where will this occur?

   bottom of the first vertical drop — bottom of the second vertical drop

   in the water brake — at the bottom of the first dive loop

3. What is the maximum speed on Griffon?

   62 mph 68 mph 73 mph

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Pay attention to how heavy you feel at the bottom of the two drops, and how light you feel in the drops.
2. Note the feel of the "water brake."

WHAT TO MEASURE AND NOTICE OFF THE RIDE

1. Time the coaster at the bottom of the first hill, between posts A and B. A is the first post inside the fence, and B is at the very bottom of the hill.

	#1	#2	#3	Average
Time from A to B				

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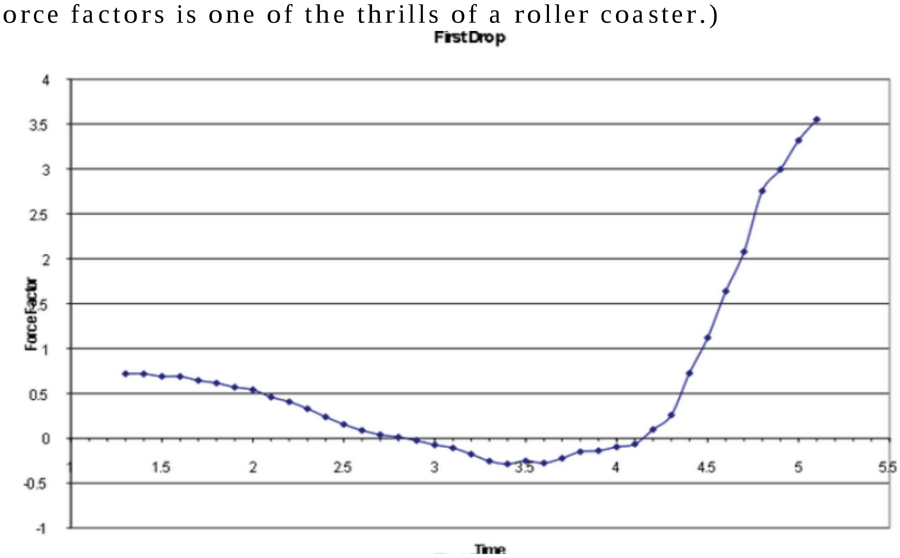
Questions:

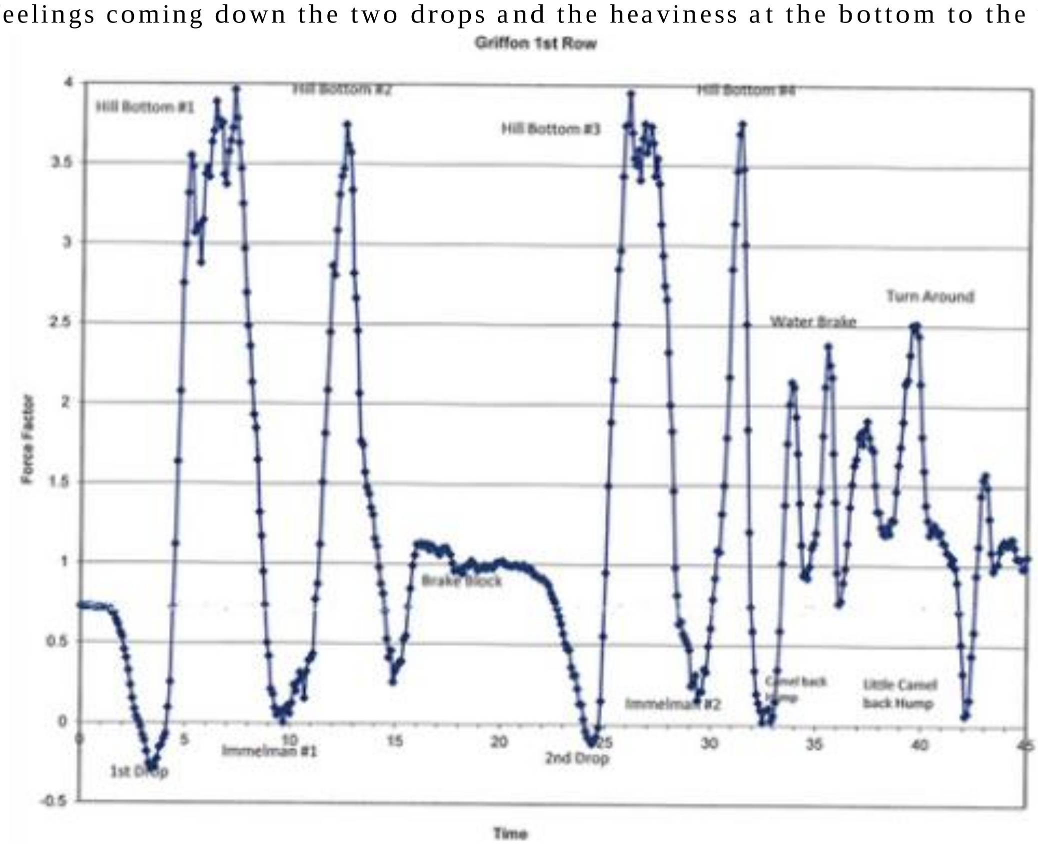
1. Using the graph below, determine how long that it takes for the force factor to rise from its lowest level to its maximum of 3.5 on the first drop. (This going quickly back and forth between high and low force factors is one of the thrills of a roller coaster.)



2. Using the Griffon 1st Row graph below, find which part of the ride has the greatest force factor. List the force factor. Which part has the second highest force factor?

3. Which element of the ride maintains a high force factor for the longest time?

4. Compare your feelings coming down the two drops and the heaviness at the bottom to the values on the graph?



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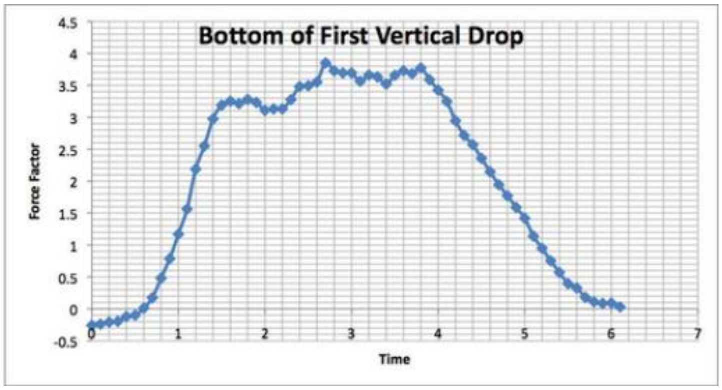
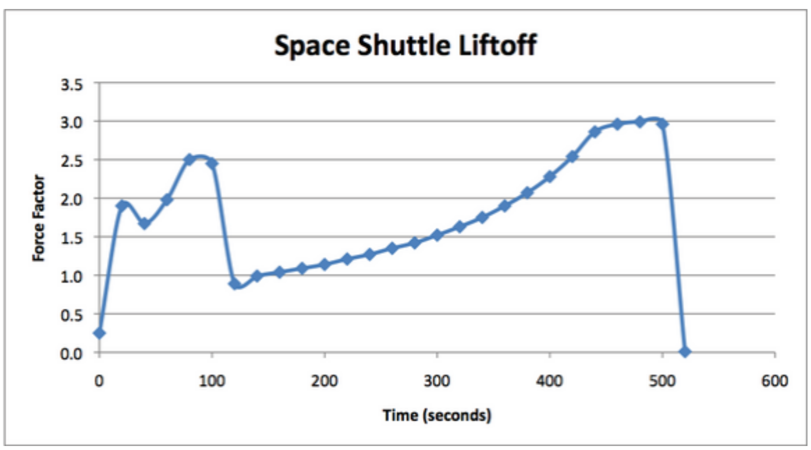
5. Why does the coaster pause at the top of the first hill for about five seconds, before dropping?

6a. Looking at the expanded version of the force factor graph for the bottom of the first vertical drop, indicate how long you feel heavy. (Let's define heavy as a force factor of greater than 2).



6b. The graph below represents the force factor experienced by the space shuttle astronauts between their lift off and being inserted into orbit, where they experience a force factor of 0. Compare and contrast the space shuttle and the Griffon. You may use the graph above of the first hill bottom, along with the complete graph at the end of the section.



7. The second drop is only 130 feet, compared to 205 feet for the first vertical drop. Why is the force factor at the bottom of the second drop about the same as for the first drop?

Problems:

1. Using your time measurement between A and B, compute the velocity at the bottom of the first hill. The distance between posts A and B is 26.8 meters. Compute the speed in m/s and convert to miles/hour by multiplying by 2.24.

2. Compute the force factor at the bottom of the first hill. Use the velocity that you computed in problem 1. The radius of curvature of the track is 40.0 meters. How does your computed force factor compare to the force factor indicated on the Griffon force factor graph?

3. Compute the force factor at the bottom of the second drop. The radius of curvature is 25.0 meters, and the speed at the bottom is 26.9 meters/second. How does this compare with the force factor graph?

4. The speed at the beginning of the water brake is 22.4 m/s, and the speed at the end is 20.5 m/s. What fraction of the energy is lost in the water brake? Given that the water brake is 30 meters long, what is the force factor experienced by the riders? Was this noticeable on the ride as a deceleration? (Note: the force factor at the “water brake” of Escape from Pompeii is about 1.0.)

Estimations:

1. How many cubic yards of dirt were removed to create the trench at the bottom of the first hill?

200 970 2,500 3,800 10,316

2. How many dump trucks could you fill with this amount of dirt?

15 81 116 225 380

3. How many gallons of water are in the water brake?

97,000 150,000 225,000 350,000 660,000

4. How many bathtubs could you fill with this water?

100 500 2,000 50,000 100,000

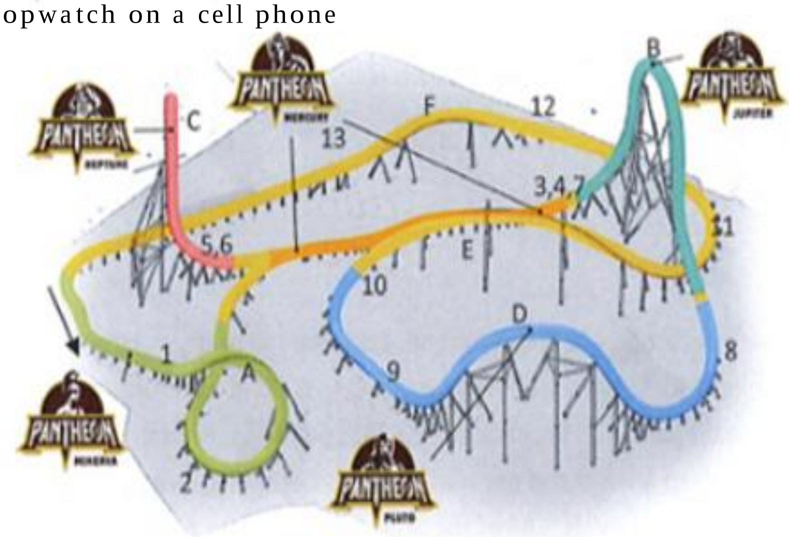
5. There are concrete footers, above which the columns are placed. What is the average depth of the footers?

8 ft 12 ft 20 ft 35 ft 70 ft

Interpreting Graphs

Pantheon

Instrument Needed: Stopwatch, or stopwatch on a cell phone



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

1. Which row will have generally experience a higher force factor at the hill bottoms

   a) 1 b) 10

2. Which row of the coaster will experience the greatest force factor at the bottom of hill C.

   a) Row 1 b) Row 10 (Hint: the coaster is going backwards as it first approaches hill C)

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WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Where do you feel heavy? Which element made you feel the heaviest?
2. Where do you feel light? Which Element made you feel the lightest?

WHAT TO MEASURE AND NOTICE OFF THE RIDE

l. Measure the time of passage of the coaster at the top of hill B (the tallest hill). Coaster Length is13.1m. Make three measurements and compute the average. (Start your stopwatch when the front of the first car arrives at
the top, and stop it when the back of the last car arrives.) You can also use your measurement and two of your friends.

2. Measure the time of passage of the coaster at the top of hill D. Make three measurements and compute the average.

3. Estimate how far close to the top of B the coaster goes on its initial approach. Express your value as a % of the total height. (Here is one way to do it. Find a location on the bridge over the railroad tracks, or somewhere else, where it is easily visible. You can hold this paper at arms-length, and mark on the paper the apparent position of the bottom of the hill B, the top of the hill T, the high point of the coaster P. You can measure the distances (BP and BT) later with a ruler. If ratio BP/BT is equal to .62, that means that it is 62%)

	#1	#2	#3	Average
1. Time of Passage at Hilltop B				
2. Time of Passage at Hilltop C				
3. Estimate how close to the top the coaster goes	BP =	BT =	BP/BT =	%

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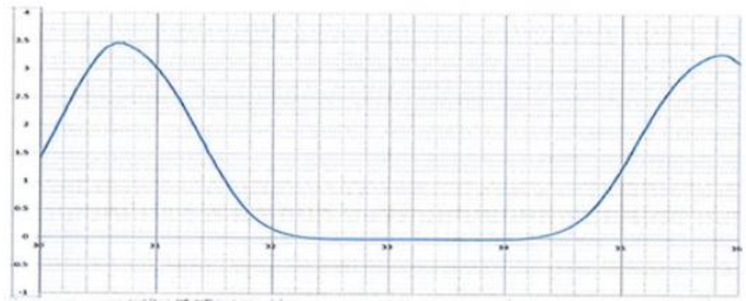
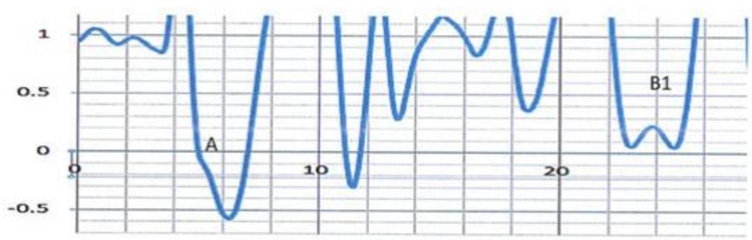
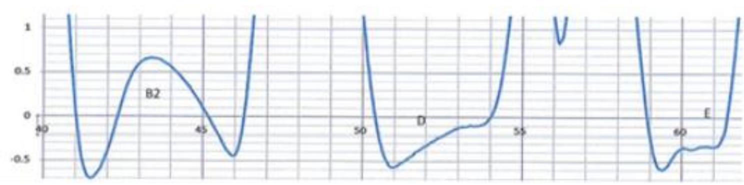
Questions:

The Vertical Force Factor graphs for Pantheon, have the hill bottoms labeled with numbers and the hilltops labeled with Letters. (A force factor of 1, is the same thing as 1 g) These numbers correspond to the diagram on Pantheon on the first page of this Pantheon workbook section. Use the Row 1 graph to answer the questions, unless otherwise directed. The numbers 10, 20, 30, etc. are the times in seconds. All of the graphs, have Force Factor (or g Force) on the y axis and time on the x axis.

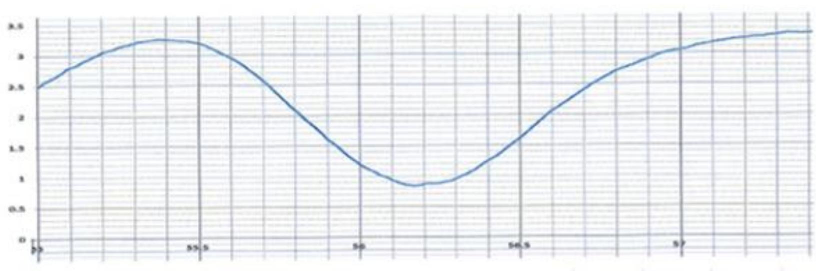
1. Identify where the graph to the right was produced on the Row 1 graph. Why does it have the flat bottom, where most of the air time hills look more like the pictures below.



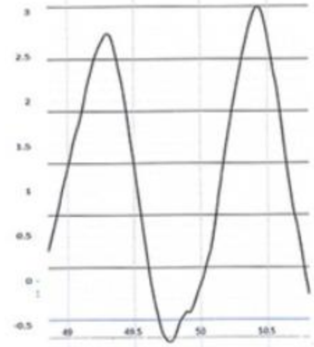




2. The graph below shows the force factor between hill bottom 9 and hill bottom 10, where the maximum force factor is about 3.2. and the lowest force factor is approximately 1 (The analysis is easier if you assume that it is exactly 1



On lnvadr, the wooden roller coaster, the graph between two hill bottoms and the camelback air time hills looks like this. What is happening on Pantheon between the two hill bottoms 9 and 10, that is different than lnvadr.



3. When the coaster is going backwards toward the bottom of Hill C (the Pike), the riders will feel heavy as it begins to turn uphill. Look at the graphs, located at the end of this workbook section, to find the Force Factor (g force) on the passengers at Hill Bottom 5 (starting to go up Hill C} and Hill Bottom 7 (starting to go up Hill B for the second time.), and record the values for Row 1 and Row 10

Hill Bottom 5		Hill Bottom 7	
Row 1	Row 10	Row 1	Row 10

a. How do you explain the fact that Row 1 and Row 10 don't have the same maximum g force at the bottom of the hill? (Hint the force factor depends on both the radius of the curve at the bottom and the speed of the car at that point. The radius is the same for both coaster cars.)

b. Why does Row 10 have the greatest force factor on Hill bottom 5, but Rawl has the greatest force factor on Hill Bottom 7.

c. Without looking at the charts, which car do you expect to have a greater force factor at Hill bottoms 6 and 4. (Hill bottom 6: The coaster is going forward again coming down the Hill C(the Pike) and in Hill bottom 4 the coasters is going down Hill B going backwards.

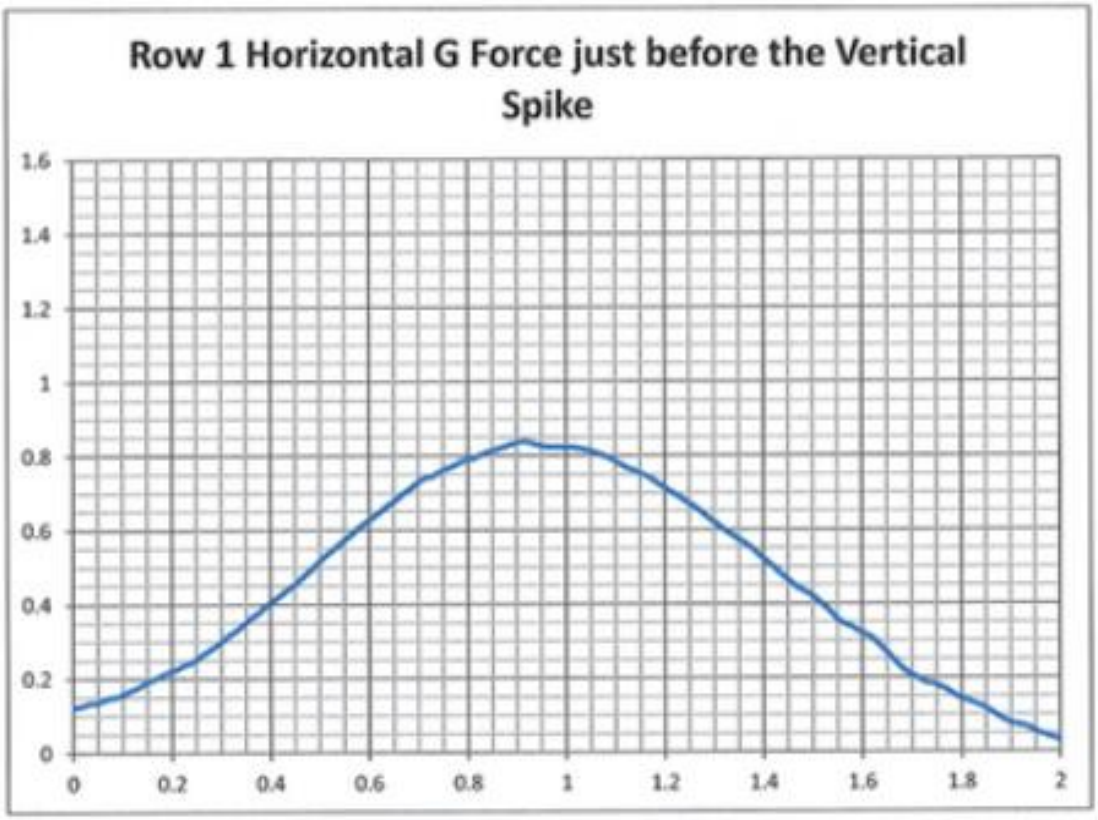
Hill bottom 6 Which car has the higher force factor 1 or 10 (circle one)

Hill bottom 4 Which car has the higher force factor 1 or 10 (circle one)

Check the Force Factor graphs for Row 1 and Row 10 to see. How did you do? Can you explain why it worked the way that it did.

4. How did your estimate for how close the coaster gets to the top of Hill B compare with your classmates? Is there a wide range of values? What does this say about the accuracy of the method used to find the answer?

5. This graph of g force versus time is for the acceleration of Row 1, in the magnetic launch just before the Vertical Spike.



The equation for velocity is V=at +Vo, where "at" is the change in velocity between the initial and final velocity. Since we have plotted Force Factor (g force) on they axis and time on the x axis, the area under the curve will be the change in velocity (V) in the two seconds of the acceleration. Now count the number of boxes under the curve.Add up half boxes. If it's mostly there, count it. Now multiply the number of boxes by (0.05*9.8m/s2)*(0.05s*)=0.0.0245 m/s, which is the area of each box, in m/s.
We had to multiply the area height of each box by 9.8m/s2 so that it would have the correct units.

V=____________ m/s=_____________ mph m/s*2.24=mph

6. Using the time of passage that you measured earlier, and knowing that the length of the coaster is 13.1 m

a. Find the speed of the coaster at the top of Hill B. v=d/t

b. Compute the speed of the coaster at the top of hill D.

c. The drop on Hill Bis 180 ft (54.9 m). What should be the speed at the bottom.
Solve v2-vo2= 2gh for v or (also 1/2mvo' +mgh=l/2mv2 yields the same result)

d. Assuming no friction, how tall would Hill D be?
Solve v2-vo2= 2gh for h.   (g=-9.8 m/s2)

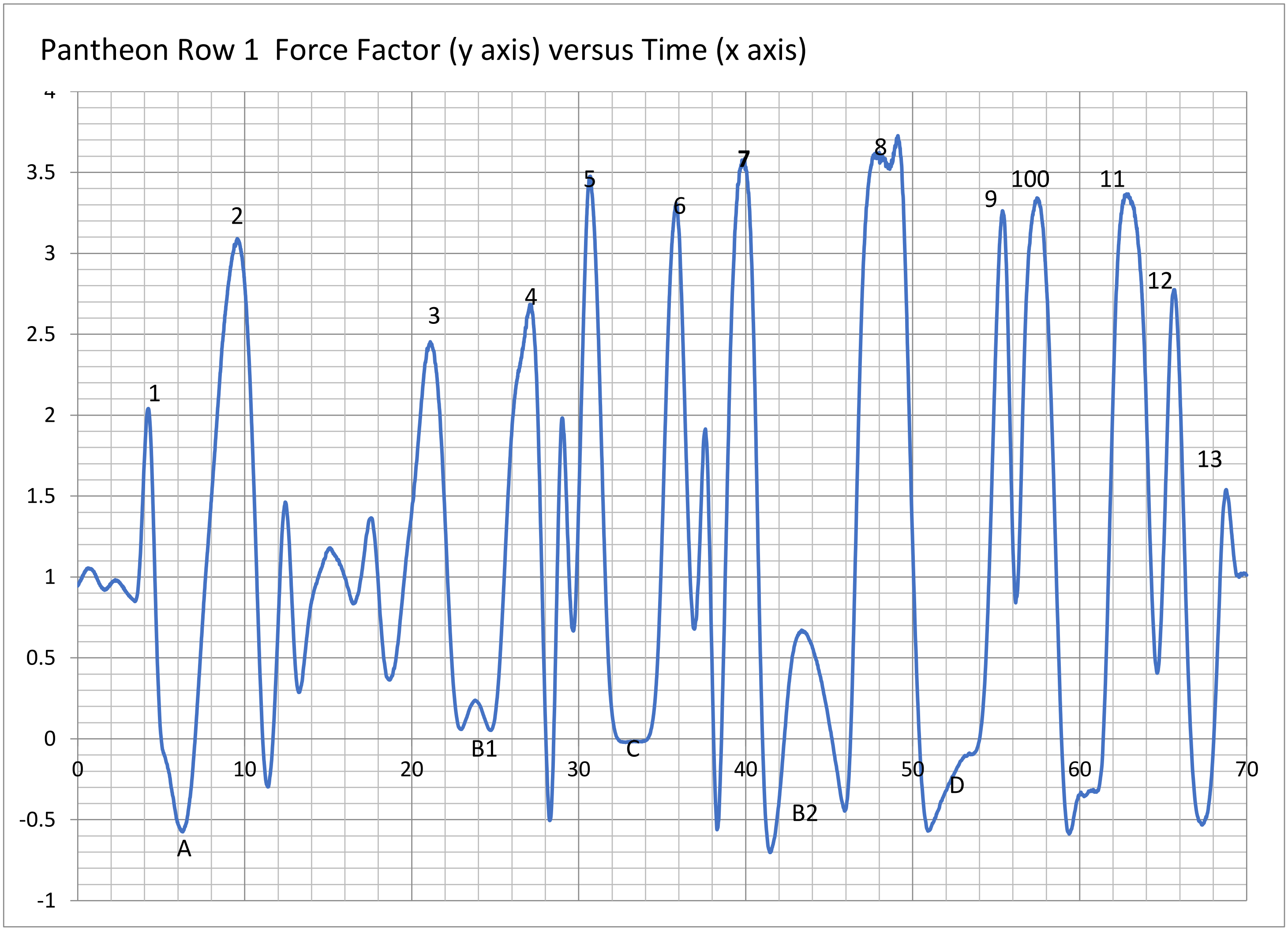
7. One of the thrills of coaster is going back and forth between zero or negative g's and feeling the high force factor of being pressed into your seat. What is the biggest change in Force Factor on the Row 1 Force Factor Chart. On the Row 10 Chart? Pick the force factors that are next to each other (Example from Row 1 Ato2 -0.6 to 3.2 total 3.7 or Row 10 10 to E 3.2 to -0.6 total 3.8) The third column is for the difference between them (i.e 4.0 and -0.5 would be 4.5)

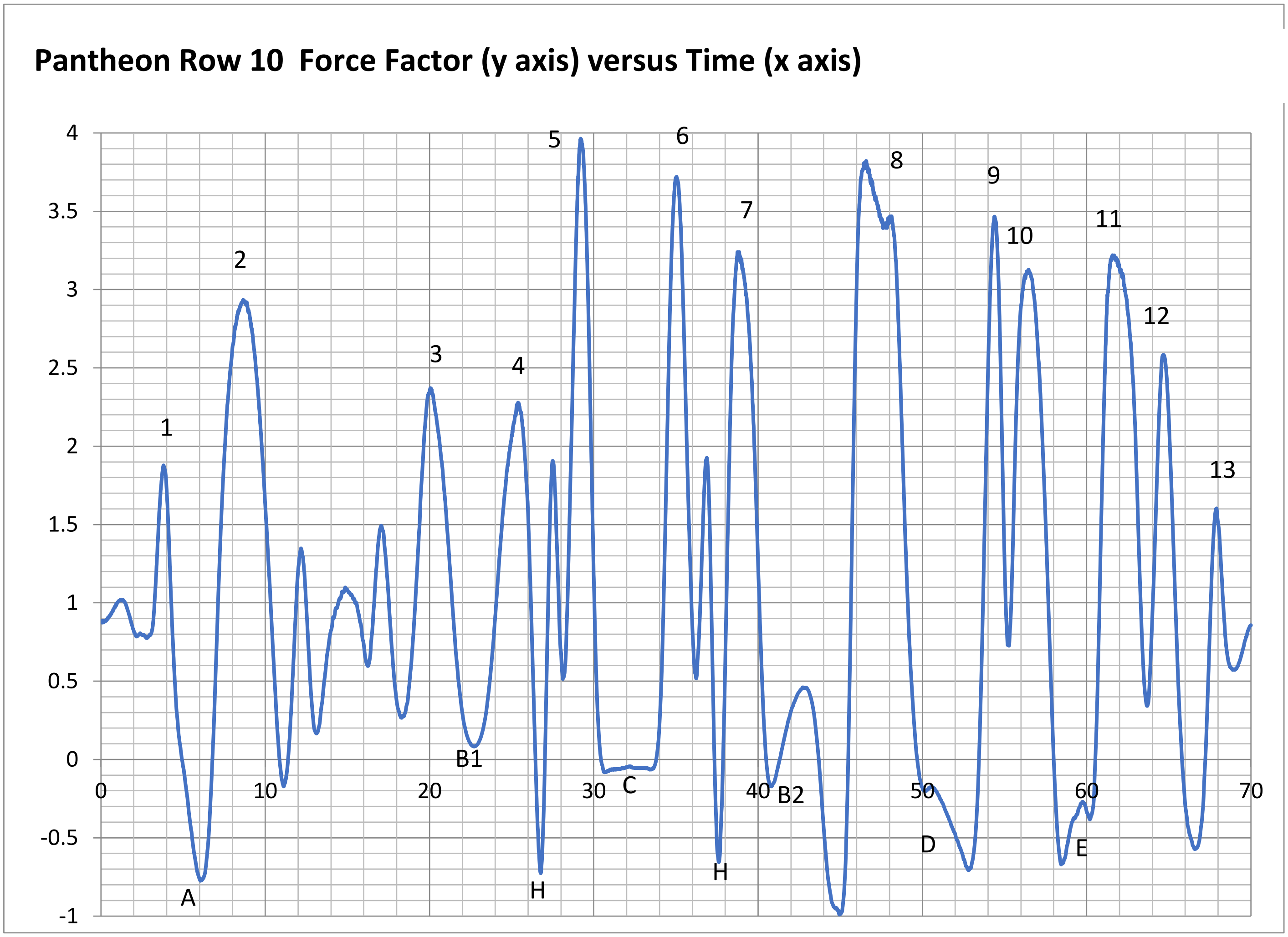
Row 1 ______ ______ difference ________   Row 10 ______ ______ difference_________

8. a. How many times does the force factor equal to or greater than 3.5 on
Row 1 __________ Row 10 _________
b. On which hill bottoms does Row 1 have a higher force factor than Row 10 __________ c. Why are the hills bottoms where Row 10 is higher different than those where it is lower?
(Hint: Look at those hill bottoms of Row 10 are at least 0.4 g's higher than Row 1. There are couple of other places, where Row 10 is only about 0.2 g's higher, but these aren't as easy to figure out without more data about the coaster.)

9. a. Which element of the coaster ride made you feel the lightest? How did your feeling compare with the force factor graphs?

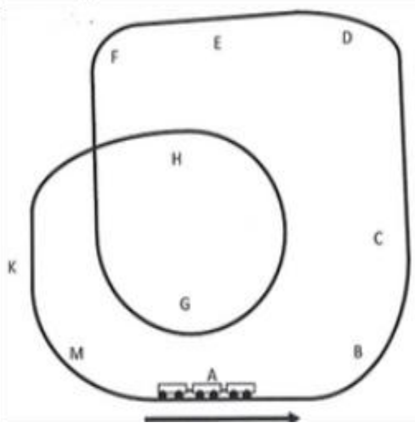
b. Which element had the most intense Force factor. How did your feeling compare to the Force Factor graphs.




Pantheon Row 10 Force Factor (y axis) versus Time (x axis)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
0
10
20
30
40
50
60
70
1
2
3
4
5
6
7
8
9
10
11
12
13
A
B1
H
C
H
B2
D
E

Interpreting Graphs

Tempesto



Instrument Needed:

None

Predictions:

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

1. Where will the greatest Force Factor occur (Heaviest Point)

   a. B b. C c. G d. M

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

   a. D b. E c. F d. G

3. What is approximately the highest speed on Tempesta?

   a. 40 mph b. 50 mph c. 60 mph d. 70 mph

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Make a note of where you feel heavy, where you feel light (weightless) and where you feel a negative force factor where you lifted out of your seat.
2. How do the horizontal accelerations (where you are speeding up), compare to each other
3. Tempesto is just 50 second long, but it really packs a punch. Prepare to rate you top three experiences in order. (i.e. Launches, negative g's, slow roll up top, zero g's, large g's, etc.) Pay attention to the various elements. You may want to ride twice, just to keep track.

WHAT TO MEASURE AND NOTICE OFF THE RIDE

1. Make a notice of what happens at point E. Point E is called a heartline roll, because you are rotating about an axis at approximately heart level. Try to figure out where the force factor will be close to or less than zero by watching Tempesto.

Questions:

1. Label the graph below, of the Force Factor in the Front Car using the sketch of Tempesta on the first page to find the "letters".

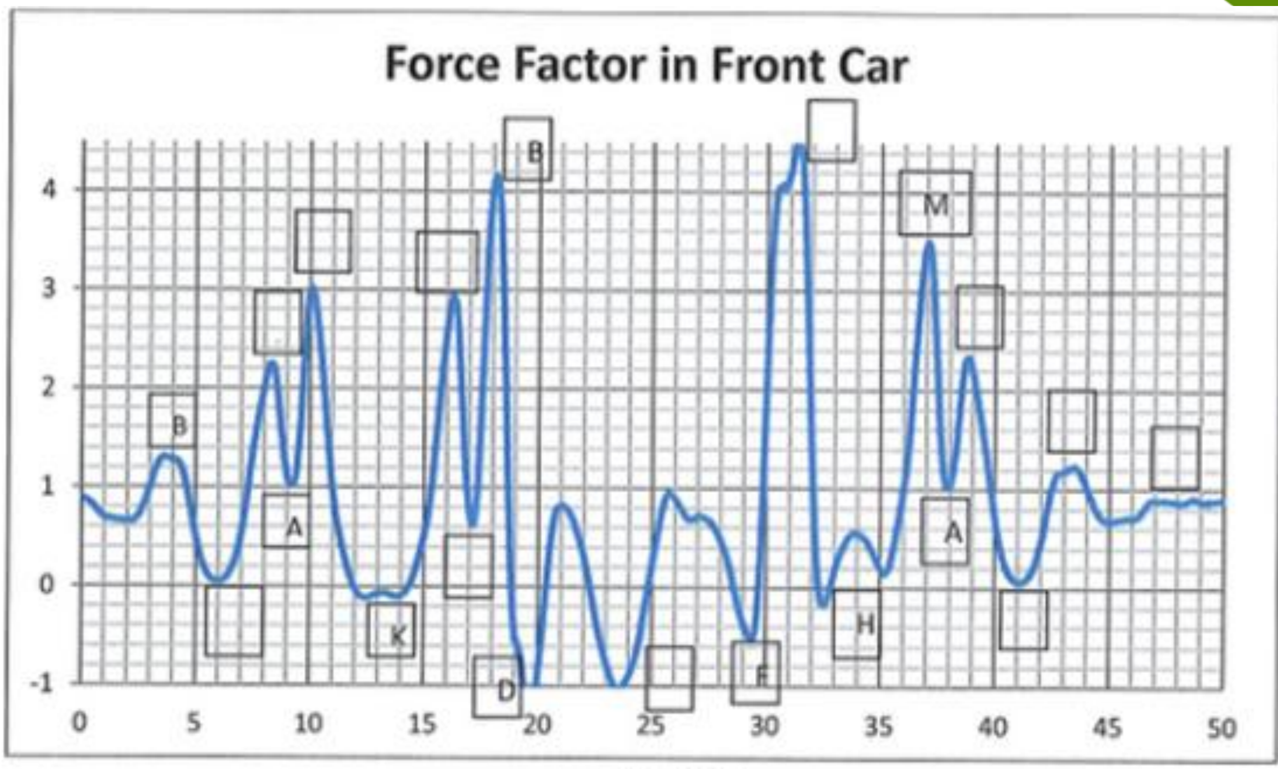


Figure 1

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

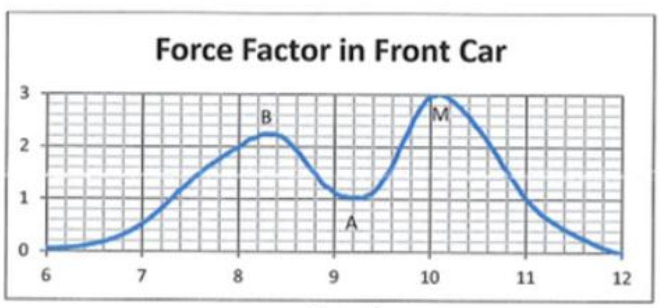


Figure 2

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

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

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

6. There were three types of experiences on this ride that made you feel close to zero, or negative g's. What were they? (On Apollo's Chariot, there was basically only one zero g /negative experience: What was that?)
7. Other than the experiences at the top at slow speed, at what point do you feel weightless for the longest period of time? What does the chart indicate for the time. How would you describe your experience. (Note two places on the ride are virtually tied for the longest time, but one has a more consistent zero g experience.) T= ¬¬¬¬¬__________

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

9. How do the Force Factors compare to the larger coasters in the park?

10. How did the acceleration of the five launches compare to each other? The higher the Horizontal Force Factor, the greater the acceleration and the more force you will feel. You can find the Horizontal Force Factor of the launches by examining the Force Factor versus time graph. The time of the launches is indicated by the arrows on the graph on the next page. This Force Factor is only easy to read off the graph at times where the coaster is moving in the horizontal direction, which it is doing during all of the launches. (The graphs underneath the main graph are close-ups of the second launch and the fifth launch, just to show that the Force Factor was approximately the same for a period of time, and not just at one point, as it appears for several launches on the graph). Record them to the nearest tenth (i.e. +0.3, -0.5, etc.)

Launch 1 ______ Launch 2 _______ Launch 3 _______ Launch 4 _______ Launch 5

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

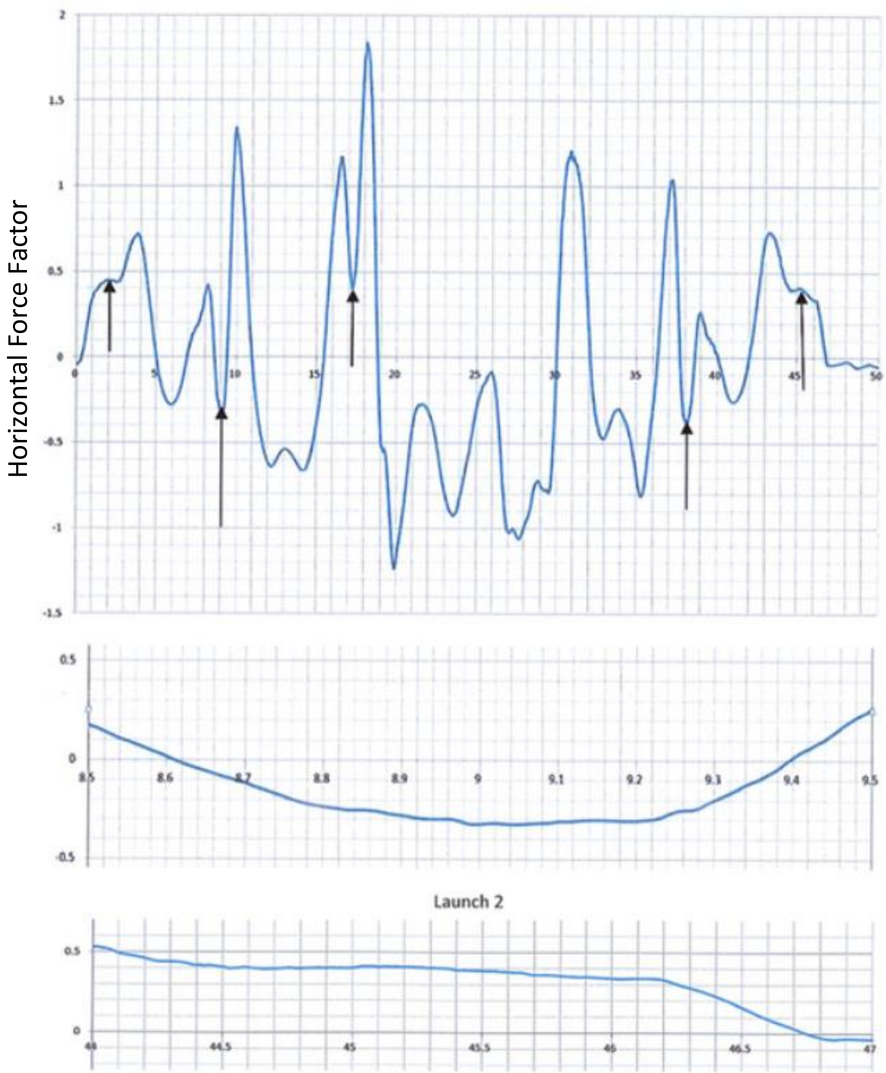
Does this match with the values of acceleration that you have recorded? (Note: Launches 1,2,3 are speeding up, 4,5 slowing down)

(Examples: Speeding up v → a → , v ← a ←

Slowing down v → a ← , v ← a →)

If you have been on Verbolten, compare the acceleration of Verbolten to that of Tempesta. The maximum Force Factor on Verboten's 1st Launch is 0.8 and the 2nd Launch is 0.9, but the average acceleration of both of these launches is about 0.5.

Figure 3



Launch 5

11. Do you feel upside down when you are upside down on Tempesta. How does this compare with being upside down on Loch Ness Monster, Griffon, or Alpengesit? Why are they different?

12. Rate your top 3 experiences, in order of preference. Include the details.

Magnetic Launch
Verbolten

Instrument Needed: Stopwatch

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

1. Estimate the maximum horizontal force factor experienced in the magnetic launches of Verbolten?

   a. 0.7 b. 0.8 c. 0.9 d. 1.0 e.1.1 f. 1.2

2. There are three turns at the bottom of the big drop. Estimate the force factor experienced in the second turn.

   a. 2.6 b. 3.0 c. 3.4 d. 3.8 e. 4.0

3. What is the speed of Verbolten at the bottom of the big drop?

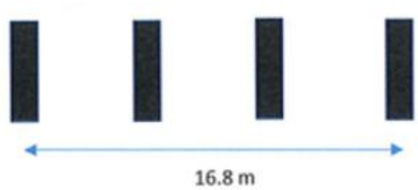
   a. 50 mph b. 55 mph c. 60 mph d. 65 mph

WHAT TO MEASURE AND NOTICE ON THE RIDE

1. Pay attention to the length and intensity of the two launches.
2. On the ride you will feel heavy in three big turns after the last big drop. In which turn do you feel heavy for the longest time? Which turn do you feel the heaviest?
3. Where on the ride to you feel the lightest? What is happening when you feel the lightest?
4. Pay attention to what is happening inside the building when you are in the dark. Try to remember the types of turns and drops, and in what order they occurred.

WHAT TO MEASURE AND NOTICE OFF THE RIDE

1. Time the coaster passing between the first and fourth supports at the bottom of the big drop. This can be viewed on the Bridge to Italy. The first support is the first one in the water. Record three measurements and find the average time. Note: The time should be less than 0.85 seconds. It may take some practice and quick reflexes to obtain a good time.



	#1	#2	#3	Average
Time (sec)				

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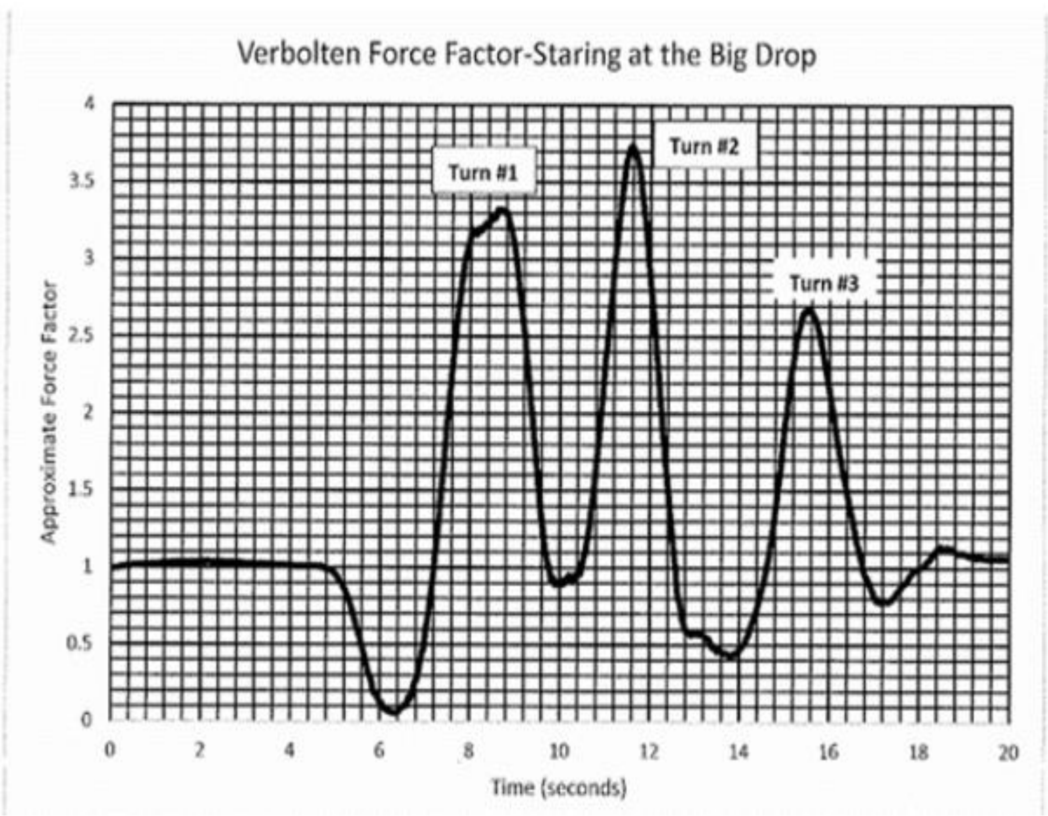
Questions:

1. How often do you feel close to "weightless" on the ride? What is the coaster doing when you felt "light".

2. The graph below is the vertical force factor for Verbolten. It starts just before the coaster train makes its big drop down to the Rhein River. This graph shows you how heavy you feel on the ride. The big drop begins at about 4.8 seconds.



a) The three big peaks are the three big turns as the coaster arrives the bottom of the hill and before it arrives back at the station. Which has the greatest force factor? What is the force factor? Does this match with your experience on the ride?

b) On which of the three turns are you heavy for the longest time (defining heavy as a force factor of greater than 1.5)? How many seconds were you were you experiencing a force factor of greater than 1.5? Does this match with your experience on the ride?

c) Where do you have the greatest weightless feeling? How long are you feeling close to weightless (defined here being a force factor of less than 0.5).

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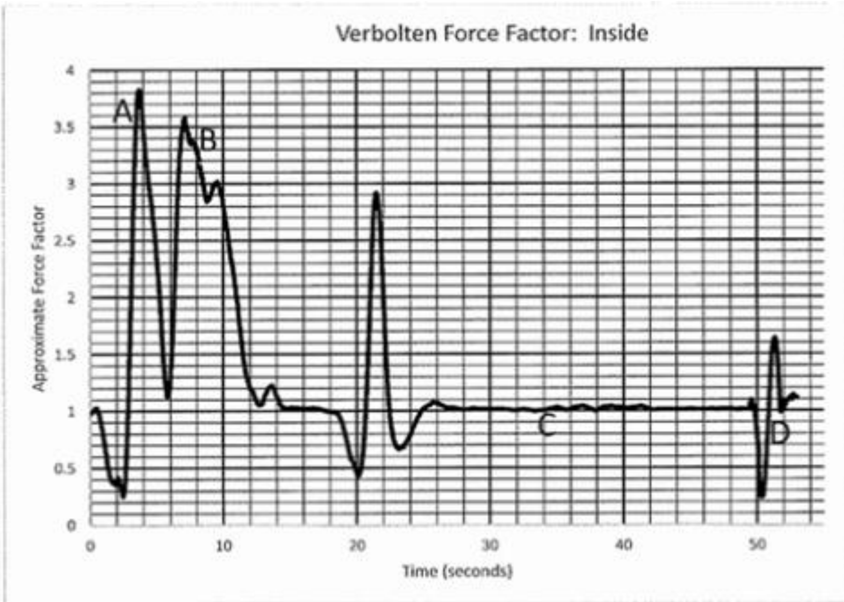
3. The graph below shows the vertical force factor that you experienced where you were inside the building, in the dark.



a) What's happening at "C" and "D"?
b) "A" and "B" are both heavy times. Why are you heavy at "B" for a much longer time?

c) How do the heavier parts of the coaster ride inside the building compare to those at the end of the ride? Is there a longer heavy time inside the building or at the end of the ride?

d) How did doing this part of the ride in the dark affect your experience?

Problems:

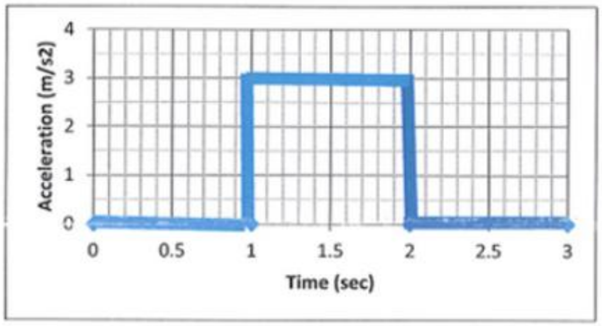
1. Using your average time, compute the speed at the bottom of the last big drop. v=d/t where the distance is 16.8 m. Convert this speed to miles/hour by multiplying by 2.24

v= d/t=16.8 meters/ t= _______m/s = _______miles/hour

How does the speed on Verbolten compare to the other big coasters here at Busch Gardens? Does Verbolten feel faster or slower than the other big coasters? Why or Why not?

2. There is no lift hill on Verbolten like you will find on Apollo's Chariot, Loch Ness Monster, Griffon or Alpengeist. Instead, electromagnets are used to launch the coaster. The system is called a Linear Synchronous Motor. There is no physical contact between permanent magnets on the coaster train, and the white electromagnets on the track. The LSM uses the principle that like magnetic poles repel and unlike poles attract.

The velocity change of an object can be determined by using an acceleration versus time graph, like the one illustrated below.



The object illustrated in the graph has an acceleration of 3 m/s2 for 1 second. The equation $\Delta v = at$ tells us that this object has a velocity change of 3 m/s. It turns out the velocity change is equal to the area under the curve. In this case area= length X width, with the length of 3 m/s2 and the width of 1 second. You can also find the area under the curve by adding up the little rectangles underneath the curve. Each little rectangle is 0.5 m/s2 long and 0.1 second wide, which is equal to 0.05 m/s. There are 60 little rectangles underneath the curve and 60 x 0.05 m/s = 3 m/s, which is the same result that we got before.

The two graphs on the next page are graphs of the two magnetic launches of Verbolten.

a) By counting the little rectangles underneath each graph and multiplying by the size of each rectangle, determine the change in velocity that each launch produces: These little rectangle are .5 m/s2 x 0.1 second, just like in the example above, so each square is 0.05 m/s. You can also add up the rectangle that are not completely underneath the curve. For example, two half rectangle to make one rectangle.

Launch 1 = ________ rectangles * 0.05 m/s = __________________ m/s

Launch 2 = ________ rectangles * 0.05 m/s = __________________ m/s

b) From the graphs, compute the total time of acceleration.

Launch 1 Graph Total time = ____________________
Launch 2 Graph Total time = ____________________

c) What was the maximum horizontal force factor in each of the launches: (To find the force factor, divide the maximum acceleration by 9.8)

Launch 1 ____________________ Launch 2 __________________

Note: It turns out, that the average acceleration of both Launches was about 4.7 m/s2 or about 0.5 g's (FF=.48). The average acceleration * time of acceleration should equal the same Δv you computed in Problem 2a.

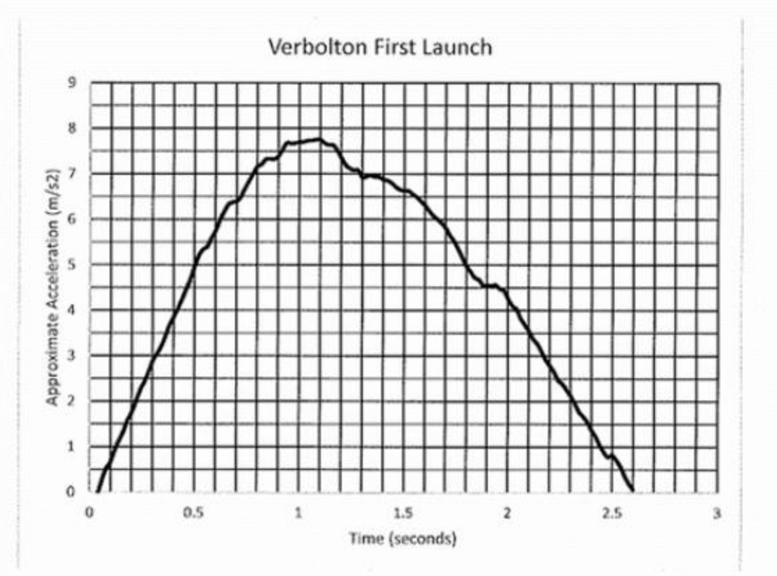
d) For some perspective, compare the maximum force factor of the second launch to the average force factor experienced in a Ferrari Enzo sports car (12 cylinders, 660 horsepower), as it accelerates from Oto 60 mph is just 3.1 sec.

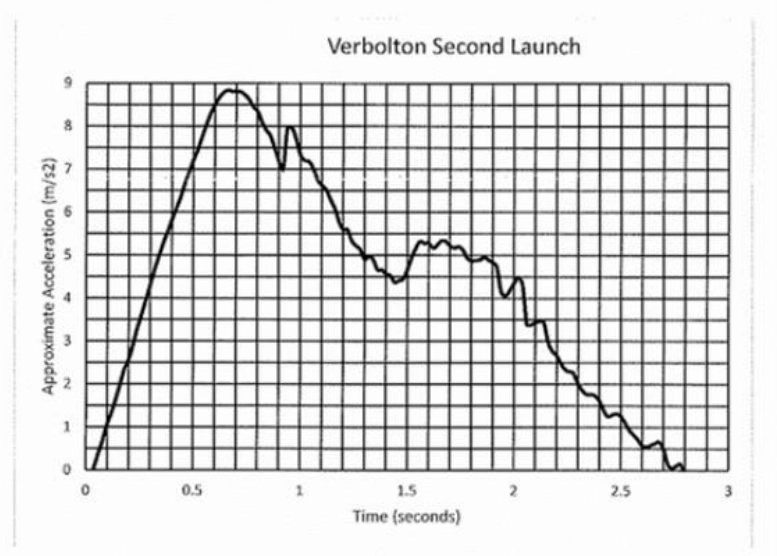
60 mph = 26.8 m/s. $a = \Delta v / t$ Horizontal Force Factor = a/g where g=9.8 m/s2

Force Factor$_{average}$(Ferrari) = ____________
Force Factor$_{max}$(Second Launch) = _______________

e) How well do your calculations for force factors for the two launches match your experiences on the ride? Were you time estimates close to the data from your graphs?

f) Describe any differences in the two launches that you experienced.





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