OUTDOOR CLASSROOM
S.T.E.M WORKBOOK

QUESTIONS FOR GRADES 6- 12

To the Teacher

The Outdoor Classroom can be an exciting and educational time for students. Make the most of the instructional opportunities available. The activities were written to focus on interesting aspects of the rides at **Six Flags Fiesta Texas**. Some of the STEM concepts addressed are more appropriate for middle school while others are more appropriate for high school students.

Special thanks goes to Vernier Software & Technology for their generous loan of equipment. Thanks also go to Clarence Bakken for his help and inspiration. He got me hooked on using an amusement park as a physics laboratory. I hope you enjoy your day of fun with science, technology, engineering, mathematics, and discovery at **Six Flags Fiesta Texas!**

Rick Rutland, Five Star Education Solutions

Suggestions

1. Review the materials prior to coming to the park. Consider practicing some of the activities/calculations at school prior to coming to the park. The calculations are based on approximate or estimated data. The problem-solving process is more important than a "right answer".
2. Consider using the videos of rides to determine times needed for the calculations. These could be done prior to coming to the park.
3. There are more activities included than can be realistically completed. Choose the activities/questions that you want your students to complete. Some of the questions would be appropriate for Middle School students while others would be better for High School physics. Focus on a small number of activities at the park. Decide how much work you will expect students to complete at the park. When are you going to collect the completed work? Consider if you want to use some of the activities back at school.
4. Develop a plan to ensure a smooth day at the park. Arrange for permission slips, transportation, meals etc. Are you prepared in case the weather turns bad? The park will still be open, but some rides may not operate. Do you need emergency contact numbers for parents? Make sure all the students know when and where to meet at the end of the day.
5. You may want to schedule some location and scheduled times so students and other adults will be able to find you throughout the day. Allow a window of time so that students will not have to leave a ride line.
6. Assign students into groups to work on the activities. Make sure students know that they do not **all** have to ride. Each student group will need a calculator, a stopwatch (or their phone), and possibly a sextant. (a sextant can be constructed easily and inexpensively.)
7. Please ask your students to **bring a photo ID** to the Outdoor Classroom Day so that they can use the high-tech equipment for collecting data. (*Since students*

usually work in groups of 2 to 4 on the activities, it is really only necessary to check out one set, and thus require only one I.D., per group.) Students borrow the equipment by trading a photo I.D. (such as a driver's license or school I.D.) for a data collection device and vest. The collateral will be returned to the students when they return the equipment This equipment is available due to generous equipment lending by Vernier Software & Technology. Students may also want to bring a USB drive to obtain the data (it will be in a Logger Pro file).

8. The altimeters will occasionally read negative values. The altimeter reading is based upon barometric pressure. Moving at high speeds probably causes a slight change in pressure.
9. Students will need to time certain events on the rides. It might help if students video the ride. Then they could replay the video several times to gather the data.
10. There are several other rides that are not addressed in these activities. Consider assigning students to choose one or more to analyze.

Please note that the devices that are commonly called "accelerometers" are not really accelerometers! The devices work by detecting forces. They measure the force acting on a small mass, divide it by the object's mass, and calculate the force per unit mass. The ratio, which ends up in units of N/kg, is the same regardless of the amount of mass. These units are conveniently equivalent to acceleration units (m/s^2), and thus the sensor has the ability to make measurements of acceleration for objects. The electronic devices are measuring the force on a tiny mass unit inside the device. The force is proportional to the acceleration that it is undergoing.

Some teachers call these devices Force Factor meters and label the graphs Force Factor. Other teachers prefer to label their graphs N/kg. We choose to use the term acceleration and will use m/s^2 as the unit.

Adapted from materials from California's Great America and Six Flags St. Louis

Resources

There are many sites with information and sample workbooks from various amusement parks. These are some that have been found most useful.

http: rcdb.com

This site has data for roller coasters from all over the world.

http://www.physicsday.org

This site is hosted by Clarence Bakken and has many resources related to the physics day at California's Great America.

http://www.slapt.org/resources/sixflags

This is part of the site for the St. Louis Area Physics Teachers group. There are many resources related to their physics day at Six Flags.

http://www.compadre.org

This site has many resources for physics. Search under amusement park to find related materials. *Amusement Park Physics, 2nd Edition: Supplemental Materials* has been posted by Clarence Bakken. The scambler ride simulation and PowerPoint presentation on vertical loops are very helpful.

http://vip.vast.org/BOOK/HOME.HTM

Virginia Instructors of Physics: This site contains Tony Wayne's book and a variety of other related files.

http://www.vernier.com

Vernier Software and Technology sells the WDSS system as well as the Amusement Park Physics book.

Bakken, C. (2011) *Amusement Park Physics, 2nd ed*. American Association of Physics Teachers. ISBN 978-1-931024-12-9

Unterman, N. (1990) *Amusement Park Physics: A Teacher's Guide*. J. Weston Walch Pub. ISBN 0-8251-1681-3

Before you come to Outdoor Classroom

What to Bring:

1. **Workbook/handouts:** Edit and print appropriate pages.

2. **Timing device**: At least one person in each group should have a timing device that can measure tenths of a second. This could be a digital watch or phone.

3. **Protractor-Sextant (optional)**: This device can be used for triangulation to determine heights. Construction directions are included below. If you choose not to triangulate, necessary heights are given in the workbook.

4. **Calculating device**: This can be a calculator or phone. It should have trig function capability (high school).

5. **Pen or pencil**

6. **Storage bag**: A one-gallon plastic zipper bag or small pack will help to keep materials together and organized.

7. **Picture ID**: A driver's license or school ID will be needed to leave as collateral in order to check out the electronic data collection devices.

Don't bring:

1. Clipboards or other heavy objects, which are not allowed on the rides.

2. Homemade vertical and horizontal accelerometers are allowed at some parks, but we will not use them at Fiesta Texas. They are difficult to read and not very accurate. There is also concern about them falling from rides. Students will be able to check out electronic devices to gather data. More details are provided below.

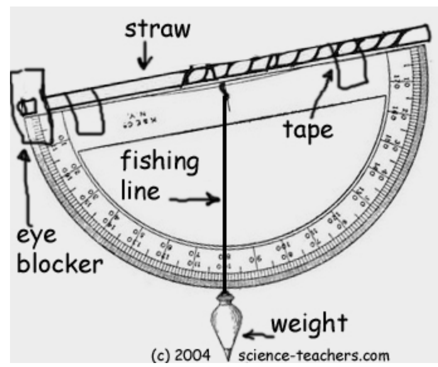
Electronic Data Collection:

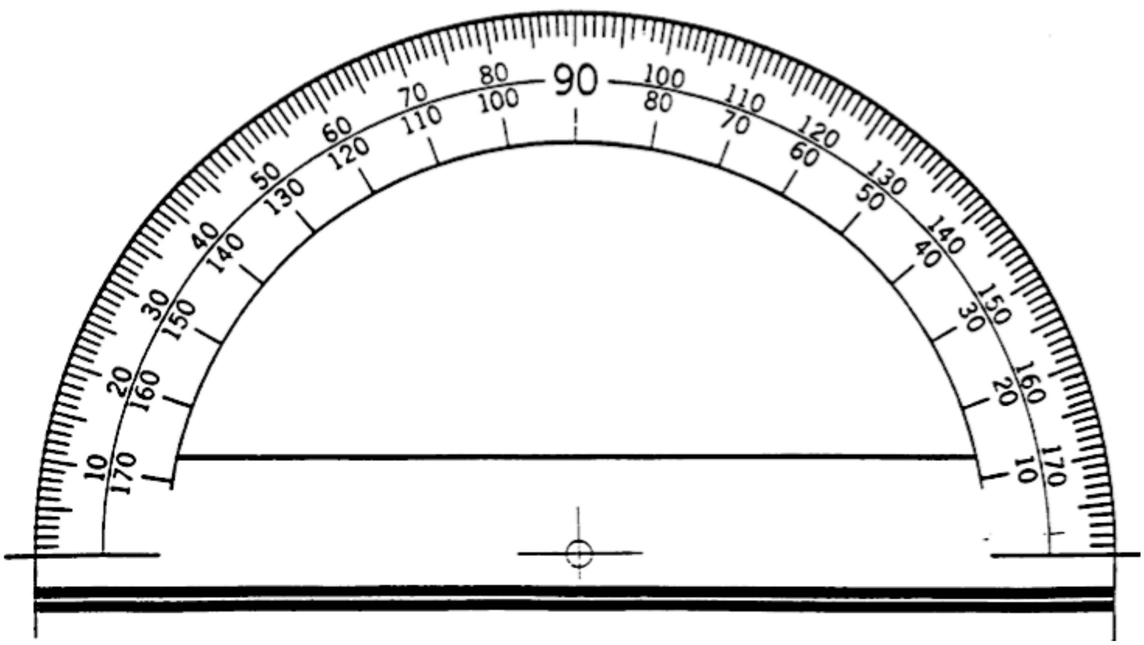
A generous donation from Vernier Software & Technology will allow students to check out devices to collect data on selected rides. The Wireless Dynamic Sensor System (WDSS) is about the size of a cell phone and will be secured in a Data Vest that students will wear. The WDSS will measure acceleration along 3 axes (x, y, z) as well as altitude. The 3 axes can also be represented as vertical (x), lateral (y) and longitudinal (z). The device will be programmed and the students will be shown how to start data collection during the check out process. The EDC booth will be located near the entrance to the Iron Rattler.

1. An item of value such as a driver's license, credit card etc. must be left as collateral in order to check out the equipment.
2. Only one device per group will be checked out.
3. The unit must be returned within one hour.
4. Students may want to bring a USB drive to collect their data. It will be in a Logger Pro file.
5. The unit may **ONLY** be used on the Iron Rattler. Data gathered from other rides may be available to students.
6. No units will be checked out after 2:00 PM.

Constructing/using a simple sextant

Tape or glue a soda straw to a plastic or cardboard protractor. Tie a small weight to a string and hang it from the hole of the protractor (above the 90º mark). Sight through the tube at a distant object and record the angle. Subtract this angle from 90º to obtain the angle of elevation. In the example to the left, the angle read is 80º so the angle of elevation is 10º.





Cut out the protractor and glue to index card or cardboard.
Graphic taken from Six Flags St. Louis workbook.

Taking Measurements

It is a very good idea to read all of the questions for a ride before you start working on them. Many of the measurements that you will need can be taken while standing in line waiting for the ride. Use your time efficiently!

TIME

The times that are required to work out the problems can easily be measured by using a digital watch or a phone. When measuring the period of a ride that involves harmonic or circular motion, measure the time for several repetitions of the motion and divide by the number of repetitions. This will give a better estimate of the period of motion than just measuring one event. You may also want to measure a time two or three times and then average them.

DISTANCE

Since you are not allowed to interfere with the normal operation of the rides, you will not be able to directly measure many heights, diameters, etc. Many of the distances can be measured remotely using the following methods. They will give you a reasonable estimate. Try to keep consistent units, i.e. meters, centimeters, etc., to make calculations easier.

Pacing: Determine the length of your stride by walking at your normal rate over a measured distance. Divide the distance by the number of steps and you can get the average distance per step. Knowing this, you can pace off horizontal distances.

My pace = _____________ m

Ride Structure: Distance estimates can be made by noting regularities in the structure of the ride. For example, tracks may have regularly spaced cross-members as shown in Figure a. The distance **d** can be estimated, and by counting the number of cross members, distances along the track can be determined. This method can be used for both vertical and horizontal distances.

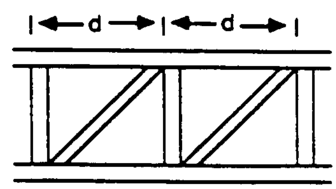
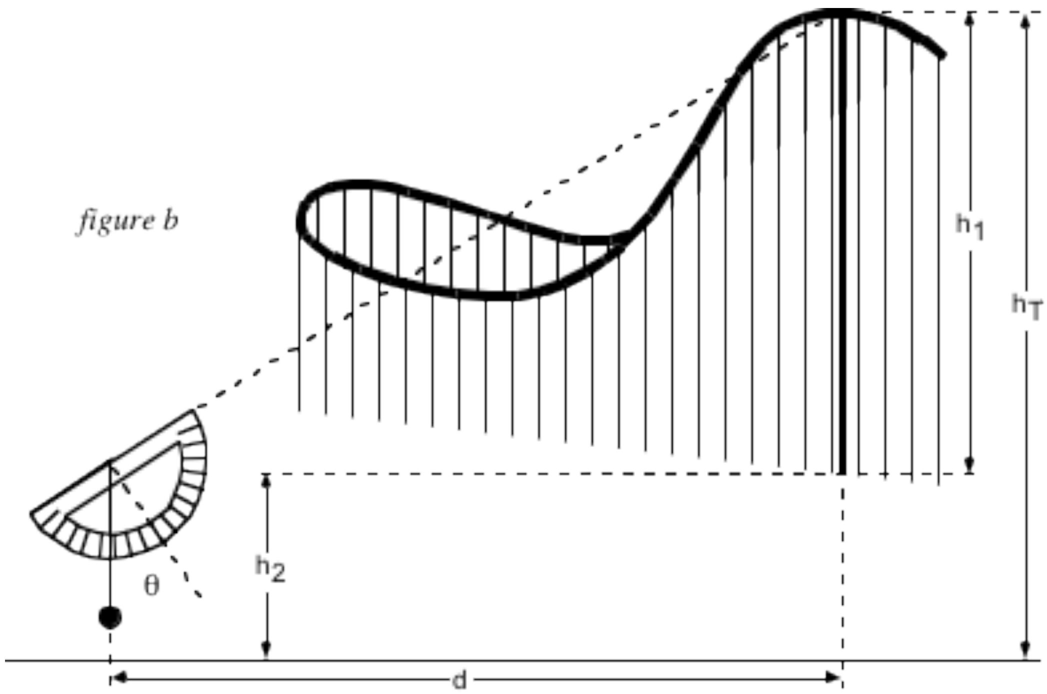
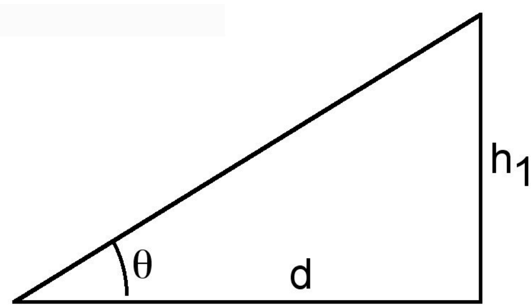


figure a

Triangulation: For measuring height by triangulation, a sextant can be used. Suppose the height $\mathbf{h_T}$ of a ride must be determined. First the distance **d** is estimated by pacing it off (or some other suitable method). Sight along the sextant to the top of the ride and read the angle $\boldsymbol{\theta}$. Add in the height of your sextant (h_2) to get the total height.





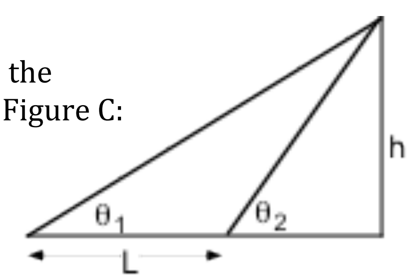
Then since

$h_1/d = \tan\theta$ $h_1 = d(\tan\theta)$

The height of the ride (h_T) is the sum of the distance from the ground to the sextant (h_2) and the distance from the sextant to the top of the ride(h_1).

$h_T = h_1 + h_2$

A similar triangulation can be carried out where you cannot measure the distance to the base of the ride. Use the law of sines as illustrated in Figure C:



Knowing $\boldsymbol{\theta_1}$, $\boldsymbol{\theta_2}$, and **L**, the height **h** can be calculated using the expression:

$$h = \left[\frac{\sin\theta_1 \sin\theta_2}{\sin(\theta_2 - \theta_1)}\right] L$$

SPEED

The average speed of an object is simply distance divided by time. For circular motion, it is the circumference divided by time, if the speed is constant.

$$v_{avg} = \Delta d / \Delta t = 2 \pi R / \Delta t \text{ (circular)}$$

To measure the instantaneous speed of a moving train, divide its length by the time it takes to pass a particular point on the track.

$$v_{inst} = \Delta d / \Delta t = \text{length of train / time to pass point}$$

In a situation where friction is ignored and the assumption is made that total mechanical energy is conserved, speed can be calculated using energy considerations:

$$GPE = KE$$

$$m g h = 1/2 \, m v^2$$

$$v^2 = 2 g h$$

$$v = \sqrt{2 g h}$$

Consider a more complex situation:

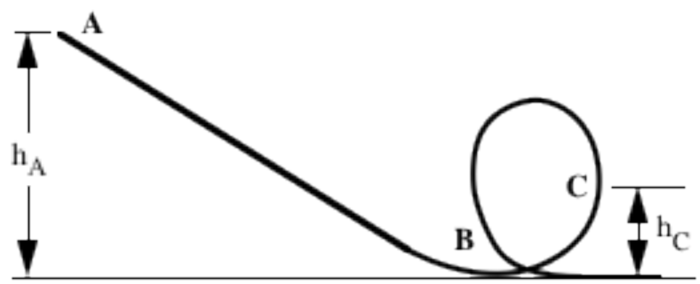


Figure D

$$GPE_A + KE_A = GPE_C + KE_C$$

$$mgh_A + 1/2 \, mv_A^2 = mgh_C + 1/2 \, mv_C^2$$

Solving for v_C:

$$v_C = \sqrt{2 g (h_A - h_C) + v_A^2}$$

ACCELERATION

Centripetal Acceleration

Calculations of acceleration in uniform circular motion are possible. Where **R** is the radius if the circle and **T** is the period of rotation, centripetal acceleration can be determined by the equations given below.

Centripetal Acceleration: $a_c = v^2 / R = 4 \pi^2 R / T^2$

Direction of Acceleration

The net force that causes an object to accelerate is always in the same direction as the resulting acceleration. The direction of that acceleration, however, is often not in the same direction in which the object is moving. To interpret the physics of the rides using Newtonian concepts, you will need to determine the direction of the accelerations from the earth's (inertial) frame of reference. From this perspective, the following statements are true.

a) When an object traveling in a straight line speeds up, the direction of its acceleration is the same as its direction of motion.

b) When an object traveling in a straight line slows down, the direction of its acceleration is opposite its direction of motion.

c) When an object moves in a circle at a constant speed, the direction of its acceleration is toward the center of the circle.

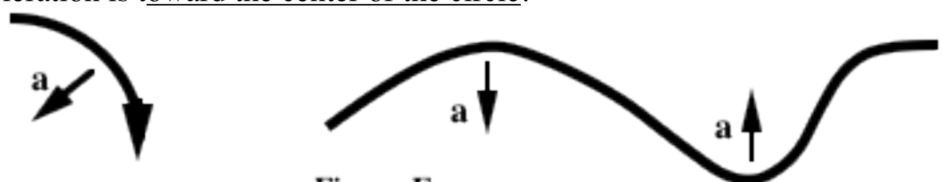


Figure E

d) When an object moves in a parabola (like those in a coaster ride), the direction of acceleration is along the axis of the parabola.

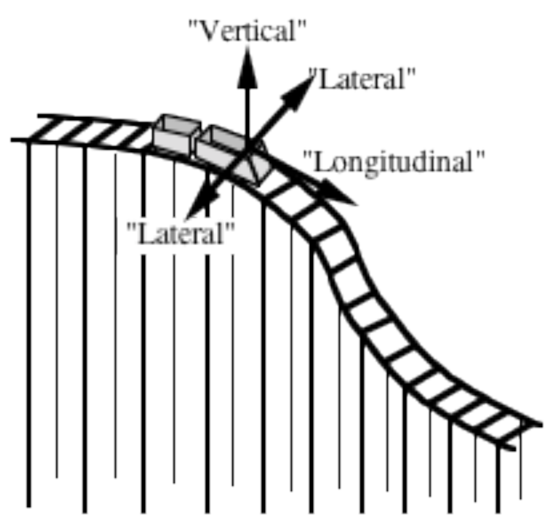
Naming the Directions

Vertical means perpendicular to the track (x on the electronic WDSS)

Longitudinal means in the direction of the train's motion (z on the electronic WDSS)

Lateral means to the side relative to the train's motion (y on the electronic WDSS)

Figure F



Accelerations on a Roller Coaster

Accelerations

Some accelerometers are calibrated in g's. The chart below contains examples of vertical accelerometer readings. A description of the sensation experienced is given.

Accelerometer Reading in g's	Sensation Experienced
3	3 times heavier than normal (maximum g's pulled by space shuttle astronauts)
2	Twice normal weight against the coaster seat
1	Normal weight against the coaster seat
0.5	Half of normal weight against the coaster seat
0	Weightlessness: No force of weight between the rider and the coaster seat
-0.5	Half the normal weight, but directed away from the coaster seat (as if the weight were measured on a bathroom scale mounted at rider's head!)

Your body has its own way of detecting accelerations. Let's take a look at how your "natural accelerometer" detects different kinds of accelerations.

When you experience …

Direction of Acceleration	Physics Term	Gut Feeling
Upwards	Vertical	You feel pressed into your seat. The greater the acceleration, the more squished you feel.
Downwards	Vertical	You feel like you are rising out of your seat. Your stomach feels like it's in your throat. You feel queasy.
Forwards	Longitudinal	You feel pushed back against your seat. Your head and shoulders may swing backwards.
Backwards	Longitudinal	You feel pushed forward against the safety harness. Your head and shoulders may lurch forward.
Left or Right	Lateral	You slide sideways across the seat. Your shoulder may be pressed against the side wall or your ride partner. Your head or knees may bang against the side wall.

Useful Equations				
Linear Motion				
$v = \Delta d/\Delta t$	$a = \Delta v/\Delta t$	$v_f = v_i + at$	$v_f^2 = v_i^2 + 2ad$	$d = v_i t + 1/2 at^2$
Work, Power, Energy, Momentum				
$F = ma$	$W = Fd$	$P = W/\Delta t$	$P = E/\Delta t$	$\Delta E = W$
$PE = mgh$	$KE = 1/2 mv^2$	$\rho = mv$	$Ft = m\Delta v$	$w = mg$
Circular Motion				
$C = 2\pi r$	$v = 2\pi r/T$	$F_c = mv^2/r$	$a_c = v^2/r$	$a_c = 4\pi^2 r/T^2$
$\omega = 2\pi/T$	$v = \omega r$	$a_c = \omega^2 r$		
Electricity				
$I = V/R$	$P = VI$	$R_t = R_1 + R_2 ...$	$1/R_t = 1/R_1 + 1/R_2 ...$	
Right Triangle Trig				
$\sin \Theta$ = opp./hypot.	$\cos \Theta$ = adj./hypot.	$\tan \Theta$ = opp./adj.		

Assume a mass of 60 kg for the mass of an average rider.
Assume 9.8 m/s^2 equals 1g.
Assume 4.2 J equals 1 calorie.

Table of tangents

Angle	Tan	Angle	Tan	Angle	Tan	Angle	Tan	Angle	Tan
1	.02	17	.31	33	.65	49	1.15	65	2.14
2	.03	18	.32	34	.67	50	1.19	66	2.25
3	.05	19	.34	35	.70	51	1.23	67	2.36
4	.07	20	.36	36	.73	52	1.28	68	2.48
5	.09	21	.38	37	.75	53	1.33	69	2.61
6	.11	22	.40	38	.78	54	1.38	70	2.75
7	.12	23	.42	39	.81	55	1.43	71	2.90
8	.14	24	.45	40	.84	56	1.48	72	3.08
9	.16	25	.47	41	.87	57	1.54	73	3.27
10	.18	26	.49	42	.90	58	1.60	74	3.49
11	.19	27	.51	43	.93	59	1.66	75	3.73
12	.21	28	.53	44	.97	60	1.73	76	4.01
13	.23	29	.55	45	1.00	61	1.80	77	4.33
14	.25	30	.58	46	1.04	62	1.88	78	4.70
15	.27	31	.60	47	1.07	63	1.96	79	5.14
16	.29	32	.62	48	1.11	64	2.05	80	5.67

Adapted from materials of Six Flags Fiesta Texas, California's Great America and Six Flags St. Louis.

Six Flags Fiesta Texas Approximate Data

Roller Coasters

Iron Rattler: Track length: 995.5 m Height 54.9 m Max. Speed 31.3 m/s Drop: 52.1 m @ 81º Length of train: 14 m; 24 seats Mass empty train: 7,020 kg Ride Time: about 2 minutes 300 hp motor on lift hill	**Superman Krypton Coaster:** Track length: 1,226.8 m Height: 51.2 m Max. Speed: 31 m/s Length of train: 13.7 m; 32 seats Mass empty train: 7,257 kg Height of loop: 36.6 m
Goliath: Track length: 820.8 m Height: 32.0 m Drop: 24.4 m Max. Speed: 22.4 m/s Length of train: 14.3 m; 28 seats Mass empty train: 7,500 kg	**Road Runner Express:** Track length: 731.5 m Height: 22.3 m Max. Speed: 19 m/s Length of train: 15.8 m; 28 seats Mass empty train: 7,711 kg
Boomerang: Track length: 285.0 m Height: 10 m Max. Speed: 21.0 m/s Length of train: 15 m; 28 seats Mass empty train: 6,350 kg Height of loop: 10 m	**Poltergeist:** Track length: 824.4 m Mass empty train: 4968 kg Length of train: 14.6 m; 24 seats Acceleration period: about 3 s Launch Energy: 4,500 A, 520 V

Park power comes in at 34,500 volts; peak usage is 7 Megawatts.

Others

Power Surge: Height: 17 m Length of boat: 5.2 m; 20 seats Mass of empty boat: 771 kg	**Fender Benders:** 90 Volts DC; 1 hp motor 136 kg empty car
Scream! Height: 82 m 12 seats per tower; 3 towers	**Whirligig:** Radius of rotation (full speed): 11.3 m Period of rotation: about 6 s

Legal Notices

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Education Solutions

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Vernier

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