

Data Collection at the Amusement Park



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Published by
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Beaverton, Oregon 97005-2886
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Fourth Edition 2007
Third Edition 2004
Second Edition 2003
First Edition 2001
First Printing
Printed in the United States of America

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Table of Contents

Introduction.....	1
Instrumentation	
Traditional Accelerometers	3
Electronic Accelerometers	3
Barometer.....	5
WDSS.....	6
Carrying Equipment.....	6
Electronic Data Collection	
Equipment Needed.....	8
Steps for Collecting Data.....	8
Specific Steps.....	8
Sampling Rate.....	9
Orientation.....	9
Calibrating Sensors.....	9
Zeroing Sensors.....	10
Vector Sum for 3-Axis Accelerometers.....	10
Smoothing Data.....	11
Pre-trip Suggestion.....	12
Ride Suggestions	
Directions on Rides.....	12
Dips.....	12
Vertical Loops.....	13
Corners.....	13
Barrels.....	13
Starts And Stops.....	13
Scramblers.....	14
Investigations at the Park	14
Extensions.....	15
Web Sites	15
Appendix 1 – WDSS Remote Option.....	16
Appendix 2 – Logger <i>Pro 3.x</i> Remote Option.....	19
Appendix 3 – Logger <i>Pro 2.2.1</i> Remote Option	20
Appendix 4 – Using Calculator EasyData Program.....	21
Appendix 5 – Using Calculator <i>DataMate</i> Program	23
Appendix 6 – Using Calculator <i>PHYSICS</i> Program.....	25
Appendix 7 – Using Palm OS.....	27
Appendix 8 – Video Analysis.....	30
Appendix 9 – Video Syncing.....	33
Appendix 10 – Creating A Ride Profile.....	36
Appendix 11 – Accelerometers and Forces.....	38
Appendix 12 – Sample Worksheet for Data Collection.....	41
Appendix 13 – Questions & Answers.....	43

Introduction

Since the mid-1980's, physics teachers have been taking their students to amusement parks in ever-increasing numbers. The purpose of such trips is to study the forces and accelerations that students experience on various rides and to apply science concepts to help explain their experiences. These concepts include Newton's laws, momentum, energy, centripetal force, projectile motion and free fall. This booklet discusses many of the issues and decisions relative to collecting data at an amusement park, including specific directions for data collection with Vernier equipment. While most references will be to collecting data on roller coasters, the discussion applies equally to other rides one encounters at an amusement park.

Interpreting data gathered at the amusement park is a learned activity. Students need guidance in determining what to look for and how to make sense of the “wiggles and squiggles” on the graphs. This document doesn't go into interpretation. However, the forthcoming second edition of the Handbook on Amusement Park Physics, available from AAPT in mid-2007, will discuss data interpretation and give several examples. <http://www.aapt.org/Store/index.cfm>



Grizzly at Paramount's Great America in Santa Clara, CA.

Physics Day at Paramount's Great America in Santa Clara, CA, is one of the larger physics days. The Gunn High School Physics Club has operated a booth at Physics Day since 1995. Students check out accelerometer units consisting of an interface (CBL™, CBL2™ or LabPro™), one or more accelerometers and a carrying case or DataVest™ (or a WDSS™) to take on a ride. When the ride is done, the students return to the Electronic Data Center to download their data and print their graphs. The data is then published through the Physics Day web site (www.physicsday.org) so they can download it back at their schools. Experience has shown several things.

- Practice using the equipment before going to the park is essential for a successful physics day.
- Plan ahead to make the most of your data collection experience.
- Capturing data from an entire ride, while interesting, is not necessarily the best strategy. It is often better to focus on one section of the ride rather than the whole.

- Smoothing data often makes it easier to interpret.
- Collecting three axes of data is often preferable to a single axis, although valuable insight can be gained with single-axis accelerometers.
- Computers are more efficient for downloading and displaying data than calculators, although calculators can still be used effectively to load instructions into an interface.



Invertigo at Paramount's Great America

The major sections of this document are as follows:

Instrumentation

While there is discussion of both traditional and electronic instrumentation for use at the amusement park, the primary focus of this document is on electronic sensors and the software that drives them.

Data Collection

This section discusses the steps one takes to gather electronic data. Several issues such as calibrating sensors and smoothing data are also discussed.

Ride Suggestions

This section discusses several aspects of amusement park rides. What are some of the key questions to have students focus on while they are riding? A must-read section if you are going to the amusement park for the first time.

Appendices

There are thirteen (13) appendices to this document, including specific step-by-step instructions for seven different combinations of sensors, interfaces and computer/calculator/Palm. Two sections cover video capabilities built into Logger *Pro* beginning with version 3.1. A section on Creating A Ride Profile precedes a discussion of Accelerometers and Forces. A sample worksheet for students is included, too. A section of questions and answers completes this document.

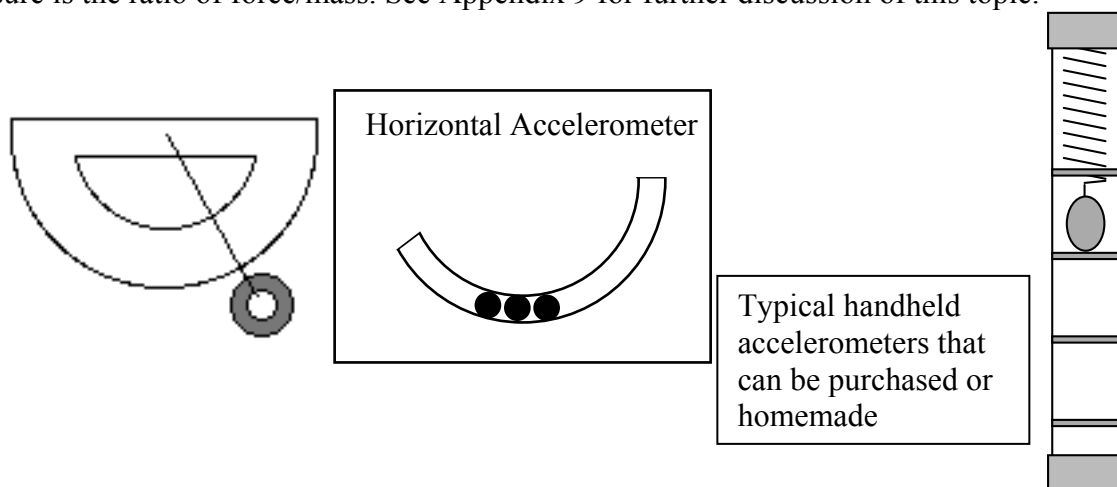
Although we may not have covered every possible question that you or your students will have, we have tried to hit most of the highlights. For questions about sensors, interfaces or software, contact Vernier Software & Technology by email at info@vernier.com or by phone at (888) 837-6437.

We'd like to thank Paramount's Great America in Santa Clara, California, and Six Flags Marine World in Vallejo, California, for the use of specific ride photographs in this document.

Instrumentation

Traditional Accelerometers

Before the availability of electronic data-collection technology, students traditionally used hand-carried devices called "accelerometers". In general, these accelerometers measured the forces felt by a mass attached to a spring or rubber band, by the behavior of a mass on a string hanging from a protractor, or BB's in a curved tube. The forces acting on the object with small mass is proportional to the force felt by our larger mass. We interpret the readings as "acceleration" or more properly, "force/mass" (force per unit mass). If the small mass feels a force that is double its weight, then the person holding the mass is also experiencing a force that is twice their weight. In this case, both the person and the mass experience forces that we can say are equal to $2g$'s. While many people may call the reading of these devices "acceleration," what they really measure is the ratio of force/mass. See Appendix 9 for further discussion of this topic.



Traditional handheld devices are limited due to three factors:

1. Students are occupied trying to watch the measuring instrument at the same time that they are being terrified by the ride experience. Accuracy is questionable.
2. Readings have to be taken "on the fly" and then remembered until they can be written down at the end of the ride.
3. Even under ideal conditions, the readings taken are single values and there is no effective way to record values over the entirety of a ride or even over a section. All of these effects lead to measurements that are at best estimates and are indeed guesses in many situations.

Electronic Accelerometers

For the reasons listed above, it is advantageous to employ electronic sensors. Students can collect data at short time intervals over part or over a whole ride using one of the Vernier accelerometers and an interface unit (CBL, CBL2 or LabPro) or WDSS. Compare getting values every 0.1 s or even every 0.02 s to trying to remember one reading. The primary focus of this manual is collecting amusement park data with electronic sensors.

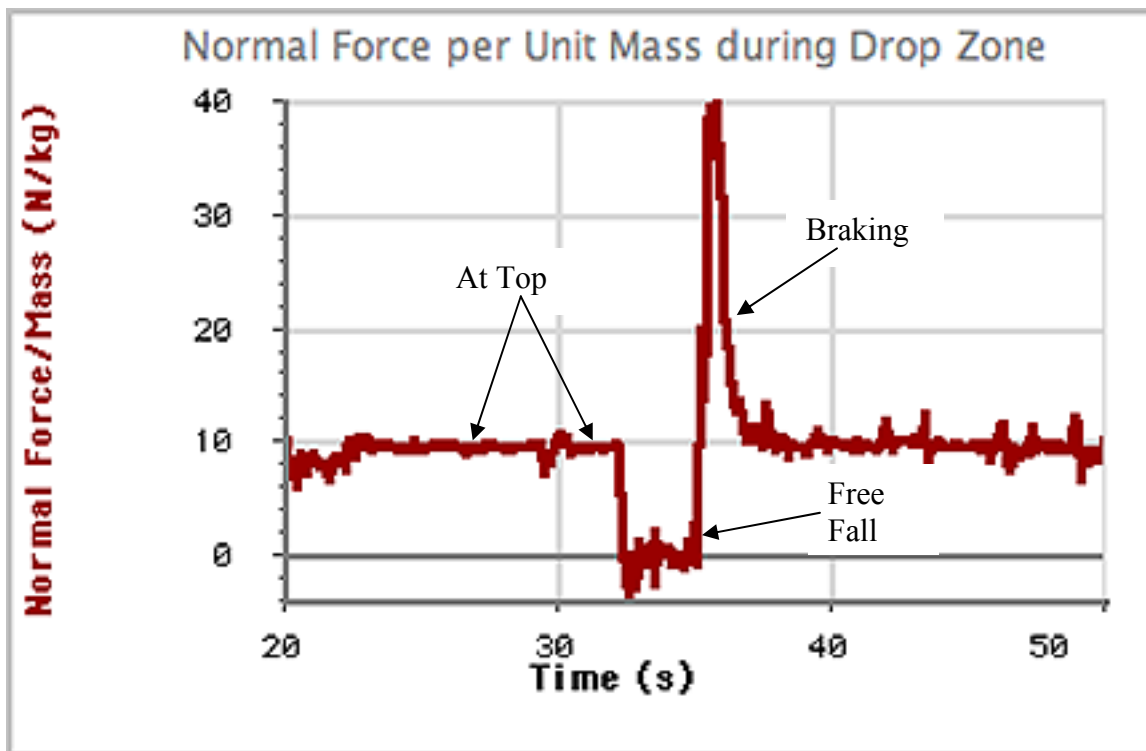


Single-axis accelerometer on left; 3-axis accelerometer on right.

During a typical roller coaster ride, a student may be pushed up or down, left or right, forward or back. A single axis accelerometer is capable of recording only one direction at a time. For some rides like free fall rides there is only one important axis. A good example is Drop Zone at Paramount's Great America (shown on the right). A single axis works well on this ride because the ride is a one-dimensional, free-fall drop.



The next graph shows data collected on this ride. Note the steady 1-g reading (10 N/kg) while the riders are held at the top. Then the 0-g reading lasted for about three seconds while they fell. Finally the electromagnetic brakes bring the vehicle to a stop with a large, but short-lived upward force that approached 4 g's.



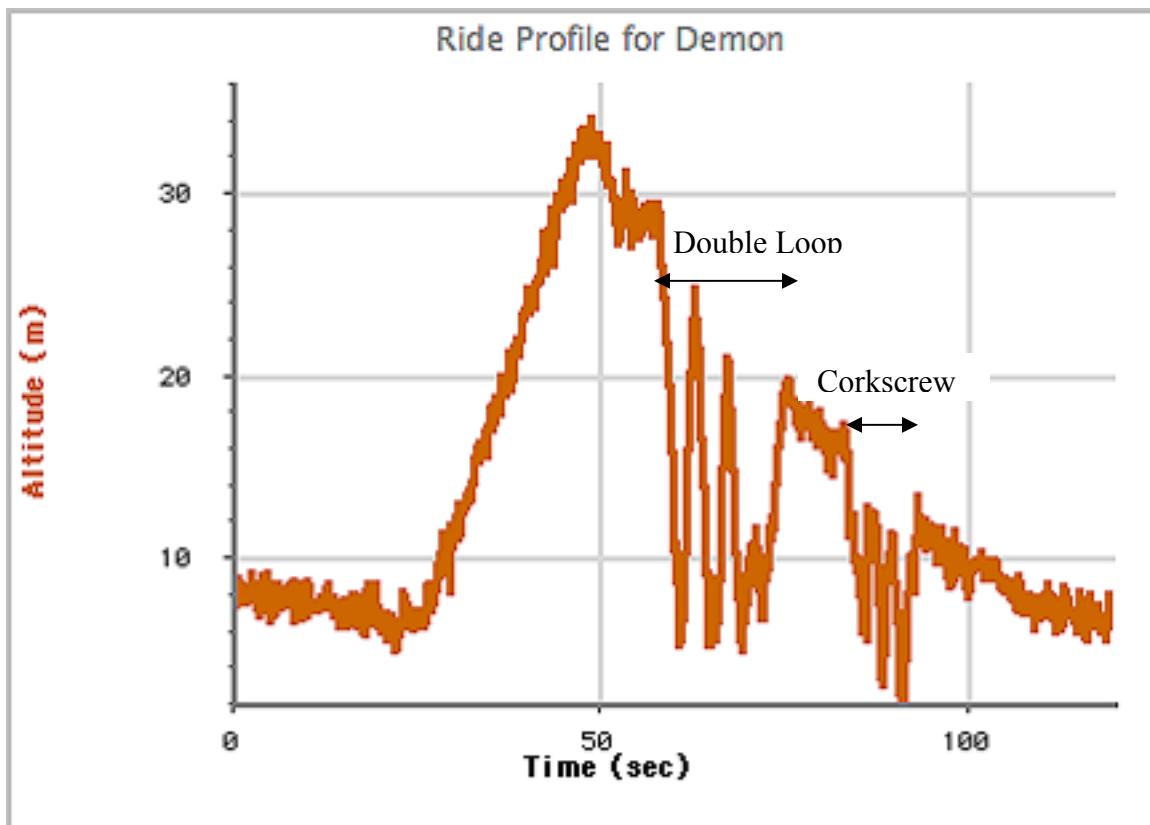
Data from **Drop Zone** at Paramount's Great America.

On other rides where the motion is more complex, choosing which axis to record is an important critical thinking step for students while planning their experiment. For example, many steel roller coasters have very small lateral forces due to the banking of the turns, so it may not be important to study that specific axis.

Barometer

Important data can be collected using a barometer. Barometric pressure changes follow the altitude changes during the course of a roller coaster ride, except pressure decreases as the altitude increases. The ratio is approximately 1 mm Hg equivalent pressure change for every 11.1 meters of altitude change. Subtracting all pressure values from the highest one and multiplying by 11.1, you “invert” the graph and the result is a ride profile where height is given in meters relative to the lowest point on the ride. See Appendix 8.

A major advantage of adding this ride profile is being able to more easily see where you were along the ride and to judge what the motion must have been that produced the corresponding force values.



Ride profile data collected for Top Gun, a roller coaster at Paramount's Great America. This ride features two vertical loops at the bottom of the first hill. Then the riders go through a corkscrew section before returning to the station.

WDSS

The device shown to the right is a Wireless Dynamics Sensor System, WDSS. It contains a 3-axis accelerometer, an altimeter and an independent force sensor. The whole unit is powered by a rechargeable battery and communicates using Bluetooth radio.



WDSS is by far the best choice for amusement park data collection with its combination of large data capacity, small size, rechargeable battery, and absence of connecting wires.

In practice, the WDSS is programmed to collect data at some rate for a period of time, then set up for remote collection. When the students get to the ride, they press the start/stop button when the ride begins or they reach the desired place in the ride, then press the button again when the ride stops. Multiple runs can be collected before downloading the data. WDSS holds approximately 240,000 readings.

See Appendix 1 for additional information and step-by-step instructions for carrying out the remote data collection with WDSS.

Carrying Equipment

Two systems work fairly well to carry the interface and sensors. The first is a customized case such as the one used to ship the original CBL. Cutting out the top of the case to reveal the display (original CBL only) and gain access to the buttons makes it very usable in the park. Plus the case protects the interface and the accelerometer while on the ride. Most parks require the case to be tethered to the rider, a good practice. The accelerometer is held in place with Velcro inside the case and on the bottom of the sensor. A barometer could also be carried in the case, or even several single-axis accelerometers.



(Similar cases could be purchased from local sporting goods stores where they are designed to carry target pistols. Other options are available at kitchen supply stores, but they tend to lack the convenient carrying handle. Cutting foam to fit your components will complete the installation.)

A second option, shown on the next page, is Vernier's DataVest. Placing the accelerometer in the pouch that is built into the DataVest holds the accelerometer in a constant orientation to the rider.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Getting the interface, a 3-axis accelerometer, and cables into the pouch on a DataVest could be challenging. One solution is to utilize the calculator cradle furnished with a LabPro and CBL 2 to hold the accelerometer and cables. Rubber bands will manage the cables nicely. In this diagram, the accelerometer has a Velcro fastener on the bottom and the calculator cradle has the matching piece of Velcro.

The DataVest also has two smaller pockets on the inside. You can place a barometer inside one of these pockets and bring the cord into the interface pocket through the buttonholes in the large pocket. In practice, the LabPro or CBL2 doesn't have to be removed from the pocket as access is furnished on the sides and bottom of the pocket with buttonholes.

WDSS can be safely carried in a DataVest if one obtains either a stack of corrugated cardboard equal in thickness to the height of the WDSS or a piece of fairly rigid foam that just fits inside the large pocket. Cut out a space to just fit the WDSS, making sure the start/stop button is available through the window in the large pocket and you can see the two status LED's.



Electronic Data Collection

Equipment Needed

One can collect data using a number of combinations of sensors, interfaces, computers/calculators/Palm OS devices, etc. From experience, the process goes smoother and is more flexible if one uses a computer as the central device for programming your interface (LabPro or WDSS) and for downloading the data. However we provide specific instructions for a variety of situations as described below and in Appendices 1 through 5.

Steps for Collecting Data

When we use an interface and sensors to record data on amusement park rides, there is a general flow to the process:

1. Set up data rate and duration for the collection process
2. Load these instructions into the LabPro, CBL or WDSS unit
3. Get on ride. Press [Start/Stop] button once just before the section you wish to measure
4. Following the ride, download the data and print graphs. Save the data for further analysis or inclusion in projects.

Specific Steps

Several Appendix sections give specific directions for different combinations of interface software.

- **Appendix 1: Using WDSS.** Materials: Wireless Dynamics Sensor System, Computer with Bluetooth wireless capability, Logger *Pro* 3.4.5 or newer.
- **Appendix 2: Logger *Pro* Remote Option.** Materials: LabPro interface, Computer, Logger *Pro* 3.2 or newer
- **Appendix 3: Logger *Pro* Remote Option.** Materials: LabPro interface, Computer, Logger *Pro* 2.2.1
- **Appendix 4: Using Calculator *EasyData* Program.** Materials: TI-84Plus or TI-83Plus Silver Edition graphing calculator, LabPro, CBL2 or EasyLink™ interface, *EasyData* program.
- **Appendix 5: Using Calculator *DataMate* Program.** Materials: LabPro or CBL 2 interface, TI-83Plus, 84Plus, 86, 89, 92, or 92Plus graphing calculator, *DataMate* program.
- **Appendix 6: Using Calculator *PHYSICS* Program.** Materials: Original CBL interface, TI-83Plus, 84Plus, 86, 89, 92, or 92Plus graphing calculator, *PHYSICS* program.
- **Appendix 7: Using Palm OS Device and *DataPro* Program.** Materials: LabPro Interface, Palm OS Device, *DataPro* program. Covers remote data collection as well as attached.

Sampling Rate

For any ride it is essential to plan data collection carefully. It is often best to concentrate on a single portion of a ride, such as a particular loop or dip of a roller coaster. Decide which part of the ride you wish to study, and estimate the length of time over which you will need to collect data. Measure the total time interval while watching others on the ride. Give yourself lead time to initiate data collection on your interface, too. The time between samples can then be calculated by dividing the desired time by the number of points you want to collect. Collect as many points as your calculator, Palm or computer can conveniently handle.

Example: A particular portion of a ride lasts 20 seconds. If you collect 200 data points, the samples must be $20 \text{ s}/200 = 0.1$ second apart. If several movements happen in that time, an even shorter interval may be preferable and thus more samples should be collected. [As a rule of thumb, at Paramount's Great America we usually collect at a rate of 20 samples per second. But in some cases we increase the rate to 50 samples per second for fairly short time intervals.]

Orientation

Plan how you will orient a single-axis accelerometer during the ride. Which axis do you want to record? Hold or fasten the accelerometer so the arrow is parallel to this axis. The direction of the arrow corresponds to positive acceleration. See page 11 for more ideas on orientation.

Calibrating Sensors

Calibration of sensors is usually not necessary. There may be some variation from unit to unit, but the default calibration is sufficiently accurate to give good readings at normal temperatures.

Calibration of the accelerometer can be done, however, using gravity. **Calibration** is found under **Experiment** on the menu bar for *Logger Pro*. To calibrate the sensor, position the accelerometer with the arrow pointing down for the first calibration point. Define this as -9.8 N/kg or -1 g . Turn the accelerometer so the arrow points up and use the reading you get for the second calibration point. Define this as $+9.8 \text{ N/kg}$ or $+1 \text{ g}$. The accelerometer will then read 0 when held horizontally. Calibration must be done one axis at a time if you are using 3-axis accelerometers.

If the arrow remains pointing upwards during a ride, the readings that are obtained will be $+9.8 \text{ N/kg}$ or $+1 \text{ g}$ except when going over a bump, through a dip or some other complex motion. Values go up or down when the rider goes upside down or goes through a banked turn.

If you seek a net value, you will need to know what the orientation of the accelerometer is at that point. If the arrow points upward, the net value will be the reading minus 9.8 N/kg , or the reading minus 1 g . On the other hand, if you are upside down, the net value is the reading plus 9.8 N/kg or the reading plus 1 g . The author recommends calibrating the sensors as described and then determining net values on a case-by-case basis depending on the nature of the individual ride.

Zeroing Sensors

If you wish to make sure the reading is indeed zero (0) when the arrow is held horizontally, you can zero the sensor. This function is found in the **Experiment** menu. Hold the sensor with the arrow horizontal, choose Zero Sensor from the menu, and follow the on-screen instructions.

Be cautious. If you zero all three axes at once (assuming a 3-axis accelerometer), you will change the calibration points of the axis that's oriented vertically at that moment. Read the dialog boxes carefully and zero only one axis at a time rather than all at once if you are using a 3-axis accelerometer.

Vector Sum for 3-Axis Accelerometers

On many roller coasters, good readings in all three axes can be inhibited by either the manner in which the student holds the sensors, or by the "toss and turn" nature of the ride. In such cases, we suggest looking at the vector sum of all values, and then compare the resulting values to the relative location along the ride. To get a vector sum, take the square root of the sum of the squares:

$$a_{\text{sum}} = \sqrt{(a_x^2 + a_y^2 + a_z^2)}$$

Under **Data**, select **New Calculated Column**. In the dialog box, choose a logical name like "Vector Sum." Then for the definition, use a combination of pull-down menus and typing to get a formula similar to the following:

$$\text{sqrt}(\text{"Vertical"}^2 + \text{"Lateral"}^2 + \text{"Longitudinal"}^2)$$

or

$$(\text{"Vertical"}^2 + \text{"Lateral"}^2 + \text{"Longitudinal"}^2)^{0.5}$$

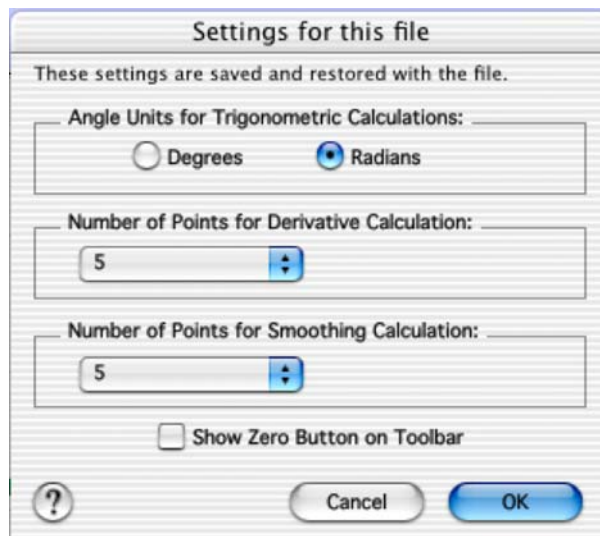
Note that you'll be able to select an appropriate color for this plot under Options. You will be able to display this graph the same as you would the graph of any individual axis by clicking on the vertical axis label and choosing "Vector Sum" from the menu that appears.



Smoothing Data

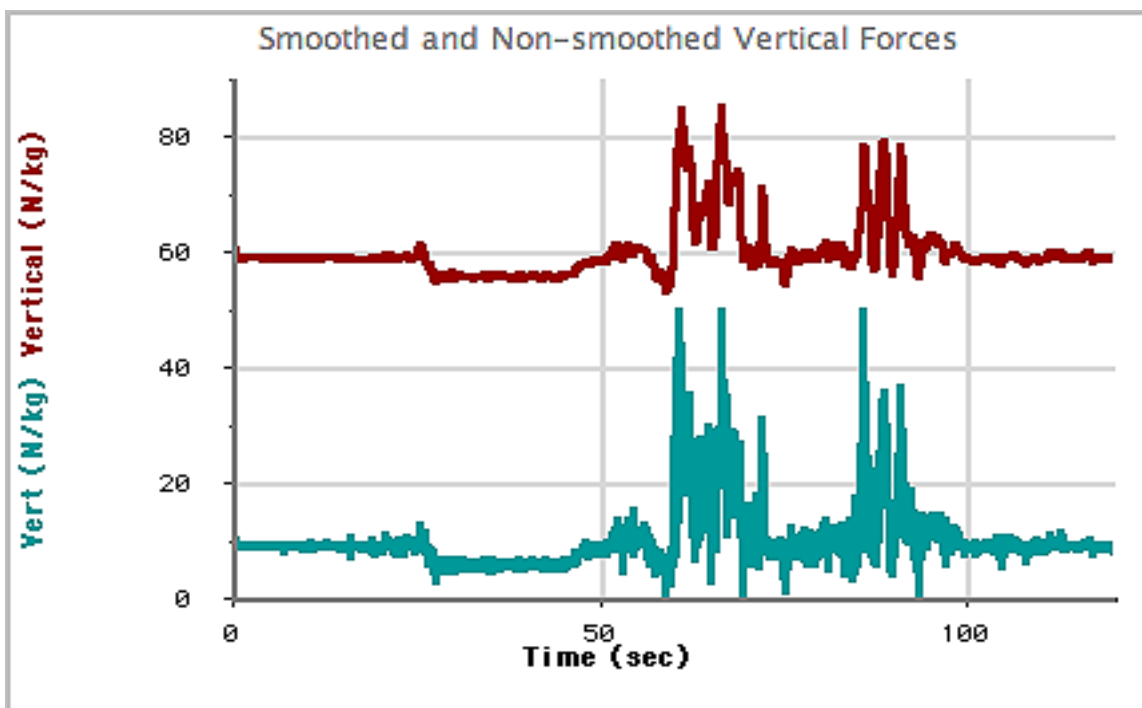
Smoothing of data is taking averages of every 3, 5, 7, ... points and plotting the resulting values instead of the original values. The result of doing this is to remove some of the "electronic jitters" that occur in the data due to digitizing analog data. It also helps to smooth out some of the vibrations that are inherent in most coasters. It is useful to be able to look at a smoother graph rather than one filled with lots of little spikes. The method used to smooth data depends on whether you are using calculators or computers.

For *Logger Pro 3.x*, go to **File** then choose **Settings for this file**. You set the number of points to use while smoothing here. See screen shot on right where the smoothing has been set for every 5 data points.



Under **Data**, select **New Calculated Column**. In the dialog box, choose a name like "Smooth Vertical" or similar. For **Definition** or **Equation**, start by choosing **SmoothSG** from the drop-down functions menu. Then choose the appropriate quantity from the drop-down **Variables** menu.

The graph below shows the same data in two different ways. The lower, teal trace is original data while the upper, red one is smoothed. Significant details stand out more when the data has been smoothed. Students should be aware, though, that smoothing will change the magnitude of peaks, especially sharp ones, and data values should be taken from unsmoothed data.



Pre-trip Suggestion

Try remote data collection at school before going to the park. Make sure you and your students know how the equipment works and have some hands-on experience gathering, downloading and interpreting data before going to the park. Some suggestions:

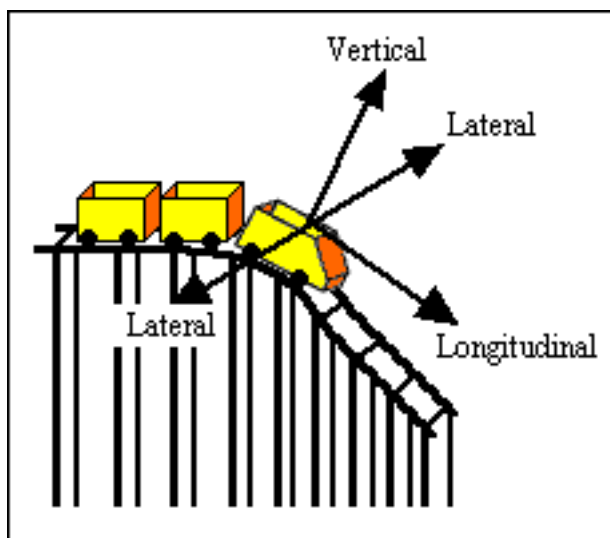
- Jump straight up and land on the ground in different ways (bend your knees different amounts to absorb more or less of the shock)
- Jump down from a chair or low table; try to minimize the maximum value
- Spin around in a circle holding the sensor with its measuring direction pointed radially; compare to spinning around with the sensor oriented tangentially
- Swing your arm with the accelerometer acting like a pendulum
- Swing your arm in a vertical circle at a constant rate

The important thing is to practice so you will know what to do and how to think about the data you gather at the park.

Ride Suggestions

Directions on Ride

When describing the directions of forces on an amusement park ride, it is convenient to have a common vocabulary. The diagram to the right defines the terms “vertical,” “lateral” and “longitudinal.” These designations are from the frame of reference of the rider. While it might be tempting to impose the earth frame of reference, when you are in the middle of a corkscrew section of a ride or partway through a vertical loop, it has little or no meaning to you!



With a 3-axis accelerometer, students can gather data in all three axes - vertical, lateral and longitudinal. For many rides, the primary forces are vertical, but large lateral forces may be present, particularly on scrambler rides and wooden roller coasters. Being able to look at all three axes enables students to unravel their total experience. A key step in the interpretation of the data is identifying which axis is being recorded by which channel. To match the readings with the rider's position, one axis should be aligned with the rider's spine, a second should be directed side-to-side, and the third forward and back.

Dips

Most roller coasters feature a dip following the first major climb, as well as several others during the course of the ride. If you know the speed of the train at the top of the hill and the vertical distance to the bottom, the speed of the train at the bottom can be calculated using conservation of energy. Knowing the radius of the curve at the bottom, the acceleration due to circular motion

can be calculated using kinematics.

The normal force to mass ratio (F/m) can be measured as the train descends, and the maximum value can be determined by tracing along the graph. Note that the total experience is due not only to the circular motion but also to the background effect of gravity. Basic physics shows that the force from the seat on the rider equals the weight (mg) plus the centripetal force (mv^2/R).

$$F_{\text{seat}} = mg + \frac{mv^2}{R}$$

Compare the readings obtained with your electronic sensors and the values that you calculated from energy considerations. Compare the readings at the front of the train with those at the center or at the back of the train. Explain any differences.

Vertical Loops

Many roller coasters feature vertical loops. How does the F/m ratio at the bottom of the loop compare to the F/m ratio at the top of the loop? How does the value at the top compare to normal gravity, $9.8 \text{ N/kg} = 1 \text{ g}$? What does the reading you get at the top mean? Is the loop circular in shape? If not, why isn't it circular?

Corners

Wood roller coasters have cars riding on top of the rails. Many corners may be nearly horizontal. If the axis of the sensor is held level with the car and perpendicular to the direction of the motion, the lateral forces can be studied. Measure the speed of the ride and estimate the radius of curvature. A value for the centripetal acceleration can then be calculated using kinematics. Compare the calculated acceleration with the measured F/m ratio. What could lead to the two values being different?

Barrels

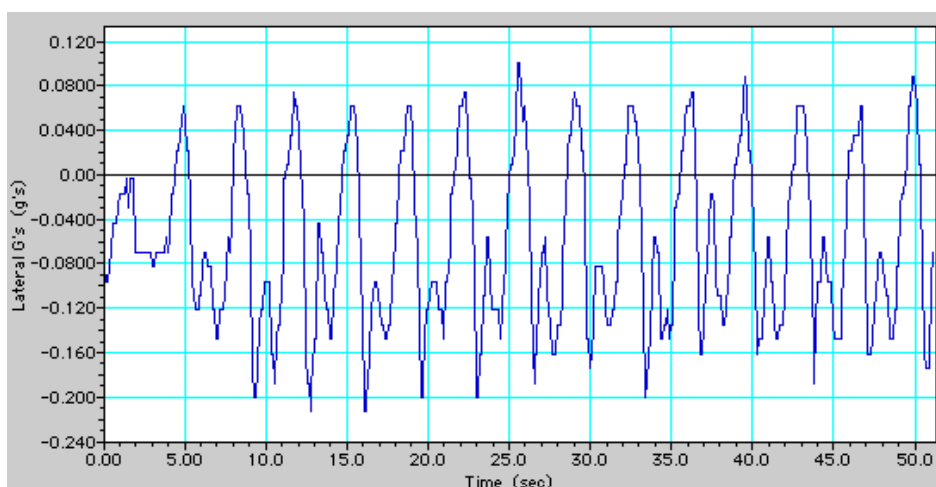
Some rides at amusement parks and carnivals feature a barrel in which the riders appear to be held to the inside surface by an outward force. In fact, there is no outward force. The inward normal force from the wall keeps the riders moving in a circular path. To take data in a barrel ride, first zero the accelerometer with the axis held horizontally. Collect data for the radial acceleration. Because this type of ride is rotating at a constant angular velocity, the physics is that of uniform circular motion. The acceleration is radially inward and should be equal to $4\pi^2 R/T^2$. Calculate the acceleration from measurements of R and the period T for comparison to the acceleration measured while on the ride. The changes in this value while the ride is starting up and also while slowing down can be studied using the data.

Starts And Stops

Many rides feature large linear accelerations. If the direction is forward or back, the reference is to longitudinal acceleration, while if it is up or down, it is vertical. Rapid starts and stops are usually short lived. A data collection time period of 10–15 seconds is usually enough to capture the entire acceleration, allowing you to start the collection just before the ride begins or just before it enters the station and comes to a stop. Study the ride in advance to choose an appropriate data collection time and trigger point. Which is larger, the starting or the stopping acceleration? Why might one be larger than the other?

Scramblers

Some parks rides are known as scramblers. In a scrambler, the rider's seat rotates about a pivot point with a small radius while that point is carried around in a larger radius by the overall ride. If the axis of the sensor is held so it is directed to the side of the rider, it will record the lateral values throughout the ride. If the sensor is pointed forward or backward relative to the rider, it will record the longitudinal values. For these rides, zero the accelerometer while the arrow is held horizontally. How close are the radial values experienced on the scrambler to 1 g?



Data from **Triple Play** at Paramount's Great America, a scrambler ride. This is the lateral acceleration in g's.

Investigations at the Park

Here are some useful questions that might be investigated with the use of electronic instruments:

1. Expert riders such as members of American Coaster Enthusiasts (ACE) tell us that they can feel the difference in ride between the front right and front left seats of a roller coaster. They can also tell the difference between front, middle and back. Gather data that shows how much difference there is between different seats on the same train of the same ride.
2. Compare the speeds, forces and degree of curvature at the bottom and top of a vertical loop. How do the forces compare to theory? Why don't passengers fall out at the top of the loop?
3. Where do passengers experience the greatest force on a given ride? Why is the largest force at this point and not at another point on the same ride?
4. We can record forces along the longitudinal, lateral and vertical axes. In terms of the total force felt for a given ride, which of these is the biggest contributor? As you compare rides at a park, which rides give the most lateral force? Which rides give the most longitudinal force? Which rides give the most vertical force? Why?
5. Research along which axis people can best tolerate high force. How does this relate to the design of roller coasters and the forces experienced there?
6. Develop a question or series of questions you would like to investigate. Design your methodology then carry it out, reporting your results.



Celebration Swings at Paramount's Great America

Extensions

1. Carry an accelerometer while snow skiing or snowboarding. Make several turns while recording the lateral acceleration. A procedure similar to the one described could be employed to study the turning accelerations as the skier makes sharp and gradual turns.
2. Have a skier, skateboarder or a bicyclist go over a vertical jump and record the acceleration in the vertical direction during the jump. Video analysis measurements could be used as a comparison to the interface measurements.
3. Have a rider on a skateboard, ice skates or roller blades execute a series of turns while carrying an accelerometer and interface. Basic kinematics can be used to compare to the recorded values
4. Other carnival and amusement park rides can be studied using techniques similar to the ones described above. Most have a preferred direction of acceleration that can be ascertained by studying the motion of the ride.
5. Strap an accelerometer to a bungee jumper to record the forces during a jump. Typically, the jumper tumbles while in the air. As a result, better quality data can be obtained by recording the three orthogonal axes using three accelerometers or a 3-axis accelerometer. The vector sum of the three is the instantaneous magnitude of the force of the jumper.
6. Use a Vernier barometer to measure air pressure during the motion of an elevator or roller coaster ride, and convert air pressure data to altitude. The conversion is approximately a 1-mm Hg equivalent drop in pressure per 11.1 meters gain in altitude.

Web Sites

<http://www.vernier.com>

<http://www.physicsday.org> (extensive links page and student ride activity pages)

Whatever else you do, have fun with the technology. Plan to learn a little more each year. Not only will there be new rides, but your own ability to sift through the data and to make sense of it will improve with experience.

Appendix 1 – WDSS at the Amusement Park

MATERIALS

Wireless Dynamics Sensor System (WDSS)

Computer that is Bluetooth enabled

The following steps will guide you through configuring the WDSS with a computer to collect data so that you need to carry only the WDSS to the ride. After collecting data, reconnect the WDSS and data can then be transferred to the computer for analysis.

You will need to set the time between samples and/or the number of points collected for your particular ride. Adjust these values as you design your experiment.

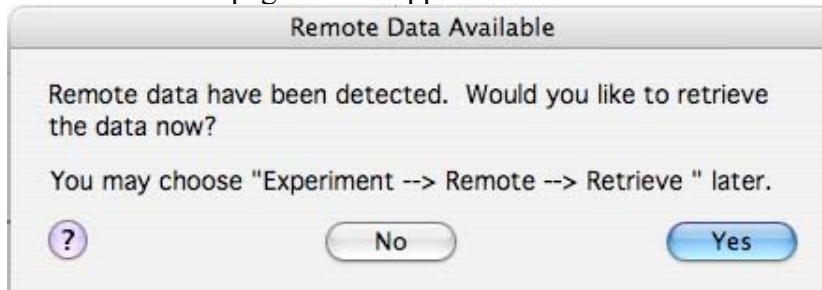
GENERAL PROCEDURE

1. Connect WDSS to your computer.
 - Launch *Logger Pro*
 - Under **Experiment**, choose **Connect Interface > Wireless > Scan for Wireless Devices**
2. Once the WDSS has been found and connected (follow onscreen menu), select **Open**. In the Experiment folder, choose **Additional Physics > Amusement Park Physics > WDSS**.
3. Click on the WDSS icon that's immediately above the data table. In the menu that drops down, make sure the boxes for the three Accelerometer directions and the Altimeter are checked and the box for Forces is unchecked. For each of the Accelerometer directions, use the drop-down **Configure** menu to set the units to N/kg. Click on [Close] when finished.
4. Click on the “stopwatch” icon immediately left of the Collect button. In the window that appears, set your data rate and collection time. We recommend you set the collection time longer than the actual ride duration. Click on [Done] when finished.
5. Under **Experiment**, choose **Remote > Setup > WDSS**: Click [OK] to complete the operation. The LED above the power switch should change from green to red, indicating that the WDSS has disconnected from the computer. The WDSS is now ready to collect data. Note that the WDSS can actually be powered off at this point, and when re-powered, it will still be in remote data collection mode.
6. Proceed to the ride. Once on the ride, orient the WDSS as appropriate for your experiment. Collect data when you are ready by pressing the Start/Stop button. When the green LED just below the accelerometer label is blinking, data is being collected by the WDSS. A steady green light means the unit is on, but not actively collecting data.
7. At the end of the run, pressing Start/Stop will halt data collection. If you do not press the button at this time, WDSS will continue collecting data until the end of the collection time you set in step 4, when it will stop automatically.
8. You can now move to another ride and repeat data collection, or you can repeat your run on the same ride. WDSS supports multiple data runs until its memory is completely full.

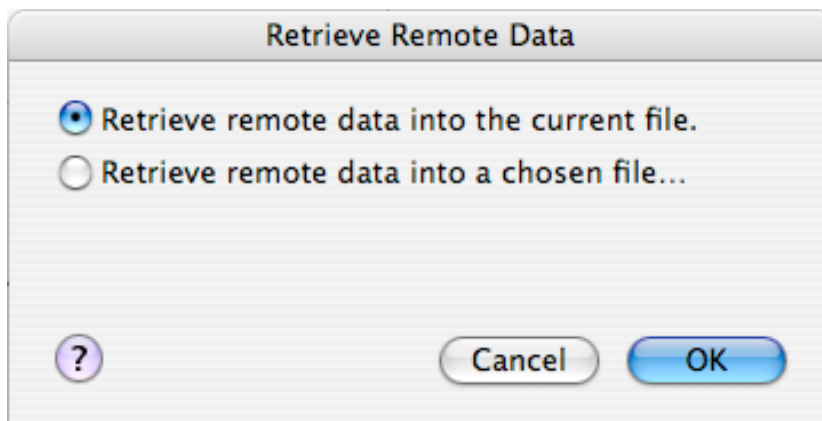


DOWNLOADING DATA

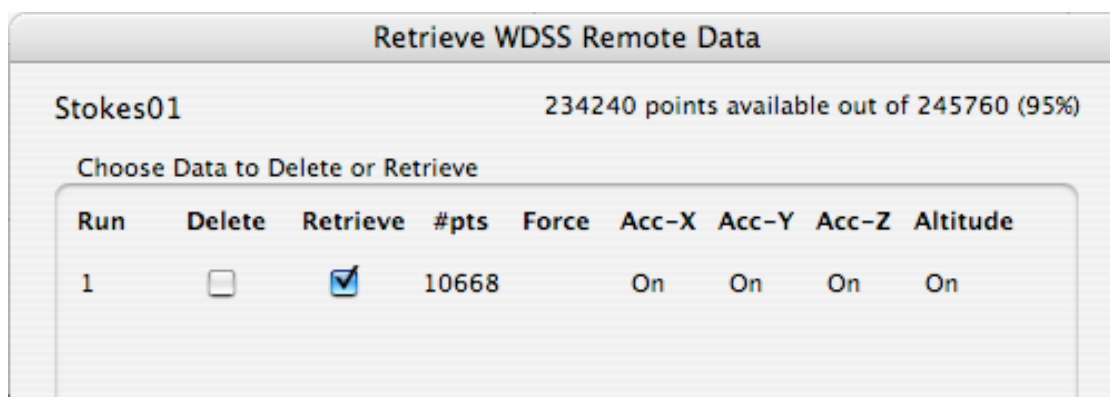
- Return to the computer that programmed the WDSS. Launch *Logger Pro* and reconnect. (**Experiment > Connect Interface > Wireless > Scan for Wireless Devices**)
- The window on the next page should appear.



Click on **Yes** to retrieve your data, bringing up the next window.



OK would be a good choice. Then the next window appears.



Clicking on the box under Retrieve will begin the download process. If you collected data on more than one ride, the data can be collected for multiple “Runs” or one run at a time.*

11. Label the data columns with the appropriate axes (Vertical, Lateral, etc.) Analyze the data, change the graph that is displayed, print out the graphs, etc. Save the data with an appropriate name indicating the ride and the riders.

Remote Data				
		Y Acc	X Acc	Z Acc
		(N/kg)	(N/kg)	(N/kg)
1	0	-0.44	6.98	6.76
2	0	-1.18	6.44	7.28

Destiny's Child				
		Lateral	Vertical	Longitudinal
		(N/kg)	(N/kg)	(N/kg)
1	0	-0.44	6.98	6.76
2	0	-1.18	6.44	7.28

12. The WDSS can be reset to collect fresh data by repeating step 5.

* It is recommended that the user delete runs as they are retrieved to clear up memory space on the WDSS for future data runs. If you wish to return to the screen seen in Step 10 above, click on the WDSS icon just above the data table. In the menu that appears, click on [Manage Memory] to have access to downloading or deleting data runs.

Appendix 2 – Logger Pro 3.x Remote Option

MATERIALS

- LabPro interface Low-g or 3-axis accelerometer
- Computer Serial or USB cable
- Barometer (optional)

The following steps will guide you through configuring the LabPro interface with a computer to collect data so that you need to carry only the interface and sensor(s) without a computer. After collecting data, the interface is reconnected and data are then transferred to the computer for analysis.

You will need to set the time between samples and/or the number of points collected for your particular ride. Adjust these values as you design your experiment.

GENERAL PROCEDURE

1. Connect LabPro to computer using either a serial cable or USB cable. Launch *Logger Pro*.
2. Select then open the appropriate file below. All are available for download from <http://www.vernier.com/cmat/datapark.html> and are available with versions of *Logger Pro* software beginning with 3.3 in the Experiments folder. **Open > Experiment > Additional Physics > Amusement Park Physics**
 - amuse1 - Single axis accelerometer only
 - amuse3 - 3-axis accelerometer only
 - amuse1b - Single axis accelerometer plus barometer - use CH1, CH2(barometer)
 - amuse3dacbaro - 3-axis accelerometer plus barometer - use CH1, CH2, CH3, CH4(barometer)
3. Connect the sensor(s) to LabPro.
4. Check the sample rate and number of samples.
 - a. Under Experiment, choose Data Collection... (or click on the stopwatch icon)
 - b. Under Collection, set the total time for collection and the samples per second.
5. Under **Experiment**, choose **Remote > Remote Setup... > LabPro 1**. Click **OK** to complete the operation. A yellow LED should be lighted on the LabPro indicating that it is ready to collect data.
6. Disconnect the serial or USB cable and proceed to the ride.
7. Orient the accelerometer as appropriate for your experiment. Collect data when you are ready by pressing the START/STOP button on the interface once*. At the end of data collection, the LabPro will beep and stop automatically. You do not need to press the START/STOP button to stop data collection unless the ride is surprisingly short.
8. Launch *Logger Pro* and open the same file that was used to load the data into the LabPro. Re-connect the LabPro to the computer with the serial or USB cable. Follow instructions from the dialog boxes to download the data. It will fill the data table automatically.
9. Save the data with an appropriate name indicating the ride and the riders. Label the data columns appropriately (Vertical, Lateral, etc.)
10. The LabPro can be reset to collect fresh data by simply repeating step 5.

* Notes: LabPro currently supports only one set of data collection at a time. It is important to press the START/STOP button just before you wish to begin collection. Pressing it too early may leave you with a set of meaningless data. Pressing the START/STOP button twice will result in data collection stopping prematurely. Press the button just once.

Appendix 3 - Logger Pro 2.2.1 Remote Option

MATERIALS

- LabPro interface Low-g or 3-axis accelerometer
- Computer Serial or USB cable
- Barometer (optional)

The following steps will guide you through configuring the LabPro interface with a computer to collect data so that you need to carry only the interface and sensor(s) without a computer. After collecting data, the interface is reconnected and data are then transferred to the computer for analysis.

You will need to set the time between samples and/or the number of points collected for your particular ride. Adjust these values as you design your experiment.

GENERAL PROCEDURE

1. Connect LabPro to computer using either a serial cable or USB cable. Launch *Logger Pro 2.2.1*.
2. Select then open the appropriate file below. All are available for download from <http://www.vernier.com/cmat/datapark.html>.
 - AMUSE1.MBL - Single axis accelerometer only - use CH1
 - AMUSE3.MBL - 3-axis accelerometer only - use CH1, CH2, CH3
 - AMUSE1B.MBL - Single axis accelerometer plus barometer - use CH1, CH2(barometer)
 - AMUSE3B.MBL - 3-axis accelerometer plus barometer - use CH1, CH2, CH3, CH4(barometer)
3. Connect the sensor(s) to LabPro.
4. Check the sample rate and number of samples.
 - a. Under **Setup**, choose Data Collection...
 - b. Under Sampling set the total time for collection and the samples per second.
 - c. Under Experiment, make sure Live Readouts is unchecked. If it is checked, move the mouse to it and let up on the mouse button.
5. Under **Remote** choose Set Up LabPro... Click OK to complete the operation. A yellow LED should be lighted on the LabPro indicating that it is ready to collect data.
6. Disconnect the serial or USB cable and proceed to the ride.
7. Orient the sensor(s) as appropriate for your experiment. Collect data when you are ready by pressing the START/STOP button on the interface once*. At the end of data collection, the LabPro will beep and automatically stop. You do not need to press the START/STOP button to stop data collection.
8. Launch *Logger Pro* and open the same file that was used to load the data into the LabPro. Re-connect the LabPro to the computer with the serial or USB cable. Follow instructions from the dialog box(es) to download the data. It will fill the data table automatically.
9. Label the data columns with the appropriate axes (Vertical, Lateral, etc.) Analyze the data, change the graph that is displayed, print out the graphs, etc. Save the data with an appropriate name indicating the ride and the riders.
10. The LabPro can be reset to collect fresh data by simply repeating step 5.

* Notes: LabPro currently supports only one set of data collection at a time. It is important to press the START/STOP button just before you wish to begin collection. Pressing it too early may leave you with a set of meaningless data. Pressing the START/STOP button twice may result in data collection stopping prematurely. Press the button just once.

Appendix 4 - Using Calculator *EasyData* Program

MATERIALS

- LabPro or CBL2 interface or EasyLink
- Low-g or 3-Axis accelerometer (Low-g accelerometer only with EasyLink)
- TI Graphing Calculator: TI83 Plus or TI-84 Plus series
- EasyData* program
- Barometer (optional)

The following steps will guide you through configuring *EasyData* to collect data at the park. After collecting data, the calculator can be connected to a computer for downloading and saving the data.

Memory: The memory space in graphing calculators is somewhat limited. It is used for both programs and data storage. With no programs, we were able to gather over 300 sets of data using a 3-Axis accelerometer and a barometer (4 sets of data plus time). To enhance data space, clear out programs.

GENERAL PROCEDURE

1. **Interface:** Connect the TI graphing calculator to a LabPro or CBL2 using the supplied link cable. **EasyLink:** Connect the EasyLink to the TI-84+ using the mini-USB port.
2. Connect the accelerometer (and barometer if you are using it) to the interface or to the EasyLink.
3. Launch *EasyData*, found under the [APPS] button. The sensors you have installed should show up on the screen.
4. If you wish to change units for the barometer, press the button under **Setup**. Choose the Barometer. Then press the button under **Units** and choose the pressure unit you wish to use.
5. Set up the calculator and interface for data collection.
 - a. Press the button under **Setup**. Choose **Time Graph**.
 - b. Examine the time settings. To change these, press the button under **Edit**. Enter the time between samples and the number of samples as requested. If you do not achieve the correct values you wish, press the button under **Edit** again and repeat.
6. When you get on the ride, orient the accelerometer as appropriate for your experiment. Press the button under **Start** to initiate data collection. You may be asked if you wish to overwrite existing data, to which you should reply **OK**. A green LED on the LabPro or CBL2 will blink to indicate the interface collecting data.
7. Examine individual graphs by pressing the button under Plots and choosing the plot you wish to study. Tracing is automatically turned on, so you can step across the graph noting important values by using the arrow keys.
8. Note: If the data is not downloaded to a computer for safe storage, a second data collection will likely end up deleting your data.

DOWNLOADING DATA

The data from the calculator can be downloaded to a computer for storage and printing of the graphs using either *Graphical Analysis* or *Logger Pro*. The instructions depend on your version of the software. If the steps that follow (written for *Logger Pro* 3.x) don't work for you, refer to the Help menu on your software.

1. Quit the *EasyData* program. You will be informed which lists contain the data you just collected. Remember which lists you need to download.
2. Connect the calculator to the computer using a TI-Graph Link Cable or the USB-to-mini USB cable supplied with the TI-84 Plus.
3. Launch *Graphical Analysis* or *Logger Pro* from Vernier.
4. Click once in the first cell of the data table. Go to the button that looks like a calculator (Download from TI Device). In the dropdown menu, select the specific connection device you are using (either TI Connectivity Cable or USB Direct). If necessary, have *Graphical Analysis* or *Logger Pro* scan for devices.
5. Follow the indicated steps in the dialog box, including selecting which lists of data to download.
6. Label the columns of data you have in the computer program to complete this step, including appropriate units. Save the file with the ride name and the names of the riders.
7. Disconnect the calculator.

** You can also connect a LabPro or CBL2 directly to a TI-Graph Link USB Cable. This allows you to extract the data directly into the computer without using the calculator. The steps are essentially the same.

Appendix 5 - Using Calculator *DataMate* Program

MATERIALS

- LabPro or CBL 2 interface Low-g or 3-axis accelerometer
- TI Graphing Calculator: TI73, 83 Plus, 84 series, 86, 89, or 89 Plus
- DataMate* program
- Barometer (optional)

The following steps will guide you through configuring the LabPro or CBL 2 interface to collect data so that you need to carry only the interface and sensor(s) without the calculator. After collecting data, the calculator is reconnected and data are then transferred to the calculator for analysis.

GENERAL PROCEDURE

4. Connect the Vernier accelerometer to LabPro or CBL 2. CH1 if single axis, CH1, CH2, CH3 if 3-axis. The barometer goes into CH2 if used with single axis accelerometer, or CH4 if used with a 3-axis accelerometer on LabPro only.
5. Link to TI graphing calculator with black link cable. Start *DataMate* program (under APPS for models with flash memory).
6. To set up manually:
 - a. Select SETUP from the main screen.
 - b. Select CH1.
 - c. Choose ACCELEROMETER from the SELECT SENSOR list.
 - d. Select LOW G ACCEL (M/S²) from the ACCELEROMETER list.
9. Repeat steps above for CH2 and CH3 if using a 3-Axis Accelerometer.
10. If using a Barometer, select appropriate channel. Select BAROMETER from the SELECT SENSOR list. Choose "mm Hg" for the units.
11. Set up the calculator and interface for remote data collection.
 - a. Select MODE then TIME GRAPH from the SELECT MODE screen.
 - b. Select CHANGE TIME SETTINGS from the TIME SETTINGS screen.
 - c. Enter your time between samples in seconds.
 - d. Enter your number of samples.
 - e. Select ADVANCED from the TIME GRAPH SETTINGS screen.
 - f. Select CHANGE TRIGGERING from the ADV. TIME GRAPH SETTINGS screen.
 - g. Select MANUAL TRIGGER from the SELECT TRIGGERING screen.
 - h. Select OK three times to return to the main screen.
12. Select START from the main screen. A yellow LED on the LabPro or CBL 2 will light to indicate the interface is ready to collect data.
13. Disconnect the black link cable from the interface. You do not need to carry the calculator during data collection.
14. Orient the accelerometer as appropriate for your experiment. Collect data when you are ready by pressing the START/STOP button on the interface once*.
15. Use the calculator to retrieve data from the interface:
 - a. Reconnect the calculator to the interface using the black link cable.
 - b. Start the *DataMate* program. After the opening title screen, the calculator will display a message showing that data collection is complete.
 - c. Select TOOLS from the main screen.

- d. Select RETRIEVE DATA from the TOOLS screen. Data will now be transferred from the interface to your calculator.
16. Examine the graph of acceleration vs. time.
 - a. Trace along the graph with the cursor keys to read out particular values.
 - b. Press ENTER to return to the main screen.

* Notes: LabPro currently supports only one set of data collection at a time. It is important to press the START/STOP button just before you wish to begin collection. Pressing it too early may leave you with a set of meaningless data. Pressing the START/STOP button twice may result in data collection stopping prematurely. Press the button just once.

The data from the calculator can be downloaded to a computer for storage and printing of the graphs using either *Graphical Analysis* or *Logger Pro*. The instructions depend on your version of the software. If the steps that follow (written for *Logger Pro* 3.2) don't work for you, refer to the Help menu on your software.

8. Quit the *DataMate* program. You will be informed which lists contain the data you just collected. Remember which lists you need to download.
9. Connect the calculator to the computer using a TI-Graph Link Cable**.
10. Launch *Graphical Analysis* or *Logger Pro* from Vernier.
11. Click once in the first cell of the data table. Go to **File** on the menu bar and select **Download from TI**. A dialog box will appear indicating the computer is expecting to receive data from a TI device.
12. Follow the indicated steps in the dialog box, including selecting which lists of data to download.
13. Label the columns of data you have in the computer program to complete this step, including appropriate units. Save the file with the ride name and the names of the riders.
14. Disconnect the calculator.

** You can also connect the LabPro or CBL2 directly to the TI-Graph Link Cable. This allows you to extract the data directly into the computer without using the calculator. The steps are essentially the same.

Appendix 6 - Using Calculator *PHYSICS* Program

MATERIALS

TI-82, 83, 83 Plus, 84 Plus, 89, 92, or 92 Plus, Voyager200

PHYSICS program loaded in calculator

Original CBL

Low-g or 3-axis accelerometer

The following steps will guide you through configuring the original CBL to collect acceleration data so that you need to carry only the interface and sensor. After collecting data, the calculator is reconnected and data are then transferred to the calculator for analysis. Note that the *PHYSICS* program does not support barometers.

GENERAL PROCEDURE

1. Connect the Vernier accelerometer to the original CBL. CH1 if single axis, CH1, CH2, CH3 if 3-axis.
2. Turn on the interface and the calculator. Start the *PHYSICS* program and proceed to the MAIN MENU.
3. Select SET UP PROBES from the MAIN MENU.
 - a. Select ONE as the number of probes for a single axis accelerometer or THREE for 3-axis accelerometer.
 - b. Select ACCELEROMETER from the SELECT PROBE menu for each of your channels.
 - c. Select USE STORED from the CALIBRATION menu.
 - d. Select LOW-G from the ACCELEROMETER menu.
4. Set up the interface for manual triggering. This allows you to take data when the interface is not connected to the calculator.
 - a. Select TRIGGERING from the MAIN MENU.
 - b. Select MANUAL from the TRIGGERING menu.
5. You can zero the accelerometer in the orientation you plan to collect data.
 - a. Select ZERO PROBES from the MAIN MENU.
 - b. Select CHANNEL 1 from the SELECT CHANNEL menu.
 - c. Orient your accelerometer so the orientation is horizontal for the axis you are zeroing and wait for the reading on the screen to stabilize.
 - d. Press [+] to accept the current value as being zero.
 - e. Repeat for other channels if present.
6. Set up the calculator and interface for data collection.
 - a. Select COLLECT DATA from the MAIN MENU.
 - b. Select TIME GRAPH from the DATA COLLECTION menu.
 - c. Enter the time between samples in seconds and the number of samples. The maximum number of data points that the original CBL can accumulate is 512.
 - d. Press ENTER, then select USE TIME SETUP to continue. If you want to change the sample time or sample number, select MODIFY SETUP instead.
7. Press ENTER to set the CBL up for remote data collection. Disconnect the link cable from the interface. The interface will collect data when you press the TRIGGER button. You do not need to carry the calculator during data collection.
8. Orient the sensor as appropriate for your experiment, and collect data when you are ready by pressing the TRIGGER key on the CBL unit. When data collection is finished, the

CBL display will show DONE. Only press TRIGGER once* to start data collection; the CBL will quit collecting when the time has expired.

9. Retrieve the data from the interface.
 - a. Reconnect the calculator to the interface using the black link cable.
 - b. Return to the MAIN MENU.
 - c. Select RETRIEVE DATA from the MAIN MENU.
 - d. Confirm that the interface is through collecting data, then press ENTER.
10. View your acceleration graph and analyze data as needed.
 - a. Press ENTER to view your graph.
 - b. Trace along the graph with the cursor keys to read out particular values.

The data from the calculator can be downloaded to a computer for storage and printing of the graphs using either *Graphical Analysis* or *Logger Pro*. The instructions depend on your version of the software. If the steps that follow (written for *Logger Pro* 3.2) don't work for you, refer to the Help menu on your software.

1. Quit the *PHYSICS* program. You will be informed which lists contain the data you just collected. Time is in L₁. Remember which lists you need to download.
2. Connect the calculator to the computer using a TI-Graph Link Cable.
3. Launch *Logger Pro* or *Graphical Analysis* from Vernier.
4. Click once in the first cell of the data table. Go to **File** on the menu bar and select **Download from TI**. A dialog box will appear indicating the computer is expecting to receive data from a TI device.
5. Follow the indicated steps in the dialog box, including selecting which lists of data to download.
6. Label the columns of data you have in the computer program to complete this step, including appropriate units. Save the file with the ride name and the names of the riders.
7. Disconnect the calculator.

* Notes: CBL supports only one set of data collection at a time. It is important to press the TRIGGER button just before you wish to begin collection. Pressing it too early may leave you with a set of meaningless data. Pressing the TRIGGER button twice may result in data collection stopping prematurely. Press the button just once.

Appendix 7 - Using Palm OS device and *DataPro* Program

MATERIALS

- Palm OS device with *DataPro* program loaded
- Low-g accelerometer or 3-axis accelerometer
- LabPro System
- Barometer (optional)
- Handheld-to-LabPro Cable
- Computer with *Graphical Analysis* or *Logger Pro* software
- TI-Graph Link (optional)

Remote Collection

The following steps will guide you through configuring the LabPro to collect data so that you need to carry only the interface and sensor. After collecting data, the LabPro is connected to the computer with a serial cable, USB cable or TI-Graph Link. Data are then transferred to the computer using *Graphical Analysis* or *Logger Pro* software for analysis.

You will need to modify either the time between samples or the number of points collected for your particular circumstances. Adjust these values as you design your experiment.

GENERAL PROCEDURE

1. Connect the Vernier accelerometer to LabPro. CH1 if single axis, CH1, CH2, CH3 if 3-axis. Barometer goes into CH2 if used with single axis, or CH4 if used with 3-axis.
2. Connect the Palm OS device to the LabPro with the Handheld-to-LabPro cable. Note that you do not use the pouch that traditionally holds the Palm device to the LabPro. The accelerometer can be carried using a calculator cradle as shown on page 6.
3. Start the *DataPro* program and proceed as follows once the program reaches the main screen.
 - a. Tap on [Setup]. If the program has identified the sensor(s) you are using correctly, skip ahead.
 - c. Tap on CH1: From the pop-up menu, tap on the specific Accelerometer you are using. For example, you might choose “ACCEL3D-X axis (m/s²)”. Tap on that option to set the sensor.
 - b. Continue this process until you have selected all of the sensors you will be using. For the Barometer, you should choose “BARO(mmHg)”.
 - c. Use the Calibrate and Zero buttons to calibrate and/or zero the sensors.
4. Set up the interface for Remote operation. This allows you to take data when the interface is not connected to the Palm device.
 - a. Tap on “Mode:” Choose “Remote Setup” by tapping on it.
 - b. On the screen that pops up, you can set the seconds per sample and the number of samples. Make sure the total time you will be collecting data covers the portion of the ride you are studying.
 - c. Tap [Setup] to transfer the instructions to the LabPro. The yellow “ready” light will light up, indicating the LabPro is ready to begin data collection.
5. Following the instructions on the screen, you disconnect the LabPro from the Palm device and proceed to the ride. Press the [Start/Stop] button on the LabPro once to initiate data collection. The LabPro will stop collecting data after its programmed time.
6. Return the LabPro to a computer to download the data you have collected.
 - a. Launch either *Graphical Analysis* or *Logger Pro*. Either program can be used to

- download the data from the LabPro.
- b. Connect the LabPro to the computer with either a serial or USB cable, or with a TI-Graph Link.
- c. The following steps assume a TI-Graph Link.
 - i. Click on the icon with the mini-calculator on it (“Import from TI Device” appears when you hold the cursor over the icon).
 - ii. On the dialog box that appears, you may need to choose the type of TI-Graph Link you are using. You may also need to click the [Scan for Device] button.
 - iii. Once the LabPro has been found, select the channels in which you recorded data plus time. Click [Okay] to download the data.
- d. The following steps assume a serial or USB cable.
 - i. When you connect the LabPro, you should get a dialog that indicates “Remote data have been detected...” Click on [Yes] to retrieve this data.
 - ii. If you have a generic file open, the data will go in as a separate data set. That is fine.
- e. Label the data by double-clicking at the top of the respective columns of data. Hint: The one that progressively and regularly increases is time.
- f. Save the data with a title that will be meaningful for future reference. For example, you might want to include the name of the ride plus names from your group.

Attached Collection

The Palm OS device can accompany the LabPro and accelerometers (and barometer) throughout the ride experience. With the exception of trying to tap a small [Start] button while the ride is moving, this is an excellent way to collect data. There are some advantages that will be pointed out as well as disadvantages.

1. Connect the Palm OS device to the LabPro with the Handheld-to-LabPro cable. Note that you will use the pouch that traditionally holds the Palm device to the LabPro. The accelerometer could be mounted on the pouch if a piece of Velcro is sewn on the outside, or it can be mounted on a plastic card and carried in a pocket on the DataVest.
2. Start the DataPro program and proceed as follows once the program reaches the main screen.
 - a. Tap on [Setup]. If the program has correctly identified the sensor(s) you are using correctly, skip to step (4).
 - b. Tap on CH1: From the pop-up menu, tap on the specific Accelerometer you are using. For example, you might choose “ACCEL3D-X axis (m/s²)”. Tap on that option to set the sensor.
 - c. Continue this process until you have selected all of the sensors you will be using. For the Barometer, you should choose “BARO(mmHg)”.
 - d. Tap on the Mode button and set it to “Time Graph”.
 - e. Click on the Settings button and set the Seconds/Sample and Number of Samples to values you have previously determined. The total collection time will be shown so you can check to be sure you are collecting enough data. Tap [OK] when you have the setting you wish to use.
 - f. Note: The more data you collect, the longer it will take to download.

- g. Use the Calibrate and Zero buttons to calibrate and/or zero the sensors. Then press [OK] to accept the settings you will be using.
3. While on the ride, tap on [Start] to begin data collection. The LabPro should beep and the green light should be lighted during collection.
4. Following the data run, the data will be imported back into the Palm. This may take a while. Once it is there, you can save it to a file for future downloading and analysis.
 - a. Tap the menu bar button for *DataPro*. Invoking the Save command will bring up a dialog box that indicates the name of the file that has been saved. This should be noted. (The file name includes the date and time of the save.)
5. After saving, a fresh set of data can be gathered by tapping the [Start] button. This overwrites the data that had been previously collected. If you wish to keep that run and have two different runs to compare, tap [Store] which will put the current run into temporary memory. It will be called something like Run1. Then tap [Start] to collect a second run. Subsequent runs will be considered part of the whole file that you will be saving once you are finished.
6. Launch *Logger Pro* or *Graphical Analysis*. Follow normal procedures for hot syncing the Palm OS device to the computer. The program can now open up the saved files for analysis and printing.

Advantage for Palm OS device: Multiple runs can be gathered without having to return to a main computer for downloading. The memory size for Palm is much larger than for a TI graphing calculator. For example, one group could study the accelerations in the front right, then the front left of a ride, while another could study the front right and back right of the same ride. All this data could be stored on the Palm until hot synced to the computer.

Note that you can use Store to temporarily save a run, then make another before saving for easily comparing two different seats on the same ride, for example. Saving then saves a file on the Palm device that will be transferred to the computer upon hot-syncing.

Note: The maximum number of rows of data in *Data Pro* is 500 if you wish to display the data on the Palm device.

Appendix 8 – Video Analysis

Beginning with version 3.2, *Logger Pro* supports video analysis. One marks the progress of an object from frame to frame on a video clip, sets the scale, and then obtains a graph of position or velocity vs. time. Calculations can be done on the data to yield acceleration (derivative of the velocity), kinetic energy or gravitational potential energy.

Requirements for the video

- The format of the video clip should be QuickTime (.mov) or AVI (.avi).
- The camera must not pan or zoom during the scene to be analyzed. A tripod is definitely recommended.
- The camera should be as flat-on to the motion as possible to avoid errors introduced due to perspective. The motion should be confined to a plane.
- Some object within the video frame should be of known size in order to set an accurate scale. Pacing off the length of a roller coaster car is one way to accomplish this task.



Boomerang at Six Flags Marine World in Vallejo, CA.

Obtaining video clip

While there are many ways to obtain digital video that can be imported into *Logger Pro*, three will be outlined. A wide variety of specific computer programs can be used to accomplish this task. In all cases, if you have control of the shutter speed, it is advantageous to make it as fast as possible to obtain the sharpest images for analysis.

1. Digital Still Camera

Use the movie function on a digital still camera to capture the video clip you want. This can then be imported into your computer and then imported into *Logger Pro*. Formats vary from brand to brand and model to model. Save the file in .mov or .avi format.

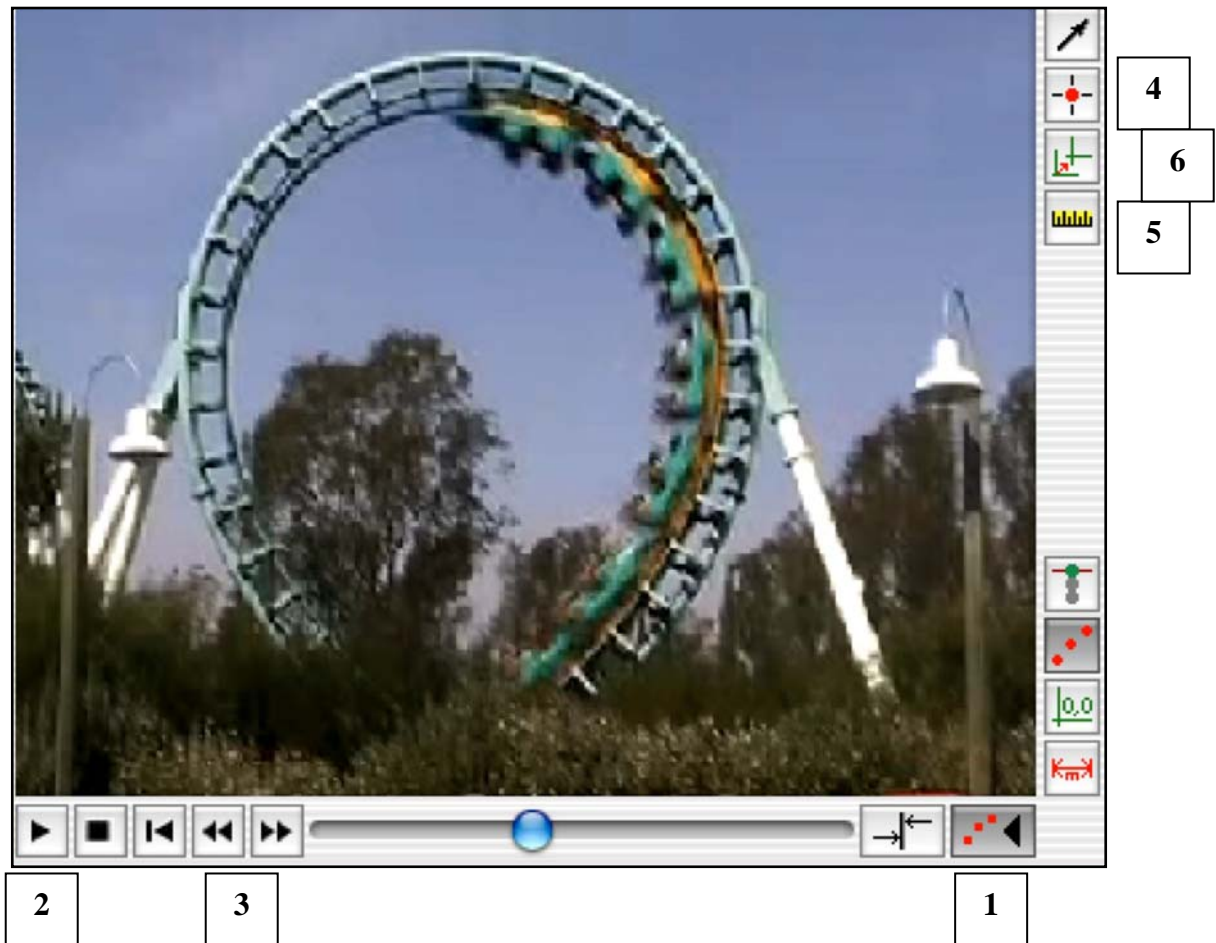
2. Digital Video – Macintosh

Footage taken with a digital camcorder can be imported into iMovie or another video editing program on a Macintosh. After selecting and editing the clip you wish to study, it can then be exported to QuickTime (.mov) and then imported into *Logger Pro*.

3. Digital Video – PC

Footage taken with a digital camcorder can be imported into a video editing program on a PC. After selecting the clip you wish to study, it should then be exported to .avi format and then imported into *Logger Pro*.

Basic Steps



0. Open the movie using the **Insert** menu and choosing **Movie**. Once the movie has been inserted, go to **Page** and choose **Auto Arrange**.
1. Click this button to initiate Video Analysis. The buttons on the right side of the video clip will appear now as will the data table and graph.
2. Click this button to Play the video. Get close to the beginning of the action you wish to analyze then click the square button to Stop.
3. Use these buttons to step forward or backward to zero in on the beginning frame.
4. Click this button to begin marking points on the video. Move your cursor to a point such as the front of the train and click the mouse. A spot will be marked on the video and it automatically advances to the next frame. When finished, click button #4 to stop marking

points.

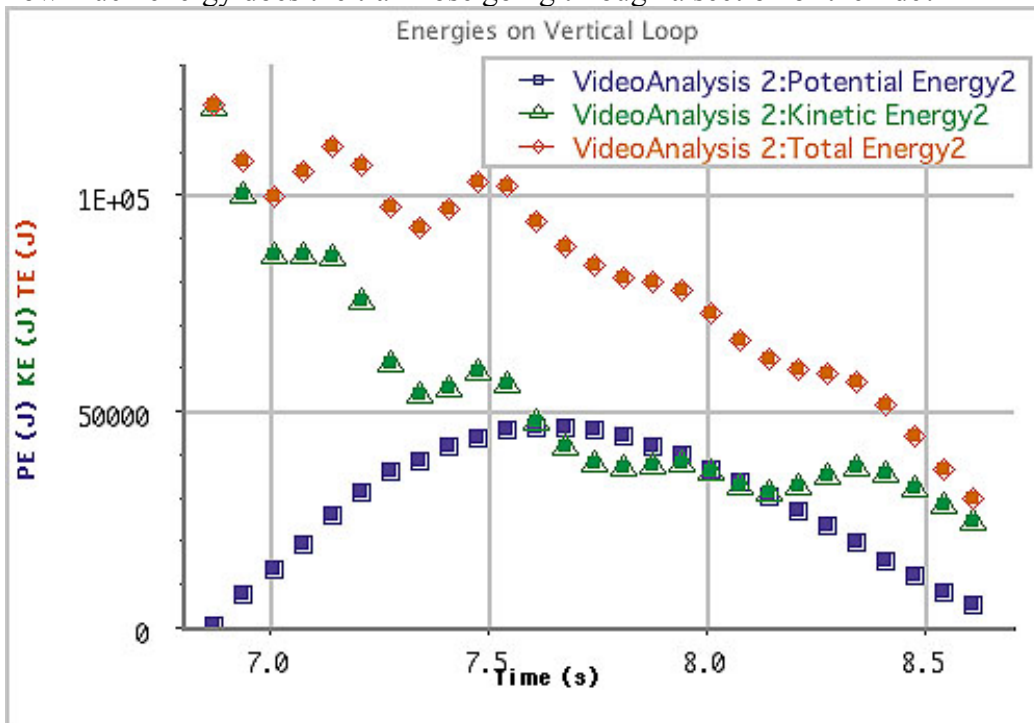
- Click this button to set up the scale. You will drag a line from one end of your standard length to the other. In the diagram above, the length of one car was paced off at approximately 3 meters. After dragging the line, you will be asked to enter the length that it represents.
- This button allows you to set the origin on the screen. For example, you could choose the first point you marked as 0,0 if you wish.

Once you've marked the video and set the scale, graphs of X-position, Y-position, X-velocity and Y-velocity can be plotted and studied. To find the speed, calculate as follows:

$$\text{speed} = ((\text{X-velocity})^2 + (\text{Y-velocity})^2)^{1/2}$$

Some Questions to Investigate

- What is the maximum acceleration of the train?
- How does the speed of a train change as it goes through a series of bumps and dips.
- How does the speed of the train change as it goes through a vertical loop?
- How does the speed at the front of a train as it goes through a vertical loop compare to the speed at the back of the train?
- Is there a place on the train that behaves the same way that a point object going through the same ride would in terms of energy or motion?
- How much energy does the train lose going through a section of the ride?



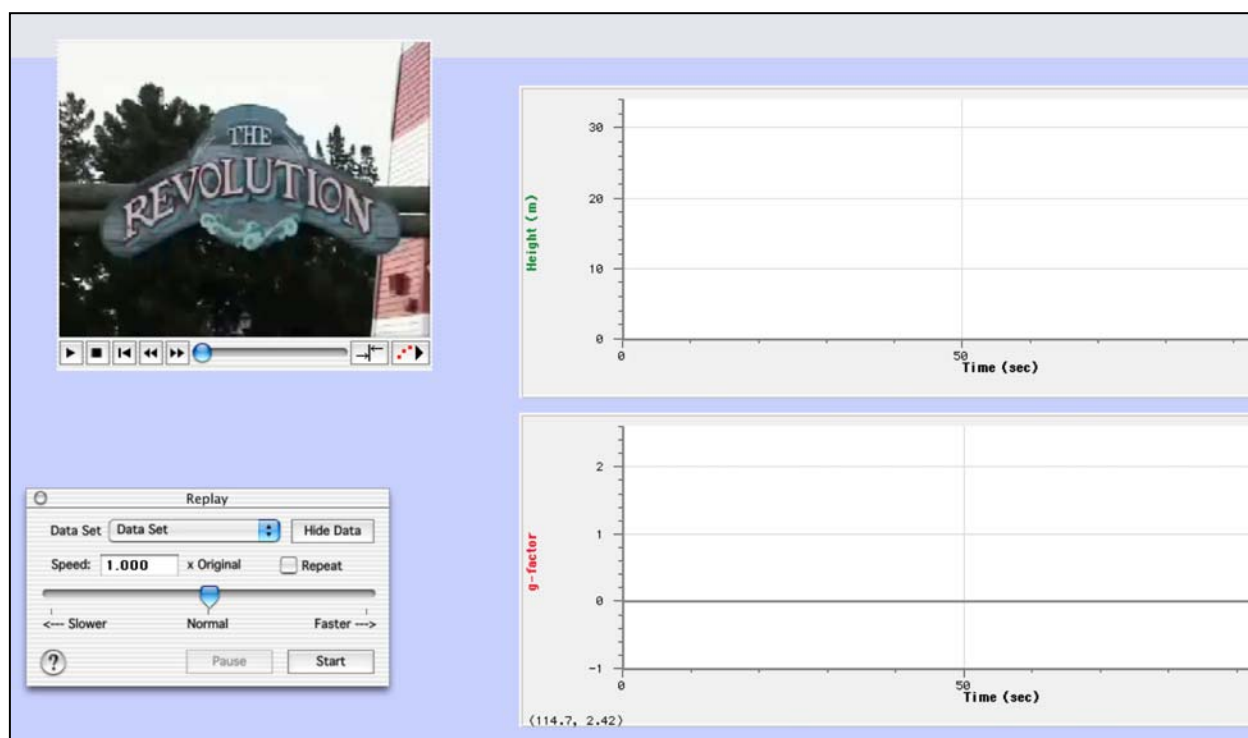
The graph above came from the Boomerang video and an analysis of the front car. Energy was calculated based on a mass of 500 kg. Some of the irregularity is due to the difficulty in finding the specific point to mark in each frame. Notable is the drop-off in total energy as the train goes through the vertical loop. Part of this is due to “dragging” the back part of the train up the side of the loop, while some of it is due to frictional losses.

Appendix 9 – Video Syncing

Starting with *Logger Pro 3.1*, users have been able to import objects such as photographs and movies. Application of this ability can yield powerful results at the amusement park.

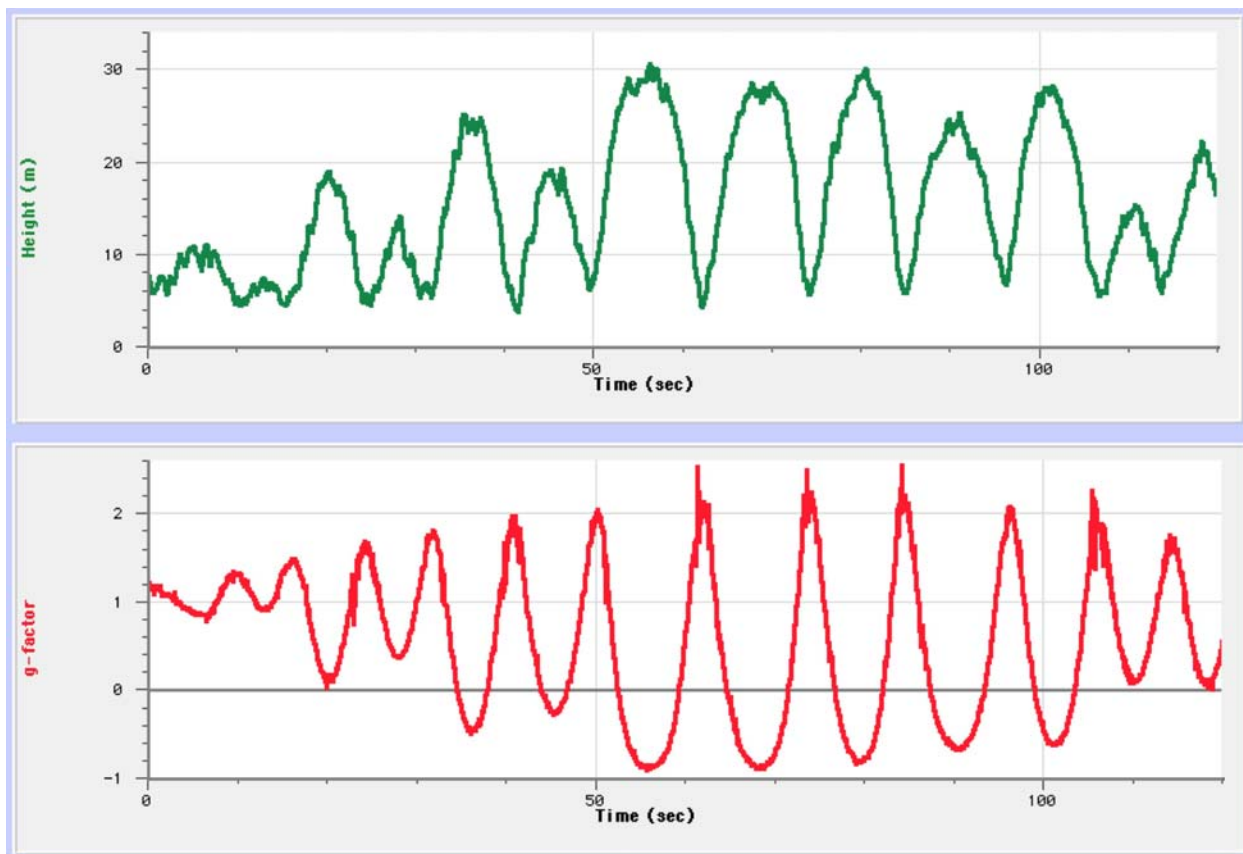
Briefly, probes are used to gather data while a video camera is used to record the actions of the collection process. The movie is converted into QuickTime or AVI format and imported into the same page as the data. A significant point in the data is identified and the time is determined using the **Examine** feature under **Analyze** in *Logger Pro*. The same point in the video is determined and synchronized to that time. Afterwards, the video can be replayed while the data that was gathered is also played.

In the experiment files, you will find several examples that have already been done for you. Under **File**, choose **Open**. Navigate to **Experiments**, then **Sample Movies**, then **Drop Zone** or **Revolution** or **Vortex**. Inside each folder you will find a .cml file that can be opened.



This is the page as it opens for *Revolution.cml*. The video on the left was constructed by taking several different shots of the ride and piecing them together with simple video editing. The graphs don't show data, yet, as it has been hidden. The **Replay** dialog box under **Analyze** has been activated, enabling the user to replay the video with the data displayed. Playback may not be completely synchronized, though, as the number of data points is fairly large and some slower computers will not be able to keep up with the demands of the video and the graphing.

The resulting data is shown on the next page. Several interesting questions arise when one examines it closely.



The “g-factors” above are the vertical normal force per unit mass expressed in a form where 1.0 equals 9.8 N/kg. The large negative values at about 55, 68 and 80 seconds occurred when the ride was completely upside down but moving slowly. The large positive forces came when the rider was passing through the lowest point of the pendulum motion.

How to Make Your Own File

Collect Data

Follow the instructions in one of the appendices to collect data on the ride you are studying. Be sure to save the data once it has been downloaded into the computer.

Take Video

Use a digital video camera or the movie capability on a digital still camera to record the ride in question. Import the video into a computer and produce an AVI or QuickTime video. If the ride is shot from different angles, these can be edited together into a continuous sequence from beginning to end. Be sure to get the entire ride and don't skip or duplicate any portions of the ride. Get the finished video and the data onto the same computer.

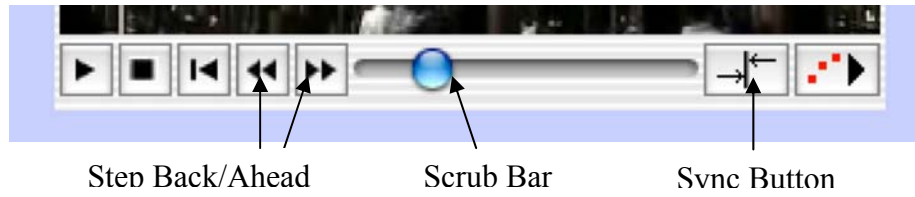
Import Video

1. Open the *Logger Pro* file. Resize the graph(s) to leave space to place the video. The data table can be removed from the screen or minimized in size.

2. Under **Insert** choose **Movie...** Navigate to your video and choose it. It will appear on the *Logger Pro* page. Under **Page**, choose **Auto Arrange**.
3. Note: Videos that have pans or zooms can be used for this activity, however they cannot be used for video analysis.

Synchronize Video

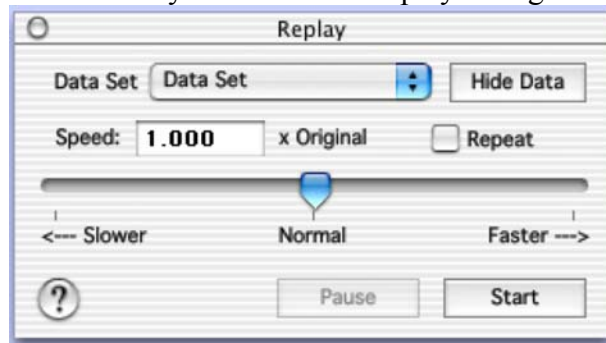
1. In your graph, determine an important point such as the lowest height or the highest acceleration. This is where the Altitude vs. Time graph is particularly helpful.
2. Choose **Examine** under **Analyze**. Move the cursor and the resulting vertical line to the point in the graph you've previously identified. Note the time in the dialog box that appears.



3. Use the scrub bar to move the video to the point you've identified. Use the step forward or step backward buttons to zero in on the frame you seek.
4. Click the Sync button. In the dialog box that appears, type in the time from your earlier work. Click **[OK]** to synchronize the two. Save the modified file at this point. A unique name should be given to this file.

Play Back

1. Choose **Replay** from the **Analyze** menu. The **Replay** dialog box will appear.



2. In the dialog box you can simply click **[Start]** to replay the video and data from the beginning. With the video inactive, you can click **[Hide Data]** to present a blank graph upon opening the file. The slider can be used to show the video and data at either reduced or increased speed.

Notes

1. The synchronizing of video and data can take place well after you actually visit the park.
2. If you take less data and employ smoothing, you will get a file that places fewer demands on the computer's CPU.
3. If you select **Examine** under **Analyze**, moving the cursor along the graph will also move the video forward or backward in step with the cursor position.

Appendix 10 – Creating a Ride Profile

If you collect pressure data with a barometer, you will get a resulting graph that resembles the shape of the ride, but upside down. As the altitude increases, the pressure decreases.

To get a ride profile, subtract all pressure readings from the highest pressure reading (often at the beginning of the ride). Then multiply the pressure difference by the ratio between height and pressure, 11.1 m/mm Hg. The formula will look like this:

$$11.1*(\max(\text{“Pressure”})-\text{“Pressure”})$$

Step-by step for Logger *Pro 3.x*:

1. Under **Data**, select **New Calculated Column...**
2. Type “Altitude” or “Height” for the name. “Alt” or “Ht” might be used for the Short Name. Use “m” or “meters” for the unit.
3. Equation:
 - a. Type in “11.1*(“
 - b. Then use the **Functions** drop-down menu to get to **statistics** and then to **max**.
 - c. Within the parentheses that are provided, use the **Variables** drop-down menu to choose **Pressure**.
 - d. Add a “-“ outside the parentheses and go back to **Variables** again for **Pressure**.
 - e. Finally, add one more parenthesis to close the equation.
4. Choose the color for this plot under **Options**.
5. If you wish to smooth the data for a nicer plot, start the same way, but before typing in the equation, go to **Functions** and choose **SmoothSG**. Everything in steps (a) to (e) will go inside the parentheses that are provided. The final result will be:

$$\text{SmoothSG}(11.1*(\max(\text{“Pressure”})-\text{“Pressure”}))$$

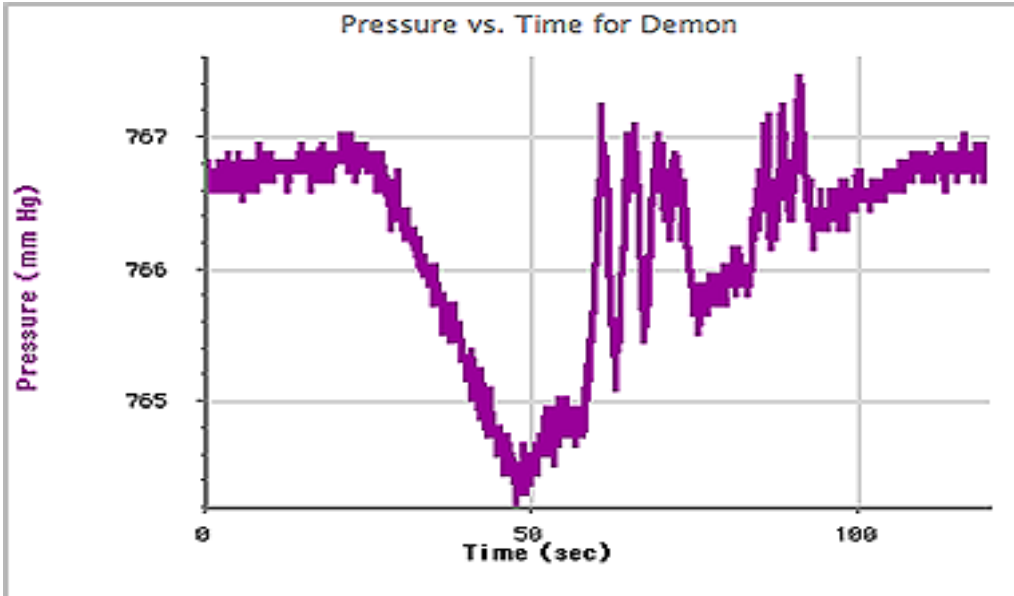
The procedure is essentially the same for Logger *Pro 2.2.1*:

1. Examine the pressure data either perusing the data table or using the **Examine** function (under **Analyze**) on the graph. Determine the largest pressure value. You will need this number. We’ll use **762.0** as the maximum pressure in the example that follows.
2. Under **Data**, select **New Column...** then **Formula...**
3. Choose an appropriate name “Altitude”, short name “Alt” and units “m or meters”.
4. Click **Definition**. Under **Equation**:
5. Type “11.1*(762.0-“
6. Under **Variables**, choose **Pressure** and add close parenthesis to complete the equation. The final result will be:
$$11.1*(762.0-\text{“Pressure”})$$
7. If you wish to smooth the data for a nicer plot, Under **Functions**, choose **Smooth()**
8. Inside the parentheses, type “11.1*(762.0-“
9. Then under **Variables**, choose **Pressure** plus close parenthesis to complete the equation. The final result will be:

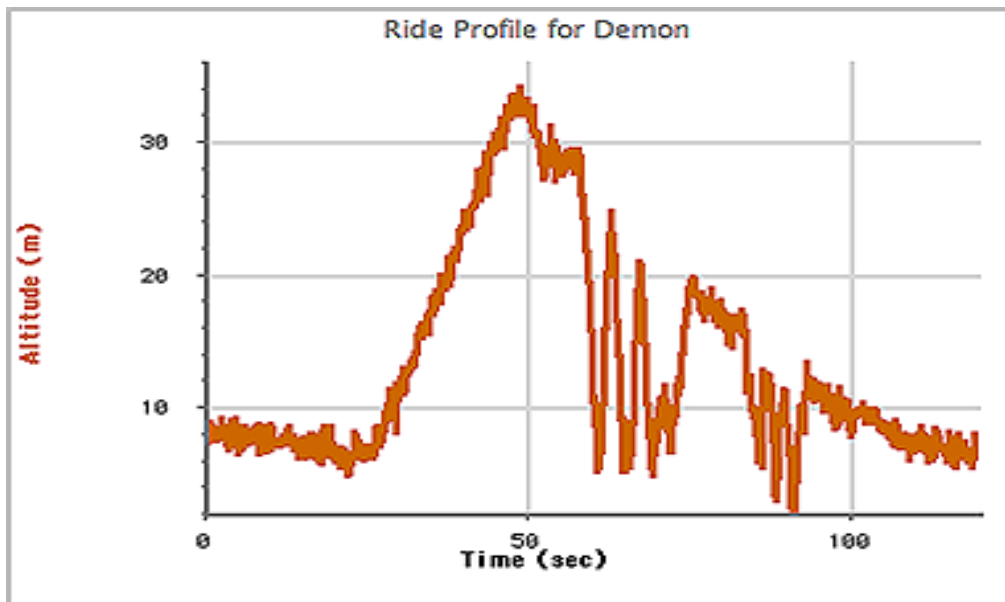
$$\text{Smooth}(11.1*(762.0-\text{“Pressure”}))$$

The procedure for *Graphical Analysis* depends on which version you are using. If you have difficulties, use the Help menu.

The graphs below will demonstrate both the pressure profile and the final ride profile. The altitude values have been smoothed.



Pressure data from **Demon** at Paramount's Great America



Ride profile for **Demon** at Paramount's Great America. Smoothing has been done on the data. The maximum altitude gradually decreases from the top of the lift hill through the end of the ride.

UNITS:

If you use different units for pressure, the conversion factor will be different. Here are several combinations:

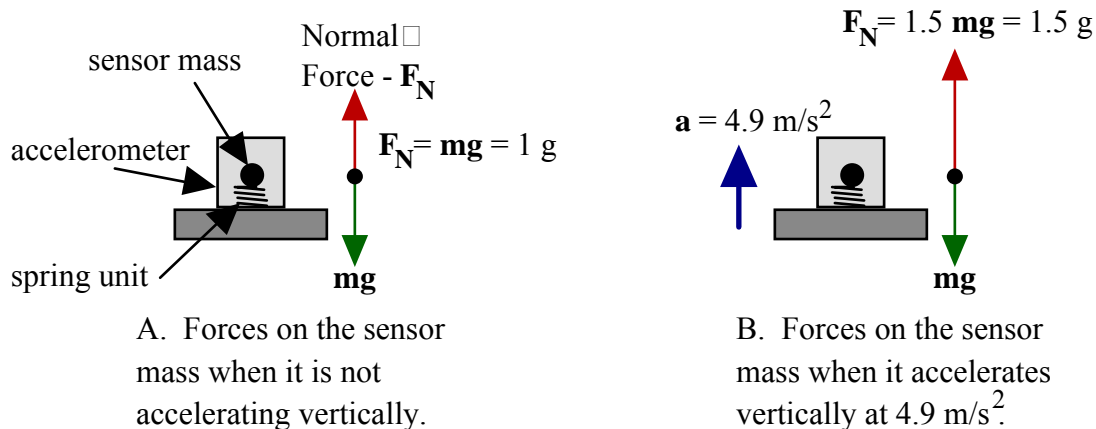
11.1 m/mm Hg 83.3 m/kPa 8436 m/atm

Appendix 11 - Accelerometers and Forces

Accelerometers work by detecting forces. We look at 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 direct measurements of acceleration for objects that are moving linearly.

At the amusement park the predominant use of accelerometers is to indicate sizes and directions of forces experienced by riders. The origins of force, combinations of gravity and the actions of the rides, leads to forces that vary in size and direction throughout a ride experience. The electronic accelerometer is well suited for recording these forces.

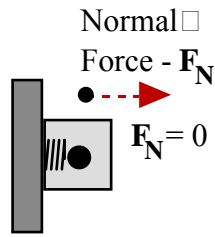
Visualize the accelerometer having a small mass unit that is held in place with a spring element. This is shown in the diagram below.



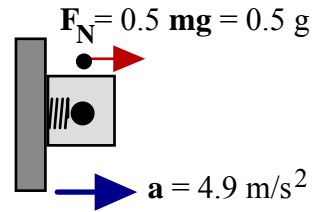
When the sensor is not accelerating in a vertical direction (A), the spring element must exert a force upward equal to the weight of the mass, mg . A voltage is sent to the interface that we interpret as either 9.8 N/kg or $1g$. But if the sensor is accelerated upwards at 4.9 m/s^2 (B), half the normal free-fall acceleration of gravity, the spring element must exert a larger force to accelerate the mass unit. The new force is $1.5mg$, or we could say that it is 14.7 N/kg or $1.5g$'s. In this way, the sensor is constantly monitoring the upward force exerted on the mass unit, and by extension, the upward force exerted on us.

If we have the accelerometer oriented horizontally, the situation is diagrammed as shown on the next page. If there is no horizontal acceleration (C), the spring unit does not have to exert any force on the mass. The voltage sent to the interface would be interpreted as 0 N/kg or $0g$'s. However, if the sensor is accelerated at 4.9 m/s^2 (D), the spring unit must exert a force equal to $0.5mg$, and the voltage is interpreted as 4.9 N/kg or $0.5g$.

It is important to note that whether the accelerometer is oriented vertically or horizontally, the force we are talking about is normal to the support. Although it's a mouthful, we label the readings "Normal Force Per Unit Mass", although we may shortcut this to simply " F/m ".



C. Force on the sensor mass when it is not accelerating horizontally.



D. Force on the sensor mass when it accelerates horizontally at 4.9 m/s^2 .

Units: Accelerometers are usually calibrated in units of m/s^2 . This is the same as N/kg and we infer that we are measuring *normal force per unit mass* even though the units say *acceleration*. 9.8 m/s^2 is the same as 9.8 N/kg , which could also be interpreted as 1 g , while 19.6 m/s^2 or 19.6 N/kg would be 2 g 's, etc. We recommend converting the units to N/kg or g 's to emphasize the nature of the readings.

Axes: In practice, we analyze different axes separately. We discuss the forces in the forward/reverse (longitudinal), side-to-side (lateral), or up and down (vertical) directions. Breaking the forces up into the three major axes relative to our bodies and our motion helps us to explain the different forces we are experiencing and what led to those forces.

If we are standing still or moving along a level track at a constant speed, there is one unit of force from gravity pulling us downward. The ground or seat exerts an opposing 1-g force upward on us to counteract this downward force. We feel this force constantly in our daily lives, and almost forget that it's there. Elevators that are rising or descending at a constant speed also exert a constant 1-g upward force on us.

The accelerometer measures the combined effects of both gravity and any actions of the ride we are on at the time. On a typical roller coaster, there is a dip at the bottom of the lift hill. As the riders pass through the bottom of the dip, they feel a very large upward force from the seat. This force is partly due to counteracting gravity and partly due to changing our motion into the curved path, which requires a net force towards the center, which is up at that point. So the force here is typically several times that of normal gravity.

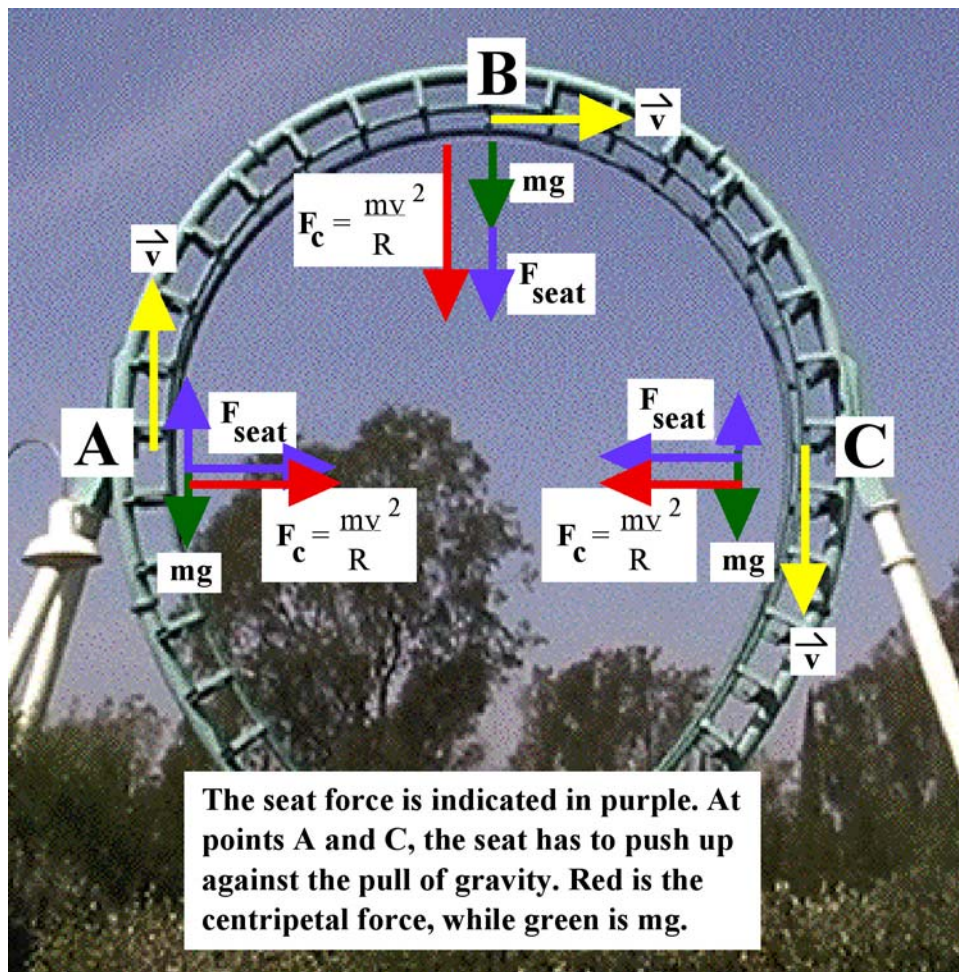
When the riders go over the top of a bump with some speed, they feel lighter than normal, almost as if they were lifted out of the seat. Again this is due to the reaction to gravity and the effect of the ride's motion. The center of the curve is below the riders so part of the gravitational force is used to pull them down towards the center, leaving less of their weight that must be supported by the seat. The force recorded here will be less than 1 g .

If the riders go over a bump with sufficient speed, they may feel the car being moving out from beneath them, and they are pulled down by the restraint system. This is called "negative g's". The car is held on the track by wheels that ride below the track, while the shoulder harness pulls the

rider down.

When riders go through a vertical loop, their force reading varies throughout the loop for several reasons. For one, the angle relative to gravity changes throughout the loop. The speed also changes due to climbing up the side of the loop then rolling down the other side. Finally, the degree of curvature in the loop changes. To understand the force readings throughout the loop one must understand how all of these factors are playing out. For example, on the side of the loop, whether rising or descending (A or C below), gravity acts along the longitudinal axis of the rider but not along the vertical axis. At the top of the loop (B), gravity acts to help hold the rider in the circular path, acting in a centripetal manner. The total force needed to go in the circular path, mv^2/R , is partially supplied by gravity so the seat force towards the center of curvature at

that moment is $\frac{mv^2}{R} - mg$. If designers have calculated correctly, the seat will supply a force on the riders, holding them in their seat throughout the ride.



As this discussion shows, the combination of gravity and the ride forces is complex. This is one of the fascinating aspects of amusement parks - trying to unravel the complexity presented by the twists and turns of the rides.

Appendix 12 – Sample Worksheet for Electronic Data Collection LabPro/CBL2 on a Roller Coaster

Before you ride

- The name of the ride you went on is: _____
- Make a sketch of the ride profile on the back of this page. Mark the approximate position of a passenger every 10 seconds on your sketch. (This can be worked out either before or after riding.)
- In the space below, describe your data collection strategy for this ride. Will you collect data for the entire ride, or concentrate on a specific portion? Which portion? How long does it take to go through the ride or that part of the ride, and how many data points would you like to acquire? Which axis or axes of acceleration will you focus on in your analysis?

While you ride

Secure the accelerometer in a fixed orientation relative to your body. The three axes are straight ahead (longitudinal), directly to the side (lateral) and/or straight up and down (vertical). If an axis is not used, don't circle it.

Accelerometer X (#1): **longitudinal - lateral - vertical** (circle one)

Accelerometer Y (#2): **longitudinal - lateral - vertical** (circle one)

Accelerometer Z (#3): **longitudinal - lateral - vertical** (circle one)

When you reach the place on the ride where you want to begin collecting data, press [Start/Stop] on the CBL2 or LabPro.

After you ride

Download the data. If possible, print the graphs of your normal force per unit mass vs. time so you can do onsite analysis. Save the data with your names and the name of the ride for further analysis.

Questions:

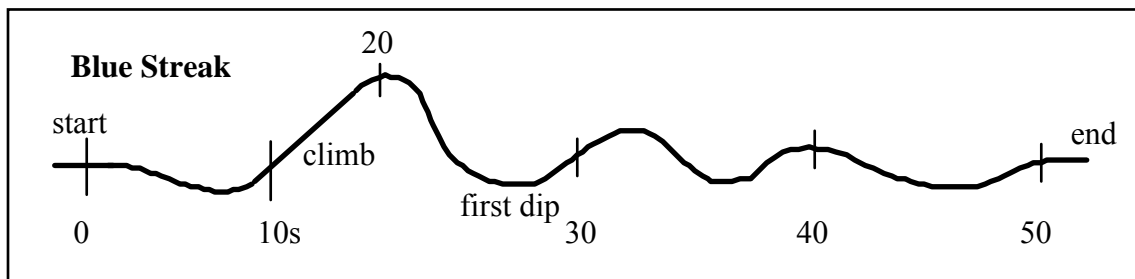
Use a separate page to answer the questions that follow. Use the ride profile to determine where you were on the ride for each of these portions. Also note any unusual forces encountered.

1. Describe the graph(s) during the initial seconds you recorded. Compare the shape of the graph(s) to your movement during that portion of the ride.
2. For each of your axes, where were the readings the greatest? What were the readings there? Explain why the readings were the greatest at those points.
3. For each of your axes, where were the readings the least? What were the readings there? Explain why the readings were the least at those points.
4. Are the places where the sensors recorded the largest values the same places you felt the largest forces? Why or why not?

Ride Profile:

- In this area, sketch the shape of the ride if it were stretched out linearly. Sketch loops as loops. Make other notations that will help you to decode your data later on.
- Indicate on your ride profile the approximate location of a passenger every 10 seconds. This will enable you to match up your accelerometer data with your location on the ride.

Example: A simple roller coaster for toddlers that makes a single loop around a closed track.



Appendix 13: Some Questions and Answers about Amusement Park Physics

Q In short, what is the process for gathering data on an amusement park ride?

A 1) Set up data rate and duration for the collection process. 2) Load these instructions into the LabPro, CBL2 or WDSS unit, setting it for remote data collection. 3) Get on ride. Press [Start/Stop] button once just before the section of the ride you wish to measure. 4) Download the data and print graphs. (Be sure to save the data for further analysis.)

Q Can I use a calculator or must I use a computer?

A A calculator can be used to program your interface. The steps are given in **Appendix 3** and **4**. A calculator can also be used to download the data. However, the memory in most graphing calculators is very limited (20 Kb) so only a short data run can be imported into the calculator.

To facilitate downloading more data, all programs that aren't needed should be deleted. Trials should be run at school before going to the park to be sure the data downloads successfully. This avoids frustration at the park when things don't work as you believe they should.

The author has had good luck using the calculator to program the interface, but using a computer with TI-Graph Link to download the data. You can use either *Graphical Analysis* or *Logger Pro* to download the data.

Q I have an original CBL and want to work with a TI-83 calculator while I'm at the park. Do you have any tips?

A As noted in Appendix 4, you can use the *PHYSICS* program suite to program an original CBL and set it up for remote data collection. On the CBL you will press the [TRIGGER] button to initiate data collection.

The TI-83 memory allows only a limited quantity of data points you can gather. Plan to use this system to study a section of a ride rather than the entire experience. You can also study repeating rides such as scramblers well with a limited number of data points.

CBL has limited discrimination in the data it collects. Plan to smooth the data once you get it collected. This will give more meaningful graphs for your interpretation. Consider using one calculator per ride or portion of ride. Then take the data back to the classroom for downloading and plotting on the computer.

Finally, download the latest version of the *PHYSICS* program from the Vernier web site (www.vernier.com) so that it will work as well as possible.

Q Is there a central source of information on amusement park rides giving data and force values?

A Most parks and ride manufacturers tend to guard this information fairly closely. Some online sites give data but it should be advisory rather than exact.

Q Does an accelerometer really measure acceleration? Why do you keep saying it measures force?

A An accelerometer properly measures “normal force per unit mass”. This term has two parts. The first is that it measures forces normal to the accelerometer unit. If one is looking in a vertical direction, the sensor indicates the normal force pushing up on it. The second part is that the units are properly Force/Mass, N/kg. The combination reduces to m/s^2 , acceleration units, but the sensor is properly a force measuring device.

Q Can I use a Palm OS device at the amusement park?

A Yes. **Appendix 5** will give you step-by-step instructions for using a Palm OS device with a LabPro. You will need *DataPro* software loaded in the Palm device. If you work in Remote mode, you will also need a computer to download the data from the LabPro.

Q Are there any issues with DataVest when collecting data at an amusement park?

A Two issues arise with DataVest. The first is orientation of the accelerometer. If you are using the cradle scheme described on page 6, the LabPro will be tilted to an angle depending on the person. Thus the vertical axis accelerometer may not be completely aligned with the spine. One solution would be to remove the accelerometer from the LabPro and mount it so it will always be vertical, independent of who is wearing the vest. One possible location is inside the strap that goes from front to back or on top of the shoulder.

The second issue is that with the accelerometer near the rider’s shoulders, we are actually recording what happens to the rider’s body. As the car turns, the body reacts a short time later. The body may move back and forth a lot more than the ride itself. A nice study would be to compare the readings with an external case such as on page 6 and those using a DataVest on the same ride.

Q What is the most common mistake that students make when collecting data?

A The most common mistake is to press the [Start/Stop] button more than once. As the name implies, this button will initiate data collection but it will also stop it. Pressing the button once will begin data collection that will continue until the end of the time that has been previously programmed.

Q Are there any advantages for using LabPro over using CBL2?

A Yes. (1) You can connect the LabPro to computers or Palm OS devices in addition to calculators. This makes using it more flexible.

(2) You can connect four (4) analog devices to LabPro vs. three (3) in CBL2. This enables you to record all three acceleration axes plus barometric pressure.

(3) The A-D converter, the device that converts the sensor readings into digital information, in the LabPro has 12 bits rather than 10. The extra two bits means that it is four times (4X) more sensitive to changes than CBL2. This is especially important when reading pressures and doing the ride profile. However, with smoothing, you can get quite presentable graphs from CBL2.

Q Are there any advantages for using WDSS over using other Vernier products?

A Yes. (1) The small package size means you can carry it in a DataVest, a fanny pack, or even in your hand (if it's tethered so you can't accidentally drop it). The small size and weight are distinct advantages of WDSS.

(2) You can collect multiple runs on a WDSS versus a single run on a LabPro or CBL2. This allows one to pre-program the WDSS then use it on multiple rides before needing to download the data. In fact, the WDSS will hold up to 240,000 data points.

(3) The data runs on WDSS can be longer than LabPro, enabling you to step up the data rate even higher and still capture a whole ride experience while seeing more detail. Note: we recommend you set a collection time longer than the longest time you expect to capture, then use the Start/Stop button to turn data collection off at the end of the ride.

(4) The rechargeable battery means your ongoing expense at the park will be less than with LabPro or CBL2 unless you were to equip them with rechargeable batteries.

Q What kinds of projects can students do in conjunction with going to an amusement park and carrying out data collection?

A Students get the most out of their experience when they turn the information they gather into a new product, especially when they are responsible for presenting their information to an audience. The graphs in *Logger Pro* or *Graphical Analysis* can be copied and inserted into a wide variety of programs ranging from word processors to video production. Data tables can be exported as data files which can then be imported into a variety of analysis programs, too. Some possible products:

- Presentation to class analyzing a portion of a ride
- Presentation to a younger class explaining how science applies at the park
- Presentation comparing similar features on several different rides
- See the Investigations or the Extensions on pages 13-14

Presentations can be in the form of prepared overhead slides, *Powerpoint* or similar presentation program, videos either from videotape or from an edited final video, or in *Logger Pro 3.x*, students can use the pages feature to produce an effective and stunning electronic presentation.

Q Can I simply integrate the acceleration values (a function provided in *Logger Pro*) to obtain a new graph of velocity vs. time?

A The “acceleration” values we obtain while on a roller coaster are the result of combining gravity and ride forces. Riders are typically not traveling in straight lines, but at various angles including upside down. Integrating acceleration in most cases doesn’t yield anything useful.

However, if the ride goes in a straight line (free fall ride where the rider is simply dropped, launching of a catapult ride, stopping of a coaster if it’s in a straight, level section, etc.) then integrating the recorded acceleration will yield a “Change in Velocity” graph. The steps to accomplish this in *Logger Pro 3.2* are outlined here:

1. Highlight the section of your graph you wish to study. Notice that the corresponding lines in the data table have been highlighted or selected.
2. Now click on the data table to select it. Under **Edit**, select **Copy**.
3. Under **Data**, select **New Data Set**. Click in the first cell of the new columns that are created in the data table. Under **Edit**, choose **Paste**. This will put the selected data into a new data set that can be graphed separately from the original data.
4. Under **Data**, select **New Calculated Column...** Give the column a name like “Area Under Acceleration Graph” or “Change in Velocity.” Units would be m/s if you recorded acceleration in m/s^2 .
5. For Equation: Under **Function**, choose **calculus** then **integral**. With the cursor between the parentheses, go to **Variables** and choose the acceleration axis you wish to use (there may be up to three different axes recorded).

6. Click on **Options** to select the color of the graph trace that will be used for your calculated values.
7. Either create a new graph, or use the graph that already exists. (A new page can be created and the results of your analysis can be displayed there.) For the vertical axis, choose “More...” then select the new column from the data series that you selected. Click the Autoscale button to make this data display over the whole size of the graph.

Note: This document advocates calibrating a vertically oriented accelerometer so it registers +9.8 N/kg or +1 g when there is no net acceleration occurring in the vertical direction. This is commensurate with the constant upward normal force experienced as a reaction to gravity. The net acceleration is zero (0). To get the net acceleration in any vertical situation, simply subtract 9.8 N/kg or 1 g from the instantaneous value. During free fall, then, the recorded value of zero would be converted into a net value of -9.8 N/kg or -1 g. If you are creating a “Change in Velocity” graph for free fall, this additional correction must be added to the Equation. And of course you would be working with the m/s^2 equivalent of N/kg.