

Activities for the Wireless Dynamics Sensor System

Revised with permission from activities by Chris Butlin

This booklet contains seven activities using the Vernier Wireless Dynamic Sensor System (WDSS) and Vernier Logger *Pro* software for collecting, displaying, printing, graphing, and analyzing data. Many of the data-collection features of the WDSS are illustrated in these activities, providing a foundation to explore accelerations, forces and their interrelationships.

The WDSS is a Bluetooth[®] wireless combination sensor that contains a three-axis accelerometer, a dual-range force sensor, and an altimeter. The experiments in this booklet make use of the wireless feature of the WDSS, providing opportunities to study physics principals without the added complication that comes from friction due to wired sensors.



Each activity contains a student section that can be reproduced and distributed when doing the activities. The extensive Teacher Information section includes sample results, answers to questions, directions for preparing equipment, useful web sites, and other helpful hints regarding the planning and implementation of a particular experiment.

ABOUT THE AUTHOR

Chris Butlin has dedicated his time and energy to teaching and developing resources for teachers and students in schools, universities, and the Education Department at the Institute of Physics in London. Currently he advises on the development and purchase of dataloggers, designs resource materials to support datalogging, designs other activities in physics education, conducts workshops for teachers on the use of dataloggers, and writes articles for the media on ICT in physics education. He has served on many UK national committees and working parties and is currently Chairman of the Schools Physics Group. Chris was awarded the Institute of Physics' Teachers' of Physics Award in 1988 and its Bragg Medal for significant contributions to physics education in 1993.

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	WDSS Sensors				
	Force	Accelerometer			Altimeter
		x-axis	y-axis	z-axis	
1 WDSS Bungee Jumper		x	x	x	
2 Centripetal Accelerations on a Model Centrifuge		x			
3 Mission to Titan – Investigating Surface Composition	x				
4 Physics at Amusement Parks		x	x	x	x
5 Newton’s Second Law	x	x			
6 Newton’s Third Law (Requires two WDSS units)	x				
7 Investigating Collisions with Crumple Zones		x			

WDSS Bungee Jumper

Bungee jumping as we know it today started when the Oxford Dangerous Sports Club made a jump from the Clifton Suspension Bridge in Bristol back in April 1979. However, the origin of such jumps goes back centuries to the 'land divers' of Pentecost Island, one of the many islands making up Vanuatu north east of Australia. These 'land jumpers' used vines to support their jumps. Since 1979 bungee jumping has become very popular. Jumps can be from bridges, towers, cranes and balloons. You might even recall seeing such a jump in the Bond film Golden Eye which, in 2002, was voted the best movie stunt.

The bungee cords are specially made for the task and are designed to stretch to two, three or even four times their original length. There are two main types, sheathed (often called shok or mil-spec) and all-rubber. The former have a rubber core encased in a cotton or nylon sheath and, depending on the weight of the jumper, between three and six of these would be bundled together. The all-rubber cords are made up of over one thousand individual strands of rubber tied together to form one solid core.



*Figure 1 – Beginning the fall
(Photograph courtesy Glyn Jones)*



Figure 2 –WDSS attached to a bungee

The physics of bungee jumping is all about competing forces and the resulting acceleration of the jumper. As the jumper leaves the platform and begins to fall, the predominant force is from gravity, and the jumper is nearly in freefall. Initially the gravitational force accelerates the jumper downward. As the bungee cord goes taut, it begins applying a force opposing that of gravity; at some point the cord's force balances the gravitational force. The jumper continues to fall, however, further increasing the cord's force. The acceleration is then upward. At the jumper's nadir the cord is applying a force much larger than the gravitational force. As the jumper then rises, the cord may go slack, and the jumper is again in freefall. When the jumper falls far enough to make the cord taut, the cycle begins again. Eventually the motion dies down due to air resistance

and non-conservative forces in the bungee cord.

Modeling a bungee jump is not difficult to do once a good match has been found between a length of rubber cord and whatever is to do the ‘jump’ – in this activity the WDSS.

OBJECTIVES

In this activity, you will investigate

- how the acceleration of a bungee jumper changes during a jump.
- how the scalar acceleration is related to the individual accelerations during a bungee jump.

MATERIALS

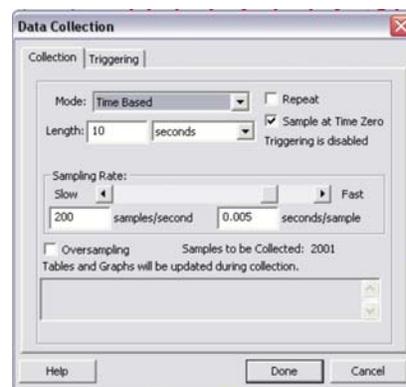
Bluetooth [®] equipped computer	ring stand and right angle clamp
Logger <i>Pro</i> Software	extra ring stand rod
Vernier Wireless Dynamics Sensor System	c-clamp
bungee cord (long flexible rubber band)	

PROCEDURE

Setting up your WDSS

1. Turn on the WDSS. Note the name on the label of the device.
2. Make sure Bluetooth is activated on your computer. Some computers have Bluetooth built into them. If that is the case, make sure Bluetooth is turned on.
3. Start Logger *Pro*.
4. Establish a wireless connection with the WDSS.
 - a. Choose Connect Interface from the Experiment menu. Choose Wireless and then Scan for Wireless Device.
 - b. There will be a short delay while Logger Pro attempts to establish a connection. If the WDSS is not found, try scanning again.
 - c. A dialog box will appear showing your WDSS on the list of available devices. Select your WDSS device and then click . Once a connection is made, the two LEDs on the WDSS will be lit green.
5. Open the file “Scalar Acceleration” in the *Probes & Sensors/WDSS* folder.

- Choose Data Collection from the Experiment menu. Adjust the data collection experiment length to 10 seconds with a sampling rate of 200 samples/second as shown in Figure 3.



The Bungee Jump

- Attach the bungee to the hook on the WDSS, so that the x-axis acceleration arrow points towards the floor.
- Attach the other end of the bungee cord to the ring stand support rod. Adjust the length of the rubber cord so when the WDSS is dropped from the height of the support rod, it does not hit the floor.
- Collect acceleration data.
 - Hold the WDSS by the hook connected to the bungee. The x-axis acceleration arrow should be pointing towards the floor as shown in Figure 4.
 - Bring the hook up even with the ring stand support rod.
 - Click **Collect** to begin data collection. Wait about one second then release the WDSS.

Figure 3

QUESTIONS

- Describe the key features of the acceleration-time graphs for each axis of the accelerometer.
- Describe the key features of the scalar acceleration-time graph. How does this graph compare to the other acceleration vs. time graphs?

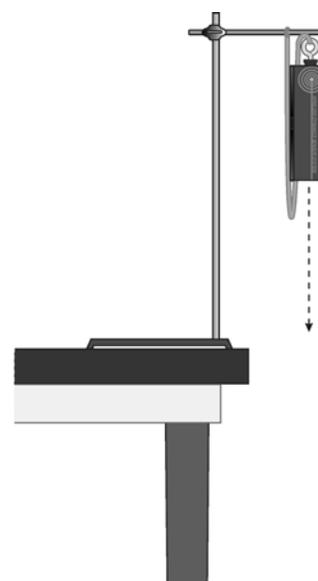


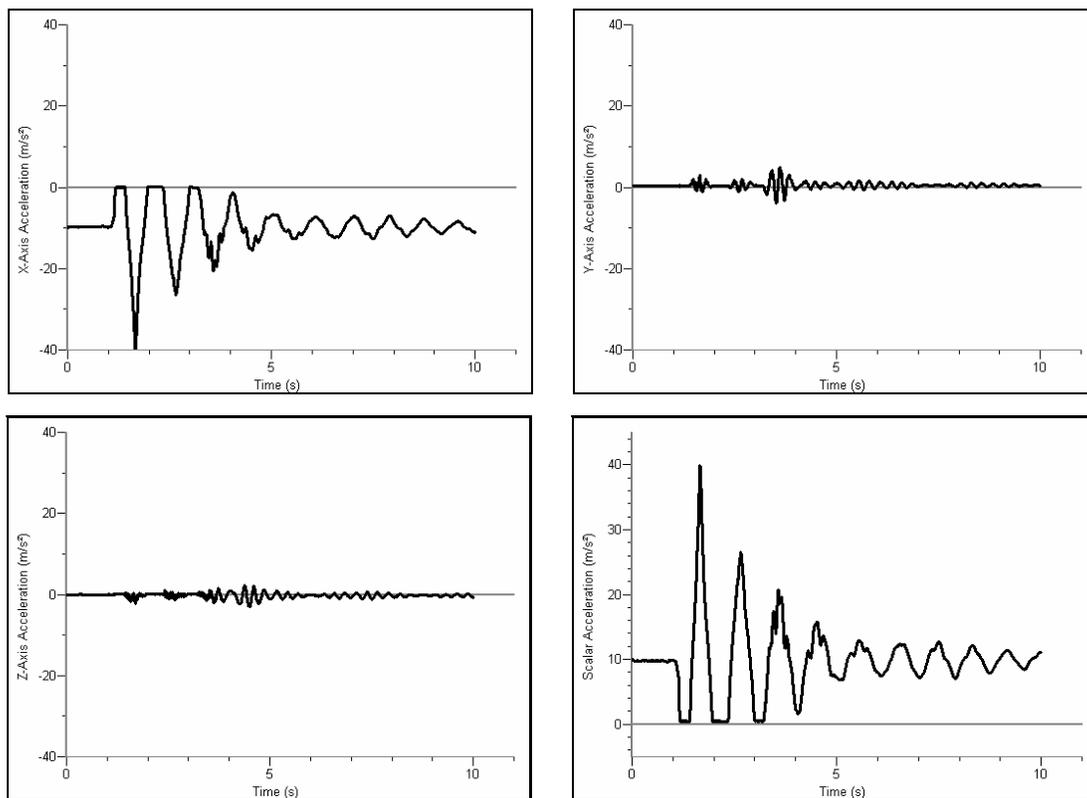
Figure 4

TEACHER INFORMATION

WDSS Bungee Jumper

1. A bungee jump provides an excellent opportunity to let students see a link between force and acceleration, assuming that they first have an understanding of what each means.
2. Here are a number of web sites with information on the technology of bungee jumping, its history, some fantastic images and the physics involved.
 - **Reporter's Notebook: South Pacific Ritual Bungee Jumping** – This is a news report on the land diving ritual, the Naghol, performed on Pentecost Island, one of many making up Vanuatu.
http://news.nationalgeographic.com/news/2002/11/1125_021126_TVVanuatu.html
 - **Steve Fettke Bungee Jumping** – This site contains lots of bungee facts, details about the equipment used, photographs, and videos.
<http://www.fettke.com/bungee/equip.htm>
 - **The Oxford Stunt Factory** – This organization performed the bungee jump shown in the Bond movie *Golden Eye*. Images of this and other stunts are available here.
<http://www.oxfordstuntfactory.com/html/stunts.htm>
 - **Vertige Aventures** – This company manufactures bungee ropes and provides information on their construction.
<http://www.bungee-jump.com/xvms.htm>
3. The bungee cord needs to be selected for reasonable elasticity. The rubber cord used in a paddle-ball toy works well for this experiment. You can also create a cord by connecting several smaller rubber bands together.
4. When discussing the accelerometer reading, it is proper to refer to it as a measure of Normal Force per Unit Mass, with units of N/kg, where “normal” is in the direction of that particular accelerometer. This is what the accelerometer is actually measuring. (Note that it is not the net force per unit mass which would be acceleration.) A motionless accelerometer oriented in the vertical direction will give a reading of +9.8 N/kg when pointed up and -9.8 N/kg when pointed down. A motionless accelerometer oriented in the horizontal direction will read 0 N/kg. An accelerometer in freefall will give a value of 0 N/kg regardless of its orientation. Since most people prefer the measurement be in m/s^2 , we have used these units in this manual.

SAMPLE RESULTS



WDSS Bungee Jumper (x-axis, y-axis, z-axis, and Scalar acceleration)

ANSWERS TO QUESTIONS

1. Most of the acceleration is along the x-axis. While the WDSS is in free fall, all accelerations are zero.
2. The students should note the periodicity of the oscillations and the damping effect. They should also note that the scalar acceleration is only positive and represents the scalar sum of the individual accelerations.

Centripetal Accelerations on a Model Centrifuge

In normal circumstances, you experience +1g of acceleration as a result of Earth's gravitational field. You get the same effect when you are accelerated at 9.8 m/s^2 . To produce larger g-forces (+2g to +9g) you would need larger accelerations (19.6 to 88.2 m/s^2). The easiest way to produce such accelerations is by rotation in a centrifuge. Astronauts and cosmonauts, as part of their training, are exposed to accelerations and g-forces they might have to experience during their space flights. QinetiQ at Farnborough have a man-carrying centrifuge (see Figure 1) that produces such accelerations and g-forces up to +8g. Dr. Gregory Olsen, the American scientist who paid \$20 million to visit the International Space Station (ISS) in October 2005, trained on it before being launched into space aboard a Russian Soyuz spacecraft.



Figure 1 – The man-carrying centrifuge at Farnborough
(Image courtesy of QinetiQ)

The average person can withstand around +5g before blacking out or experiencing g-loc (loc stands for loss of consciousness). You can momentarily experience $\pm 5g$ of force on various roller-coaster rides. Trained astronauts, cosmonauts, and fighter pilots can cope with up to +9g.

In this activity you will model a centrifuge using an old record-player turntable. The record player turntable can provide rotational speeds of $16\frac{2}{3}$, $33\frac{1}{3}$, 45, and 78 revolutions per minute (rpm). Calculating the centripetal acceleration, the acceleration necessary to keep an object moving in a circular path, can be done using the formula:

$$a_{\text{centripetal}} = \frac{4\pi^2 R}{(t_{\text{revolution}})^2}$$

where R is the radius of the circular path, and $t_{\text{revolution}}$ is the time for one revolution (measured in seconds).



Figure 2 – Turntable set up to measure centripetal acceleration

OBJECTIVES

In this activity, you will

- measure the centripetal acceleration of a record turntable.
- compare the measured accelerations to the theoretical accelerations.

MATERIALS

Bluetooth[®] equipped computer
Logger *Pro* Software
Vernier Wireless Dynamics Sensor System
phonograph record

turntable (with 33 $\frac{1}{3}$, 45, and 78 rpm settings)
masking tape
level

PROCEDURE

Establish a connection to your WDSS

1. Turn on the WDSS. Note the name on the label of the device.
2. Make sure Bluetooth is activated on your computer. Some computers have Bluetooth built into them. If that is the case, make sure Bluetooth is turned on.
3. Start Logger *Pro*.
4. Establish a wireless connection with the WDSS.
 - a. Choose Connect Interface from the Experiment menu. Choose Wireless and then Scan for Wireless Device.
 - b. There will be a short delay while Logger Pro attempts to establish a connection. If the WDSS is not found, try scanning again.
 - c. A dialog box will appear showing your WDSS on the list of available devices. Select your WDSS device and then click . Once a connection is made, the two LEDs on the WDSS will be lit green.

Sensor and Data Collection Setup

5. Choose Set Up Sensors from the Experiments menu and then select your WDSS device. This will display the WDSS setup dialog that will allow you to turn sensors on or off. Set up the sensors as indicated in Figure 3.
6. Choose Data Collection from the Experiment menu. Adjust the data collection experiment length to 60 seconds with a sampling rate of 200 samples/second.
7. Place the WDSS on a level surface with the power switch located at the top. Click to zero the sensor.



Figure 3

Collecting Data

8. Set up the experiment.
 - a. Place the turntable on a level surface. Check to make sure that the turntable platter is horizontal using a level.
 - b. Place a phonograph record on the turntable.
 - c. Position the WDSS so that two of the corners are at the edge of the record while the x-axis acceleration arrow is pointing towards the center of turntable. Secure the WDSS with tape.
 - d. Set the turntable speed to $33\frac{1}{3}$ rpm.
9. You are now ready to collect data for the three different angular speeds of the turntable.
 - a. Click to begin data collection.
 - b. Wait about 5 seconds then turn on the turntable.
 - c. Wait an additional 15 seconds then increase the speed of the turntable to 45 rpm.
 - d. Wait an additional 15 seconds then increase the speed to 78 rpm.
 - e. Wait an additional 15 seconds then turn the turntable off.
 - f. Wait for data collection to finish.
10. Once the turntable has stopped rotating, measure the distance (in meters) from the center of the accelerometer label on the WDSS to the center of the turntable. Record this value in the table provided.

DATA TABLE

Angular Speed (rpm)	Average Centripetal Acceleration (m/s ²)
33 $\frac{1}{3}$	
45	
78	

Radius (m)		
Angular Speed (rpm)	Time for one Revolution (s)	Theoretical Centripetal Acceleration (m/s ²)
33⅓		
45		
78		

QUESTIONS

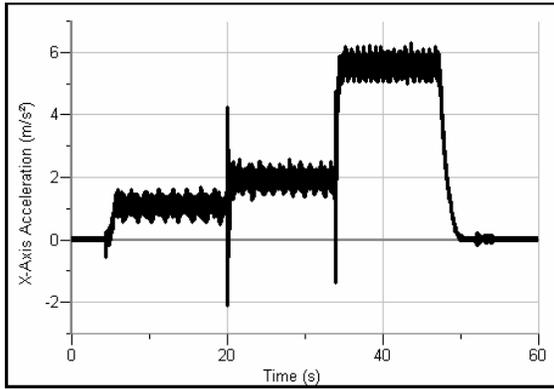
1. What are the average values of the x-axis acceleration for each speed of rotation? Record these values in the table provided.
2. For each angular speed, calculate the time for one revolution in seconds.
3. Calculate the centripetal accelerations expected with each of the turntable speeds. How do these values compare to the average accelerations you measured?
4. In terms of the g-factor, what is the greatest g-factor achieved in this activity? (Note: a centripetal acceleration of +9.8 m/s² is equivalent to +1g.)
5. How might you increase the maximum g-factor on this turntable without increasing its angular speed?

TEACHER INFORMATION

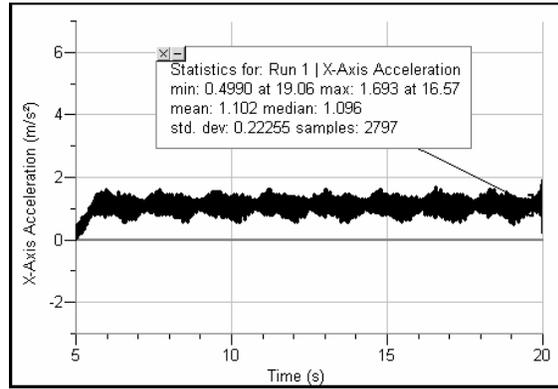
Centripetal Accelerations on a Model Centrifuge

1. Special thanks to QinetiQ of Cody Technology Park, Farnborough, Hampshire, UK, for providing the photograph of their man-carrying centrifuge.
2. The man-carrying centrifuge is a piece of equipment that was used in the James Bond film Moonraker. Hugo Drax, the villain, tried to kill 007 by accelerating him beyond the level of human endurance.
3. Web sites with information on both acceleration and centripetal acceleration.
 - Wikipedia – this site provides an explanation of what is meant by “g” and why its value is as it is. Details are provided of situations in which one can experience both high positive and negative g forces, as well as 0g.
http://en.wikipedia.org/wiki/Acceleration_due_to_gravity
 - Aerodynamics and G forces – this site discusses G forces experienced by F-16 fighter pilots and the effects on them.
<http://www.voodoo.cz/falcon/agf.html>
 - Dream comes true with space flight – this site provides a transcript of a discussion with Dr. Greg Olsen following his trip to the International Space Station in 2005.
http://newstranscript.gmnews.com/news/2006/0125/Front_Page/001.html
 - QinetiQ helps ‘space tourist’ Greg Olsen pass the physical – this site provides a report on the training provided for Dr. Greg Olsen in QinetiQ’s man-carrying centrifuge.
http://www.qinetiq.com/home/newsroom/news_releases_homepage/2005/3rd_quarter/qinetiq_helps_space.html
 - QinetiQ’s Centrifuge – this site provides a video of the QinetiQ centrifuge in action.
http://www.qinetiq.com/home/technologies/technologies/Sub_Landing1/facilities/centrifuge.html
4. When discussing the accelerometer reading, it is proper to refer to it as a measure of Normal Force per Unit Mass, with units of N/kg, where “normal” is in the direction of that particular accelerometer. This is what the accelerometer is actually measuring. (Note that it is not the net force per unit mass which would be acceleration.) A motionless accelerometer oriented in the vertical direction will give a reading of +9.8 N/kg when pointed up and –9.8 N/kg when pointed down. A motionless accelerometer oriented in the horizontal direction will read 0 N/kg. An accelerometer in freefall will give a value of 0 N/kg regardless of its orientation. Since most people prefer the measurement be in m/s^2 , we have used these units in this manual.
5. The acceleration graph will probably show a cyclic time variation. This once-around variation in the acceleration value is likely to be due to the record wobbling or the turntable not being level.

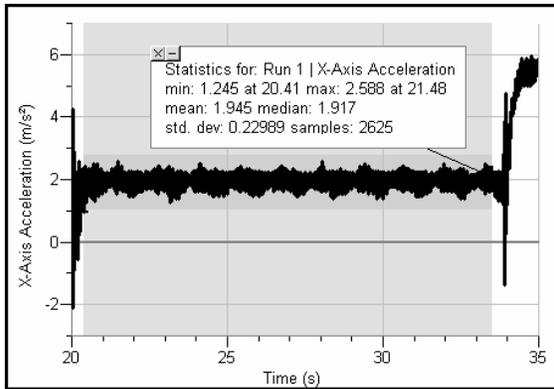
SAMPLE RESULTS



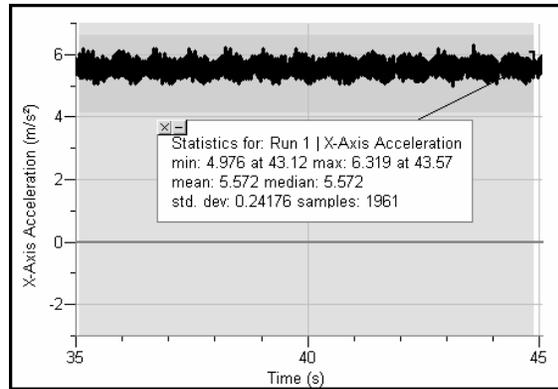
Centripetal acceleration data



Average acceleration at 33 1/3 rpm



Average acceleration at 45 rpm



Average acceleration at 78 rpm

Angular Speed (rpm)	Average Centripetal Acceleration (m/s ²)
33 1/3	1.10
45	1.95
78	5.57

Radius (m)	0.085	
Angular Speed (rpm)	Time for one Revolution (s)	Theoretical Centripetal Acceleration (m/s ²)
33⅓	1.80	1.04
45	1.33	1.89
78	0.77	5.66

ANSWERS TO QUESTIONS

1. See Table
2. See Table
3. See Table. The values are in close agreement.
4. 0.78 g
5. Position the WDSS further away from the center of the turntable.

Mission to Titan – Investigating Surface Composition

The Cassini-Huygens mission to Saturn and its moons began back in October 1997 with a launch from Cape Canaveral. Seven years later on Thursday, July 1, 2004, the Cassini orbiter with its Titan probe Huygens (see Figure 1), went into orbit around Saturn. On Christmas Day 2004 the 318 kg Huygens probe was released from the orbiter and entered Titan's atmosphere on January 14, 2005, landing shortly afterwards on this moon's surface. The Huygens probe, named after the Dutch physicist and astronomer Christiaan Huygens (1629 – 1695) who discovered Titan in 1655, was designed to investigate Titan's atmosphere and surface. One experiment involved investigating the composition of Titan's surface. As the Huygens probe made contact with the surface of Titan, a force sensor (or penetrometer) collected data that was to give scientists an idea of the composition of Titan's surface. A graph of this data is shown in Figure 2.

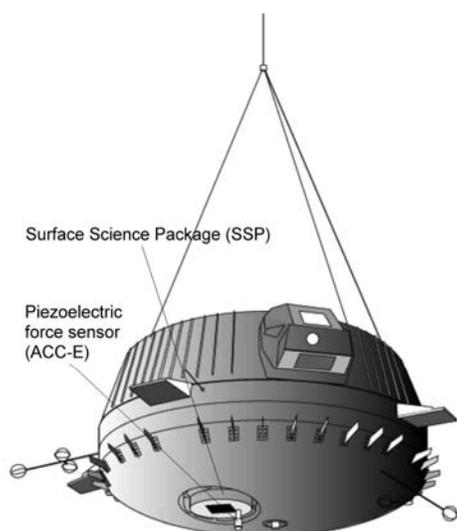


Figure 1

Courtesy Planetary and Space Sciences
Research Institute, The Open University,
Milton Keynes, UK

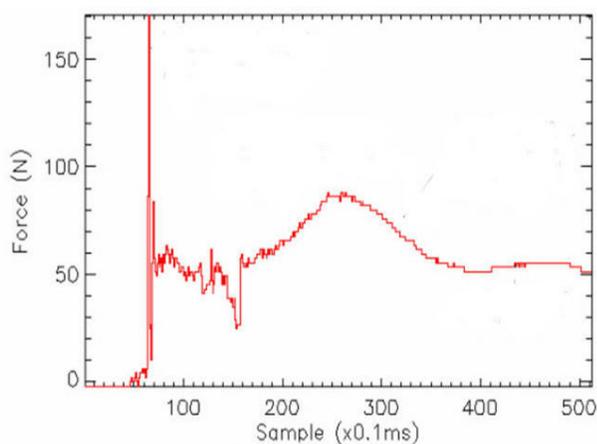


Figure 2

Courtesy Rutherford Appleton
Laboratory Space Electronics Group
and the Planetary and Space Sciences
Research Institute at the Open
University

In this activity, you will create a penetrometer using the force probe on the WDSS. Your task will be to generate model graphs of various surfaces that you will compare with the data received from the Huygens' probe to form a hypothesis as to the surface composition of Titan.

OBJECTIVES

In this activity, you will

- Collect force-time data for a penetrometer impacting various simulated surface conditions.
- Develop a hypothesis based on your research as to the composition of Titan's surface at the location where the Huygens probe landed.

MATERIALS

Bluetooth [®] equipped computer	soil container (at least 10 cm deep)
Logger Pro Software	sample soils – clay, fine gravel, fine grit,
Vernier Wireless Dynamics Sensor System	and sand
10 cm length of PVC pipe (should allow Wooden dowel to slide freely inside)	burette clamp
35 cm wooden dowel (3/8") with bolt glued to the end (1" bolt (1/4 – 20 thread))	metric ruler
	clothes pin
	ring stand

PROCEDURE

Establish a connection to your WDSS

1. Turn on the WDSS. Note the name on the label of the device.
2. Make sure Bluetooth is activated on your computer. Some computers have Bluetooth built into them. If that is the case, make sure Bluetooth is turned on.
3. Start *Logger Pro*.
4. Establish a wireless connection with the WDSS.
 - a. Choose Connect Interface from the Experiment menu. Choose Wireless and then Scan for Wireless Device.
 - b. There will be a short delay while *Logger Pro* attempts to establish a connection. If the WDSS is not found, try scanning again.
 - c. A dialog box will appear showing your WDSS on the list of available devices. Select your WDSS device and then click . Once a connection is made, the two LEDs on the WDSS will be lit green.



Figure 3

Sensor and Data Collection Setup

5. Choose Set Up Sensors from the Experiments menu and then select your WDSS device. Set up the WDSS sensors to use only Force.
6. Click below the force sensor and select Reverse Direction. This will make the force sensor report positive values for forces that push the bumper towards the sensor.
7. Choose Data Collection from the Experiment menu. Adjust the data collection experiment length to 500 milliseconds with a sampling rate of 1 samples/millisecond.

Also, uncheck the Sample at Time Zero box if it is selected.

- Click on the Triggering tab and set up the WDSS to trigger and begin recording data when the force increases above 0.1 N as indicated in Figure 4.

The Simulated Landings

- Attach the PVC tubing to the ring stand using the burette clamp. Be sure the tubing is directly above the base of the stand. Insert the wooden dowel into the PVC tubing with the threaded end pointing down towards the ring stand base.
- Screw the bumper into the force sensor end of the WDSS. Thread the WDSS onto the wooden dowel using the mounting hole at the end opposite the bumper. Align the bumper so it is centered above the base of the ring stand. Raise the WDSS as high as it can go and hold it in place with the clothes pin.
- Fill the soil container 10 cm deep with the first test soil. (Since you will be testing all four types of soil, it does not matter which is done first.) Place the soil container on the base of the ring stand so the container is centered directly below the WDSS.
- Click to zero the force sensor.
- Hold the wooden dowel and remove the clothes pin. Click to prepare the WDSS for data collection. (The graph will display the message “Waiting for Trigger or Data...”.) Release the dowel and allow the WDSS to impact the soil sample. When data collection is complete, raise and secure the WDSS to its highest position with the clothes pin.
- Study the force-time graph (impact signature) carefully. Pay close attention to how the impact force changes with time and how fast the changes take place. You may want to repeat Step 12 – 13 several times to be sure you understand the characteristics of the impact signature for this type of soil. Save at least one of your force-time graphs by choosing Store Latest Run from the Experiments Menu.
- Repeat Steps 11 – 14 using the other three soil samples.



Figure 4

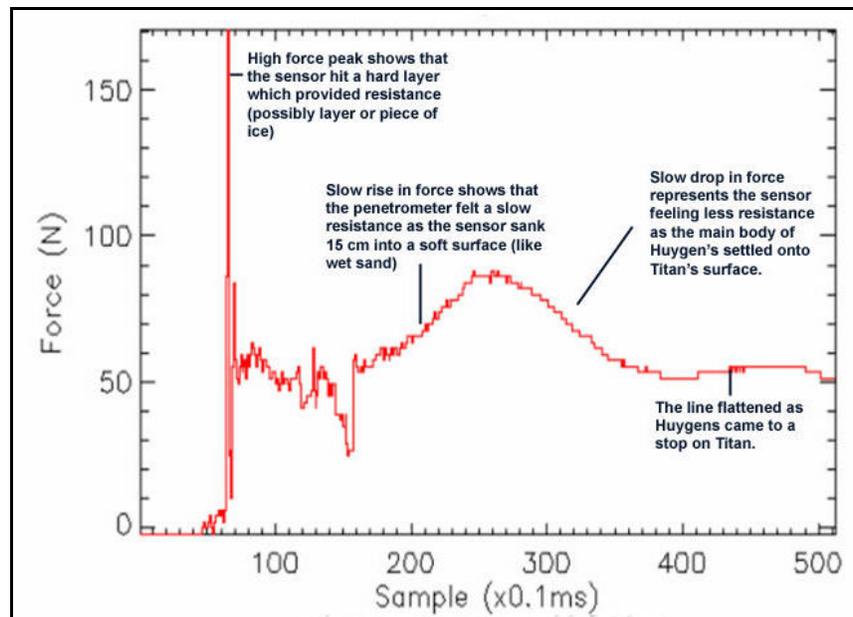
QUESTIONS

- Sketch a typical impact signature for each of the soils you tested. Label the key features of the graphs.
- Review the Huygens' probe data. Based on the results of your tests, hypothesize as to the composition of the soil on Titan. Defend your hypothesis.
- Describe the limitations of this procedure for determining the composition of Titan's soil at the location of impact.
- Describe changes to this experiment and additional tests you would recommend to test your hypothesis.

TEACHER INFORMATION

Mission to Titan – Investigating Surface Composition

1. Special thanks to Professor John Zarnecki and Mr. Mark Leese of the Planetary and Space Sciences Research Institute at the Open University, Milton Keynes, UK, and Dr Ralph Lorenz of the Space Department, Planetary Exploration Group, John Hopkins University, USA, for their help in developing this activity.
2. In preparing the soil samples, use modeling clay, playground sand, fine grit (for use in a bird cage), and fine gravel (for use in an aquarium). It is recommended that you sieve the gravel so that it has a particle size between about 2.36mm and 5mm.
3. When collecting data using the playground sand, make sure that the sand is not compacted. If the sand is compacted, mix it up to reduce compacting.
4. The following figure shows Huygens data with annotations.

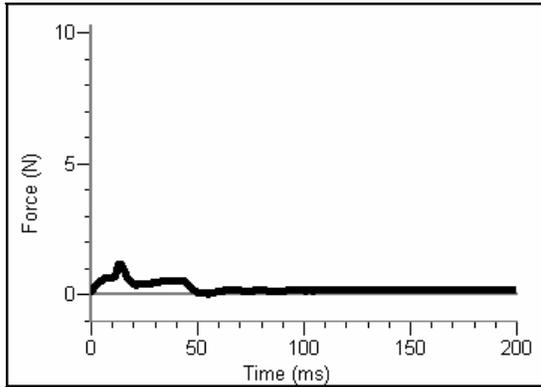


Impact signature – Courtesy Rutherford Appleton Laboratory Space Electronics Group and the Planetary and Space Sciences Research Institute at the Open University

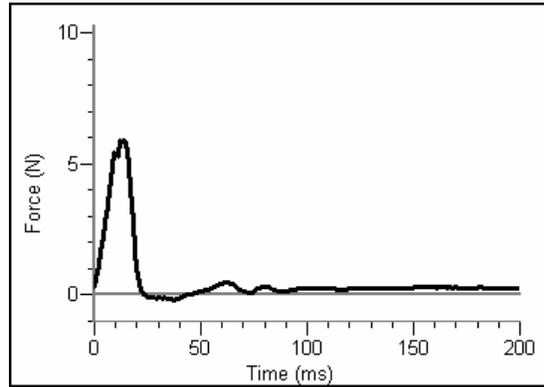
5. Professor John Zarnecki, Principal Investigator for the Surface Science Package, on seeing the impact signature, said: “A crust and a pebble will give you an initial peak, but the match looks better with a pebble and, if we’re seeing lots of them in the ground image it’s hardly fanciful that we’ve bashed one of them”. His comments are based on the tests scientists at the Planetary and Space Science Research Institute at the Open University did subsequent to the landing, trying to reproduce the Force-time graph with various combinations of materials.

6. Here are a number of web sites with information on the Cassini-Huygens mission.
 - British National Space Centre (BNSC) – Cassini-Huygens
<http://www.bnsc.gov.uk/default.aspx?nid=4395>
 - Cassini-Huygens card models to make
http://www.nasa.gov/pdf/59402main_model_simple.pdf
http://www.nasa.gov/pdf/59403main_model_challenging.pdf
 - ESA Cassini-Huygens
<http://www.esa.int/SPECIALS/Cassini-Huygens/>
 - Mission: Cassini-Huygens
http://www.uk2planets.org.uk/m_cassini.htm
 - NASA Cassini-Huygens Mission to Saturn and Titan
<http://saturn.jpl.nasa.gov/home/index.cfm>
 - Open University , Planetary and Space Sciences Research Institute
<http://pssri.open.ac.uk/missions/mis-casa1.htm>
 - PPARC Cassini-Huygens School Resources
<http://www.pparc.ac.uk/Ed/ch/Home.htm>
 - Ralph Lorenz's web site – This site includes a document that describes an impact penetrometer for a landing spacecraft.
<http://www.lpl.arizona.edu/~rlorenz/>
<http://www.lpl.arizona.edu/~rlorenz/acce.pdf>
 - UK Cassini-Huygens Press Conference
<http://pssri.open.ac.uk/missions/UK%20C-H%20Press%20Conf/UK%20C-H%20Press%20Conf%203%20June%2004.pdf>
7. Here are some useful book and periodicals for additional background information and subsequent updates in information.
 - Lifting Titan's Veil. Ralph Lorenz and Jacqueline Mitton. Cambridge University Press 2002.
 - Mission to Saturn: Cassini and the Huygens Probe. David M Harland. Springer-Verlag 2002.
 - Frontiers. Free magazine on UK particle physics, astronomy and space science. Available from Strategic Planning and Communications, Particle Physics and Astronomy Research Council (PPARC), Polaris House, North Star Avenue, Swindon SN2 1SZ.
 - ESA Bulletin. Free magazine from the European Space Agency (ESA). Available from ESA Publications Division, c/o ESTEC, PO Box 299, 2200 AG Noordwijk, The Netherlands.
 - Astronomy Now, UK Periodical available at newsstands.
(<http://www.astronomynow.com/>)

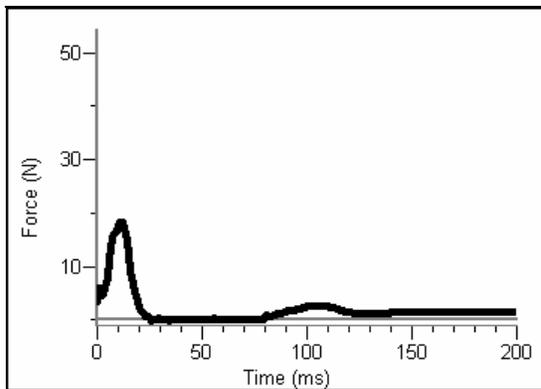
SAMPLE RESULTS



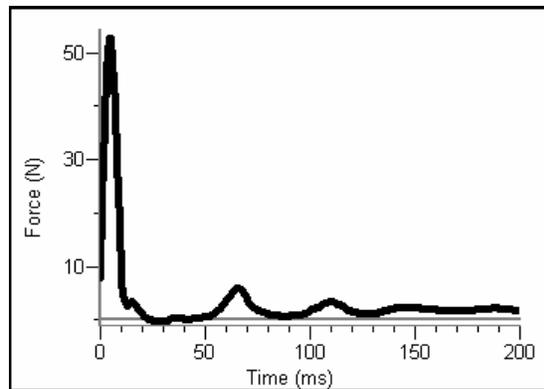
Loose Sand



Fine Grit



Fine Gravel



Clay

ANSWERS TO QUESTIONS

1. The students should notice that the impact signatures show high forces over short times for harder surfaces and lower forces over longer times for more spongy surfaces.
2. Answers will vary.
3. In this activity, the students are not using the same equipment as used by the research team.
4. Using a force sensor identical to that on Huygens to sample different soils (including combinations of soils) to try and reproduce the impact signature. Unfortunately such a sensor is most likely not available.

Physics at Amusement Parks

There are few who would turn down an opportunity to learn some physics through amusement park rides. They are usually great fun and are absolutely full of physics to discuss in advance and afterwards. The rides may be at local fairgrounds or at large theme parks (such as Six Flags or Great America). Some of these rides can usually provide the basics of ‘freefall’ drops, spins and rotations in the horizontal plane, ‘pendulum’ swings, and ‘up and overs’ with and without extra rotations. Some of these are shown below.



The images (from left to right) are the Drop Zone (freefall accelerations), and HMB Endeavor (pendulum), and Celebration (swings)

The most useful sensors for such activities are the accelerometers and the altimeter. As it difficult to predict precisely which accelerometer(s) will be most useful, you will measure accelerations using all three accelerometers. Once you are back in the classroom, you can select which of these data make the most sense to study for each ride. The altimeter is useful when analyzing the graphs of acceleration vs. time. After your visit, the altimeter data can help you identify the feature of the ride you are trying to study.

OBJECTIVES

In this activity, you will

- measure accelerations in a real world setting.
- compare the different accelerations produced by various amusement park rides.

MATERIALS

Bluetooth[®] equipped computer
Logger *Pro* Software
Vernier Wireless Dynamics Sensor System

Vernier Data Vest or elastic cord for holding the WDSS
stopwatch

PROCEDURE

Part I – Before you go to the amusement park

1. Turn on the WDSS. Note the name on the label of the device.

Activities for the Wireless Dynamics Sensor System

2. Make sure Bluetooth is activated on your computer. Some computers have Bluetooth built into them. If that is the case, make sure Bluetooth is turned on.
3. Start *Logger Pro*.
4. Establish a wireless connection with the WDSS.
 - a. Choose Connect Interface from the Experiment menu. Choose Wireless and then Scan for Wireless Device.
 - b. There will be a short delay while *Logger Pro* attempts to establish a connection. If the WDSS is not found, try scanning again.
 - c. A dialog box will appear showing your WDSS on the list of available devices. Select your WDSS device and then click . Once a connection is made, the two LEDs on the WDSS will be lit green.
5. Open the file “Amusement Park” from the *Probes & Sensors/WDSS* folder.
6. Set up the WDSS for remote data collection.
 - a. Choose Remote Setup from the Experiment menu, and then choose your WDSS.
 - b. Select the option Disable Stop Button During Remote Data Collection.
 - c. Click to exit this dialog box and use the WDSS for remote data collection. The WDSS disconnects from the computer and readings from the WDSS no longer appears on the *Logger Pro* toolbar. The Bluetooth connection LED on the WDSS will turn steady red, indicating that the WDSS is no longer communicating with the computer.
7. Turn off the WDSS, connect it to the power adapter, and allow it to fully charge.

Part II – At the Amusement Park

8. Before each ride, look for specific features on the ride that you are interested in. Use a stopwatch to determine approximately when in the ride these features occur. Record this information along with other ride details in your lab notebook.
9. Turn on the WDSS and check to be sure the data collection LED is steady green. Orient the WDSS so the x-axis accelerometer arrow is pointing straight up and the On/Off switch directed away from you. You are now ready to get on the ride.
10. Once properly seated on the ride, start data collection by pressing the Start/Stop button () on the WDSS. The button is slightly recessed to prevent accidental pressing. You need to press the button carefully to make sure you start the data collection run. The Data Collection LED will change from steady green to flashing green during data collection.
11. Once data collection is complete, the Data Collection LED will flash red and then turn steady green, indicating data are stored. As long as the data collection light turns steady green, you have enough memory to complete another full data collection run. If the light becomes steady red, you will not be able to complete another full data run.
12. Repeat Steps 8 – 11 for other rides as directed by your teacher.
13. Turn off the WDSS when you are finished collecting data.

Part III – Back from the Amusement Park

14. Turn on the WDSS. Make sure Bluetooth is activated on your computer.
15. Start Logger Pro and open the file “Amusement Park” from the *Probes & Sensors – WDSS* folder.
16. From the Experiment menu, choose Remote ► Retrieve Remote Data and then the name of your WDSS. If your WDSS is not listed, choose the Scan for Wireless Device option. Click **Yes** to retrieve the data. Choose the option to retrieve your data into the current file and click **OK**.
17. When the Remote Data Retrieval dialog is displayed, it lists all data runs on the WDSS. Select the data you want to retrieve from the WDSS and click **OK**. You can retrieve data without deleting it, so that the data could be retrieved to several different computers.

QUESTIONS

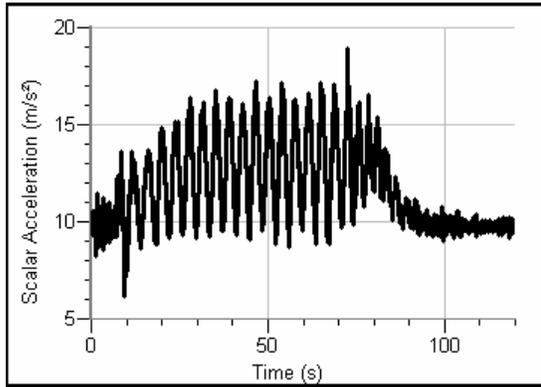
1. Prepare a presentation describing the physics of the rides you went on. Be sure to include graphs that help explain the accelerations a rider experiences on each ride.

TEACHER INFORMATION

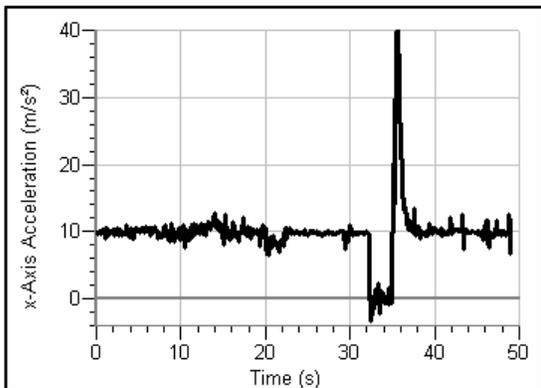
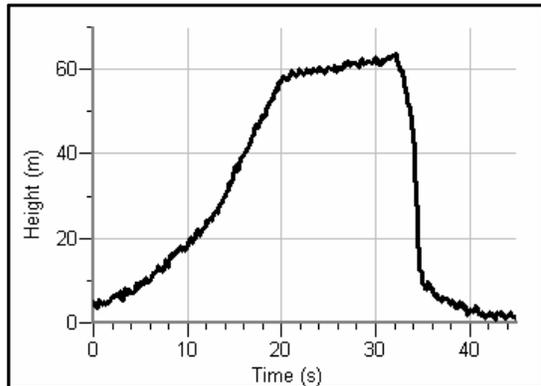
Physics at Amusement Parks

1. Amusement parks and fairgrounds provide excellent opportunities to let students experience accelerations and energy transfers through drops, swings, and rotations. For better understanding of the physics behind the rides, it is best to limit the number of rides each group should study.
2. As with any activity it is essential to make risk assessments bearing in mind the type of activities to be engaged in and who the students are. Ensure there are enough staff to supervise and that they have ‘presence.’ Some students should not, on health grounds, go on some rides, so make sure that this is checked out in advance.
3. The maximum number of runs you can collect on a WDSS is 20.
4. Unless the height of drop is large, the extent of the free-fall will be very limited and so a value of around 0 m/s^2 is likely to be noted for only a short time. Pendulum type swings are useful to investigate, particularly if the full extent of the swings takes one from horizontal to near vertical and back. Up and over rotations provide interesting data, as do rotations in the horizontal plane. Some rides incorporate twists into rotations and these tend to make interpretation of the data more awkward.
5. The altimeter readings will be relative to the initial altitude measurement.
6. When discussing the accelerometer reading, it is proper to refer to it as a measure of Normal Force per Unit Mass, with units of N/kg, where “normal” is in the direction of that particular accelerometer. This is what the accelerometer is actually measuring. (Note that it is not the net force per unit mass which would be acceleration.) A motionless accelerometer oriented in the vertical direction will give a reading of $+9.8 \text{ N/kg}$ when pointed up and -9.8 N/kg when pointed down. A motionless accelerometer oriented in the horizontal direction will read 0 N/kg . An accelerometer in freefall will give a value of 0 N/kg regardless of its orientation. Since most people prefer the measurement be in m/s^2 , we have used these units in this manual.
7. Here are a number of web sites with information on amusement park physics.
 - Data collection at the Amusement Park – some additional resources from Vernier
<http://www.vernier.com/cmat/datapark.html>
 - Amusement Park Physics – this site has material related to carousel, roller coaster, freefall, pendulum, and bumper car rides.
<http://www.learner.org/exhibits/parkphysics/>
 - Education Related Amusement Park Physics Links
http://www.newton.dep.anl.gov/app/nau_links.htm
 - The Physics of Amusement Parks
<http://library.thinkquest.org/2745/data/openpark.htm>
 - Theme Park Sites in UK Net Guide
http://www.uknetguide.co.uk/Entertainment/Theme_Parks/

SAMPLE RESULTS

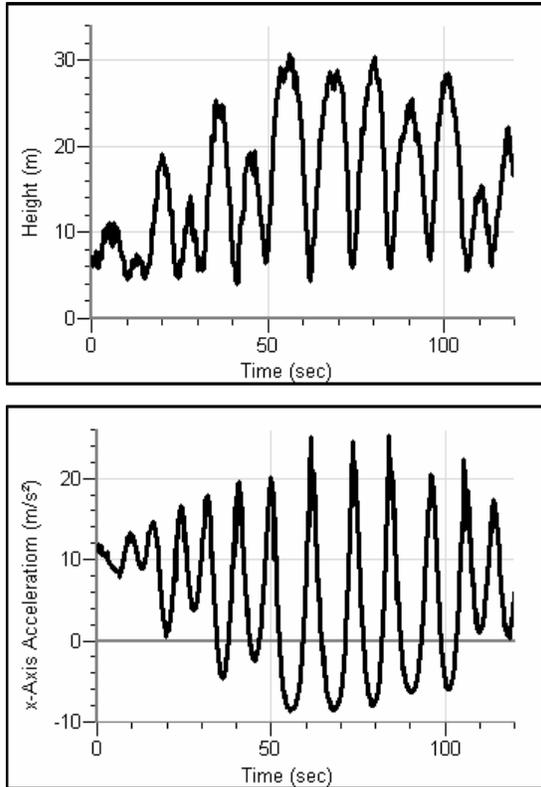


*Celebration Swings at Great America in Santa Clara, California
Sensors of interest; 3 axis (x, y, and z) accelerometer*



*The Drop Zone freefall drop at Great America in Santa Clara, California
Sensors of interest; x-axis accelerometer and altimeter*

Activities for the Wireless Dynamics Sensor System



*The HMB Endeavor pendulum swing at Great America in Santa Clara, California
Sensors of interest; x-axis and z-axis accelerometer and altimeter*

Newton's Second Law

How does a cart change its motion when you push and pull on it? You might think that the harder you push on a cart, the faster it goes. Is the cart's velocity related to the force you apply? Or does the force just *change* the velocity? Also, what does the mass of the cart have to do with how the motion changes? We know that it takes a much harder push to get a heavy cart moving than a lighter one.

The WDSS's force sensor and x-axis accelerometer will let you measure the force on a cart simultaneously with the cart's acceleration. The total mass of the cart is easy to vary by adding masses. Using these tools, you can determine how the net force on the cart, its mass, and its acceleration are related. This relationship is Newton's second law of motion.

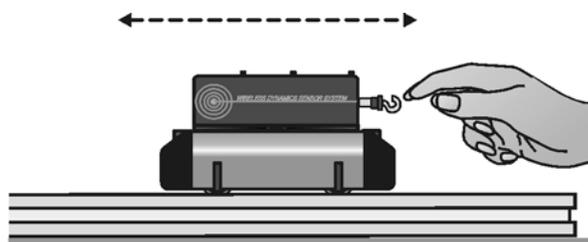


Figure 1 – WDSS on a Vernier dynamics cart and track

OBJECTIVES

In this activity, you will

- collect force and acceleration data for a cart as it is moved back and forth.
- compare force-time and acceleration-time graphs.
- analyze a graph of force *vs.* acceleration.
- determine the relationship between force, mass, and acceleration.

MATERIALS

Bluetooth[®] equipped computer
Vernier Wireless Dynamics System

Logger *Pro* Software
Vernier Dynamics System

PRELIMINARY QUESTIONS

1. When you push on an object, how does the magnitude of the force affect its motion? If you push harder, is the change in motion smaller or larger? Do you think this is a direct or inverse relationship?
2. Assume that you have a bowling ball and a baseball, each suspended from a different rope. If you hit each of these balls with a full swing of a baseball bat, which ball will

change its motion by the greater amount?

3. In the absence of friction and other forces, if you exert a force, F , on a mass, m , the mass will accelerate. If you exert the same force on a mass of $2m$, would you expect the resulting acceleration to be twice as large or half as large? Is this a direct or inverse relationship?

PROCEDURE

1. Turn on the WDSS. Note the name on the label of the device.
2. Make sure Bluetooth is activated on your computer. Some computers have Bluetooth built into them. If that is the case, make sure Bluetooth is turned on.
3. Start Logger *Pro*.
4. Establish a wireless connection with the WDSS.
 - a. Choose Connect Interface from the Experiment menu. Choose Wireless and then Scan for Wireless Device.
 - b. There will be a short delay while Logger Pro attempts to establish a connection. If the WDSS is not found, try scanning again.
 - c. A dialog box will appear showing your WDSS on the list of available devices. Select your WDSS device and then click . Once a connection is made, the two LEDs on the WDSS will be lit green.
5. Open the file “09 Newtons Second Law” from the *Physics with Computers* folder.
6. Attach the force sensor hook to the force sensor end of the WDSS. Attach the WDSS to one of the Vernier Dynamics System carts.
7. Find the mass of the cart with the WDSS attached. Record the mass in the data table.
8. Place the cart on a level surface. Make sure the cart is not moving and click . Check to make sure both the force sensor and x-axis accelerometer are highlighted and click .

Trial I

9. You are now ready to collect force and acceleration data. Grasp the force sensor hook. Click and take several seconds to move the cart back and forth on the table. Vary the motion so that both small and large forces are applied. Make sure that your hand is only touching the hook on the Force Sensor and not the Force Sensor or cart body.
10. Note the shape of the force-time and acceleration-time graphs. Click the Examine button, , and move the mouse across the force vs. time graph. When the force is maximum, is the acceleration maximum or minimum? To turn off Examine mode, click the Examine button a second time.
11. The graph of force vs. acceleration should appear to be a straight line. To fit a straight line to the data, click on the graph, then click the Linear Fit button, . Record the equation for the regression line in the data table.

12. Print copies of each graph.

Trial 2

13. Attach the 0.500 kg mass to the cart. Record the mass of the cart, sensors, and additional mass in the data table. Repeat Steps 9 – 12.

DATA TABLE

Trial 1

Mass of cart with WDSS (kg)	
-----------------------------	--

Regression line for force vs. acceleration data

Trial 2

Mass of cart with WDSS and additional mass (kg)	
---	--

Regression line for force vs. acceleration data

ANALYSIS

1. Compare the force-time and acceleration-time graphs for a particular trial. How are they different? How are they the same?
2. Are the net force on an object and the acceleration of the object directly proportional? Explain, using experimental data to support your answer.
3. What are the units of the slope of the force vs. acceleration graph? Simplify the units of the slope to fundamental units (m, kg, s).
4. For each trial compare the slope of the regression line to the mass being accelerated. What does the slope represent?
5. Write a general equation that relates all three variables: force, mass, and acceleration.

EXTENSIONS

Use this apparatus as a way to measure mass. Place an unknown mass on the cart. Measure the acceleration for a known force and determine the mass of the unknown. Compare your answer with the actual mass, as measured using a balance.

TEACHER INFORMATION

Newton's Second Law

1. Traditional experiments for Newton's second law often use motion detectors or spark timers to measure distance data and calculate acceleration. This experiment uses the accelerometer in the WDSS to actually measure the acceleration. This device, along with the Force Sensor of the WDSS, makes it easy to quickly collect accurate force and acceleration data.
2. In this experiment, the students will analyze the force *vs.* acceleration graph. During this analysis they will perform a linear fit on the data. The slope of this fit should be close to the mass of the cart and added objects. To get the best possible results, you may want to calibrate both the WDSS's force sensor and accelerometer.
3. Since the accelerometer of the WDSS is sensitive to inclination, the students are instructed to make sure the surface is level and zero the sensors prior to data collection.
4. This lab was written using 0.500 kg dynamics carts. If you are using large carts, you may need to change the maximum and minimum values for force and acceleration on the graphs.
5. The mass used in this experiment is the *inertial mass*, as opposed to the *gravitational mass*. You may wish to make this distinction with your students.
6. If the accelerometer data seem noisy, make sure that the sensor is securely fastened to the cart. If it isn't fastened firmly, it could rattle and introduce more noise to the data set.
7. Explore all magnitudes of force by moving the cart back and forth in a random way. Do NOT just pull the cart at a uniform speed or at uniform acceleration, since you'll concentrate points in a small region of the force *vs.* acceleration plot that way.
8. When discussing the accelerometer reading, it is proper to refer to it as a measure of Normal Force per Unit Mass, with units of N/kg, where "normal" is in the direction of that particular accelerometer. This is what the accelerometer is actually measuring. (Note that it is not the net force per unit mass which would be acceleration.) A motionless accelerometer oriented in the vertical direction will give a reading of +9.8 N/kg when pointed up and -9.8 N/kg when pointed down. A motionless accelerometer oriented in the horizontal direction will read 0 N/kg. An accelerometer in freefall will give a value of 0 N/kg regardless of its orientation. Since most people prefer the measurement be in m/s^2 , we have used these units in this manual.

ANSWERS TO PRELIMINARY QUESTIONS

1. The larger the force, the more the motion changes. This is a direct relationship.
2. The baseball will change its motion more than the bowling ball.
3. The new acceleration would be half as large. This is an inverse relationship between

mass and acceleration.

SAMPLE RESULTS

Trial 1

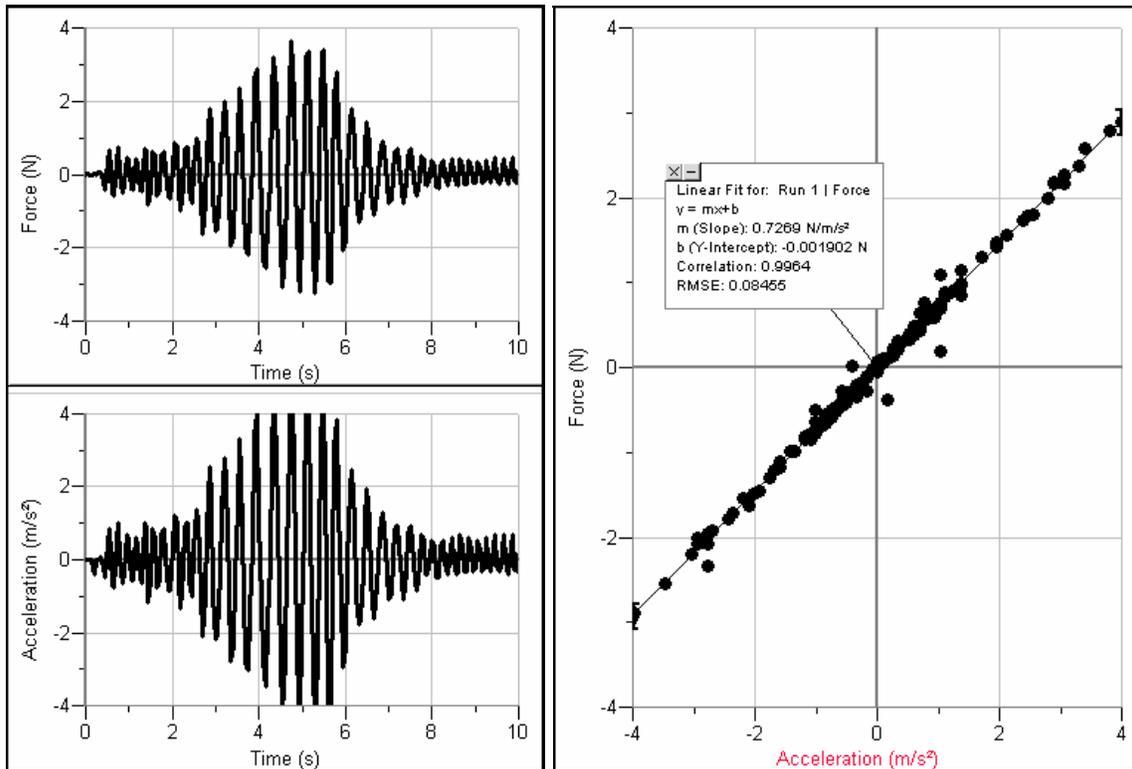
Mass of cart with WDSS (kg)	0.70 kg
-----------------------------	---------

Regression line for force vs. acceleration data
$y = 0.73x - 0.002$

Trial 2

Mass of cart with WDSS and additional mass (kg)	1.20 kg
---	---------

Regression line for force vs. acceleration data
$y = 1.21x - 0.05$



Force and acceleration graphs for cart equipped with force and acceleration sensors

ANSWERS TO ANALYSIS QUESTIONS

1. The graphs look very similar, showing that force and acceleration are closely related. The peaks on one graph occur at the same time on each graph.
2. Force and acceleration are directly proportional. This relationship can be seen when the force-time and acceleration-time graphs are compared. Also, the graph of force vs. acceleration shows a linear relationship.
3. $\text{N}/(\text{m}/\text{s}^2) = \text{kg}$
4. In Trial 1, the mass was 0.7 kg while the slope of the linear regression line was 0.73 $\text{N}/(\text{m}/\text{s}^2)$. In Trial 2, the mass was 1.20 kg while the slope of the linear regression line was 1.21 $\text{N}/(\text{m}/\text{s}^2)$. In both cases the mass was within the uncertainty of the fitted slope. The slope corresponds to the combined mass of the cart, sensors, and any added mass.
5. $F = m a$

Newton's Third Law

You may have learned this statement of Newton's third law: "To every action there is an equal and opposite reaction." What does this sentence mean?

Unlike Newton's first two laws of motion, which concern only individual objects, the third law describes an interaction between two bodies. For example, what if you pull on your partner's hand with your hand? To study this interaction, you can use two Force Sensors. As one object (your hand) pushes or pulls on another object (your partner's hand) the Force Sensors will record those pushes and pulls. They will be related in a very simple way as predicted by Newton's third law.

The *action* referred to in the phrase above is the force applied by your hand, and the *reaction* is the force that is applied by your partner's hand. Together, they are known as a *force pair*. This short experiment will show how the forces are related.

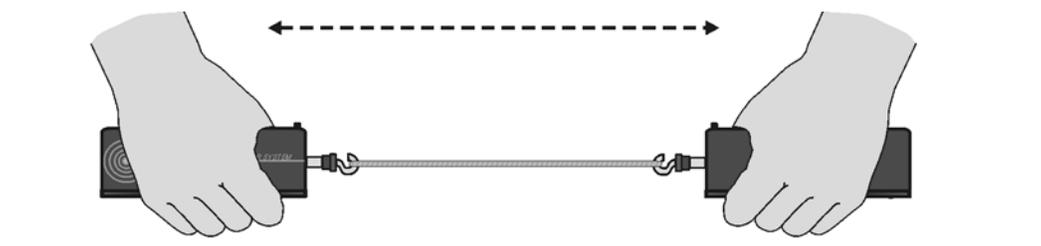


Figure 1 – Collecting force pairs with two WDSS units

OBJECTIVES

In this activity, you will

- observe the directional relationship between force pairs.
- observe the time variation of force pairs.
- explain Newton's third law in simple language.

MATERIALS

Bluetooth [®] equipped computer	500 g mass
Logger Pro Software	string
two Vernier Wireless Dynamics Sensor Systems	rubber band

PRELIMINARY QUESTIONS

1. You are driving down the highway and a bug splatters on your windshield. Which is greater: the force of the bug on the windshield, or the force of the windshield on the bug?
2. Hold a rubber band between your right and left hands. Pull with your left hand. Does your right hand experience a force? Does your right hand apply a force to the rubber

- band? What direction is that force compared to the force applied by the left hand?
3. Pull harder with your left hand. Does this change any force applied by the right hand?
 4. How is the force of your left hand, transmitted by the rubber band, related to the force applied by your right hand? Write a rule, in words, for the force relationship.

PROCEDURE

1. Turn on the two WDSS units. Note the name on the label of the devices.
2. Make sure Bluetooth is activated on your computer. Some computers have Bluetooth built into them. If that is the case, make sure Bluetooth is turned on.
3. Start Logger *Pro*.
4. Establish a wireless connection with the WDSS.
 - a. Choose Connect Interface from the Experiment menu. Choose Wireless and then Scan for Wireless Device.
 - b. There will be a short delay while Logger Pro attempts to establish a connection. If the WDSS is not found, try scanning again.
 - c. A dialog box will appear showing your WDSS on the list of available devices. Select your WDSS device and then click . Once a connection is made, the two LEDs on the WDSS will be lit green.
5. Open the file “11 Newton’s Third Law” in the *Physics with Computers* folder.
6. Attach the Force Sensor Hooks to the force sensor ends of the two WDSS units.
7. Force sensors measure force only along one direction; if you apply a force along another direction, your measurements will not be meaningful. The WDSS force sensor responds to force directed parallel to the long axis of the sensor.
8. OPTIONAL – Since you will be comparing the readings of two different Force Sensors, it is important that they both read force accurately. In other words, you need to *calibrate* them. To calibrate the first sensor,
 - a. Choose Calibrate from the Experiment menu. Select one of the WDSS force sensors. Click on the button.
 - b. Remove all force from the first sensor and hold it vertically with the hook pointed down. Enter a **0** (zero) in the Value 1 field, and after the reading shown for Reading 1 is stable, click . This defines the zero force condition.
 - c. Hang the 500 g mass from the sensor. This applies a force of 4.9 N. Enter **4.9** in the Value 2 field, and after the reading shown for Reading 2 is stable, then click .
 - d. Click to complete the calibration of the first force sensor.
 - e. Repeat the Steps a-d for the second WDSS force sensor.
9. You will be using the sensors in a different orientation than that in which they were calibrated. Zero the force sensors to account for this. Hold the sensors horizontally with no force applied, and click . Make sure both sensors are highlighted in the

Zero Sensor Calibrations box and click to zero both sensors. This step makes both sensors read exactly zero when no force is applied.

10. Click to take a trial run of data. Pull on each sensor and note the sign of the reading. Use this to establish the positive direction for each sensor. For this activity it is helpful to set up the two sensors differently, since later you will have the sensors positioned so that a force to the left will generate the same sign of force on each sensor.
11. Choose Set Up Sensors from the Experiments menu and then select your second WDSS device. Click below the force sensor and select Reverse Direction. This will make the force sensor report negative values for forces that pull the hook away from the sensor.
12. Make a short loop of string with a circumference of about 30 cm. Use it to attach the hooks of the force sensors. Hold one sensor in your hand and have your partner hold the other so you can pull on each other using the string as an intermediary.
13. Click to begin collecting data. Gently tug on your partner's sensor with your sensor, making sure the graph does not go off scale. Also, have your partner tug on your sensor. You will have 10 seconds to try different pulls. Choose Store Latest Run from the Experiment menu.
14. What would happen if you used the rubber band instead of the string? Would some of the force get "used up" in stretching the band? Use the prediction tool to sketch a prediction graph, and repeat Steps 12 – 13 using the rubber band instead of the string.

ANALYSIS

1. Examine the two data runs. What can you conclude about the two forces (your pull on your partner and your partner's pull on you)? How are the magnitudes related? How are the signs related?
2. How does the rubber band change the results—or does it change them at all?
3. While you and your partner are pulling on each other's sensors, do your sensors have the same positive direction? What impact does your answer have on the analysis of the force pair?
4. Is there any way to pull on your partner's sensor without your partner's sensor pulling back? Try it.
5. Reread the statement of the third law given at the beginning of this activity. The phrase *equal and opposite* must be interpreted carefully, since for two vectors to be equal ($\vec{A} = \vec{B}$) and opposite ($\vec{A} = -\vec{B}$) then we must have $\vec{A} = \vec{B} = 0$; that is, both forces are always zero. What is really meant by *equal and opposite*? Restate Newton's third law in your own words, not using the words "action," "reaction," or "equal and opposite."
6. Re-evaluate your answer to the bug-windshield question.

EXTENSIONS

1. Fasten one WDSS to your lab bench and repeat the experiments. Does the bench pull back as you pull on it? Does it matter that the second WDSS is not held by a person?
2. Use a rigid rod to connect the force sensor hooks instead of a string and experiment with mutual pushes instead of pulls. Repeat the experiments. Does the rod change the way the force pairs are related?

TEACHER INFORMATION

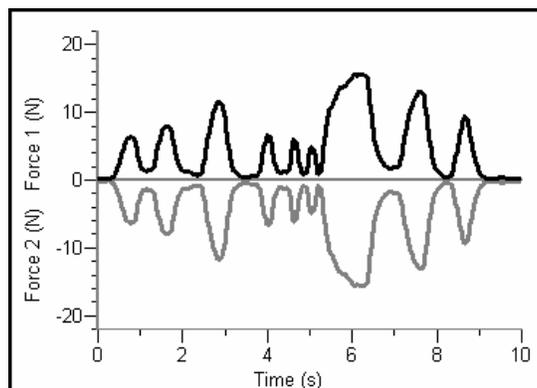
Newton's Third Law

1. This experiment may not take a full lab period; it is intended as a short in-class activity to clarify an often-misunderstood law. You may want to combine it with a Newton's second law experiment.
2. Be careful that students do not pull too hard on the Force Sensors.
3. This activity may be the first in which students calibrate a sensor, so you may need to devote time to understanding that process.
4. A push is positive for one sensor and negative for the other. Having the signs inverted is helpful in this activity, since the sensors are held facing one another. With opposite signs, a force to the right is read as the *same* sign on each sensor, so the two sensors share a single sign convention.

ANSWERS TO PRELIMINARY QUESTIONS

1. The bug exerts the same magnitude force on the windshield as the windshield exerts on the bug. The directions are opposite.
2. The right hand exerts a force on the left via the rubber band and *visa versa*; the two forces are in opposite directions.
3. Yes, increasing the force exerted by one hand increases the force exerted by the other.
4. The force exerted by the left hand is the same magnitude but the opposite direction as the force exerted by the right.

SAMPLE RESULTS



ANSWERS TO ANALYSIS QUESTIONS

1. The magnitudes are the same but the directions are opposite. This is true regardless of

the time of comparison.

2. The rubber band does not change the results.
3. When the sensors are facing one another, a pull is read as the same sign as a push on the other, meaning that the positive direction of the two sensors is the same, *while they are in that orientation*.
4. No, you can't pull without your partner pulling back.
5. Answers will vary, but should be of this content: When body A exerts a force on body B, body B exerts a force on body A of the same magnitude but the opposite direction.
6. Answers will vary.

Investigating Collisions with Crumple Zones

The design of modern railway cars such as that shown in Figure 1 incorporates a series of crush or crumple zones so that, in the event of a collision, much of the train's kinetic energy is transferred through deformation. Such zones reduce the accelerations and forces on both the train and its passengers and also make it less likely a derailment will occur. Current safety regulations for new train cars state that the crumple zones in each carriage must absorb at least 3MJ of energy. A modern car equipped with a crumple zone, and hitting a wall at 55 km/hr, only absorbs about 0.1 MJ through deformation of this zone.



Figure 1 – Virgin Rail Class 390 Pendolino train going through Rugby



Figure 2 – Energy absorbing crumpling

Crumple zones in train cars is just one example of innovations designed to keep passengers safe in the event of a collision. Other examples include seat belts and air bags particularly for use in automobiles. In this activity, you will investigate accelerations during collisions with and without crumple zones.

OBJECTIVES

In this activity, you will

- simulate collisions with and without crumple zones.
- simulate collisions with differing quantities of crumple zones.
- investigate the effectiveness of a crumple zone.

MATERIALS

Bluetooth [®] equipped computer	10 heavy-duty aluminum foil strips 3 × 10 cm
Logger Pro Software	10 standard aluminum foil strips 3 × 10 cm
Vernier Wireless Dynamics Sensor System	meter stick or measuring tape
glue stick	
dynamics cart and track with 500 g mass	

PROCEDURE

Establish a connection to your WDSS

1. Turn on the WDSS. Note the name on the label of the device.
2. Make sure Bluetooth is activated on your computer. Some computers have Bluetooth built into them. If that is the case, make sure Bluetooth is turned on.
3. Start Logger Pro.
4. Establish a wireless connection with the WDSS.
 - a. Choose Connect Interface from the Experiment menu. Choose Wireless and then Scan for Wireless Device.
 - b. There will be a short delay while Logger Pro attempts to establish a connection. If the WDSS is not found, try scanning again.
 - c. A dialog box will appear showing your WDSS on the list of available devices. Select your WDSS device and then click . Once a connection is made, the two LEDs on the WDSS will be lit green.

Sensor and Data Collection Setup

5. Choose Set Up Sensors from the Experiments menu and then select your WDSS device. Set up the sensors so that only the x-axis accelerometer is active.
6. Choose Data Collection from the Experiment menu. Adjust the data collection experiment length to 1 second with a sampling rate of 250 samples/second.

Click on the Triggering tab and set up triggering as shown in Figure 3.

7. Set up the dynamics cart and track using one set of the adjustable leveling feet to create a slight incline. Attach the track end stop to the lower end of the track and place that end against a wall or firm surface that will prevent the track from moving during the experiment. Adjust the end stop so it is positioned at the 7 cm mark on the track.

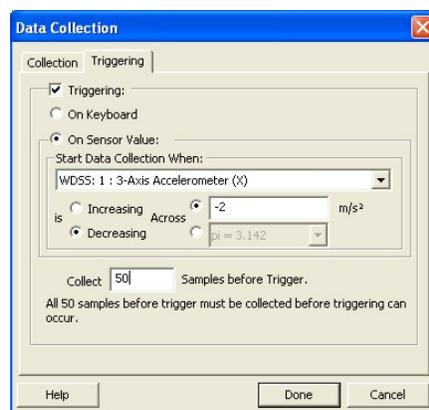


Figure 3

8. Mount the WDSS on top of the cart as shown in Figure 4. Arrange the cart and WDSS so that the x-axis accelerometer is pointing towards the track's end stop. With the cart in place and not moving, click to zero the x-axis accelerometer.



Figure 4 – WDSS attached to cart on a track

9. Attach the 500 g mass to the WDSS. For more stability, place the mass toward the center of the car.
10. Roll each strip of aluminum foil into a cylinder. Attach the two edges together using glue from the glue stick. Each cylinder should be 3 cm in height. Be sure you know which cylinders are heavy-duty and which are standard aluminum foil.

Simulating Collisions using Heavy-Duty Aluminum Foil

11. Position the front edge of the cart at the 60 cm mark on the track. The cart will be 53 cm from the end stop. Click to begin data collection. Release the cart and allow it to collide with the end stop. The collision will have triggered data collection.
12. Once data collection is complete, review the data to find the magnitude of the largest acceleration associated with stopping the WDSS. Record this value in the data table provided. Determine the time it took for the cart to stop its forward progress and record this value in the data table provided.
13. Position one foil cylinder so that it is centered on the track with the base of the cylinder against the track's end stop. Repeat Steps 11 – 12 using the foil cylinder as a crumple zone. Note the condition of the cylinder after the collision.
14. Repeat Step 13 using two foil cylinders placed side by side.
15. Repeat Step 13 using three foil cylinders placed side by side.
16. Repeat Step 13 using four foil cylinders placed side by side.

Simulating Collisions using Standard Aluminum Foil

17. Repeat Steps 13 – 16, this time using standard aluminum foil cylinders in place of the heavy-duty foil.

DATA TABLE

	Maximum Stopping Acceleration (m/s ²)	Time to stop (s)
Without Crumple Zones		

	Heavy-Duty Aluminum Foil		Standard Aluminum Foil	
	Maximum Stopping Acceleration (m/s ²)	Time to stop (s)	Maximum Stopping Acceleration (m/s ²)	Time to stop (s)
With Crumple Zones				
1 Foil Cylinder				
2 Foil Cylinders				
3 Foil Cylinders				
4 Foil Cylinders				

QUESTIONS

1. What is the relationship between the maximum stopping acceleration and the maximum stopping Force experienced by the cart? What physics principle is the relationship based on?
2. What is the relationship between the maximum stopping acceleration and the time it takes the cart to stop? What physics principle is the relationship based on?
3. What is the relationship between the number of cylinders and the maximum stopping acceleration for the heavy-duty foil? Does this same relationship hold for the standard foil? Explain.
4. Based on your data, which crumple zone was the most effective? Which was the least effective? Explain your reasoning.

EXTENSION

1. Design a crumple zone that would best protect passengers during a collision. Describe your design. Explain how you determined the right “stiffness” of the crumple zone?
2. Research how scientists design and test crumple zones. Be sure to investigate how Finite Element Analysis (FEA) is used.

TEACHER INFORMATION

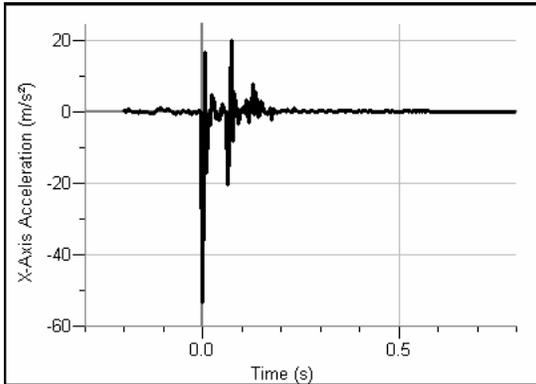
Investigating Collisions with Crumple Zones

1. Most students will know that cars have crumple zones, air bags and seat belts to aid the protection of people in collisions. They might not realize that crumple zones have also been developed for use on trains. The crumple zones also help to keep a train on the track following a collision.
2. When discussing the accelerometer reading, it is proper to refer to it as a measure of Normal Force per Unit Mass, with units of N/kg, where “normal” is in the direction of that particular accelerometer. This is what the accelerometer is actually measuring. (Note that it is not the net force per unit mass which would be acceleration.) A motionless accelerometer oriented in the vertical direction will give a reading of +9.8 N/kg when pointed up and -9.8 N/kg when pointed down. A motionless accelerometer oriented in the horizontal direction will read 0 N/kg. An accelerometer in freefall will give a value of 0 N/kg regardless of its orientation. Since most people prefer the measurement be in m/s^2 , we have used these units in this manual.
3. To prevent damaging your WDSS, be sure to keep it on the dynamics track.
4. WDSS acceleration readings greater than $\pm 50 m/s^2$ are not reliable as they exceed the maximum measurable acceleration of the WDSS. These accelerations result when the cart hits the end stop.
5. The following web sites contain information on collisions with crumple zones.
 - Finite Element Analysis – this Wikipedia web site provides a very brief explanation of what FEA is and where and how it is used, plus a number of useful external links.
http://en.wikipedia.org/wiki/Finite_element_analysis
 - Introduction to Finite Element Analysis – this site provides a simple and brief introduction to FEA, its history, what it is, how it works and where it is often used.
http://www.sv.vt.edu/classes/MSE2094_NoteBook/97ClassProj/num/widas/history.html
 - Modeling collisions of rail vehicles with deformable objects – this detailed report was produced by AEA Technology Rail for the Rail Safety and Standards Board of the UK. The report contains many images showing the stages of such simulated collisions together with associated graphs looking at the velocity and energy profiles of the colliding objects.
<http://www.rssb.co.uk/pdf/reports/research/T305%20Modelling%20collisions%20of%20rail%20vehicles%20with%20deformable%20objects.pdf>
 - Volpe Center Highlights – this article looks includes information about a crash test of railway cars colliding with a concrete wall at 26 mph. The web site is for the research and development centre in Cambridge, Massachusetts, USA for national transportation systems.
<http://www.volpe.dot.gov/ufosrc/highlts/pdf/400.pdf>

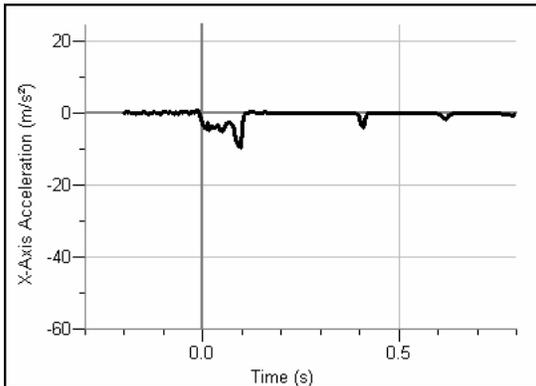
- Will the crash zone crumple? FEA tells – this article is from Machine Design which looks at the crumple zone development on the Class 390 Pendolino trains now in use with Virgin Rail in the UK.

<http://www.machinedesign.com/ASP/viewSelectedArticle.asp?strArticleId=56432&strSite=MDSite&catId=0>

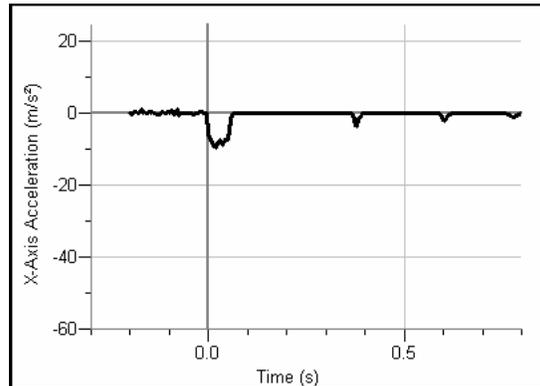
SAMPLE RESULTS



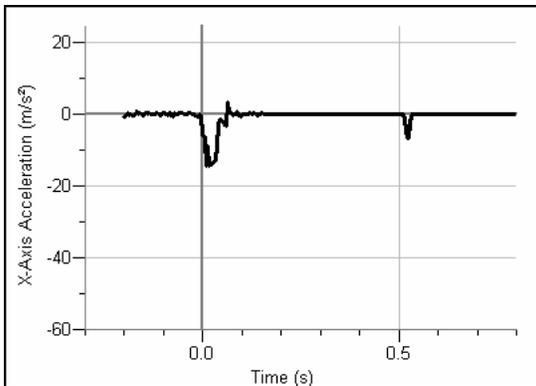
no crumple zone



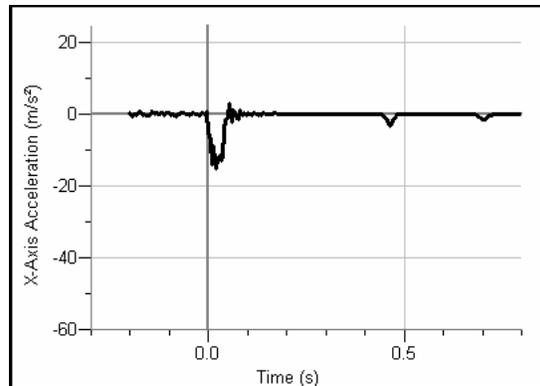
Heavy-Duty Foil – 1 cylinder



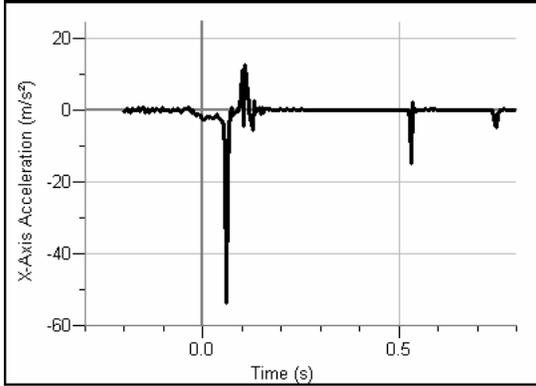
Heavy-Duty Foil – 2 cylinders



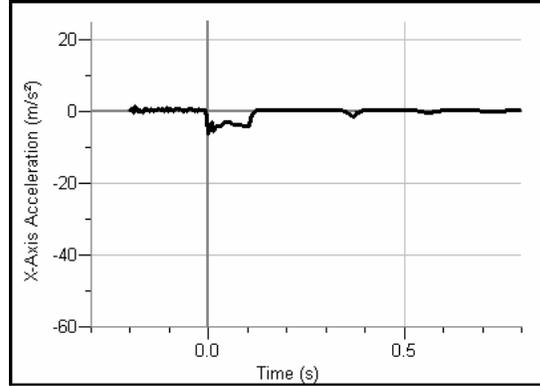
Heavy-Duty Foil – 3 cylinders



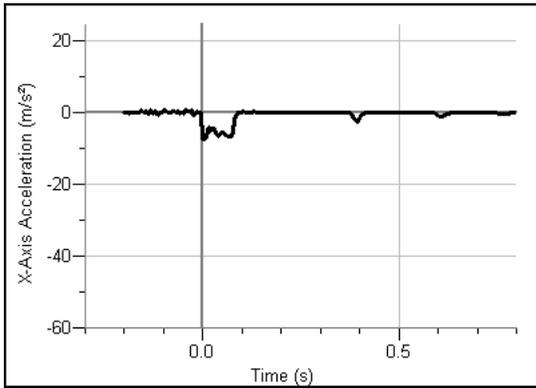
Heavy-Duty Foil – 4 Cylinders



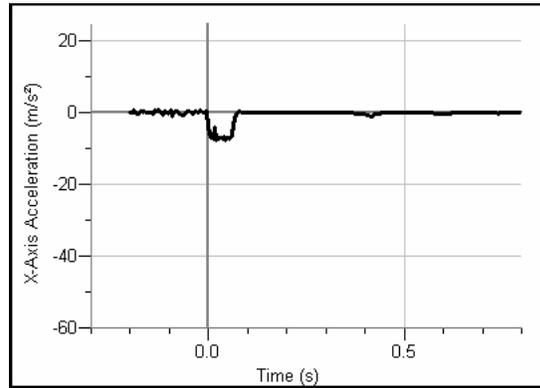
Standard Foil – 1 cylinder



Standard Foil – 2 cylinders



Standard Foil – 3 cylinders



Standard Foil – 4 Cylinders

	Maximum Stopping Acceleration (m/s ²)	Time to stop (s)
Without Crumple Zones	>50	0.008

	Heavy-Duty Aluminum Foil		Standard Aluminum Foil	
	Maximum Stopping Acceleration (m/s ²)	Time to stop (s)	Maximum Stopping Acceleration (m/s ²)	Time to stop (s)
With Crumple Zones				
1 Foil Cylinder	9.36	0.115	> 50	0.730
2 Foil Cylinders	9.43	0.066	6.24	0.122
3 Foil Cylinders	14.40	0.052	7.21	0.094
4 Foil Cylinders	15.22	0.049	7.76	0.072

ANSWERS TO QUESTIONS

1. The maximum acceleration and force are directly related. As one goes up so does the other. This is Newton's 2nd Law.
2. The maximum acceleration and time to stop the cart are inversely related. As the maximum acceleration increases, the time to stop the cart decreases. This is based on the impulse-momentum theorem. Given the carts all have the same change in momentum, they all require the same impulse to stop the cart. The cart with the largest average acceleration will stop in the shortest amount of time.
3. Answers will vary. For our data, as the number of cylinders increased, the maximum acceleration increased. This is a result of the increased "stiffness" of the crumple zones. This was not the case for the standard foil where a single cylinder was not able to significantly slow the cart before it impacted the end stop. For two or more cylinders, the results were similar to the heavy-duty foil.
4. Answers will vary. From our data, the best crumple zone was the two cylinder, standard foil crumple zone. This had the smallest maximum stopping acceleration and the longest stopping time. The worse crumple zone was the single cylinder standard foil. The cylinder was completely flattened, allowing the cart to impact the end stop with a force comparable to the collision without a crumple zone.