

Crumple Zone

Designing a Bumper to Study Impulse and Momentum

Today's cars are built with bumpers which "soften" the force of impact of a collision. A car moving with momentum $m\mathbf{v}$ can be brought to rest by a force \mathbf{F} acting during a time Δt . The product of force and time ($\mathbf{F}\Delta t$) is called the impulse. The impulse applied to a mass changes the momentum of the mass. The impulse momentum theorem can be expressed as

$$\mathbf{F}\Delta t = m\Delta\mathbf{v} = m(\mathbf{v}_f - \mathbf{v}_i)$$

A car moving at 30 mph can be brought to rest over a short period of time or a long period of time. The change in momentum is the same in each case, and therefore the impulse should be the same in each case. However, the force acting on the car to bring it to a stop and the time during which it acts is not the same in each case. The force is large for a short stopping time, and the force is smaller for a larger stopping time. Thus, a bumper can reduce the impact force by crumpling to extend the time during which the force acts on the car and its passengers during a collision.

PURPOSE

You will design a paper bumper which will soften the impact of the collision between a cart and a fixed block of wood. Your design will be evaluated by the shape of an acceleration vs. time graph produced during the collision.

MATERIALS

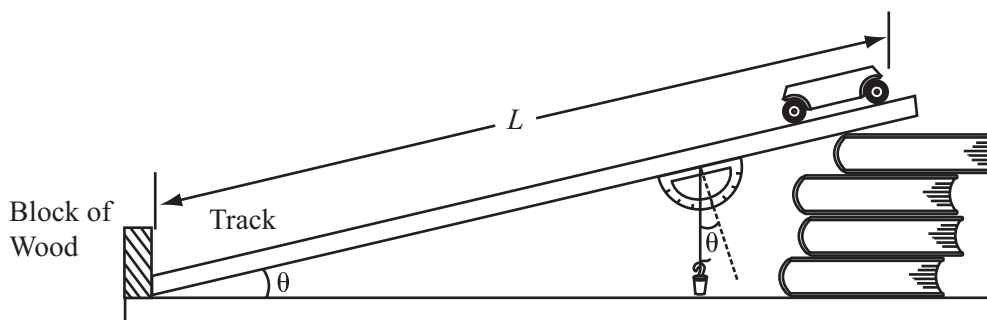
2 sheets of 8½" × 11" paper	balance
scissors	ring stand and clamp (or books)
2 50-cm strips of transparent tape	protractor with a string and weight
cart	large clamp
meter stick	computer with Logger <i>Pro</i> [®] software or graphing calculator
25-g accelerometer	4" × 4" wood block
CBL2 [™] or LabPro [®] interface device	
track	

Safety Alert

Keep your fingers out of the way when the cart strikes the block at the bottom of the ramp!

PROCEDURE

1. Obtain two sheets of $8\frac{1}{2}'' \times 11''$ copy paper, a pair of scissors, two 50-cm strips of transparent tape, and a cart from your teacher. Measure the mass of your cart and record the mass on your student answer page.
2. Elevate one end of the ramp with a ring stand and clamp or several books. Clamp a wooden block at the bottom end of the ramp so that it is securely fastened to the table. Use the protractor and hanging weight to find the angle θ of the ramp from the horizontal. See Figure 1 below. Record this angle on your student answer page.

*Figure 1*

3. Place the cart at the top of the ramp with its back wheels at the top of the ramp. Position the cart at the top of the ramp in its initial starting position. Measure the length of the ramp from the front of the cart to the front of the fixed collision block. Record this length on your student answer page.
4. Connect the 25-g accelerometer to the LabPro interface, and the interface to your computer or graphing calculator. Open the *Logger Pro* software on the computer, and choose the accelerometer probe, or an experiment using the accelerometer, such as Newton's second law. You should see an acceleration vs. time graph appear on the screen. See Figure 2.
5. Securely attach the accelerometer to the cart so that the arrow on the accelerometer points toward the front of the cart. To calibrate the probe using *Logger Pro* software, click **Experiment** on the toolbar, **Calibrate**. Click the **Calibrate** tab, then **Perform Now**.
6. Hold the cart vertically with the arrow on the accelerometer pointing downward. In the box containing -25 , type in -9.8 , to indicate the downward acceleration due to gravity. Click **Keep**. Turn the cart so that the arrow on the accelerometer points upward. In the next box that appears, type 9.8 , and **Keep**.
7. Place the cart at the top of the ramp with the front of the cart facing the fixed block. Click **Collect**, and allow the cart to roll down the ramp and strike the block. You should see an acceleration vs. time graph such as the one in Figure 2.

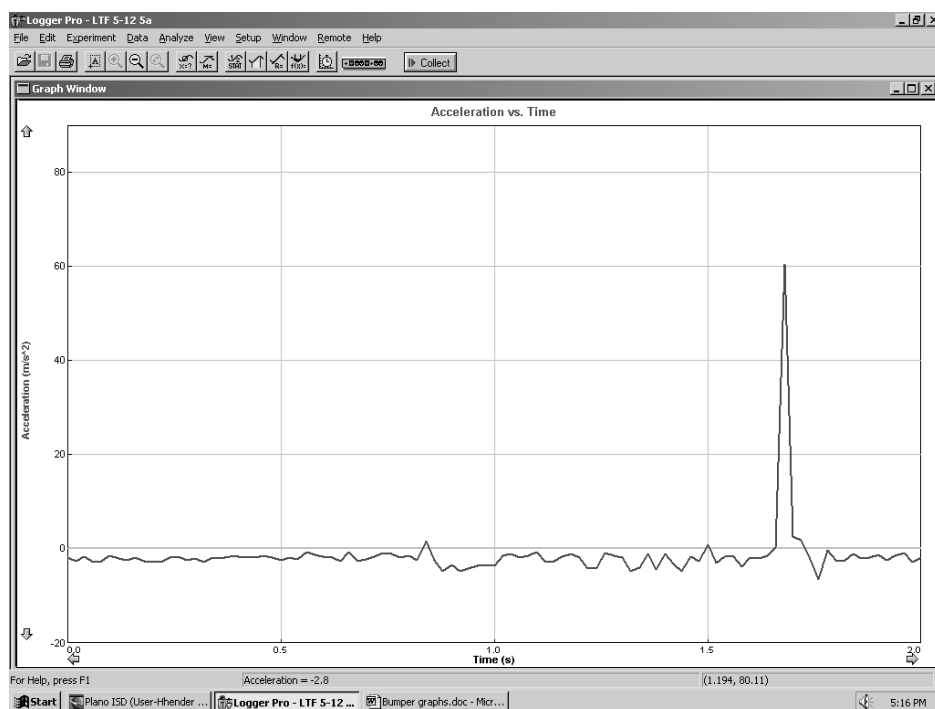




Figure 2

8. Click and drag a box around the portion of the graph which recorded the acceleration vs. time data (the “spike”). You may want to zoom in on the area of the graph you are interested in by clicking on the “zoom in” button  on your toolbar. The area under the spike can be used to find the impulse which acted on the cart during the collision. Click the button on the toolbar  which gives the area under the spike you have boxed, and record the area on your student answer page. Be sure to include the units for the area.
9. Click the **Examine** button ($x =$) on the toolbar. Trace the curve and note the time at which the collision began and the time at which the collision ended. Subtract the two times to find the time interval Δt during which the collision took place. Record the value for Δt in the data table on your student answer page.
10. Trace the curve to the top of the spike and record the maximum acceleration of the cart during the collision.
11. Your teacher may want you to print, save, or sketch the acceleration vs. time graphs you produce throughout this lab.
12. Discuss the design of your bumper with your lab partners. Your bumper should be designed to reduce the force on the cart by increasing the time during which the force of impact acts on the cart. In other words, you want the graph produced by the collision with a bumper to be shorter and wider than the graph produced in a collision with no bumper. Make a sketch of several designs you think might be effective in reducing the strike force of your cart.

13 *Crumple Zone*

13. When you have chosen a design, use the scissors, paper, and tape to build the bumper; attach the bumper to the front of the cart.
14. Repeat steps 5, 6, and 7 with your first bumper attached to the front of the cart.
15. Build a second bumper and attach it to the cart. Your teacher may want to observe your second run and the resulting graph.
16. Repeat steps 5, 6, and 7 with your second bumper attached to the front of the cart.

Name _____

Period _____

Crumple Zone

Designing a Bumper to Study Impulse and Momentum

DATA AND OBSERVATIONS

Mass of cart: _____ kg

Angle of ramp from the horizontal: _____

Length of ramp from the front of the cart at its initial starting position to the front of fixed block: _____

Run	Area Under a vs. t Graph	Mass of Cart \times Area Under Graph	Maximum Acceleration	Mass of Cart \times Maximum Acceleration	Time of Collision Δt
Without bumper					
Bumper 1					
Bumper 2					

ANALYSIS

1. In this activity, we are ultimately interested in impulse, which is the product of force and time. What are the units for
 - a. the area under the acceleration vs. time graph? _____ Does the area represent velocity or change in velocity?
 - b. the product of the mass of the cart and the area under the acceleration vs. time graph? _____

2. What is the quantity that results from the product of the mass of the cart and the maximum acceleration of the cart?

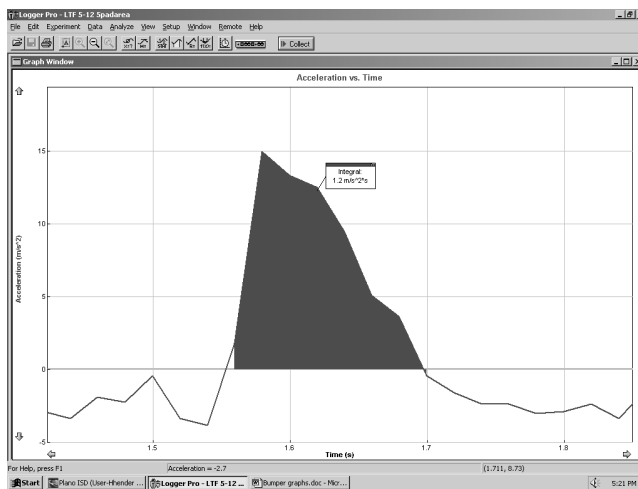
13 *Crumple Zone*

3. Compare the area under the graph produced during the collision without the bumper to the area produced with the bumper. Is the area under the spike greater than, less than, or equal in each case? Explain your answer in terms of impulse and change in momentum.
4. In terms of the graph produced in the collision, what were you trying to accomplish by attaching the bumper to the cart?
5. Using the angle of your ramp and the length of the ramp L between the cart and the block, calculate the difference in height Δh between the initial starting position of the cart and the point at which it strikes the block.
6. If there were no friction between the ramp and cart, the speed of the cart just before it strikes the block could be found by the equation $v = \sqrt{2g\Delta h}$, where $g = 9.8 \text{ m/s}^2$. Neglecting friction, calculate the theoretical speed of the cart just before striking the block. Show your work in the space below.
7. Using the information from the graph produced in the collision without the bumper and the mass of your cart, find the actual speed of the cart just before striking the block. Show your work, and be sure to treat the impulse as negative, since it is opposite to the direction of the initial velocity.
8. Find the percent difference between the theoretical and actual speeds of the cart just before impact. This value shows the effect of friction during the experiment. Show your work.

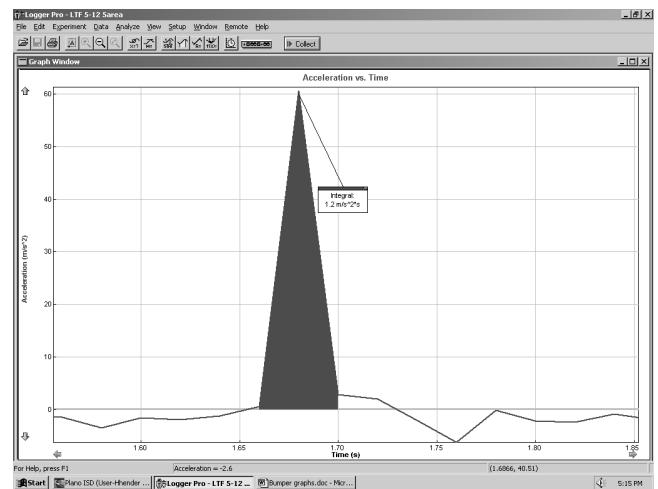
CONCLUSION QUESTIONS

1. Define impulse, and give its units.
2. State whether the following statement is true or false and explain your choice: *The impulse applied to an object is equal to its momentum.*
3. Two crash-test cars of equal mass are equipped with different bumpers, A and B. The cars are initially traveling at the same speed before striking a fixed wall. The acceleration vs. time graphs for each car are shown below.

Car A



Car B



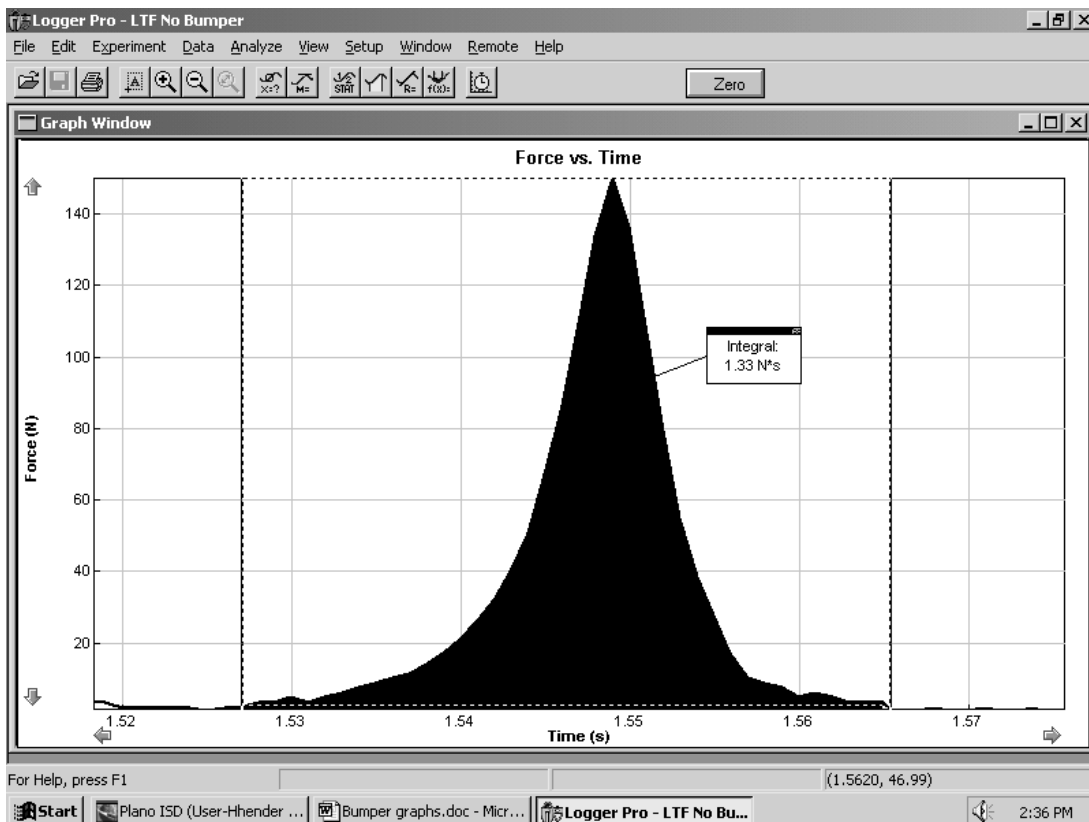
Both graphs indicate an area under the curve of $1.2 \text{ m/s}^2 \times \text{s}$.

- a. Which of the cars experiences the greater impulse? Explain your answer.
- b. Which of the cars experiences the greater maximum force? Explain your answer.

13 *Crumple Zone*

- c. Assuming the passengers in both cars are wearing seatbelts, which of the cars appears to have the bumper which is safer for the passengers in the car? Explain your answer.

4. A force acts on a cart and slows it down. The force vs. time graph below shows how the force varies with time during the collision.



- a. Estimate the maximum force acting on the cart.
- b. What is the approximate time interval Δt during which the force acts?
- c. According to the graph, what is another name for the area under the curve?

- d. Is the product of the maximum force and the time interval during which it acts approximately equal to the area under the curve? Why or why not?
- e. The cart is initially traveling at a speed of 2.0 m/s and is slowed by the force to a speed of 0.40 m/s during the time interval. Calculate the mass of the cart. Show your work, and be sure to treat the impulse as negative, since it is opposite to the direction of the initial velocity.
5. What are some ways in which you could improve your bumper design?
6. The graph below represents a collision of a moving cart and a fixed block. Suppose the block at the end of the ramp were not fixed, but could move freely when struck by the cart. On the axes below, sketch a graph of force vs. time for the collision between the cart and free-moving block.

