DESIGNING AND TESTING CRASH CUSHIONS

How can people be protected from injury when their car crashes into a solid object like a bridge column? What factors are important to control to prevent injury when stopping a car? How do highway engineers design crash cushions and how can they be modeled?

Objectives

- Learn about the physics of car crashes by creating a small-scale model.
- Learn how to design and test a model of a crash cushion.
- Learn how to redesign a crash cushion model using test data.

Materials and Equipment

- Data collection system
- PASCO Wireless Acceleration/Altimeter
- PASCO Dynamics Cart
- PASCO Dynamics Track with feet
- PASCO Dynamics Track End Stop
- PASCO Aluminum Table Clamp
- PASCO Track Rod Clamp
- PASCO 25 cm long Threaded Rod
- Card Stock
- Scissors
- Masking Tape
- Balance, 0.1-g resolution, 2,000-g capacity (1)

Safety

Follow regular laboratory safety precautions.

Procedure

1. Attach a track end stop to one end of the track so that the side with the magnets faces out. Elevate the other end of the track 10 cm using the aluminum table clamp, track rod clamp, and 25 cm long threaded rod. See Figure 1.

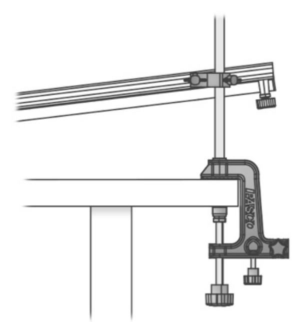

Figure 1

2. Attach the wireless acceleration/altimeter to the cart using the included thumbscrew. It is recommended that the +x-axis on the acceleration/altimeter point away from the end with the plunger. See Figure 2.

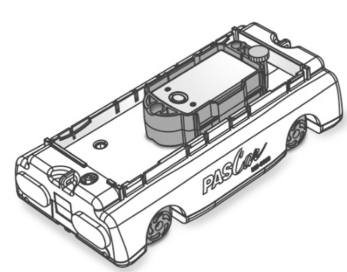

Figure 2

2. Start the data collection software and connect the acceleration/altimeter to the software.

3. Change the sample rate of the acceleration sensor to 250 Hz.

4. Create a graph display with Acceleration - x on the vertical axis and time on the horizontal.

5. Place the cart on the track so that +x-axis on the acceleration/altimeter points toward the end stop, then zero the acceleration sensor.

6. Pull the cart back so it is 60 cm from the end stop. Start recording data and release it from rest. Stop recording data after it collides with the end stop.

7. Use the tools of the data collection software to measure the magnitude of the largest acceleration during the collision and record your result below in Table 1. This value will be a negative number, so it is the minima of the acceleration.

8. Use the tools of the data collection software to find the duration of the collision. This is the time from when the acceleration starts to go below zero until the time it returns to zero. Record the duration in Table 1.

9. The magnitude of the largest acceleration represents the acceleration of the cart if there is no crash cushion to protect it. A well-designed crash cushion will significantly lower the maximum acceleration of the cart. Make a crash cushion using card stock and masking tape that is a ring less than 5 cm tall and less than 10 cm in diameter. Place it in front of the track end stop, circle side down. See Figure 3. Start recording and release the cart so it travels 60 cm down the track before hitting the crash cushion. Stop recording after the collision with the crash cushion.

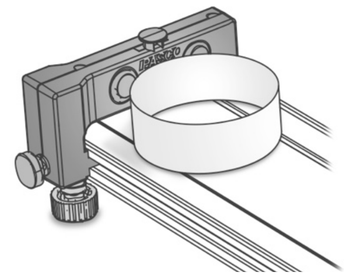

Figure 3

10. Use the tools of the data collection software to measure the magnitude of the largest acceleration during the collision and record your result below in Table 1. How does it compare to the maximum value without a crash cushion? Since the cart collided with the same velocity in both cases, how can you explain this?

11. Use the tools of the data collection software to find the duration of the collision and record your result below in Table 1. How does it compare to the duration without a crash cushion? How can you explain this?

12. Newton's Second Law is often written as $\Sigma F = ma$. In the collision, the force of the crash cushion on the cart changes during the collision. To help understand the collision, we can replace ΣF with F_{AVE}. This is the average force on the cart parallel to the track. Average acceleration can be written as $a = \Delta v/\Delta t$, where the change in velocity, Δv, is the same for each collision, assuming the cart does not bounce back. Newton's Second Law can be written for each collision as $F_{AVE} = m\Delta v/\Delta t$. If the goal of a crash cushion is to reduce the average force on the cart, how would Δt compare when using a crash cushion to a collision without a crash cushion? Does your data confirm this? Explain.

13. Reducing the largest acceleration on the cart is also an important function of a crash cushion. This also reduces the largest force. The largest force is directly related to the largest acceleration. Measure the mass of the cart plus acceleration/altimeter, and then calculate the largest force on it from each collision. Record your results in Table 1 and show your work below.

14. Place the ring crash cushion back in its original place in front of the end stop without fixing or re-forming it. When the cart collides with it again, will it reduce the largest acceleration and increase the time of collision as much as it did for the first crash? Explain your answer.

15. Pull the cart back so it will travel the same 60 cm before colliding and start recording. Release the cart from rest and stop recording after the collision. Use the tools of your data collection software to find the magnitude of the largest acceleration and the duration of the collision. Enter the results in Table 1. Calculate the largest force and enter the result in Table 1. Revisit your prediction in step 14. Were you correct? Use your data to explain.

16. Although the ring crash cushion reduces the largest acceleration, the crash duration and the largest force, it doesn't work very well for a second collision. Real crash cushions need to be replaced after a car collides with them. However, sometimes it takes days before this can be done. A crash cushion that works well after a second collision could save lives. Your goal is to design a crash cushion with a lower maximum acceleration than the ring crash cushion had. However, yours should be lower for a first and SECOND collision. Your crash cushion cannot be taller than 5 cm and longer than 10 cm. It can be constructed from cardstock and masking tape only. It can be any shape and consist of multiple parts. It cannot be taped to anything else. The cart must collide with it after travelling the same 60 cm distance. You can use 5 trials to test your crash cushion, with 2 collisions each trial. You can make changes to your crash cushion design after each trial. Record the maximum acceleration, crash duration, and maximum force for the SECOND crash of each trial in Table 2. After you are done with your 5 trials, sketch an overhead view of your best crash cushion design below. Label the dimensions. Explain why it worked better than the ring crash cushion.

Table 1

Crash	Largest Acceleration (m/s^2)	Crash Duration (s)	Largest Force (N)
No Cushion			
Ring Cushion Crash 1			
Ring Cushion Crash 1			

Table 2

Trial	Largest Acceleration (m/s^2)	Crash Duration (s)	Largest Force (N)
1			
2			
3			
4			
5			

Questions and Analysis

1. Look at the data in Table 2. What relationship do you notice between the largest acceleration and the largest force? Explain why this is so.

2. Look at the data in Table 2. What relationship do you notice between the largest force and the crash duration? Explain why this is so.

3. Another student who was absent is about to make up the crash cushion lab. Your teacher asks you to give them advice before they begin. What are the two most important things they should know to design a successful crash cushion?

4. After you advise them, the student says they want to build a crash cushion that will cause the cart to bounce back after the collision. Is this a good idea? Explain.

5. A 1,500 kg car travelling at 25 m/s collides with a real crash cushion and comes to a stop in 0.4 s. What is the magnitude of the average acceleration of the car during the collision? What is the average force on the car during the collision? Show your work and results below.

6. The 80-kg driver of the car in the previous question comes to a stop in more time than the car because of the seat belt system and driver airbag. If this time is 0.6 s, what is the magnitude of the average acceleration of the driver and the average force on them during the collision? Show your work and results below.