Crash Cart Cushion Exploration

Exploration

Nearly 1.3 million people die from car accidents worldwide each year, according to the World Health Organization. In order to reduce traffic fatalities high-speed roadways must be made safer. Building crash cushions along highways that reduce the impact force experienced by the passengers of the car in a crash can save lives. But how should these cushions be built?

You are part of a team of engineers that works for the Department of Highway Safety. Your team's job is to find ways to make roadways safer for drivers and passengers. An interchange was recently built that connects the two largest highways in your state. At one of the interchange off-ramps, there is a dangerous wall between the highway and the off-ramp. If a driver accidently crashes into the wall they would be seriously hurt or even killed. Your team must design a cushion that will be placed in front of the wall to reduce the force felt by the passengers if a car were to crash into the wall. Your design will help save lives.

Materials

- PocketLab
- Dynamics Cart
- Wall or solid object to represent wall
- Tape or Velcro to affix PocketLab to cart
- Ramp

Materials For Building Crash Cushion

Cushion A: Construction paper, scissors, masking tape

Cushion B: Newspaper, cardboard box, construction paper, notecards, straws, balloons, tape, and any other available materials.

Objective

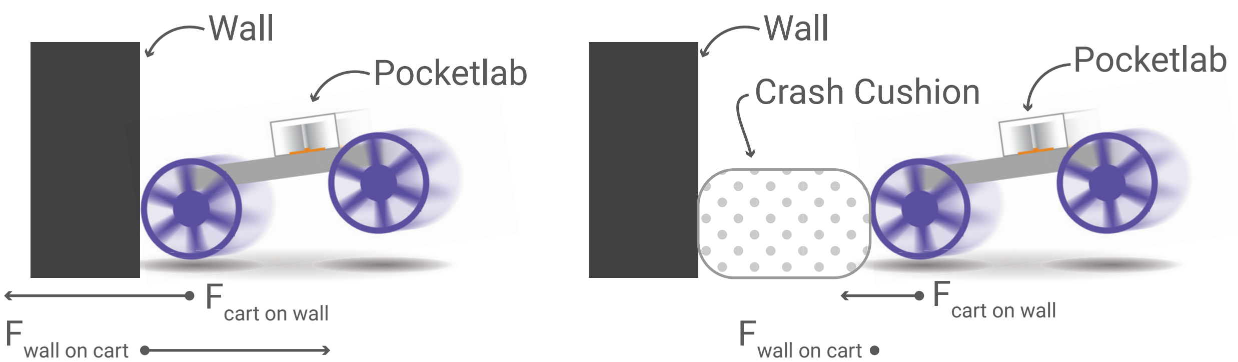
Using the available supplies, build a crash cushion that will reduce the force experienced by the cart as it crashes into the wall. You must build at least three models for Cushion A and Cushion B. You will test each model with your lab group by collecting acceleration data with PocketLab. Using the data collected from your crash cushion models, you will then draw a conclusion about how to design optimal crash cushions to prevent traffic fatalities.

Discussion

Newton's Third Law of Motion states:

For every action there is an equal and opposite reaction.

In the car crash, the car crashes into the wall and exerts a force on the wall. How does Newton's Third Law of Motion relate to the impact force experienced by the passengers in the car? Discuss your answer with your group and then complete the diagram below by drawing the final vector arrow.



Newton's Second Law of Motion tells us that acceleration and force are proportional. For the purposes of this lab, we will use PocketLab to measure the acceleration at impact to determine the proportional force experienced in the crash.

Momentum is the product of an object's mass and velocity. We can think of momentum as inertia in motion.

Equation for momentum: $p = m \cdot v$ where $p = momentum \quad m = mass \quad v = velocity$

In this experiment, you will control the cart's mass and velocity and therefore its momentum going into the crash.

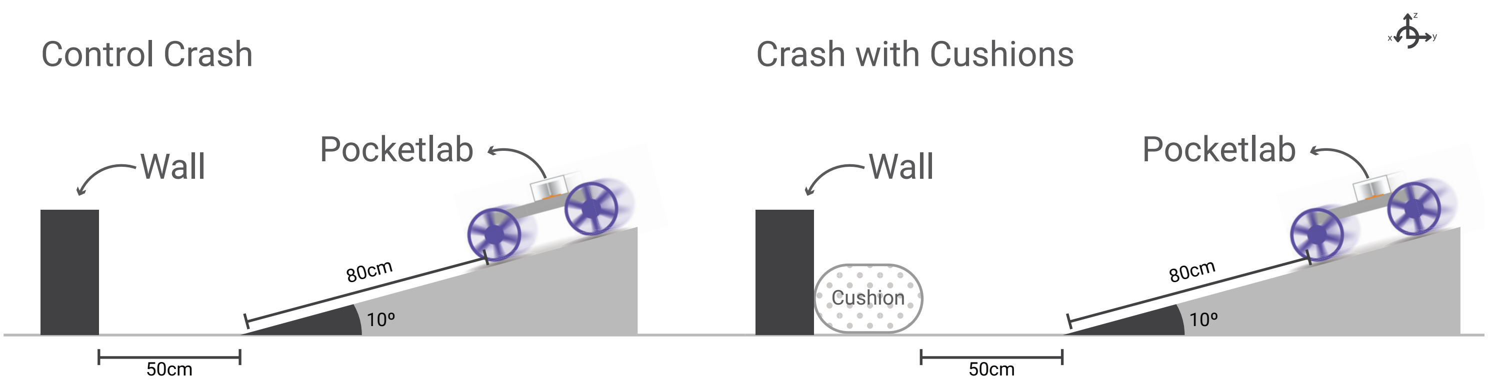
Impulse is the change in momentum of an object. Whether you are using a crash cushion or not, the change in momentum of the cart will always be the same. If your experiment is properly controlled, the cart will crash with the same momentum and then, after the crash, come to a stop with no momentum. Therefore, if the cart is crashing directly into the wall or the into any of your crash cushions, the impulse for every crash will always be the same.

Equation for impulse: $J = F \cdot \Delta t$ where $J = impulse$ $F = force$ $\Delta t = change\ in\ time$

The cushion cannot change the velocity or momentum of the cart before it crashes, so it can't change the impulse. However, an effective crash cushion will still find a way to change the force (F) in the equation above, even when the impulse cannot be changed.

Problem

The objective of your crash cushion is to reduce the force experienced by the cart. Thinking about the information from the discussion section above, identify how this is possible. What will your crash cushion need to do during the crash in order for it to reduce the force experienced by the cart?



Procedure

Control crash without cushion:

Your group will conduct a control crash without a crash cushion.

1. Set up the control crash as shown in the setup diagram.
2. Sync the PocketLab to your device, select the Acceleration graph, and change the data rate to the fastest available.
3. Begin recording data and release the cart down the ramp.
4. Stop the recording and as a group, discuss which "spike" in the graph was the actual collision. (Hint: there will be a distinctive "bump" or "spike" in the graph when the cart moves from the ramp to the flat ground/table.

This should happen just before the crash.)

5. Record the results of each trial in a data table and average the trials. Conduct at least 5 trials.

Crash Cushion Trials

For every trial of every crash cushion model your group builds, set up the ramp, cushion, wall, and cart with attached PocketLab as shown in the setup diagram. Then, follow the same procedure as the control crash.

Cushion A: Design and Redesign

Cushion A will only use construction paper and tape. Because you can only use one type of material, focus on the geometry of the design. You will make and test three different models for Cushion A. For each model you should attempt to improve upon your previous design by using the evidence and observations you gathered during your testing.

For all three models of Crash Cushion A:

- Before building, draw out your design. Explain the choices that went into your design.
- Construct your crash cushion model.
- Test your crash cushion model.
- Record your results in a data table. Be sure your table is properly labeled for the correct model.
- Conduct at least five trials for each model.
- After testing each model, explain whether or not the design was effective.

Cushion B: Design and Redesign

Cushion B will use many different types of material. Using what you learned from Cushion A and your most effective geometric design for a crash cushion, test which type of material will be the most effective. You will make and test three different models for Cushion B. For each model you should attempt to improve upon your previous design by using the evidence and observations you gathered during your testing.

For all three models of Crash Cushion B:

- Before building, draw out your design. Explain the choices that went into your design.
- Construct your crash cushion model.
- Test your crash cushion model.
- Record your results in a data table. Be sure your table is properly labeled for the correct model.

- Conduct at least five trials for each model.
- After testing each model, explain whether or not the design was effective.

Analyzing Data and Drawing Conclusions:

- Which of your designs was most effective at making the most optimal crash cushion and why? Support your conclusion with evidence that you gathered from the lab and scientific reasoning that explains why the data support your conclusion.
- If you wanted to make cars safer during head-on collisions with other cars, what would you design the front of the car to do at impact? Relate your answer to your conclusions about crash cushion?

Lab Extension:

The Department of Highway Safety is now facing budget cuts. Not only must your cushion be effective, but it also must be cost efficient. With your class/teacher decide on a per-unit cost for each of the different materials that you are allowed to use for building your crash cushion. Include those costs in table 1.

Table 1: Cost per unit

Material	Cost (Dollars)

Your challenge is to build a cost efficient cushion that would still save lives. A good cushion will have a low force experienced at collision while also being cost efficient.

While building your new crash cushion, write down every material used in Table 2. Add up the total cost of the cushion. Test the cushion in the same way you tested your previous cushion.

Table 2: Crash Cushion Cost			
Material Used	Per Unit Cost	Number of Units	Total Cost of Material
		Total Cost of Cusion	

Use the following equation to find the cost efficiency of your cushion:

$$\text{Barrier Cost Efficiency} = (\text{Max Acceleration of Collision})\,(\text{Total Cost of Barrier})$$

Remember you want the lowest possible force at collision, so in this case a lower number is more cost efficient.

- Explain the decisions that went into the design of the cushion.
- Test your crash cushion by following the same steps for testing as the main lab.

Analyzing Data and Drawing Conclusions:

Plot the Maximum Acceleration at Collision and the Total Cost of Cushion for all the lab groups in the class.

Where on the graph should the best crash cushion be located? Why?

Which group's design do you think the federal highway administration would use? Why?

Having the lowest cost efficiency doesn't necessarily mean it is the best cushion. Explain.

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TEACHER GUIDE

Set up

We recommend setting the ramp at an angle of 15° and releasing the cart from 80 cm up the ramp. The ramp should then be 50 cm from either the wall or the crash cushion. While crashing the cart into a wall works, if this is difficult to set up, you can replace the wall with a cardboard box. The cart will reach the bottom of the ramp and then run on a flat surface before the collision. This makes the data easier for students to read. The collision will be more distinctly on one axis, because the cart isn't colliding at a downward angle. The accelerometer will also give a distinct reading when the cart moves from the ramp to the flat surface. This can help students identify when exactly the collision occurred in the data, because the students will know it is the next big spike after the cart transfers from the ramp to the flat surface.

If you are using a cardboard box instead of a wall, tape it down to the floor or table so it doesn't move at impact. Make sure students start with a control by crashing the cart into the wall/cardboard box without a cushion. An essential skill for students will be matching the correct "spike" on the graph with the moment of impact. If the video function of the PocketLab app is available, have students record their trials while taking video. They can then go back and review the impact to make sure they are using the correct reading.

You can use either the "Acceleration" graph (which shows acceleration on all three axes of the PocketLab), or the "Acceleration Scalar" graph (which shows the aggregate acceleration of all three axes). The "Acceleration Scalar" graph will be easier to read, so it can be used to scaffold the difficulty of the lab if necessary. If students use the "Acceleration" graph, make sure they know which axis the PocketLab will experience the acceleration at impact. You can also use the two-graph mode and look at data from both graphs in real time.

It will be extremely important for students to conduct multiple trials. We recommend five at the minimum.

Expected Results

Students should eventually come to the conclusion that cushions which increase the time of the impulse get the best results. Because the velocity and mass of the cart is controlled, so too is the momentum at impact. The cart will come to a stop every time during the initial collision (when the cart changes directions), so the impulse (change in momentum) during the initial collision will therefore also always be the same. Because force and time are inversely proportional (impulse = force x time), by increasing the time of the impulse, the force experienced will have to decrease to keep the impulse the same. For students to come to this conclusion, push them to think about the equation for impulse throughout the experiment. Students may notice that with effective barriers, the acceleration at impact has a lower value AND the "spike" of the graph takes a longer time. Because acceleration is proportional to force, students can conclude that the "spike" they are seeing is really the impulse of the collision. By increasing the time of the impulse, they reduce the force experienced.

Designs that are most effective are designs that crumple at impact. The crumpling of the barrier slows the time of the collision and reduces the force experienced by the cart. At first, students may try to design barriers that are very strong and don't crumple, because the crumpling of the barrier looks like "damage." This is why it is important to allow them to learn from their designs and continue to build new barriers.

Our Results

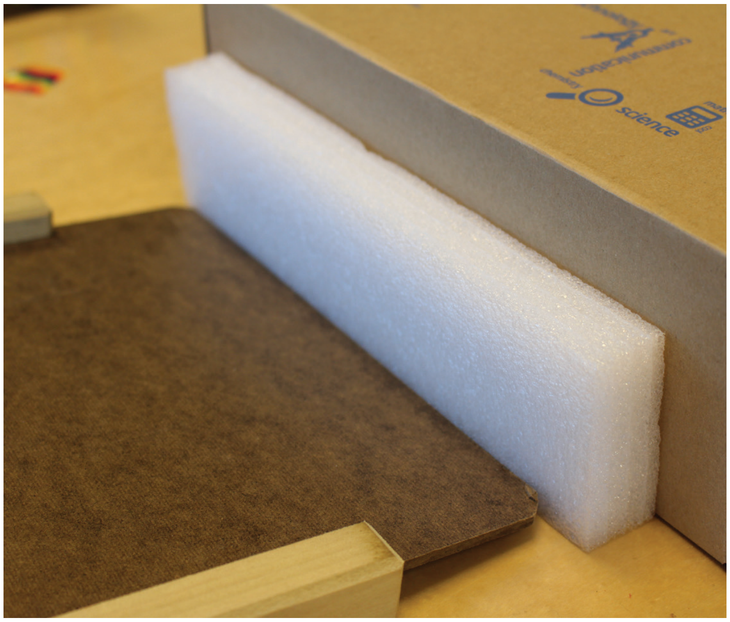
We crashed our cart into a cardboard box, and then tested four barriers. The results are below:

Cart Crash with no barrier	
TRIAL	MAX ACCELERATION (m/s^2)
Trial 1	72.49
Trial 2	51.23
Trial 3	27.42
Trial 4	45.25
Trial 5	65.41
Average	52.36

Travel distance: 40 cm
Angle of ramp: 15°
Mass of cart: ____________

Cart Crash with Styrofoam Barrier	
TRIAL	MAX ACCELERATION (m/s^2)
Trial 1	23.08
Trial 2	23.65
Trial 3	49.25
Trial 4	40.58
Trial 5	36.00
Trial 6	44.61
Average	36.195

Travel distance: 40 cm
Angle of ramp: 15°
Mass of cart: ____________

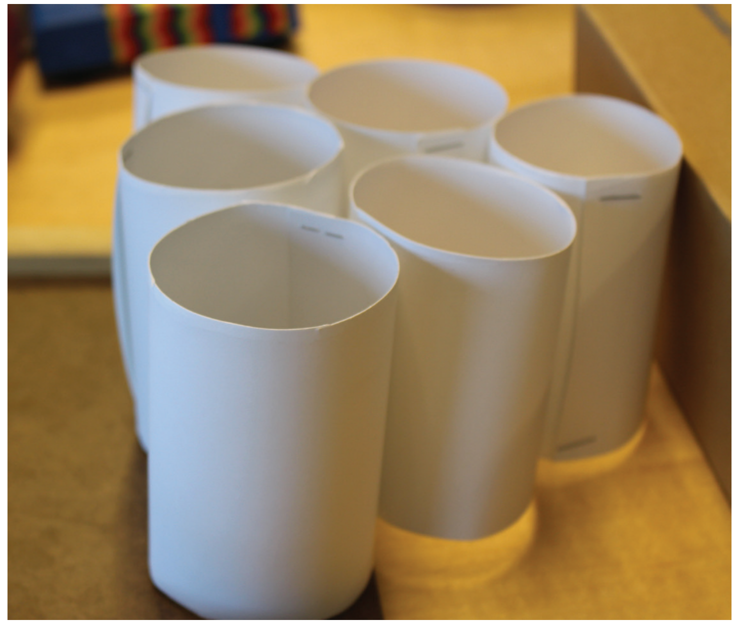


Cart Crash with Air Bag Barrier	
TRIAL	MAX ACCELERATION (m/s^2)
Trial 1	31.41
Trial 2	19.71
Trial 3	13.62
Trial 4	22.93
Trial 5	19.00
Trial 6	12.52
Average	19.865

Travel distance: 40 cm
Angle of ramp: 15°
Mass of cart: ____________

Cart Crash with Robby's Barrier	
TRIAL	MAX ACCELERATION (m/s^2)
Trial 1	17.49
Trial 2	30.93
Trial 3	12.76
Trial 4	7.74
Trial 5	12.74
Trial 6	19.15
Average	16.801

Travel distance: 40 cm
Angle of ramp: 15°
Mass of cart: ____________



Cart Crash with Clif's Barrier	
TRIAL	MAX ACCELERATION (m/s^2)
Trial 1	18.13
Trial 2	14.8
Trial 3	21.19
Trial 4	11.26
Trial 5	17.15
Trial 6	11.73
Average	15.71

Travel distance: 40 cm
Angle of ramp: 15°
Mass of cart: ____________