Crash Landing

Exploration Activity

Automobile safety can be directly related to the fundamental laws of physics. This can be demonstrated using a cart, a couple of bricks, and some aluminum pop/soda cans.

Three different bumpers have been prepared. The first represents an old-fashioned rigid bumper. The second is composed of a piece of wood and foam rubber. This one represents the spring-loaded bumpers now available on many cars. The third is an air-filled balloon. This represents a prototype model of a super-springy bumper that could be developed.

Your instructor (or a volunteer) will give the cart an identical starting push (perhaps using a ramp) so that the cart has the same starting speed for each trial. A brick wall will stop the cart before it reaches the end of the table. You will start with one undamaged aluminum can in front of the wall.

After the trials are completed, line up the cans and compare the damage done to each.

1. Discuss the damage related to the bumper used. Discuss what you observed happening during each of the three collisions, specifically describing any differences between them.

Invention Discussion

Be prepared to share your ideas with the rest of the class. Record a summary of the results of the class and any notes you have from this discussion.

2. (a) Based on this discussion, sketch a graph of the force vs. time on the cart for each collision. Identify the following quantities on these graphs: maximum force, average force, interaction time, and impulse.
   (b) How did the change in momentum of the cart vary for the three different trials? How is the value related to the graphs in part (a)?

3. (a) Give a real-world example of a situation where you would want an impulse to result in as small of a maximum force as possible.
   (b) Give a real-world example of a situation where you would want an impulse to result in as large of a maximum force as possible.

You will now apply these concepts in the following class activity.
Invention Activity to Estimate the Value of an Impulse

Open one of the two files as directed by your lab instructor: Crash - Springy bumper or Crash - Rigid bumper. These files contain graphs showing the motion and forces that result when a 1.06-kg cart hits a wall with two different kinds of bumpers.

4. Using the software tools (as described below) and your definitions, determine the following quantities from the graphs of the cart’s collision:
   (a) Initial speed (right before the collision)
   (b) Final speed (right after the collision)
   (c) Interaction time of the collision
   (d) Maximum force during the collision
   (e) Average force during the collision
   (f) Impulse during the collision (integral under the curve)

Using the Software Tools to Find Minimum, Maximum, and Mean:

- Select the graph of interest by clicking on it once with the mouse (the legend of the selected graph is highlighted in yellow).
- Select Minimum, Maximum, and Mean under the Statistics menu.
- Using the mouse, select only the region of interest on the graph. For example, if you want the mean value of a certain part of the graph, then select that part of the graph.

Using the Software Tools to Find an Impulse:

- In order to measure the impulse during the collision, you will need to find the area under the impact curve on the force-time graph. This area is equivalent to the impulse (F Δt).

The area under the curve is equal to the integral of the function force vs. time for the range of interest (Impulse = ∫F(t)dt).

For example:

- Using the formula "area = height * width" only works if your function represents the shape of a rectangle (like above). That probably is not the case for your collision data. Luckily, the computer knows how to calculate odd-shaped areas for you!
- Select the Force vs. Time data graph by clicking on the graph once (the legend of the selected graph is highlighted in yellow).
- Select Area under the Statistics menu and the computer will calculate the area under the entire data curve. Note that the value of this area is displayed on the graph.
- Using the mouse, select only the region of interest. That is, select the part of the graph that shows the forces while the cart was in contact with the wall. The computer will then calculate the area of this section.
5.  
(a) Using your values from question #4, calculate the impulse during the cart's collision (average force * interaction time).  
(b) Using your values from question #4, calculate the change in momentum during the cart’s collision.  
(c) Using percent differences, how similar are the two different impulse values (4f and 5a) and the value of the change in momentum (5b) for this collision?  

Be prepared to share your results with the class. Use the class results to answer the following question.  

6.  
(a) Compare the impulse given to the cart with the rigid bumper to the impulse given to the cart with the springy bumper during similar collisions. Is this what you expected? What significance might this have in a real car collision? Explain.  
(b) Compare maximum forces and the interaction times for these two different collisions. Is this what you expected? What significance might this have in a real car collision? Explain.  

Application #1:  
Collision of your body with the floor when jumping off of a book  

7.  
Discuss the following question with your partners:  

Suppose you placed a fat physics textbook on the floor and stood on it. You then jumped off the book, onto the floor two different times. The first time, you landed normally, allowing your knees to bend. The second time you landed stiff-legged, not allowing your knees to bend. How would these two collisions with the floor feel different? Explain.  

Record a summary of your prediction(s).  

Data Collection Procedures #1 – Jumper with Straight Knees:  

• Quit the open file and start up the file MBL – Collisions – a sensor. This file allows you to use an acceleration sensor attached to Channel B of your interface. This sensor does a direct measurement of acceleration and reports the data to the computer.  
• Pick one person in your group to be the "jumper."  
• Check that the acceleration sensor is set to FAST. Securely attach the acceleration sensor to the jumper’s hip using the provided elastic band. When attaching it, be sure that it is oriented so that the arrows (← ⊕ →) are aligned vertically, straight up and down.  
• Have the person stand on a stack of one or two textbooks. The jumper should hold onto the cable to the acceleration sensor with his/her hand. This will keep the cord from catching on their knees or the table or something when they land.  
• Once they are completely stationary and holding onto the cable, press the Tare button to set the zero point. Then start collecting data. After about 1 s, have the person scoot off of the books (do not jump up any more than necessary) and land on the floor, keeping their knees straight and stiff as they land.  
• Repeat this at least twice to insure that the data is repeatable and that you have a good data set. Tare the sensor before each run and always start by having the jumper remain motionless for 1 s before leaving the book.
Data Analysis – Jumper with Straight Knees:

*DataStudio Tip:* The acceleration sensor is set to measure acceleration in units of "g". You can use the following conversion to convert to m/s^2: \( 1 \text{ g} = 9.8 \text{ m/s}^2 \). This unit is handy because if a person accelerates at a rate of 1 g, then this is equivalent to that person experiencing a force equal to his/her weight. Likewise, 2 g is equivalent to a force equal to twice his/her weight.

8. (a) What was the **maximum net force** on the jumper during their landing in terms of their body weight?

   (b) What was the **interaction time** of the jumper’s landing?

9. Using the software tools, determine the area under the acceleration vs. time curve during the collision with the floor (that is, when the person was landing on the floor). Using this value, determine the impulse that was felt by the jumper’s body. Explain your work!

**Printing Comments:**

   Adjust the axes of the graph to show the entire jump (from being stationary until having landed). It should also **show the selected area and resulting impulse value**. Once the graph is adjusted, print a copy for each member of your group. **Label all important features on this graph including: standing still, in air, landing, and impulse.**

**Data Collection Procedures #2 – Jumper with Bending Knees:**

- Check that the sensor is still attached to the jumper’s hip in the proper orientation. Press the Tare button again to reset the zero point.
- Have the person stand on the book(s), holding onto the cable. Once they are stationary, then start collecting data. After about 1 s, have the person scoot off of the book in the same manner as before, but this time trying to land as gently as possible, allowing their knees to bend. Try to land in a way that is as quiet as possible.
- Again, repeat this jump a couple of times to improve your landing techniques.

Data Analysis – Jumper with Bending Knees:

10. (a) What was the **maximum net force** on the jumper during their landing in terms of their body weight?

    (b) What was the **interaction time** of the jumper’s landing?

    (c) Determine the impulse that was felt by the jumper’s body.

Adjust the graph to **show the entire jump and the impulse value**. Once the graph is adjusted, print a copy for each member of your group. **Label all important features on this graph including: standing still, in air, landing, and impulse.**
11. Compare and contrast the maximum forces, interaction times, and the total impulses given to the jumper in the two different kinds of landings. Why are they different/the same? Relate these results to your earlier experiments with the carts.

- Quit the MBL software before continuing.

### Application #2 – Studying Forces during Collisions with Interactive Video

- Please be advised that today’s IV lesson will include actual footage of automobile crash tests with crash-test dummies. Feel free to look away if you become uncomfortable watching the videos.

- Open the files IV – Collisions #1-3 and watch the car crashes with crash test dummies.
- If the computer asks if you want to update, choose Later.
- This videos were filmed at a rate of 1000 frames per second.
- All three sequences involved a Volvo Sedan with the same initial velocity (30 mph).

12. Summarize the three movies, noting in particular what’s different in each of the three. What do you notice regarding car crash safety from these videos?

13. Using each of the videos, estimate the time duration during which the crash test dummy is in contact with the steering wheel, dashboard, and airbag. Create a table like the following with the relevant data.

<table>
<thead>
<tr>
<th>Interaction with:</th>
<th>Frame #s of Interaction</th>
<th>Duration of interaction (# of frames)</th>
<th>Duration of interaction (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start ____________</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End _____________</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14. For each type of collision, compare the interaction time. Why do they matter?

15. Assuming the crash test dummy has a mass of 80 kg, estimate the average force felt by the crash test dummy as it interacts:

- with the steering wheel,
- with the dashboard, and
- with the air bag

Show all of your calculations and assumptions. (Hint! $F_{\text{Average}} \Delta t = m \Delta v$)
16. (a) Based on the impulse-momentum equation, explain the importance of air bags and/or seat belts in vehicle safety.
(b) What other variables may be important when considering passenger safety besides the interaction time?

End of Lab Procedures

- Return the acceleration sensor and elastic band to the lab table.
- Restart the computer at your station. If you are the last lab of the day, then shut the computer down and turn off the interface box.

Want More Information?

- Collisions (see Walker, Chapter 9)
- Impulse (see Walker, Section 9-3)