Name: Date:

**Student Exploration: Crumple Zones**

**Vocabulary:** acceleration, airbag, collision avoidance system, crash test dummy, crumple zone, force, kinetic energy, Newton’s laws of motion, safety cell, seat belt, work, work-energy theorem



**Prior Knowledge Questions** (Do these BEFORE using the Gizmo.)

Two burglars run down an alley at night, trying to escape the cops. Jack is carrying a rigid metal safe. Jill is carrying an armful of antique quilts. In the pitch dark, they both collide headlong into a concrete wall.

1. Who do you think will be hurt more in the collision, and why?

1. During a car crash, what features of the car might act like either Jack’s safe or Jill’s quilts?



**Gizmo Warm-up**

When cars were first invented, the safety of passengers was not a great concern. As vehicles grew larger and faster, accidents became more deadly. Safety features went from being a rare luxury to a legal requirement. In the *Crumple Zones* Gizmo, you will design cars that will help a **crash test dummy** survive a collision.

1. To begin, do not make any changes to the DESIGN tab of the Gizmo. Select the CRASH TEST tab, and click **Play** (). After the crash, click **Slo-mo replay**. What happens?

1. Select the RESULTS tab to read about the results of the crash. Do you think a passenger would have survived this car crash? Explain.

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| **Activity A:** **Surviving a crash** | Get the Gizmo ready: * Click **Reset** (Replay).
* On the DESIGN tab, check that **Sedan** is selected.
 |  |

**Introduction:** Modern vehicles contain features designed to keep passengers safe in a crash. The **crumple zone** in the front of the car slows the car gradually and increases stopping time. The **safety cell** is a rigid cage that prevents passengers from being crushed. Inside, **seat belts** and **airbags** prevent the driver from hitting the windshield, steering wheel, or dashboard.

**Question: How does a crumple zone help protect a passenger?**

1. Make a hypothesis: On the DESIGN tab, look at the parameters you can control. What settings do you think will make the safest car? Set up the Gizmo, and then fill in below.

Crumple zone length: Crumple zone rigidity: Safety cell rigidity:

Seat belt present? If present, seat belt stiffness:

Air bag present? If present, air bag rigidity:

1. Test: On the CRASH TEST tab, check that the **Car 1 speed** is 16 m/s, or about 35 miles per hour (mph). Click **Play**. After the crash, select the RESULTS tab.
2. By what percentage did the crumple zone deform? Safety cell?
3. Did the dummy hit the steering wheel?
4. What was the maximum **force** on the dummy?
5. How likely was the dummy to survive?

In this simulation, forces are measured in kilonewtons (kN). One kilonewton is equal to 1000 newtons, or the force of a 225-pound (102 kg) person standing on your chest. While many factors affect survival, only the maximum force and safety cell collapse are considered here.

1. Experiment: On the DESIGN tab, set the **Crumple zone length** to 100 cm and the **Safety cell rigidity** to 2000 kN. Set the **Seat belt stiffness** to 50 kN/m and turn off the **Airbag**. For each **Crumple zone rigidity** setting, run a 16 m/s crash test and enter the results below.

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| --- | --- | --- | --- | --- |
| **Crumple zone rigidity** | **Crumple zone deformation** | **Dummy displacement** | **Max. force on dummy** | **Likelihood of survival** |
| 100 kN |  |  |  |  |
| 200 kN |  |  |  |  |
| 300 kN |  |  |  |  |
| 400 kN |  |  |  |  |

**(Activity A continued on next page)**

**Activity A (continued from previous page)**

1. Evaluate: Look at the results of your experiment. What was the relationship between crumple zone rigidity, crumple zone deformation, and maximum force on the dummy?

1. Infer: For a 1.00 m (100 cm) crumple zone, how much deformation do you think is needed in order to keep the passenger the safest?

Explain your answer:

1. Explore: In the U.S., all cars are evaluated using a frontal 35 mph (~16 m/s) crash test. Using the variables on the DESIGN tab, try to design a car that produces the lowest possible force on the dummy and does not injure the dummy in a 16 m/s crash.

When you have finished, describe your car and your results below.

**Car parameters** (CZ = crumple zone, SC = safety cell, SB = seat belt, AB = airbag)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CZ length** | **CZ rigidity** | **SC rigidity** | **SB stiffness** | **AB rigidity** |
|  |  |  |  |  |

**Crash results**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CZ deform.** | **SC deform.** | **Dummy disp.** | **Max. force** | **Survival %** |
|  |  |  |  |  |

1. Test: Click **Reset**. On the CRASH TEST tab, change the **Car 1 speed** to 22 m/s (about 50 mph). Run a crash test at this speed, then look at the summary data.
2. What did you find?

1. What is a possible disadvantage of designing a car for only one crash speed?

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| **Activity B:** **Modern safety features** | Get the Gizmo ready: * Click **Reset**.
* On the DESIGN tab, check that **Sedan** is selected.
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**Introduction:** The idea of a crumple zone was conceived by Béla Barényi in 1952 and first used in the 1959 Mercedes W111. Seat belts were also first widely used in the late 1950s. More recently, airbags and **collision avoidance systems** (CAS) were introduced.

**Question: How do modern safety features and body types help keep passengers safe?**

1. Experiment: Set the **Crumple zone length** to 90 cm, the **Crumple zone rigidity** to 1000 kN, and the **Safety cell rigidity** to 1000 kN. Turn off the seat belt and the airbag. These settings represent a 1950’s car with no crumple zone, seat belt, or airbag.
	1. On the CRASH TEST tab, set the **Car 1 speed** to 16 m/s. Click **Play**. What happened to the dummy?
	2. Turn on the seat belt and set the **Seat belt stiffness** to 100 kN/s. Run another crash. What happened?
	3. Set the **Crumple zone rigidity** to 250 kN and run another test. What happened?

* 1. How did the crumple zone and seat belt work together to keep the driver safe?

1. Test: An airbag is designed to quickly inflate on impact, then deflate as the passenger hits the bag. Invented in the early 1970s, airbags did not become widespread until the 1990s. Using the crumple zone and safety cell settings above, experiment with the seat belt to find the lowest possible force on the dummy. Then, experiment with just the airbag. Finally, include both the seat belt and airbag. Report your findings below.

|  |  |  |  |
| --- | --- | --- | --- |
| **Setup** | **Seat belt stiffness** | **Airbag rigidity** | **Max. force** |
| Seat belt only |  | (No airbag) |  |
| Airbag only | (No seatbelt) |  |  |
| Seat belt and airbag |  |  |  |

How did the seat belt and airbag work together to keep the driver safe?

**(Activity B continued on next page)**

**Activity B (continued from previous page)**

1. Experiment: Another modern safety innovation is the collision avoidance system, or CAS. A CAS will apply the brakes when it senses an imminent collision. The brakes can slow the car by about 8.8 m/s for each second they are engaged.

Click **Reset**. On the CRASH TEST tab, select **Enable collision avoidance system (CAS)**. Drag the car to the far right of the track at the bottom of the Gizmo, then click **Play**.

What were the results of this test?

1. Explore: Click **Reset**. In some cases, there will not be enough time for the car to completely stop before the crash occurs. However, the CAS can still be useful. On the CRASH TEST tab, set the **Car 1 speed** to 23 m/s (about 50 mph). Play a crash without the CAS, and then run another test with the CAS on. What did you find?

1. Challenge: You work in the safety engineering department for a large auto manufacturer. Your job is to create the safest possible vehicle given each of the following design criteria. Using the Gizmo, try to create a vehicle that meets each description.
* Design the safest possible SUV with a crumple zone length of 85 cm, no CAS, and a speed of 20 m/s (45 mph). (Note: Injuries such as broken legs are not allowed.)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **CZL** | **CZR** | **SCR** | **SBS** | **ABR** | **Max. *F*** | **Surv%** |
| 85 cm |  |  |  |  |  |  |

* Design the safest possible subcompact (no injuries) with a crumple zone length of 80 cm, no CAS, and a speed of 18 m/s (40 mph).

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| **CZL** | **CZR** | **SCR** | **SBS** | **ABR** | **Max. *F*** | **Surv%** |
| 80 cm |  |  |  |  |  |  |

* Design a sedan with a crumple zone length of 110 cm that can give passengers a greater than 50% chance of surviving a 27 m/s (60 mph) crash *and* give passengers a greater than 80% chance of surviving a 16 m/s (36 mph) crash.

(Note: Crumple zone length in both experiments is 110 cm.)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Speed** | **CZR** | **SCR** | **SBS** | **ABR** | **Max. *F*** | **Surv%** |
| 27 m/s |  |  |  |  |  |  |
| 16 m/s |  |  |

|  |  |  |
| --- | --- | --- |
| **Activity C:** **Force and acceleration** | Get the Gizmo ready: * Click **Reset**.
* On the DESIGN tab, select the **SUV**.
 |  |

**Introduction:** To understand the physics of a car crash, it is helpful to consider **Newton’s laws of motion**:

* First law: An object in motion will stay in motion unless acted on by an unbalanced force.
* Second law: The **acceleration** (*a*) of an object is directly proportional to the net force (*F*) on the object and inversely proportional to its mass (*m*). In equation form: *F* = *ma*.
* Third law: For every action there is an equal and opposite reaction. If object A exerts force *F* on object B, then object B exerts force –*F* on object A.

**Question: In a car crash, how are force, mass, acceleration, and velocity related?**

1. Observe: On the DESIGN tab, check that **SUV** is chosen. Turn off the seat belt and airbag. On the CRASH TEST tab, set the **Car 1 speed** to 10 m/s and click **Play**. Observe the crash, then observe the dummy in slow motion by clicking the **Slow-mo replay** button.

How does Newton’s first law explain the motion of the dummy?

1. Select the TABLE tab. On the table, scroll down to where the **Dummy *v*** changes. The velocity change occurs when the dummy hits the steering wheel.
	1. What maximum force did the steering wheel exert on the dummy?

Notice that this force is negative. In this Gizmo, the positive direction is right to left. A negative force pushes the dummy from left to right, opposite its velocity.

* 1. According to Newton’s third law, what force did the dummy exert on the steering wheel?
1. Calculate: On the DESIGN tab, set the **Crumple zone length** to 100 cm, the **Crumple zone rigidity** to 200 kN (200,000 N), and the **Safety cell rigidity** to 4000 kN. These settings will result in the crumple zone exerting about 200,000 N of force on the wall during the crash.
	1. If the crumple zone exerts +200,000 N of force on the wall, how much force will the wall exert on the crumple zone?
	2. The SUV has a mass of 2,000 kg. According to Newton’s second law, what will be the acceleration of the SUV during the crash?

**(Activity C continued on next page)**

**Activity C (continued from previous page)**

1. Test: Select the TABLE tab and click **Play**. Look at the **Car *a*** column. Note where the SUV hits the wall and starts to slow down. What is the acceleration of the SUV?

You may notice that the acceleration of the car is not exactly what you predicted. The SUV’s acceleration depends on the rigidity of the crumple zone and the safety cell. If the safety cell were perfectly rigid, the acceleration would only depend on the rigidity of the crumple zone.

1. Predict: On the DESIGN tab, select the **Subcompact**. A subcompact has the engine in the back, so the entire front of the car is part of the crumple zone. (Engines do not compress easily, so having the engine in the front of the car reduces the length of the crumple zone.)

Set the **Crumple zone length** to 80 cm, the **Crumple zone rigidity** to 190 kN, and the **Safety cell rigidity** to 4000 kN. Turn off the seat belt, turn on the airbag, and set the **Airbag rigidity** to 15 kN.

* 1. Based on the crumple zone rigidity, approximately what force will the wall exert on the car during the crash?
	2. Based on the mass, estimate the acceleration of the car:
	3. Like the crumple zone, the airbag in this Gizmo exerts a constant force on the dummy. What force, in newtons, does the airbag exert?
	4. The dummy has a mass of 50 kg (110 lb). When the dummy hits the airbag, what will be the acceleration of the dummy?
1. Test: On the CRASH TEST tab, set the **Car 1 speed** to 16 m/s. Click **Play**. Select the TABLE tab. What is the car’s acceleration and the dummy’s acceleration during the crash?

Car acceleration during crash: Dummy acceleration during crash:

How do these values compare to your predictions?

1. Summarize: How do Newton’s laws help to explain the acceleration of the car and dummy during a crash?