Bumper Trade-Offs

Use collision data to choose and improve a protective design.

HS-PS2-3 "Design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision. (SEP: 6; DCI: PS2.A, ETS1.A, ETS1.C; CCC: Cause/Effect) Alignment may include HS-ETS1-1, HS-ETS1-3"

NAME _____ DATE _____

1 READ AND MARK

Read it twice

YOUR JOB Underline the three design limits, circle each stopping time and its average force, and number the bumpers that meet every limit.

A Cart That Must Stop

1. At a school engineering fair, a 2 kg cart rolls at 2 m/s into a wall. A team attaches different bumpers to the cart and measures how long each collision takes to stop it. In every trial, the cart begins with the same momentum and stops, so its change in momentum has the same magnitude.

2. In a collision, average force equals the magnitude of momentum change divided by stopping time. A longer stopping time lowers the average force when that momentum change stays fixed. The team needs a bumper no thicker than 5 cm, able to survive three impacts, and producing an average force below 500 N. The table shows equal-speed trials.

BUMPER TEST RESULTS

Bumper	Stopping time (s)	Average force (N)	Thickness (cm)	Impacts survived
Rigid plate	0.004	1000	1	3
Foam	0.010	400	4	3
Folded cardboard	0.020	200	6	1
Foam and folds	0.025	160	5	1

3. A bumper can stretch stopping time by compressing, but it must leave room for the cart to stop without flattening completely. Repeated impacts may crush a material or loosen its attachment. These trials report average force, not peak force. Engineers would compare the table with the limits, choose a design, then revise it and test again.

2 ANSWER WITH EVIDENCE

Use the passage

1. Compared with the rigid plate, how does the foam bumper change stopping time and average force? Explain the cause of the force change.

2. Folded cardboard produces less average force than foam. Why does it still fail the team's design limits?

3. Which tested bumper meets all three limits? Use the table to justify your choice.

4. The foam-and-folds bumper has the lowest average force. What problem must a revised version solve, and what test would show whether the revision works?

3 YOUR TURN

Your own words

Design a bumper for a 3 kg delivery robot that might hit a shelf. In four to six sentences, describe a bumper no thicker than 4 cm that could survive five collisions, explain how it would reduce average force, propose a fair test against an unpadded robot, and name one result that would make you revise your design.

ANSWER KEY

Bumper Trade-Offs

PART 1 · READ AND MARK

Underline the three design limits, circle each stopping time and its average force, and number the bumpers that meet every limit. Accept any marking that follows this job and points at the right text.

PART 2 · ANSWERS

#	QUESTION	ANSWER
1	Compared with the rigid plate, how does the foam bumper change stopping time and average force? Explain the cause of the force change.	**Foam increases stopping time from 0.004 s to 0.010 s and lowers average force from 1000 N to 400 N. With the same change in momentum spread over more time, average force decreases.**
2	Folded cardboard produces less average force than foam. Why does it still fail the team's design limits?	**It is 6 cm thick, exceeding the 5 cm limit, and survives only one impact instead of three.**
3	Which tested bumper meets all three limits? Use the table to justify your choice.	**Foam meets all three: it is 4 cm thick, survives three impacts, and produces an average force of 400 N, below 500 N.**
4	The foam-and-folds bumper has the lowest average force. What problem must a revised version solve, and what test would show whether the revision works?	**It must survive three impacts rather than one. Test the revised bumper in three equal-speed collisions and check that it remains at most 5 cm thick and produces an average force below 500 N.**

PART 3 · YOUR TURN (SAMPLE ANSWER)

I would attach a 3 cm thick rubber lattice to the front of the robot. Its gaps could compress during a collision, increasing stopping time and reducing average force. I would run the padded and unpadded robot into the same shelf at the same speed and measure force in each collision. I would repeat the padded test five times to see whether the lattice still works. If it tore or produced a higher average force than the unpadded robot, I would change the lattice and test again.

Accept other feasible revisions and bumper materials if students connect longer stopping time to lower average force and test designs under the stated limits. The table gives average forces, so students should not claim it establishes peak forces.