Lesson 7 Teacher Reference

Collision Simulation Information

The vehicle collision simulation has multiple, restricted views that are used throughout the unit using the following links. These links will be used throughout multiple lessons.

- The teacher dashboard: https://s3.amazonaws.com/p.3simulation/collisions/index.html
- Sandbox: https://s3.amazonaws.com/p.3simulation/collisions/sandbox.html
- Seat belts and airbags: https://s3.amazonaws.com/p.3simulation/collisions/seatbelts-airbags.html
- Crumple zones: https://s3.amazonaws.com/p.3simulation/collisions/crumple-zones.html
- Collision avoidance: https://s3.amazonaws.com/p.3simulation/collisions/collision-avoidance.html

This teacher reference is meant to provide detailed information about how the vehicle collision simulation models collisions, including its limitations.

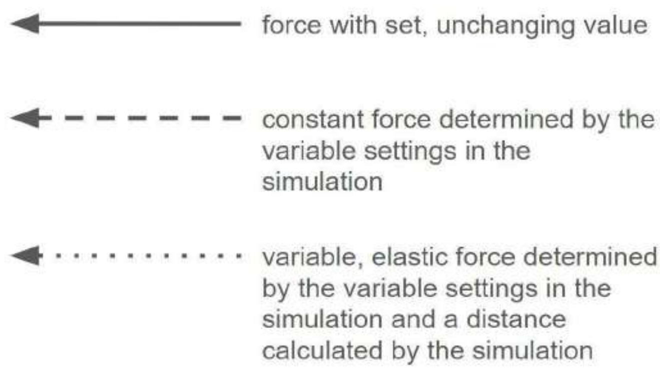
The modeling of forces in the simulation uses simplified systems. The vehicle and crash test dummy are both modeled as point masses, and the barrier is modeled as an immovable object. Forces are modeled as either a set constant force, a variable constant force, or a Hookean elastic force. No damping or friction (other than braking) is present. These simplified models allow students to engage in more-straightforward sensemaking about the forces while still producing many emergent outcomes that approximate what would occur in real-world conditions.

The vehicle collision simulation models data for a vehicle colliding with an immovable wall. This was done to help isolate variables for student sensemaking about seat belts, airbags, and crumple zones. However, this does introduce the limitation that it is difficult to design for a high likelihood of survival. A possible extension learning opportunity is to discuss this limitation. This could be done using the ideas of momentum conservation from Lesson 6 to make sense of why hitting an immovable object is more dangerous by comparing it with colliding with an extremely high-mass object.

A limitation of the simulation is that it cannot model different types of injuries since the crash test dummy is modeled as a single object, without limbs or joints. The simulation calculates likelihood of survival based on the maximum net force on the crash test dummy. If the maximum force is less than 14 kN, likelihood of survival is 100%. If the maximum force is between 14 kN and 46.904 kN, likelihood of survival is calculated with the following equation: (likelihood of survival) = $-0.05*(\text{maximum force})^2+110$. If maximum force is greater than 46.904 kN, likelihood of survival is 0%.

The following scenario and force diagrams are meant to help you understand what the simulation is doing in order to better prepare you for answering student questions. The simplified scenario diagrams show the vehicle or vehicle cabin from a side view and describe the motion and collisions occurring. Everything is approximated as a box to best represent the simulation coding model. The force diagrams show the focal object (vehicle or crash test dummy) as a square with force arrows stacked pointing away from the square.

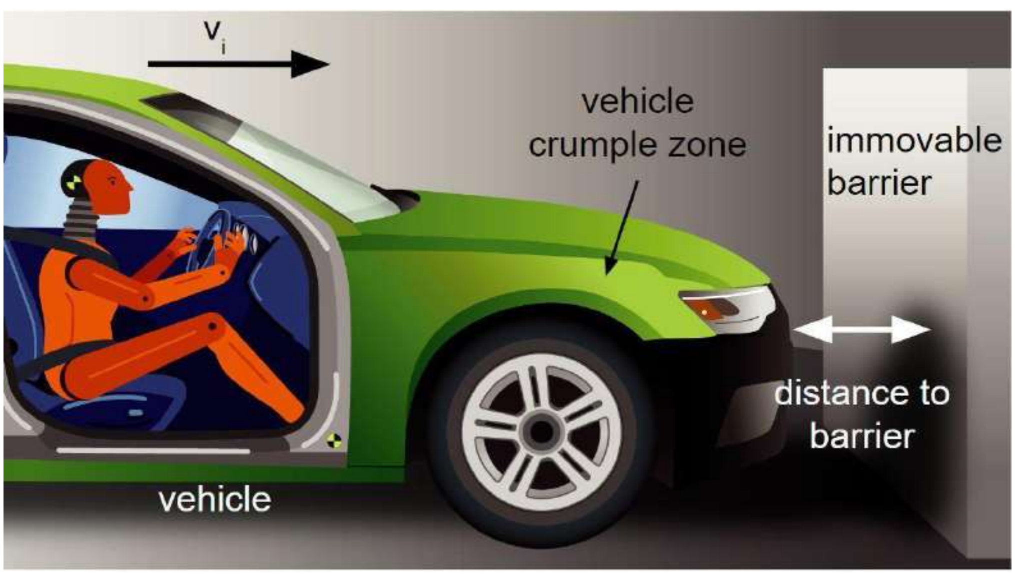
The arrows in the diagrams are only semiquantitative and may not be comparable between diagrams. As shown below, solid force arrows represent forces that have a set value; dashed force arrows represent forces that are constant and determined by the variables in the simulation; and dotted force arrows represent forces that are variable, modeled as Hookean elastic forces.



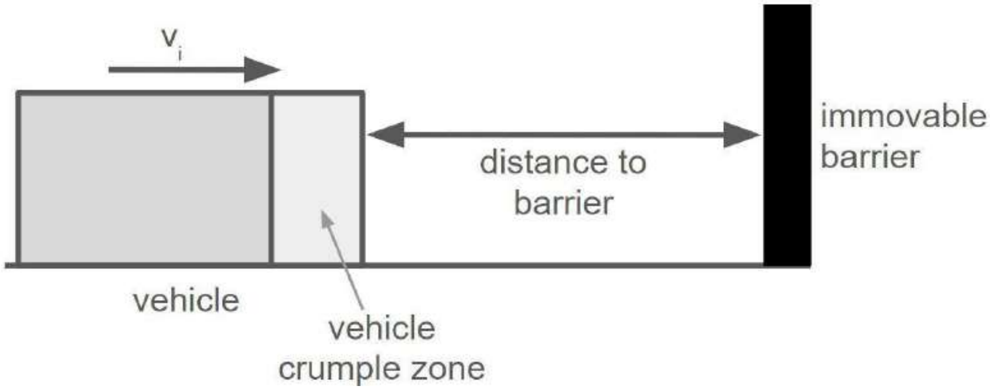
Force arrow key

Modeling the vehicle system and its surroundings

The vehicle system is modeled as a simplified box system. An image from the animation used in Lesson 8 is shown below for orientation and reference.



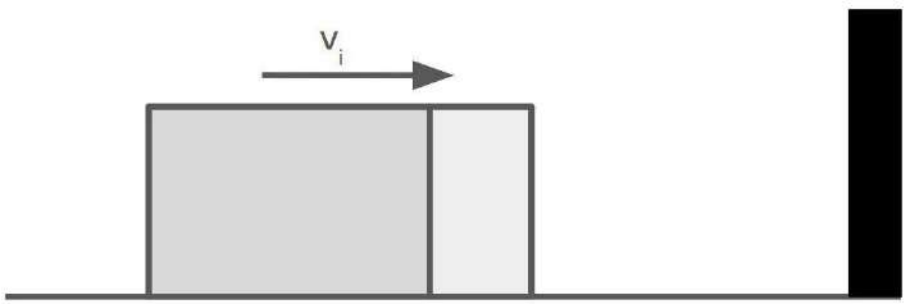
Reference image from animation



Box diagram of vehicle system and surroundings

Modeling the forces on the vehicle

If there is no braking, the vehicle continues at a constant speed until it hits the barrier. If braking is selected, this is also how the vehicle acts during the reaction time interval before braking begins.

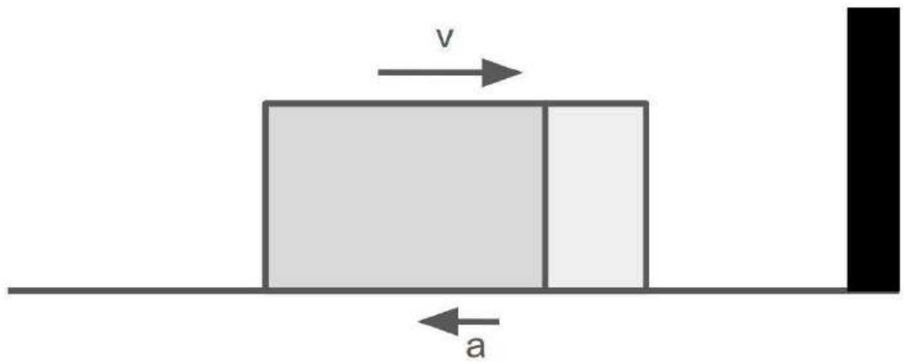


No-braking scenario diagram

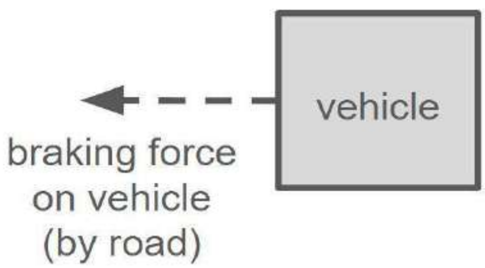
When the vehicle is moving towards the barrier without braking, there are no forces acting on the vehicle.

Nobraking force diagram

If the vehicle brakes, there is a resistive force that slows the vehicle. The braking force is only applied until the vehicle either stops or hits the barrier. The magnitude of the braking force is determined by the selected braking force and the road conditions. Wet conditions reduce the set braking force by 50%. Icy conditions reduce the braking force to 10% of the set braking force.

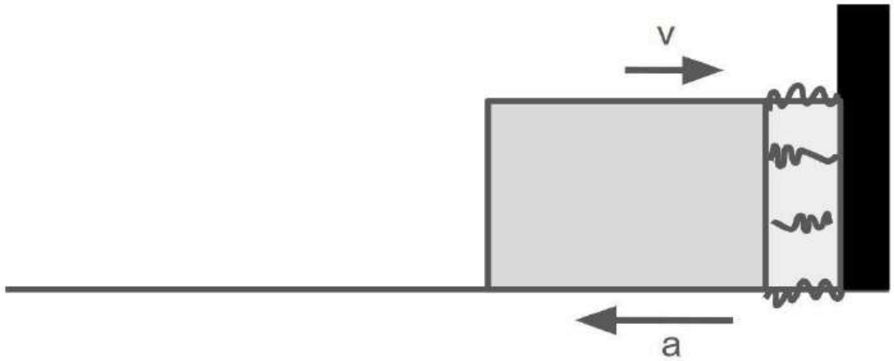


Braking scenario diagram

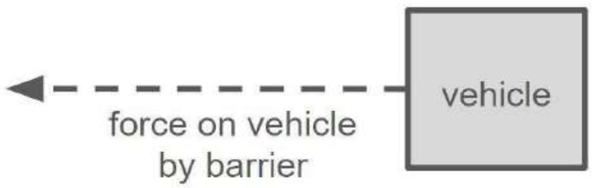


Braking force diagram

The vehicle has a crumple zone on the front of it that will deform as the vehicle collides with the barrier. If the vehicle hits the barrier, the force on the vehicle is first determined by the crumple zone rigidity. As the crumple zone deforms, a constant force is applied to slow down the vehicle. The length and rigidity of the crumple zone can be changed in the simulation, determining the force and the time and distance this force acts over.

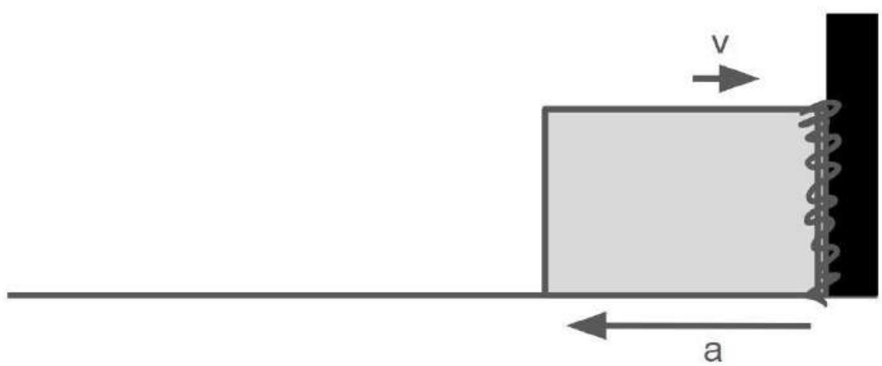


Initial collision while crumple zone is deforming scenario diagram



Initial collision while crumple zone is deforming force diagram

If the vehicle is still moving and the crumple zone has completely deformed, the rigidity of the rest of the vehicle now determines the force. This is a constant force of 3,000 kN.



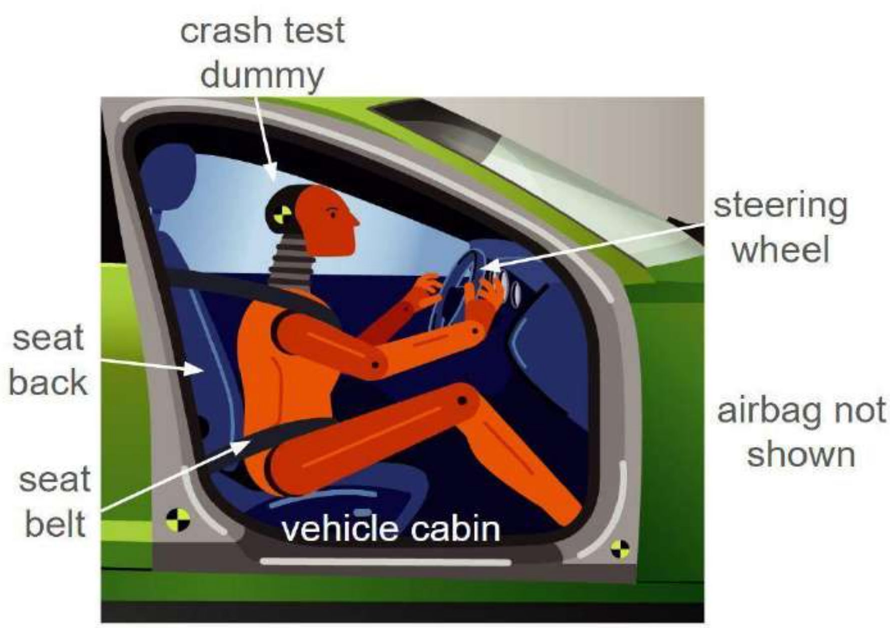
Collision once crumple zone is fully deformed scenario diagram

Collision once crumple zone is fully deformed force diagram

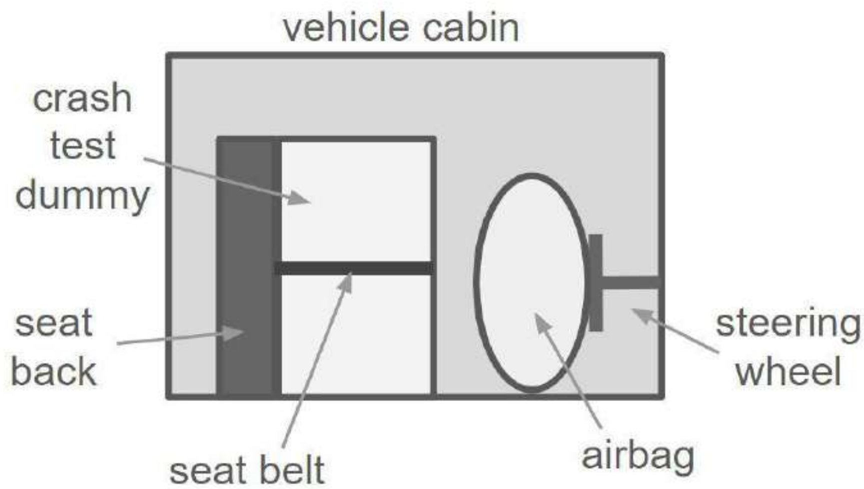
Once the vehicle comes to a stop, no forces act on the vehicle.

Modeling the crash test dummy in the vehicle cabin

The crash test dummy is modeled as a point mass and only moves linearly. Objects that the crash test dummy may interact with include the seat belt, airbag, steering wheel, and seat back. In the following diagrams, the velocities are relative to the vehicle. The simulation, however, calculates everything within one reference framing, using relative positions to calculate forces. As the motion of the vehicle and crash test dummy depend on many variables, the conditions described below can represent many different nuances of motion.



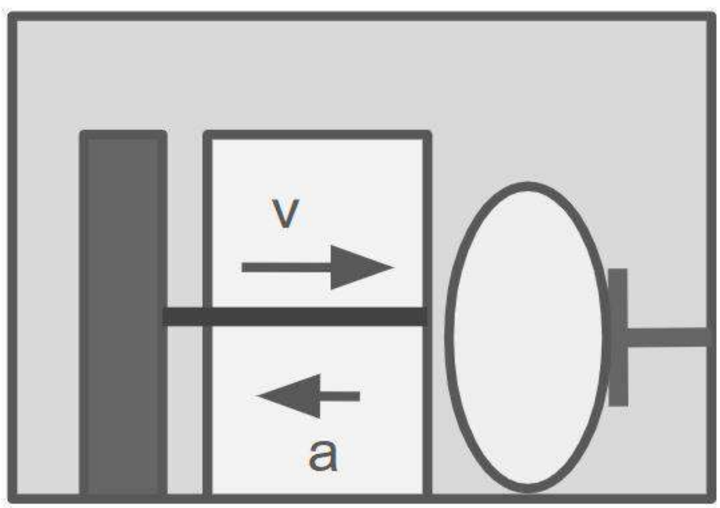
Reference image from animation



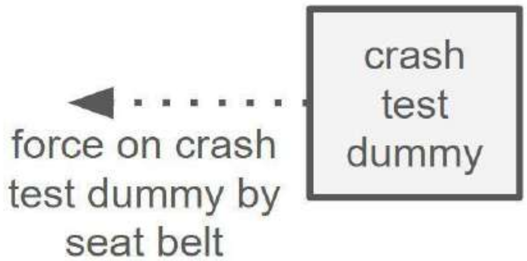
Box diagram of crash test dummy system and surroundings

Modeling the forces on the crash test dummy

When the vehicle slows down or stops, this causes the crash test dummy to move forward in the cabin due to inertia. The crash test dummy first comes in contact with the seat belt. The seat belt stretches and applies a Hookean elastic force on the crash test dummy that increases the farther the crash test dummy is from the seat back.

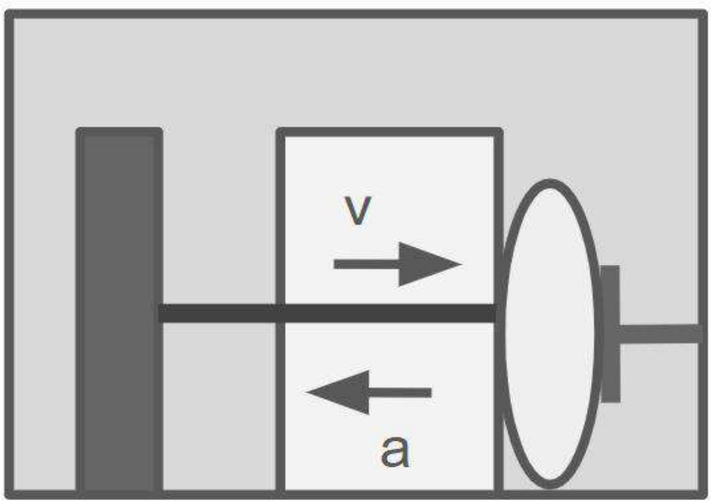


Crash test dummy moves forward in the vehicle cabin while wearing a seat belt scenario diagram

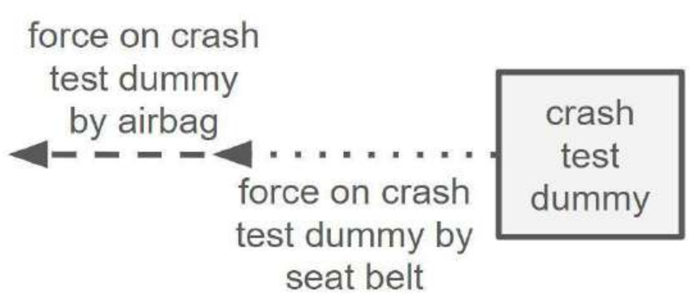


Crash test dummy moves forward in the vehicle cabin while wearing a seat belt force diagram

If the vehicle's acceleration exceeds 30 m/s/s, the airbag deploys. If the crash test dummy then moves far enough forward in the cabin to hit the airbag, the crash test dummy experiences forces from both the airbag and the seat belt. The force from the airbag is constant and determined by the airbag rigidity. If there is an airbag but the crash test dummy does not have a seat belt, then the airbag force will still apply but the seat belt force will not be present (not diagrammed below).

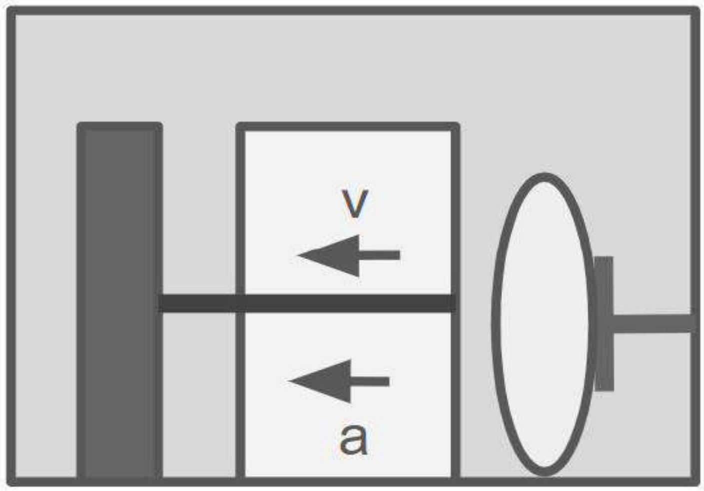


Crash test dummy hits airbag while wearing a seat belt scenario diagram

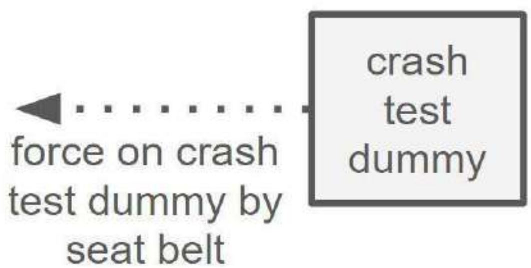


Crash test dummy hits airbag while wearing a seat belt force diagram

If the seat belt (and possibly the airbag) apply enough force to stop the crash test dummy, the seat belt then pulls the crash test dummy back toward the seat. Once the crash test dummy begins to move back towards the seat back, the airbag no longer applies a force. The seat belt continues to apply a force that decreases as the crash test dummy gets closer to the seat back.

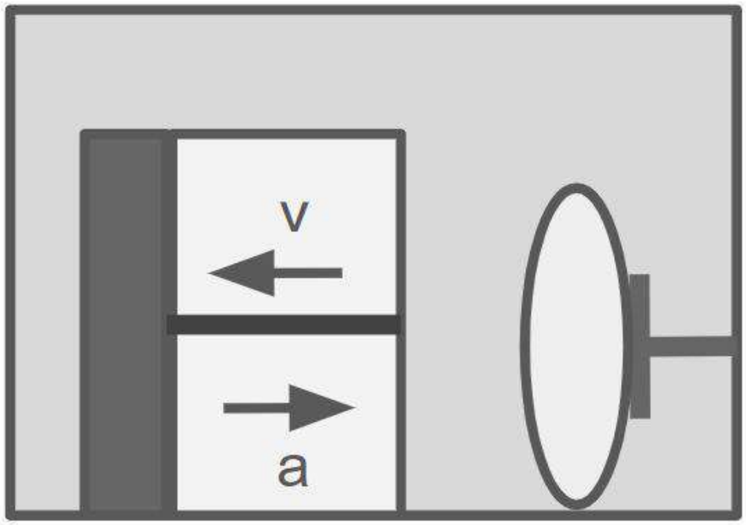


Crash test dummy moves backwards towards the seat back scenario diagram

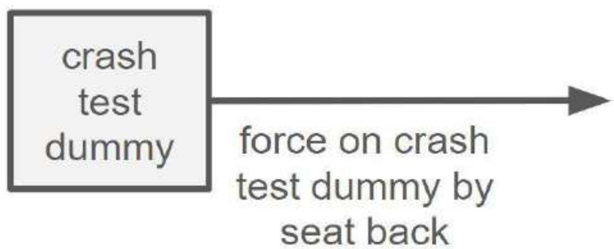


Crash test dummy moves backwards towards the seat back force diagram

Once the crash test dummy returns to the seat back, the seat belt no longer applies a force. The seat back applies a constant force of 14 kN until the crash test dummy comes to a stop. This is meant to simulate the seat back deforming to stop the crash test dummy. It is a very simplified model and assumes the seat back deforms or moves back quite a bit. This model was selected to avoid continual oscillation between the seat back and the seat belt while still acknowledging that some force needs to bring the crash test dummy to a stop. The value of 14 kN was selected because it is the maximum force that does not decrease likelihood of survival.

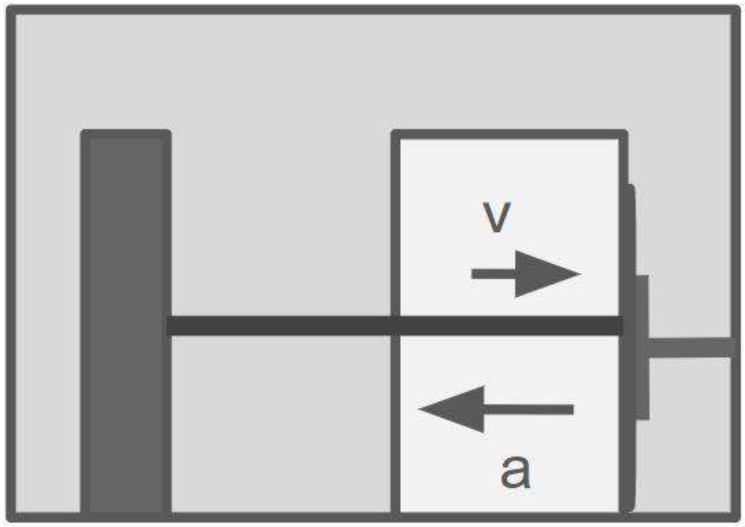


Crash test dummy hits the seat back scenario diagram

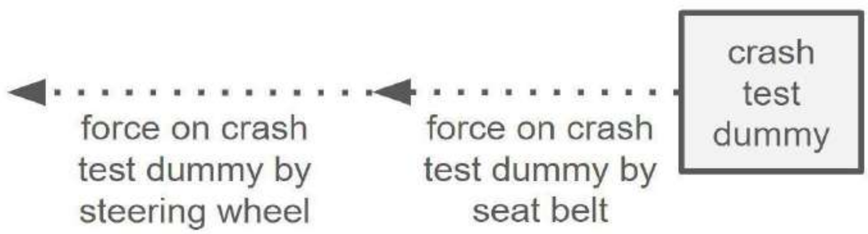


Crash test dummy hits the seat back force diagram

Another scenario is for the crash test dummy to move far enough forward in the cabin to hit the steering wheel. If the crash test dummy hits the steering wheel, the airbag has completely deflated (or was not present) and no longer applies a force. The seat belt and steering wheel will be applying forces to the crash test dummy. The force on the crash test dummy by the steering wheel is modeled as a very stiff spring. However, once the crash test dummy comes to a stop when it hits the steering wheel, it does not bounce back. Once the crash test dummy comes to a stop, it remains stopped and the simulation ends.

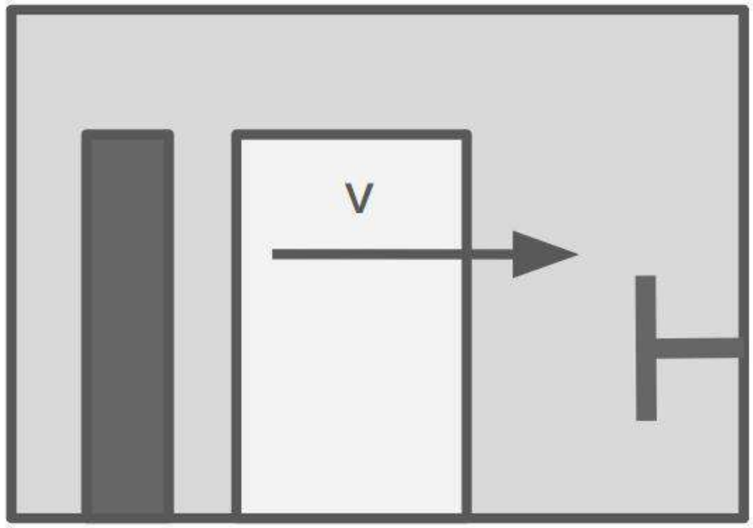


Crash test dummy hits steering wheel while wearing a seat belt scenario diagram



Crash test dummy hits steering wheel while wearing a seat belt force diagram

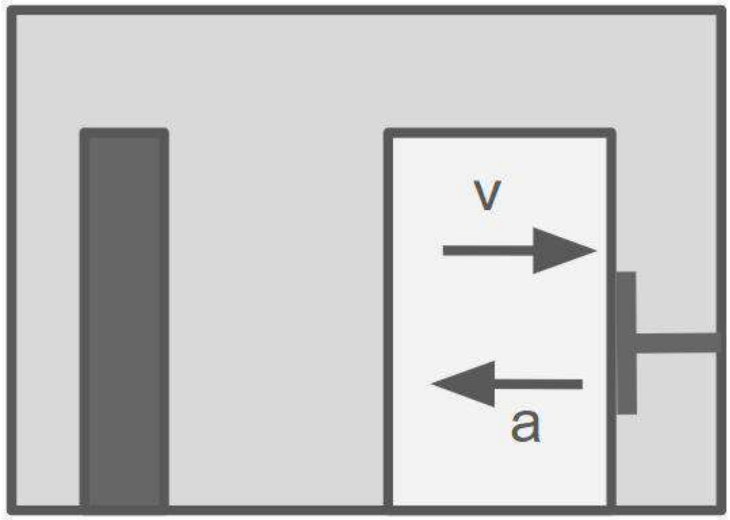
If the crash test dummy does not have a seat belt and the vehicle slows down, the crash test dummy will move forward in the cabin with no forces acting on it. This is a highly simplified model.



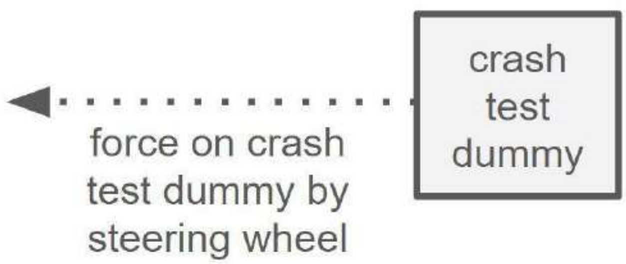
Crash test dummy moves forward in the vehicle cabin without seat belt or airbag scenario diagram

Crash test dummy moves forward in the vehicle cabin without seat belt or airbag force diagram

If there is no seat belt nor airbag, the crash test dummy will eventually hit the steering wheel directly. The force on the dummy by the steering wheel is modeled as a very stiff spring. However, once the crash test dummy comes to a stop when hitting the steering wheel, it does not bounce back.



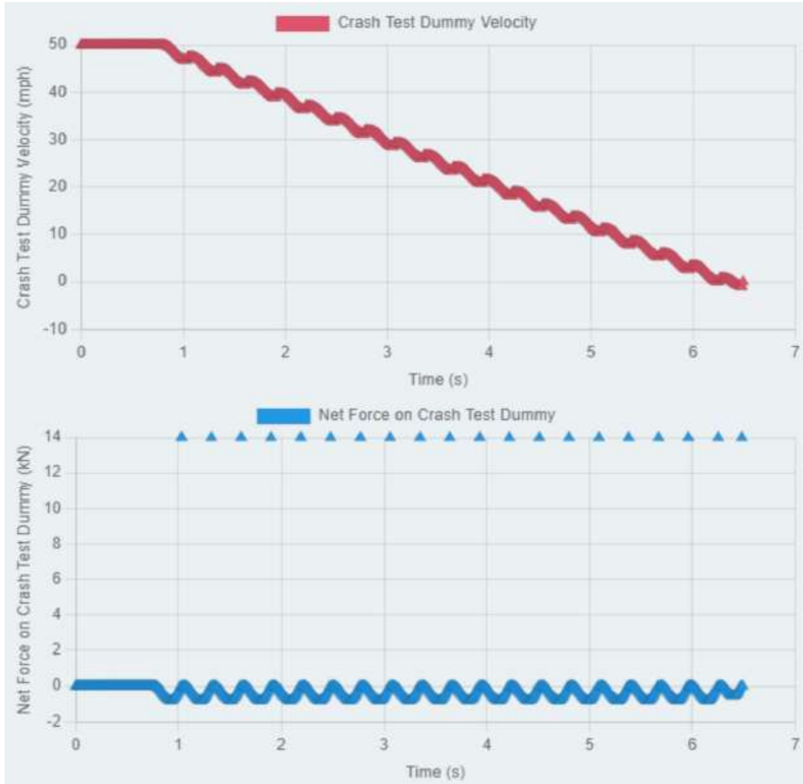
Crash test dummy hits the steering wheel without seat belt or airbag scenario diagram



Crash test dummy hits the steering wheel without seat belt or airbag force diagram

Note about crash test dummy modeling while braking

The collision avoidance view only shows vehicle variables, since it is optionally used in Lesson 3. This view only shows data for the vehicle since students aren't considering vehicle occupants at this point. In the sandbox view, you can view the crash test dummy data while braking. If students analyze these data for their projects or in an extension opportunity, students may need help making sense of what is happening. As seen in the graphs below, the crash test dummy's velocity oscillates as it slows with the vehicle due to alternating interactions with the seat belt and seat back. The crash test dummy moves forward as the vehicle slows, due to inertia, but the seat belt then applies a force. The seat belt eventually returns the crash test dummy to the seat back, and the 14 kN force from the seat back is applied to return the crash test dummy to the same velocity as the vehicle. This cycles until both have come to a stop.



Simulation graphs of crash test dummy data from a braking scenario