The Physics of Car Crashes

Can we use physics concepts to help design safer vehicles?

Collisions overview – Elastic

Momentum in = momentum out

$$Kinetic\ Energy\ in: \frac{1}{2}mv^2 = kinetic\ energy\ out$$

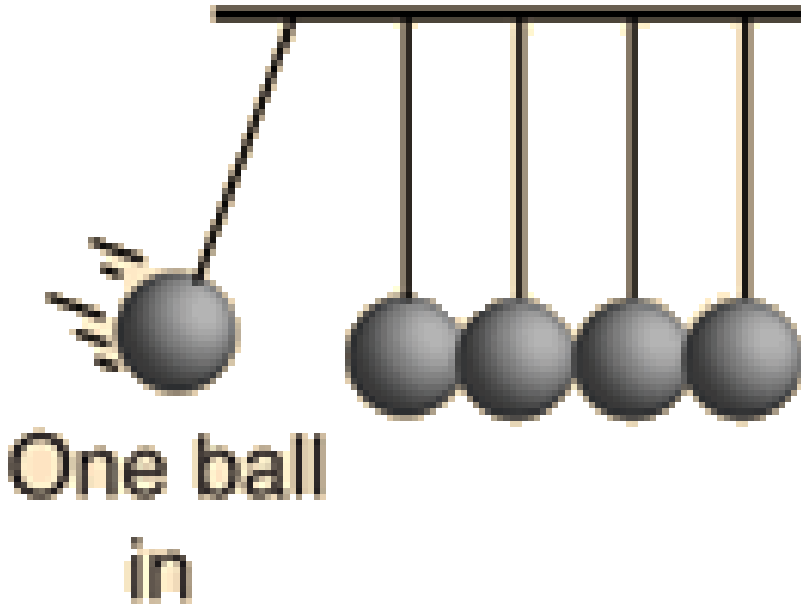

Image credit: Georgia state university

Collisions overview – Elastic

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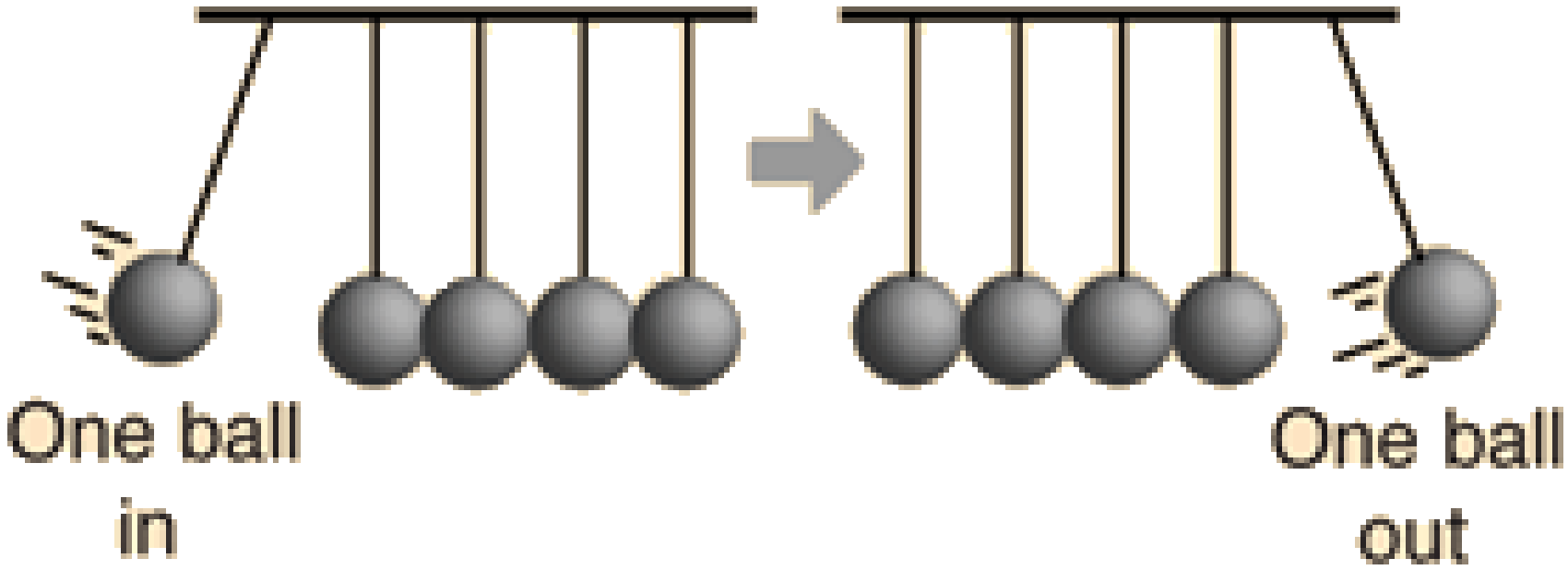
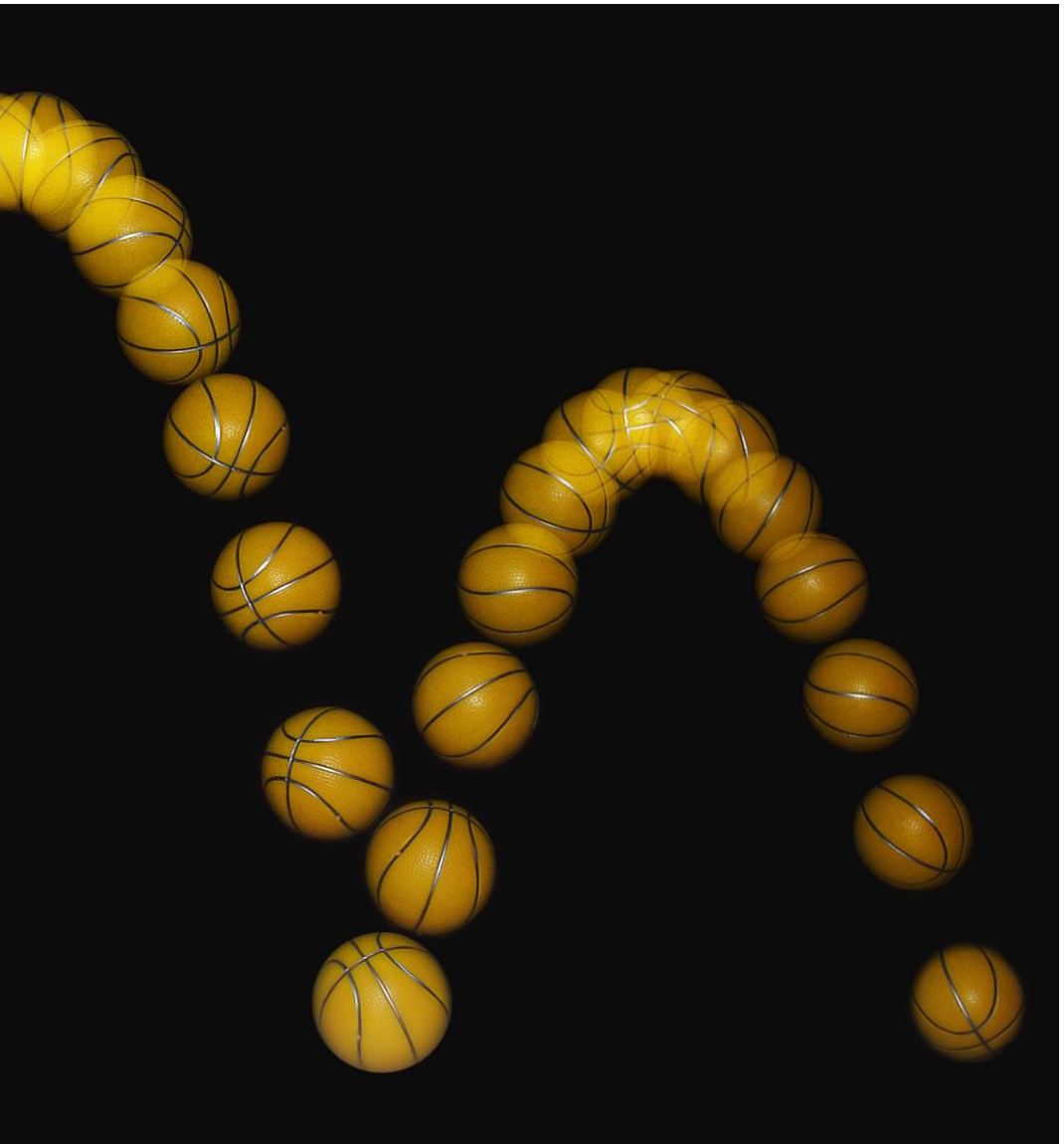


Image credit: Georgia state university

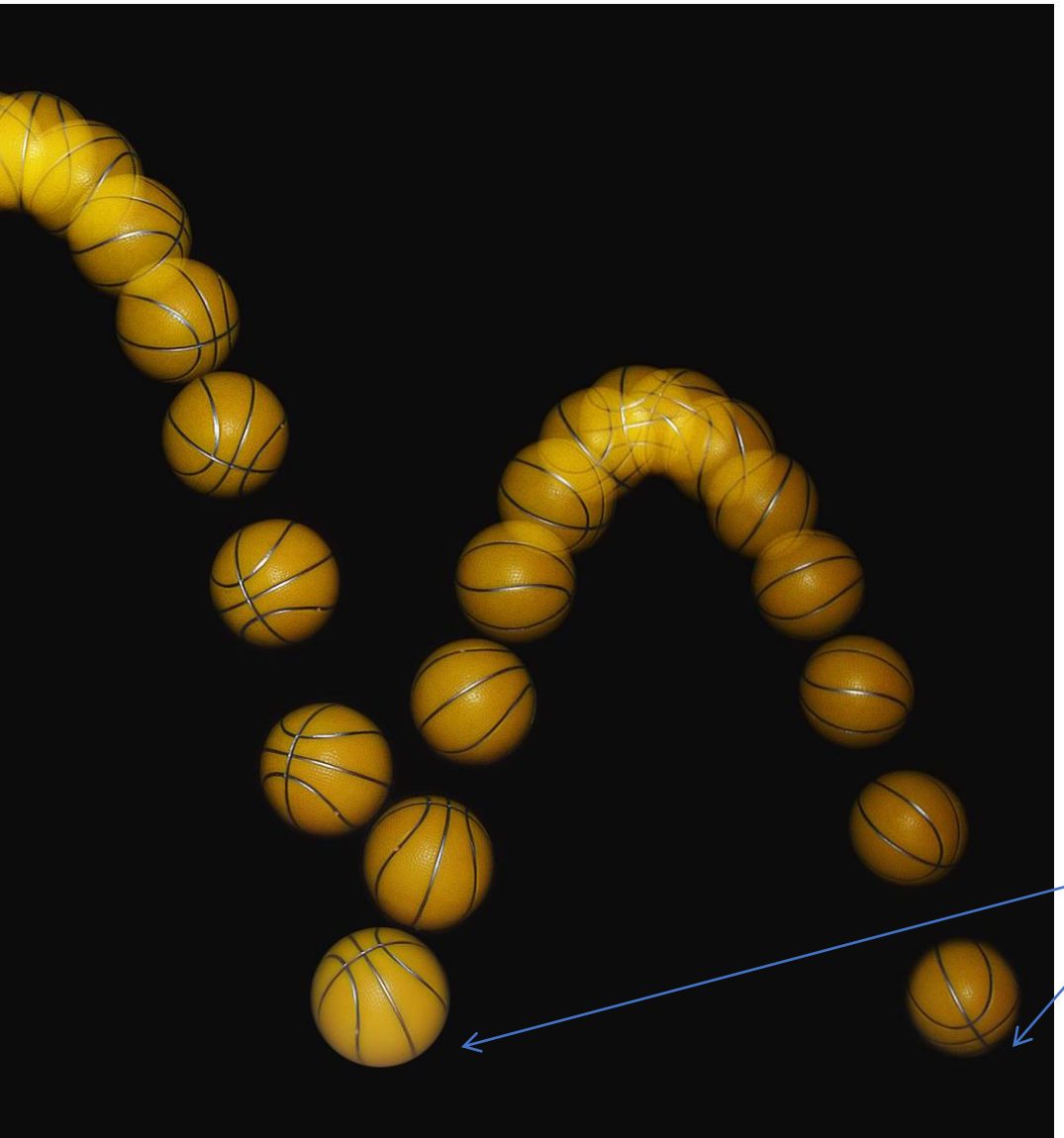
Collisions overview – Inelastic



- Momentum in (mv) = momentum out (for the whole system)
- Kinetic energy in = $\frac{1}{2}mv^2 \neq$ kinetic energy out

Image credit: wikipedia

Collisions overview – Inelastic



Momentum in (mv) = momentum out (for the whole system)

Kinetic energy in = $\frac{1}{2}mv^2 \neq$ kinetic energy out

Some KE into-> Sound and heat here

Image credit: wikipedia

Restitution

- **Newton's law of restitution** says that when two objects collide, their speeds after the collision depend on the material from which they are made

Restitution

- **Newton's law of restitution** says that when two objects collide, their speeds after the collision depend on the material from which they are made
- Coefficient of Restitution (e)

$$v_i = e \cdot v_f$$

Restitution

- Simple Basketball Experiment

Calculating coefficient of restitution (e)

- $KE = \frac{1}{2}mv^2$

$$GPE = mgh$$

$$v_i = e \cdot v_f$$

- $(initial\ energy)\ E_i = mgh_i = mv_i^2\ (KE\ as\ it\ hits\ the\ ground)$
- $(KE\ after\ bounce)\ E_f = mv_f^2 \rightarrow mgh_f\ (GPE\ of\ first\ bounce)$
- $combine\ equations$:
- $e = \sqrt{\frac{h_f}{h_i}}$

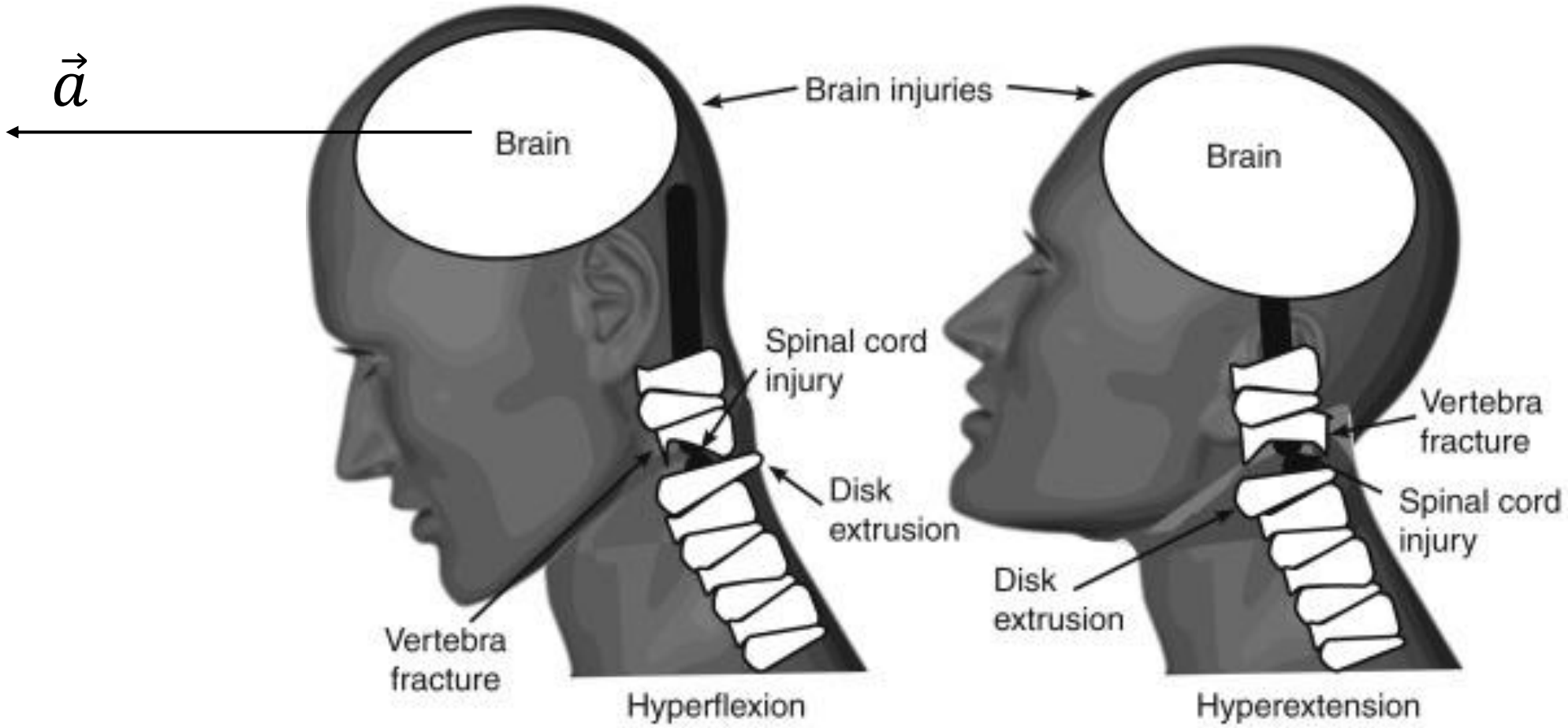
Restitution properties

- Depends on
  - Shape of materials
  - geometry of collision
- When the material can be deformed or broken (its yield strength defeated) the coefficient of restitution will be lower

Calculating the acceleration

- If the basketball collision takes .1s what is the acceleration felt by the ball?

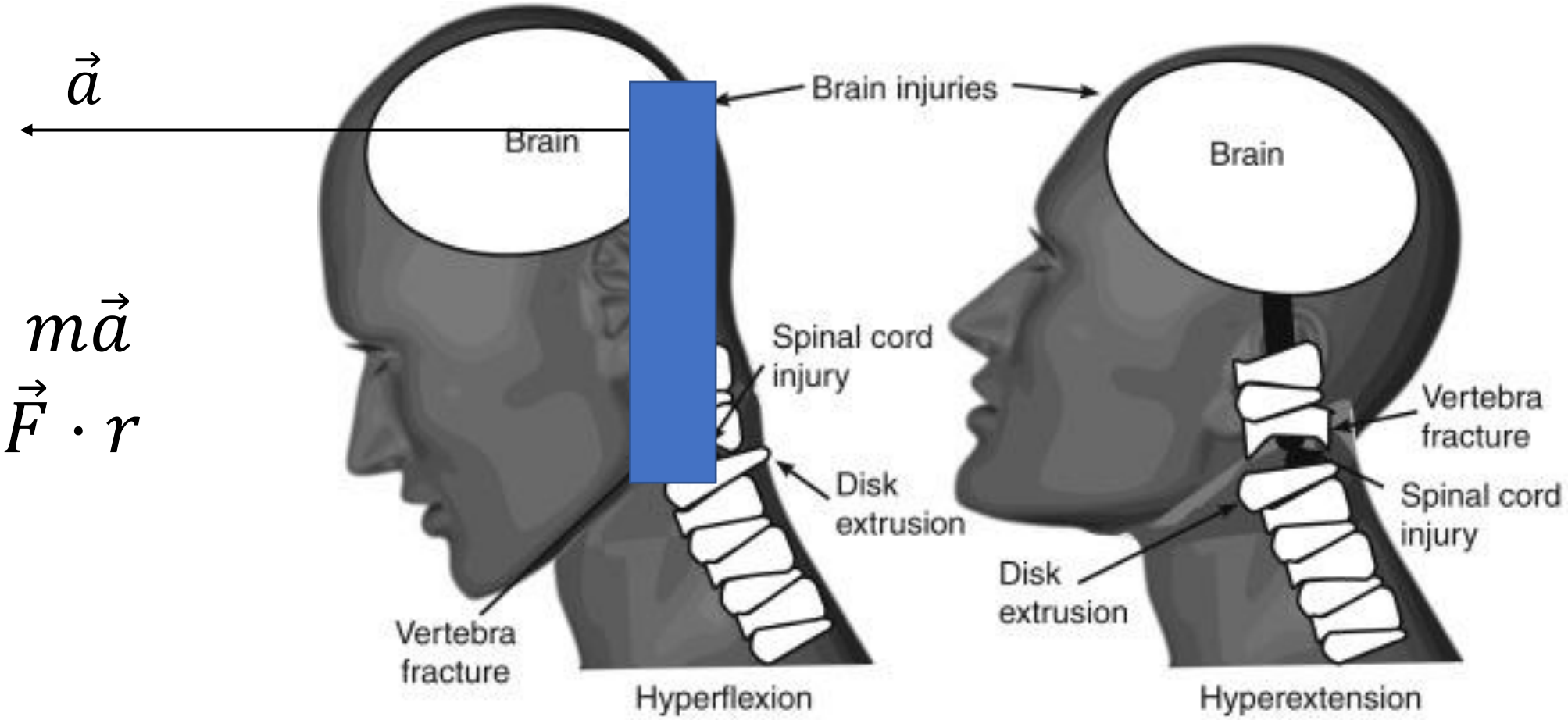
Acceleration can hurt humans!



Acceleration can hurt humans!

$$\vec{F} = m\vec{a}$$

$$\tau = \vec{F} \cdot r$$



How do we cause less harm in collisions?

- How can we reduce acceleration?
- (live demo)

Calculate the impulse to stop the car

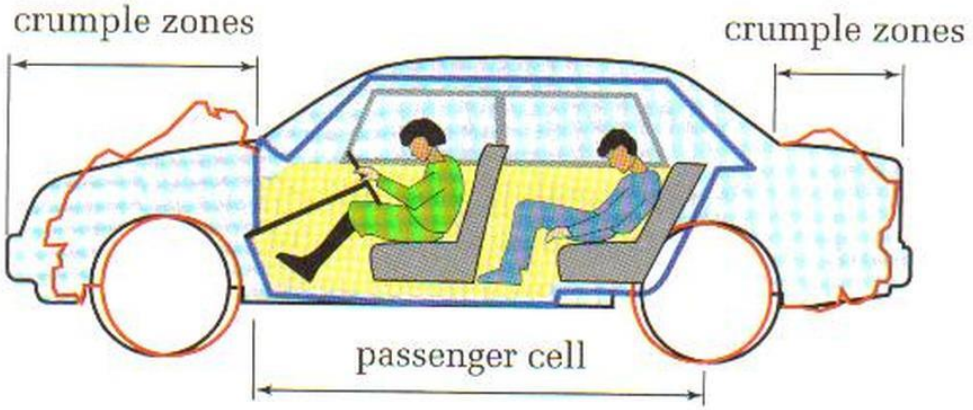
- (white Board calculations)

Calculate the impulse to stop the car

- (white Board calculations)
- Acceleration can be reduced by increasing Δt and/or converting more KE to heat/sound deforming the materials

Brainstorming Solutions

- How might we try to make the passengers in the vehicle safer
  - crumple zone to absorb energy and a passenger zone, which can't be crushed



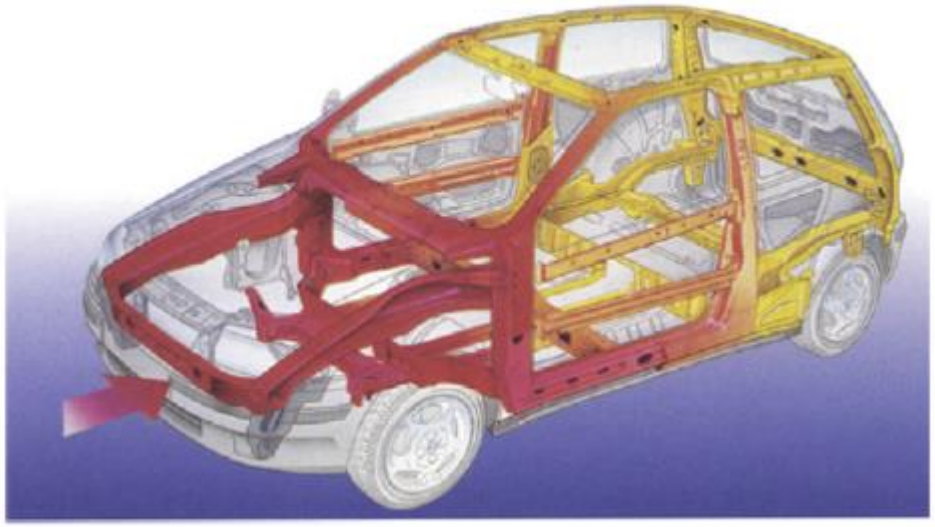


Image Source:
left cartrade.com
right: Vehicle Collision Dynamics by Dario Vangi

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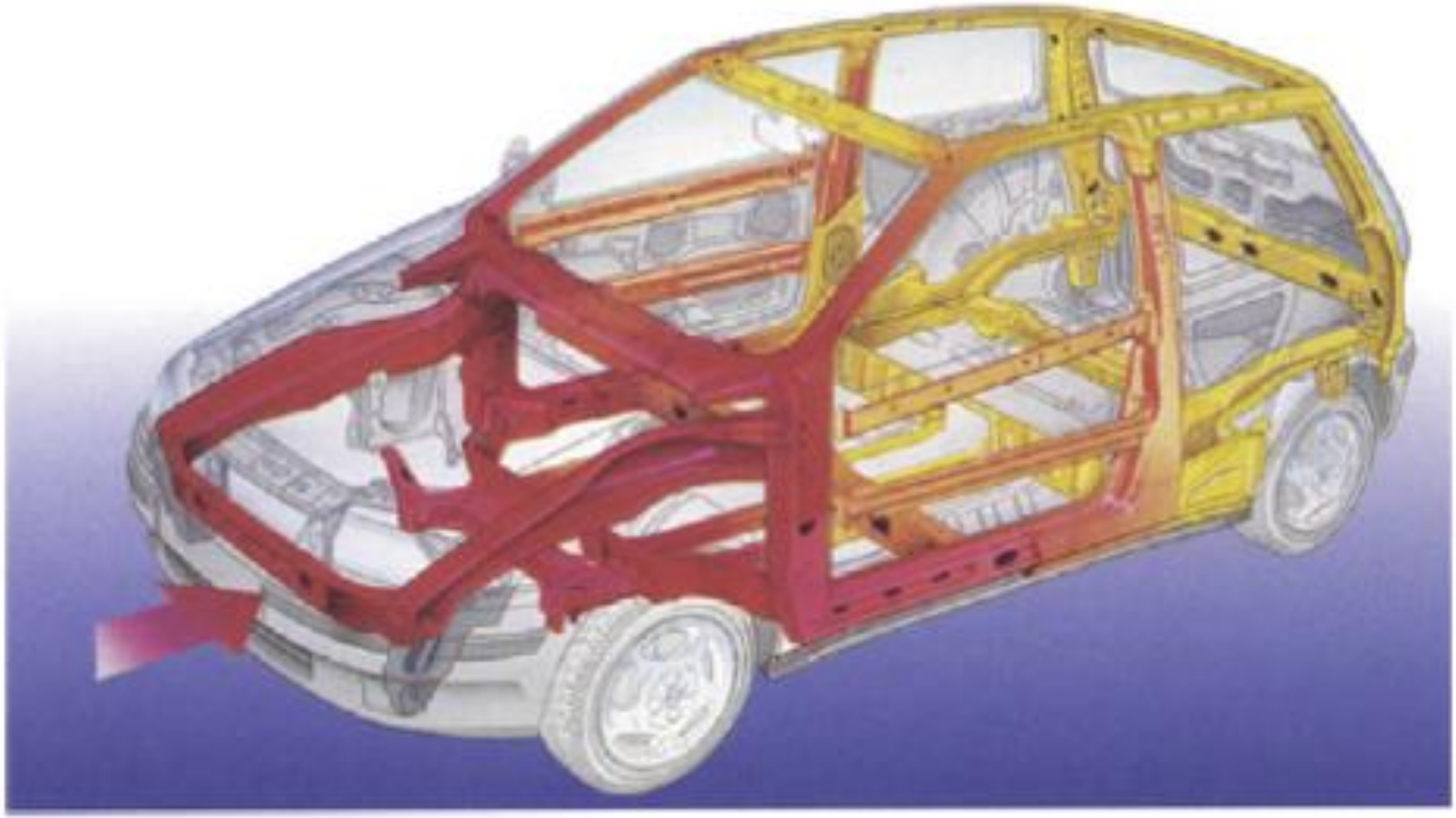


Big Bubble

Cardboard tube

Cardboard cone

Bubble-wrap

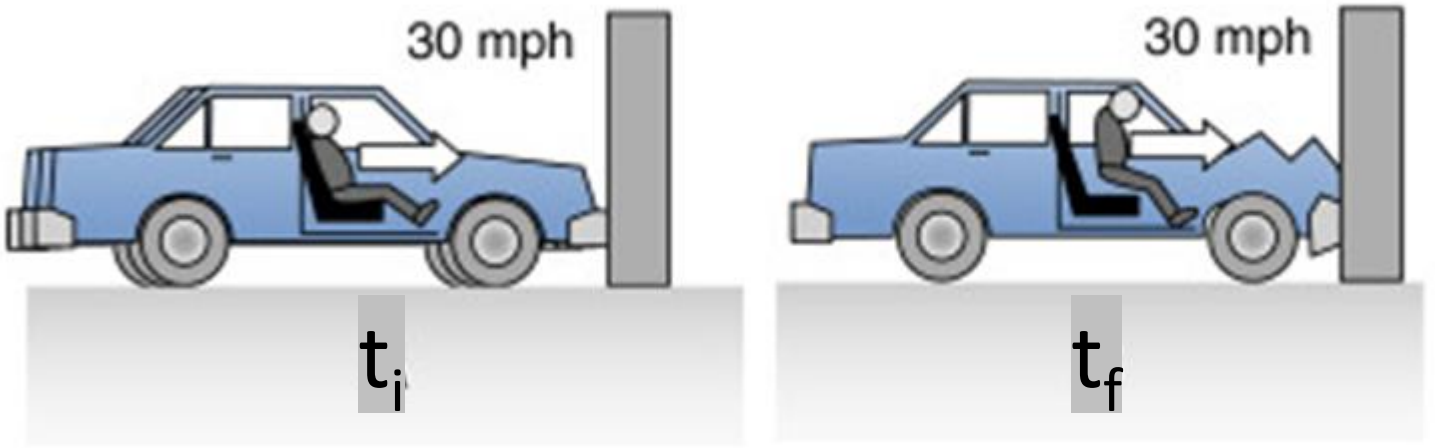
Tin foil cone single layer (and 4x layer)

Material	Collision Duration (s)	Peak acceleration (m/s^2)	Comments
Baseline (no bumper)			
Big bubble bumper			
cardboard foil cone			
Tin foil cone single layer			
Tin foil cone 4x layer			
Bubble Wrap			
Cardboard tube			

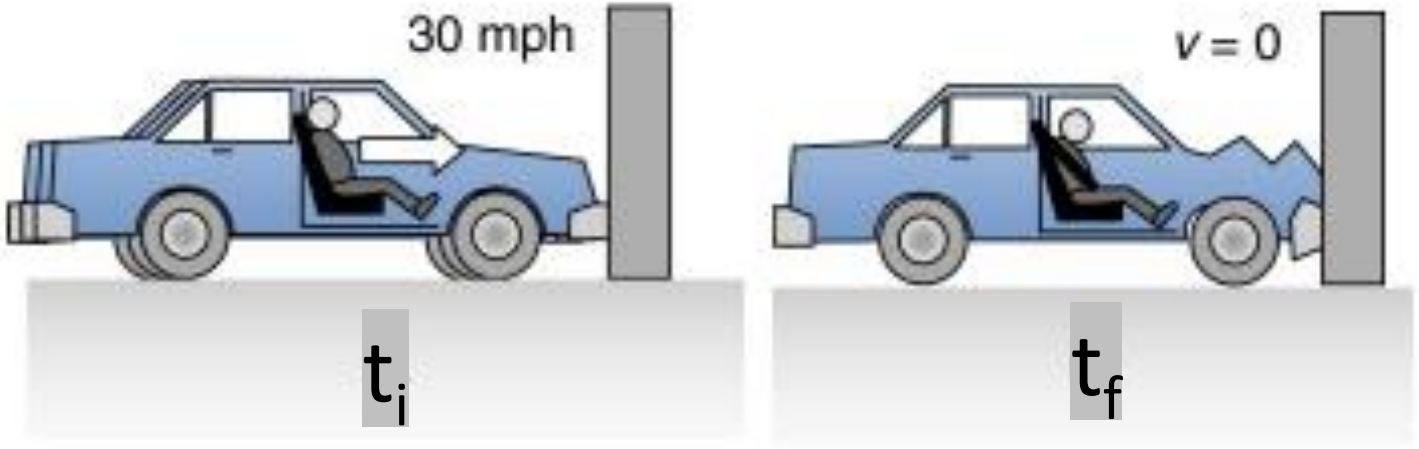
It won't work without the seatbelt & airbag

- Newton's first law, passenger in the top vehicle continues moving inside the vehicle has their own new collision inside the car
- All of the work absorbing the crash and spreading out the impulse of the crash isn't passed to the passenger if they aren't wearing a seatbelt

Without Seatbelt:



With Seatbelt:



Source image: Exploring Engineering 5th edition Chapter 16 Bioengineering

Crumple zone technology has improved over the years

Figure 4 Comparison of three Saab models: 1995, 1999, and 2003.

1995 Saab 900—Poor structure

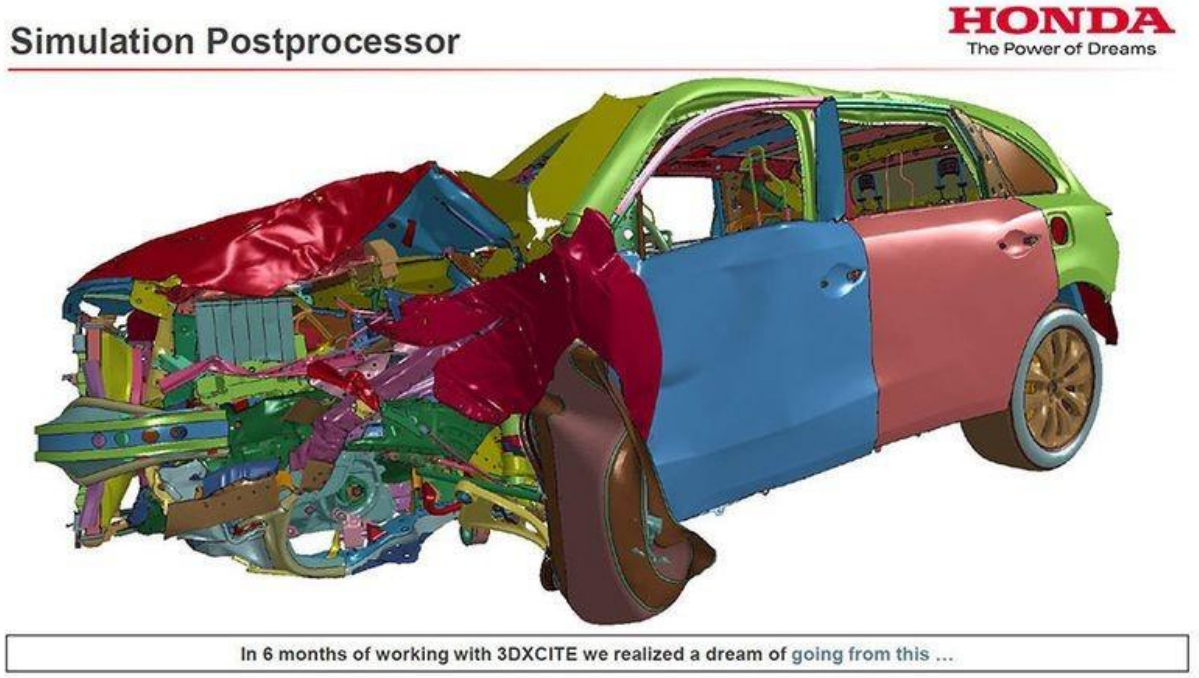
1999 Saab 9-3—Improved structure

2003 Saab 9-3—Good structure

Real life crash testing and simulations

- Vehicle manufacturers are still required to perform crash tests
- They also use that crash data to inform their crash simulations
- Its possible to do a really cool approximation of large scale crash test with simple stuff like your phone and some household items

Honda R&D Americas, Inc. May 2014



Questions?

CO Restitution math (backup slide)

- Not a property of the material
- Depends on
  - Shape of materials
  - geometry of collision
- $e \propto \sqrt{\frac{yield\ strength}{elastic\ modulus}}$ (for spherical homogenous materials)