Impulse on Eggs

Workshop

Participants learn about impulse by building vehicles to drop eggs in.

Number of Participants: 4-30

Audience: Elementary (ages 5-10) and up

Duration: 30 + minutes

Difficulty: Level 2

Materials Required (per participant):

- Raw or boiled eggs (3)
- Drinking straws (10)
- Masking tape (several rolls, shared)
- Small plastic trash bags (1)
- Twine or similar thin string (~3 ft)
- Drop cloth and/or 4' plastic child's pool (1 for all participants)

Setup:

1. Separate students into small groups (2-3 people) with each group at a table. Distribute tape, straws, string, bags, and eggs.
2. Prepare drop area with small pool and dropcloth if desired.

Presenter Brief:

Understand basic kinematics (position, velocity, acceleration), force, drag, and impulse.

Vocabulary:

- Force ($\boldsymbol{F}$) – A push or pull in a given direction. Any influence that tends to change an object's motion. Force is the negative gradient of the potential energy.
- Drag – A force against an object's motion resulting from the resistivity of a fluid.
- Terminal Velocity – The maximum velocity of an object in freefall through a medium. The magnitude of terminal velocity is terminal speed.
- Impulse – Forces of short duration, such as those experienced during a collision, are called impulsive forces. A force applied over time. The change in the

momentum of a body under the action of an impulsive force is equal to the time integral of that force. A near instantaneous change in momentum with virtually no change in position.

Physics & Explanation:

Elementary (ages 5-10):

Gravity causes an object to fall to Earth when dropped.

Drop an egg from eye level so that it breaks.

When the egg hits the ground with a given force, the ground exerts the same force back on the egg. The faster the egg falls, the greater this force is. If too large a force is delivered to the egg shell, the egg will crack.

To keep the egg from cracking, we need to minimize the force on the egg shell when it hits the ground.

Ask participants for suggestions on how to minimize the force on the egg shell. Discuss the possibilities: reduce speed with a parachute, distribute the impact force over an enclosure, create crunch zones, or a combination.

Instruct participants to use their supplies to build a vehicle that reduces the impact force on the egg.

Take turns dropping the egg from several heights onto the dropcloth or pool (use a staircase, balcony, etc. to achieve tall drops).

Lead a discussion and analyze the vehicles which protected the egg.

🔑 Reducing the impact speed also reduces the impact force. Distributing the impact force over enclosure also reduces the force exerted on the egg.

Middle (ages 11-13) and general public:

Impulse is an average force applied over time.

$$Impulse = F\Delta t = m\Delta v$$

Since the change in momentum is fixed, impulse can be controlled by increasing the impact time.

🔑 Impulse is a force applied over time and is equal to the change in momentum, for a constant mass.

Write out the equation for impulse and show the relationship between the change in momentum and impulse. Show that to lessen the impact force, you can extend the collision time.

A smaller force over a longer time will likely reduce the damage done to object undergoing a change in momentum.

Mention how airbags and crash points in vehicles protect the occupants. They allow the same change in momentum to occur over a longer time, decreasing the average force of the crash and therefore the acceleration.

Direct the participants to develop a structure that will increase the time of collision for their egg.

Once completed, drop the eggs from approximately eye-level. If any eggs do not crack, increase the drop height. Engage the participants in a discussion on their designs – why did it not work or not work and how would you improve your design?

Highschool (14 +):

Impact absorption is a common problem in engineering. Even with deceleration mechanisms, the vehicle (whether spacecraft, train, etc.) must withstand impacts (to a limit) preserve the structure of the vehicle and its contents. Development of lander and reentry vehicles to withstand atmospheric friction and land on a planet's surface is an example of this problem.

Review impulse as described in the previous section. Instruct the participants to construct their vehicle and drop it. If any eggs do not crack, increase the drop height. Engage the participants in a discussion on their designs – why did it not work or not work and how would you improve your design?

Drag forces depend on the size, shape, orientation, and material of an object and the medium its travelling through. Linear and quadradic drag are two common drag approximations:

$$F_{lin} = -bv$$

where F_{lin} is the linear drag force, b is the coefficient of linear drag, and v is the object's speed. Linear drag is common at very slow speeds where there is no turbulence. There are also quadratic drag forces:

$$F_{quad} = \frac{1}{2}C\rho Av^2$$

where F_{quad} is the quadratic drag force, C is the coefficient of quadratic drag, ρ is the density of the fluid, A is the effective cross-sectional area, and v is the object's speed. The quadratic approximation is better for larger objects and higher speeds.

There are different ways to model air drag. The details of the situation will determine the approximation to use.

While the goal for most vehicles is minimal drag, increased drag is desirable in some situations. For example, when trying to decelerate a vehicle or a falling object

> Instruct the participants to use the small trash bags, tape, and string to add a small parachute to their vehicle to increase drag. Have them measure the terminal speed (or time to fall a given distance) before and after the parachute is added. Stop watches and or video can be used to measure time.
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> Then, have students replace their small parachute with a large parachute of the same design. Again, measure terminal (or time to fall a given distance). Compare fall times for different designs. Parachute opening times have a large influence on the fall times.

Increasing drag reduces the velocity and therefore also reduces the impact force.

Additional Resources:

- [1]https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_15_feather_drop.html
- Cautionary tale: The ESA's Schiaparelli lander http://exploration.esa.int/mars/47852-entry-descent-and-landing-demonstrator-module/
- Minutephysics video for car crashes https://www.youtube.com/watch?v=v9ML4GA47Rg

Useful Equations:

Linear Drag	$F_{lin} = -bv$
Quadratic Drag	$F_{quad} = \frac{1}{2} C\rho A v^2$
Negligible-Resistance Distance	$\Delta x = \frac{1}{2} at^2 + v_o t$
Impulse	$Impulse = F\Delta t = m\,\Delta v$

$b = Constant\ dependent\ on\ fluid\ properties\ and\ object\ dimensions$

$C = numerical\ drag\ coefficient$

$\rho = fluid\ density$

$A = cross - sectional\ area$

References:

1. https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_15_feather_drop.html