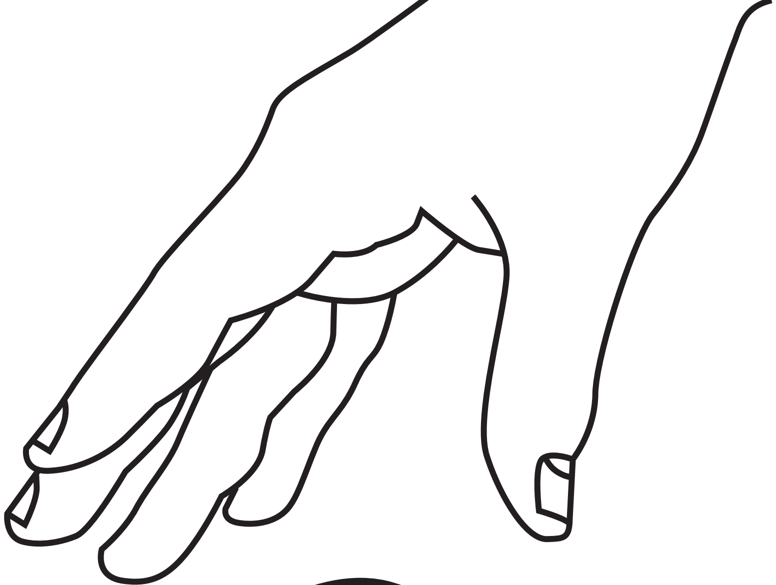

Smart EGG drop

OMSI™

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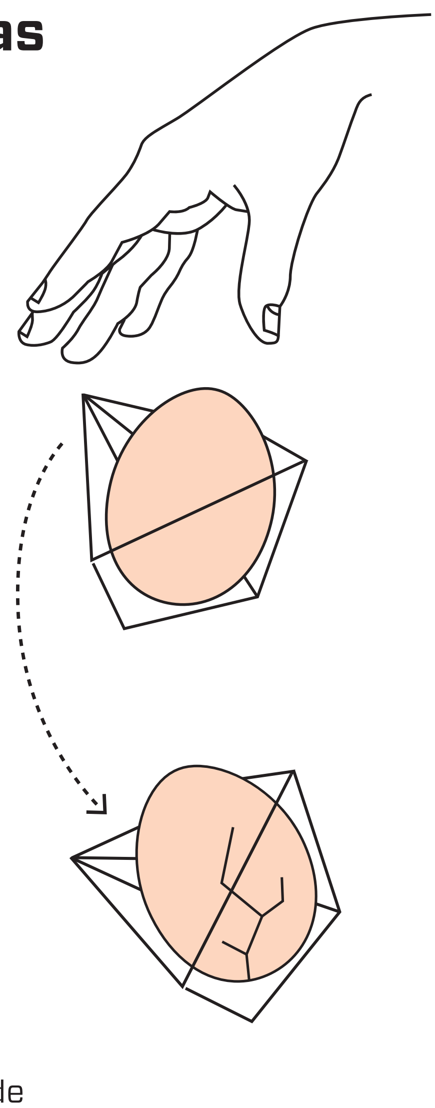
Design & Materials

The Container:
Considering the limited number of Smart Eggs in each kit, participants are encouraged to measure the egg before creating their container. Every container must be able to open and close securely around the egg. Because of the egg shape, container shape, and weight distribution, it will all rotate in the air, so consider how the container will land upon impact. A parachute-type design helps slow down how fast the smart egg falls by using air resistance, but this classic design may not be as effective when the egg is dropped from a low height.

Optional Materials:
Paper, cardboard, fabric, foam, balloons, tape, straws, tissue, rubber bands, ribbons. Yard-stick or tape measurer for measuring drop heights. Consider using recycled materials and be creative!

Design Challenge Ideas

Because the Smart Egg will not crack into a yolkey mess when "broken," participants are able to create, adjust, and refine their designs. The design challenge possibilities are endless!



- **Timed designs:** Containers can get pretty fancy if participants have unlimited time, but what happens if there is only 5 minutes or 10 minutes to design the container?
- **Change materials:** See what happens if certain build materials are withheld. Try without easier materials such as parachutes or balloons, tape or rubber bands.
- **Change drop height:** Begin drops at one foot off the ground and increase the drop height at one-foot intervals until the prototype fails.
- **Challenge teams:** Switch the challenge from individual designs to a team competition! The app will track several results on a separate tab, but to pump up the competition track your results manually where everyone can see on a scoreboard or chalkboard.

The Physics of Falling Objects

OMSI's Smart Egg Drop™ challenges participants to design a protective container that will cradle a Smart Egg to a safe landing. Understanding the physics of falling objects and the measurements the Smart Egg uses will help participants create the safest container as well as understand why the egg "survives" or "cracks."

Gravity is a universal force of attraction between all objects. Its magnitude is a function of the masses involved, the distance between them, and Newton's Gravitational Constant, G.

$$(F_{grav} = G * \frac{mass_1 mass_2}{distance^2})$$

The immense mass of Earth exerts a downward force towards its center on all masses within the gravitational field. Thus, free falling objects accelerate towards the center of the planet. The farther and longer they fall within this gravitational force results in a higher final velocity. **Velocity** is the speed of something in a given direction. Thus, the higher the object is, the faster it will be traveling when it hits the ground. We define this as having a higher **potential energy** (stored energy).

$$(PE_{grav} = \text{Height} * \text{Mass} * \text{Accel})$$

Based on the Earth's mass and size, a small object in Earth's gravitational field will always accelerate at a rate of 9.81 meters per second squared at ground level. Larger objects will affect the product of mass and increase this acceleration.

The potential energy of the egg becomes **kinetic energy** when the egg is released and then travels over the distance.

$$(E_k = \frac{1}{2} mass * velocity^2)$$

When the egg is stopped by hitting the ground, the kinetic energy in the falling egg transforms into the **force of impact**. This occurs first on the egg's container and then on the shell of the egg inside the container. How much of the impact force is absorbed by the container and then the egg will determine the outcome of the egg drop. If the container decelerates the egg enough, then the force of shell's molecules binding it together will be stronger than the forces deforming it, and the egg will remain intact.

As the egg container falls, potential energy is transferred to the shell as the egg container decelerates to zero and it hits the floor. The resulting forces will act on both the egg and container as it lands. The sum of these should equal the original potential energy due to **Conservation of Energy**.

One way to lessen the impact force on the egg is to reduce the speed of the egg's descent (i.e. parachutes use the friction of additional air molecules to oppose or slow down motion).

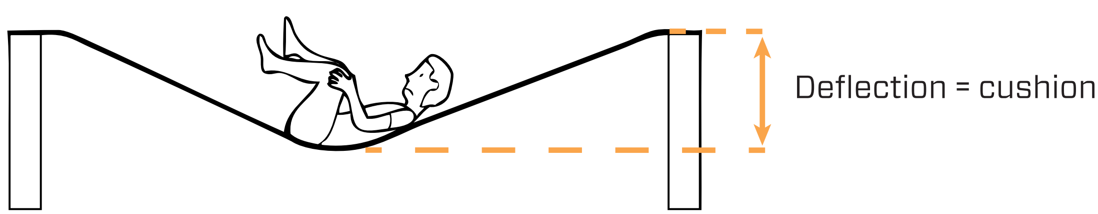
Another way to lessen the impact force is to diffuse the impact over time (the same way safe parkour landings are often followed by a somersault), or in the case of the Smart Egg Drop™, by absorbing some of the force at the container or egg boundary by adding a cushion between the egg and the point of impact. This is where **angular momentum** also comes into play (especially when considering how to design and secure an egg to its carrier/container/prototype). Because the egg is not round, it will begin to spin as it falls due to different resistances to air on different parts of the egg. This can affect both the part of the egg that touches first, (some parts of the shell are more resilient) and the impact velocity of that part as it may be spinning towards or away from the ground.

When will an egg break?

As previously stated, an egg falls at a constant acceleration of 9.81 m/s2. Because it is always accelerating, the point where it hits the ground is the egg's maximum velocity. As the egg hits, its velocity is reduced to zero. This is negative acceleration, or deceleration. If the egg hits a hard surface with little or no cushion, the velocity goes from maximum to zero very quickly. This massive deceleration is measured in **Gravitational Force** (g).

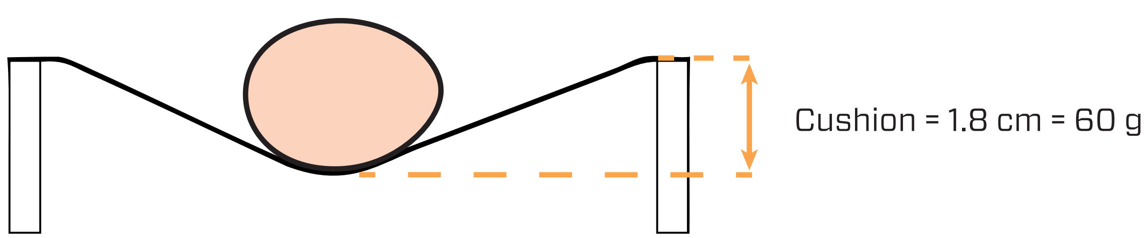
How is cushion related to deceleration?

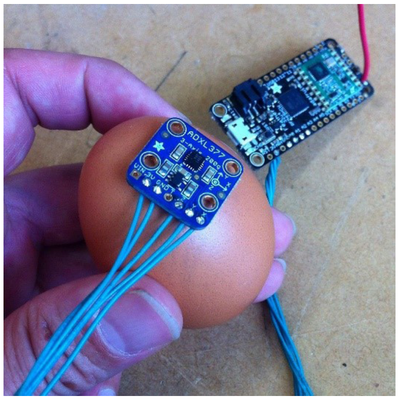
The trampoline below shows the rubber stretching, absorbing impact, and providing cushion for the gymnast. More cushion reduces the forces at impact and reduces the stress on the gymnast's body. Similarly, the more cushion you provide your egg the less stress as the egg as it hits the ground.



How much cushion is needed to protect the egg?

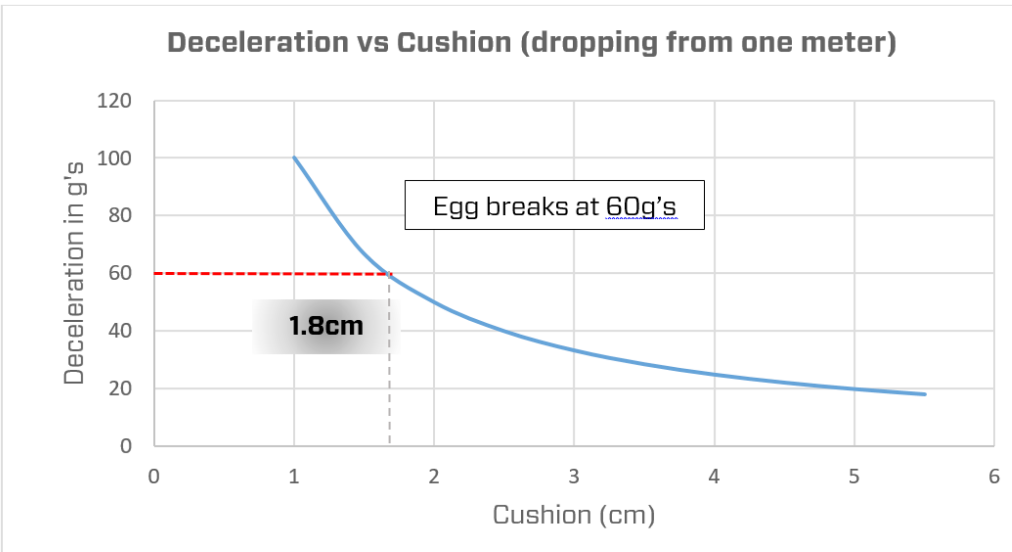
You need enough cushion to reduce the deceleration below 60 g. Below is a picture showing how much cushion is needed to keep an egg from cracking when dropped from one meter. The graph shows that at least 1.8 cm of cushion is needed. Any less cushion and the egg breaks.





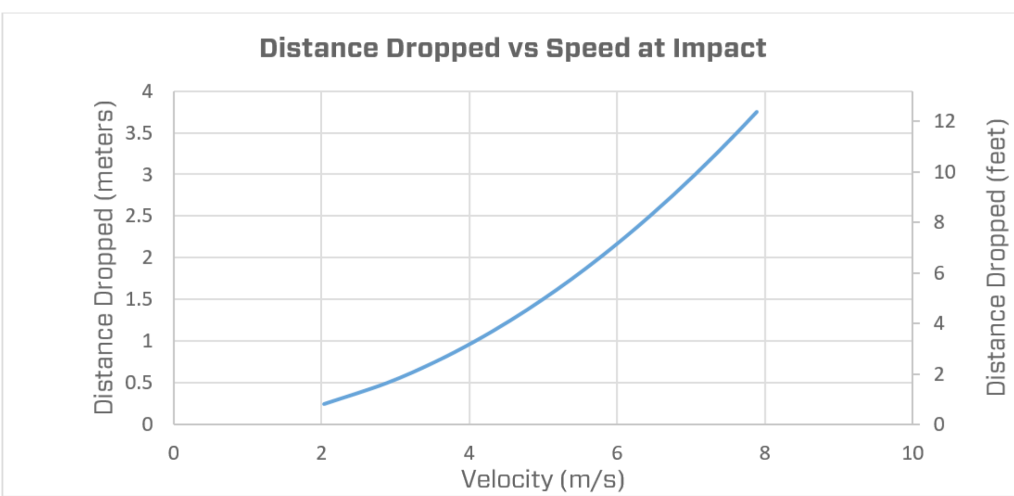
OMSI performed tests with an accelerometer and found that an egg cracks as it decelerates at more than 60 g or 60 times the normal gravitational force. Some type of cushion is needed to protect the egg during its deceleration phase on impact to keep it below 60 g.

Picture | Accelerometer glued to an egg for measuring the deceleration when an egg breaks.



Graph A | Deceleration vs cushion for an egg dropped from a distance of one meter

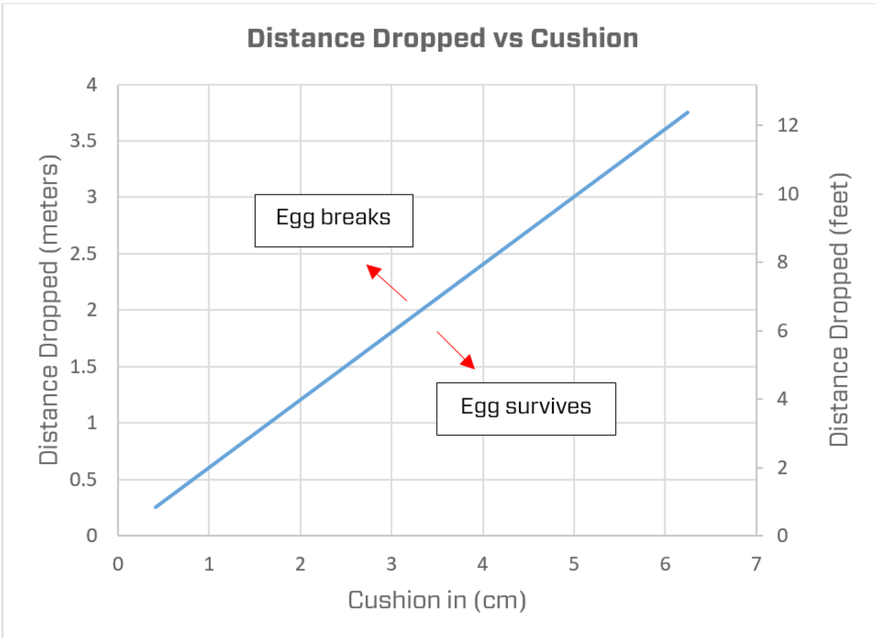
As an egg falls farther, its velocity increases. The next graph shows how velocity increases the higher the egg is dropped. The velocity is shown right before it hits the ground; that is, right before impact!



Graph B | Distance Dropped vs Speed at Impact

The equation for the final velocity of an egg is determined by the distance the egg is dropped and gravity's acceleration (9.8m/s2). The higher the egg is dropped the faster it is moving when it hits the ground.

$$velocity = \sqrt{(2 * acceleration * distance)}$$



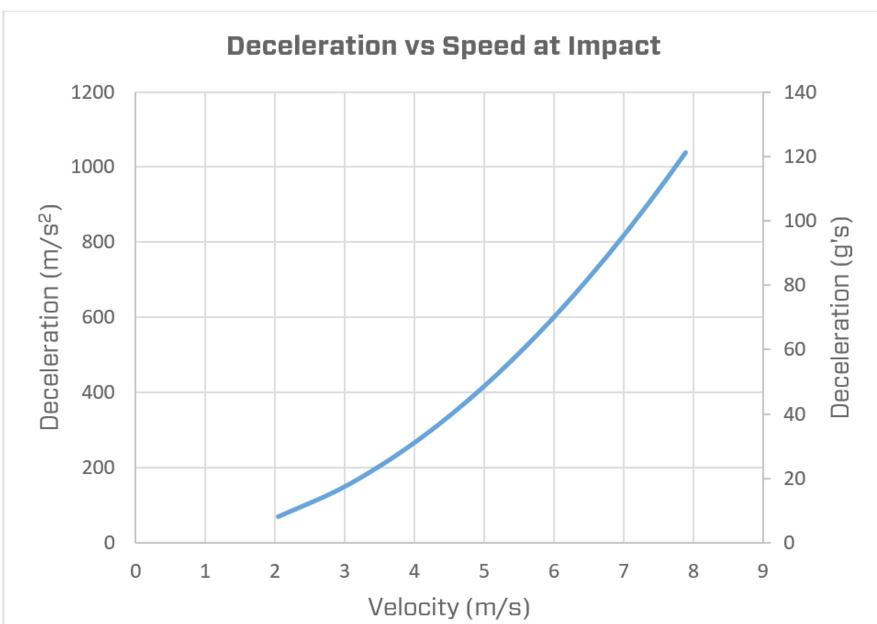
Graph C | Distance Dropped vs Cushion

As velocity increases, more cushion is needed to lower the egg's deceleration. Graph C shows how cushion needs to increase the higher the egg is dropped. This is because the egg's speed increases the higher the drop.

Finally, the deceleration is calculated based on the velocity and cushion.

Graph D shows velocity vs deceleration given a constant cushion of 3cm. This graph shows deceleration in both m/s2 and g's. The equation relating the two is given by:

$$g's = \frac{acceleration}{9.8(\frac{m}{s^2})}$$



Graph D | Deceleration vs Speed at Impact

The equation relating deceleration, cushion, and velocity is as follows:

$$deceleration = \frac{velocity^2}{2 * cushion}$$

Smart Egg Technology

We have packed a lot of technology in the Smart Egg. There are two accelerometers, a microcontroller, a Bluetooth radio transmitter, and a lithium battery inside each egg.

The first accelerometer is very sensitive and its job is to sense free fall. These are the same accelerometers used in game controllers to sense movement. Within fractions of a second, the accelerometer senses when the egg is in free fall. The accelerometer reads 0 g's in free fall. The second accelerometer senses the larger deceleration at impact. It has a sensitivity of +/- 200 g. Once the egg hits the ground, a microcontroller records the impact (deceleration), the time in free fall, and whether the egg was thrown or dropped. The microcontroller transmits the data over Bluetooth radio. The data is displayed on a web browser, and sounds and graphics are generated depending on the egg's survival.