SN EDUCATOR GUIDE

June 24, 2017

Flamingos' Bones Favor One-Leg Stance

Cross-Curricular Discussion

After students have had a chance to review the article "Flamingos' bones favor one-leg stance," lead a classroom discussion based on the questions that follow. You can copy and paste only the questions that apply to your classroom into a different document for your students.

To get your students moving and thinking about related concepts before the discussion, have them try some of the "Other Fun Center of Gravity Activities" toward the end of the Center of Gravity Experiment from Mississippi's Department of Education.

Physical Sciences
Discussion Questions:

1. **What is the center of mass, or center of gravity, of an object (these terms may be used interchangeably when the gravitational field is uniform)?** [*The center of mass, or center of gravity in a uniform gravitational field, is the point within an object where half of the object's mass is to the left of that point and half to the right of it, half of the object's mass is above that point and half is below it, and half of the object's mass is in front of that point and half is behind it. Thus it is the averaged center of the object's mass. The center of mass may not be the actual center of the object—for example, if one side of the object is especially heavy, the object's center of mass will be closer to that side. The force of gravity pulls directly downward from an object's center of mass.*]

2. **If gravitational force is pulling downward on the center of mass of an object but the object does not accelerate downward, what might be keeping the object from falling?** [*Some upward force must be supporting the object, pushing or pulling the object upward to oppose the downward pull of gravity. Examples of a supporting force include:*
   - *An upward force from a table on which the object is resting*
   - *Upward forces of rockets or aircraft*
   - *The upward buoyant force of a less dense object floating in a denser fluid*
   - *Upward force from an overhead string, rope, or hook pulling up on the object.*]

3. **For an object to be stable against tipping or falling over, where must the upward supporting force be applied, relative to the object's center of mass?** [*The upward supporting force must be directly above the object's center of mass for the balance to be stable. If the supporting force is above the center of mass but off to the side, the object will want to swing until its center of mass is directly below the supporting force. An object in this position has unstable balance. If the supporting force is below the center of mass but is not lined up directly below it, the object will tend to tip or fall over so that the center of mass would move lower. An object in this position also has unstable balance.*]

Extension Prompts:

4. **Which situation is more stably balanced, an apple being held by a supporting force pushing upward on the center of the bottom (like a finger), or an apple being held up by a supporting force pulling upward on the stem on top? Why?** [*If the upward supporting force is applied to the stem at the top of the apple, the center of mass is directly below the upward force and the apple is stable. If the finger is supporting the apple, the upward supporting force is below the center of mass, so the apple is not stable. In general, if nothing prevents a stationary object from lowering its center of gravity, then it will move to do so.*]

5. **What are the differences between objects that are stable (in stable equilibrium), neutrally stable (in neutrally stable equilibrium) and unstable (in unstable equilibrium)?** [*If an object moves and experiences forces that push it back to its original position, it is in stable equilibrium; a simple example is a ball resting at the bottom of a spherical bowl. If an object moves and does not experience forces that push it back to its original position or that push it further from its original position, it is in neutrally stable equilibrium; a simple example is a ball on a flat surface that is pushed slightly to one side and then remains still. If an object moves and experiences forces that push it further away from its original position, it is in unstable equilibrium; a simple example is a ball sitting on top of a spherical hill. If it is pushed to one side, it will move further away and cannot return to its original position.*]

Physical Sciences Question Bank

What is the center of mass, or center of gravity, of an object (these terms may be used interchangeably when the gravitational field is uniform)?

If gravitational force is pulling downward on the center of mass of an object but the object does not accelerate downward, what might be keeping the object from falling?

For an object to be stable against tipping or falling over, where must the upward supporting force be applied, relative to the object's center of mass?

Which situation is more stably balanced, an apple being held by a supporting force pushing upward on the center of the bottom (like a finger), or an apple being held up by a supporting force pulling upward on the stem on top? Why?

What are the differences between objects that are stable (in stable equilibrium), neutrally stable (in neutrally stable equilibrium) and unstable (in unstable equilibrium)?

Engineering and Experimental Design

Discussion Questions:

1. **Define the center of buoyancy of an object floating on a liquid. For a ship on the ocean to be stable, where should the center of mass be relative to the center of buoyancy? In practical terms, where should heavy supplies, equipment or pirate treasure be stored?** [*The center of buoyancy of a floating object occurs at a point where the center of mass of the displaced liquid would lie. The center of mass should*

be directly below the center of buoyancy—generally the further below it is, the more stable the ship will be. A more in-depth explanation is that the metacenter, the point where the vertical buoyancy force and the centerline of the tilting object intersect, must be above the center of gravity for the object to be stable. If the object is unstable and its center of buoyancy shifts toward the higher side, the metacenter where the vertical line of buoyant force and the tipping centerline of the object intersect will be below the object's center of mass. This method of achieving stability does not apply to an object like a submarine that is completely immersed in a fluid, since the center of buoyancy would not shift its relative location within the tipping object.
Practically, this means that to make the center of mass as low as possible, heavy supplies, equipment or pirate treasure should be stored in the lowest compartments of the ship.]

2. **For an aircraft to be stable, where should the center of mass be relative to the center of aerodynamic lift (central point at which upward supporting aerodynamic forces on the wings act)?** *In practical terms, what does that mean for where the luggage should be stored?* [*The center of mass should be directly below the center of lift. Heavy luggage should be stored as low as possible, just as with ships.*]

3. **Which is more stable, a sports car low to the ground, or a tall SUV?** [*The sports car has a much lower center of gravity and is more stable. Tall SUVs with a higher center of gravity are more prone to turning over in road accidents.*]

4. **How well could a helicopter fly upside down, if the rotor were turning in the right direction to exert an upward force?** [*It would be unstable—the upward supporting force exerted on the rotor would be below the helicopter's center of mass, so the helicopter would want to flip over. If the helicopter flipped over in this case, the rotor (turning in the direction to exert an upward force when it was on the bottom of the helicopter) would then be rotating in such a direction to pull the helicopter downward.*]

5. **Are these stable, neutrally stable, or unstable? Why?**
   - **Flamingo standing on one leg**
   - **A human standing up**
   - **A very curved banana balancing on a chair (concave side down)**
   - **Segway scooter**
   - **Rocket taking off (ignore the fins and aerodynamic forces)**

   [*All are unstable, except the banana. For the unstable scenarios, the center of mass is above the point at which an upward supporting force is applied—the ground for the flamingo, human, and Segway, and the rocket engine for the rocket. The center of mass of a very curved banana is in empty space below the concaved side (not actually on the banana itself). When the banana is balancing on a chair, the supporting upward force, which is from the chair, would be above the center of mass.*]

6. **How can fins on the back make a rocket stable when it is flying through the atmosphere?** [*If the rocket starts to tilt to the side, air hitting the fins applies a corrective force to push the rocket back toward flying straight, just as a weather vane points into the wind because of the large fins on the other end of the weather vane.*]

7. **How do unstable objects or animals, like humans or balancing flamingos, keep from falling over?** [*There must be a brain, computer, or other feedback control system. The control system senses when the object starts to tilt one way, and applies a corrective force in the opposite direction. Without even consciously thinking about it, flamingos and humans use their muscles to counteract any swaying and stay upright. (You don't usually notice that when you are standing on two feet, but try standing on one leg as long as possible, and you will notice your constant muscle movements to compensate in one direction or another.) The Segway has a computer that senses which way is up, and torques the wheels one way or the other as necessary to avoid falling over. The rocket has a guidance system that senses which way is up and tilts the engine back and forth as necessary to avoid tipping over. Model rockets and some real rockets use fins and hence do not require a guidance system for stability.*]

8. **Why might it be desirable to design fighter jets to be neutrally stable or unstable? Are passenger planes built to be stable?** [*Passenger planes are designed to be very stable so they won't flip over, even if the engines stop working. Fighter jets are designed to be able to make very fast maneuvers, including flipping over. If a fighter were very stable (center of lift well above the center of gravity), the pilot would have to apply extreme forces to overcome that stability, which would be difficult for maneuvering quickly. To compensate for the lack of inherent stability, the computer in a fighter constantly senses the fighter plane's tilt relative to the ground and applies forces to keep it from flipping over when the pilot does not want it to.*]

Engineering and Experimental Design Question Bank

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For an aircraft to be stable, where should the center of mass be relative to the center of aerodynamic lift (central point at which upward supporting aerodynamic forces on the wings act)? In practical terms, what does that mean for where the luggage should be stored?

Which is more stable, a sports car low to the ground, or a tall SUV?

How well could a helicopter fly upside down, if the rotor were turning in the right direction to exert an upward force?

Are these stable, neutrally stable, or unstable? Why?

- Flamingo standing on one leg
- A human standing up
- A very curved banana balancing on a chair (concave side down)
- Segway scooter
- Rocket taking off (ignore the fins and aerodynamic forces)

How can fins on the back make a rocket stable when it is flying through the atmosphere?

How do unstable objects or animals, like humans or balancing flamingos, keep from falling over?

Why might it be desirable to design fighter jets to be neutrally stable or unstable? Are passenger planes built to be stable?