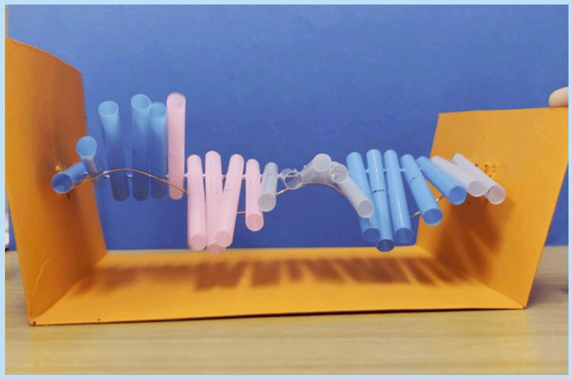
Dragonfly Flight: Waves and Wing Movement

SPS SOCK 2024

This demonstration utilises rope and a DIY wave model to show superposition of waves, phases, and constructive and destructive interference. It centres a discussion on dragonfly flight, specifically how they have the ability to modify their wing strokes. Dragonflies' front and hind wings move with a 90˚ phase shift to enhance total thrust.



PRESENTER BRIEF

The presenter should have an understanding of waves, phases, wave superposition, and constructive and destructive interference. Recommended reading for presenters is listed in *Additional Resources*. For Demo A, pre-cutting the straws before you bring them to a classroom may be helpful. A note for Demo B is that the trick is to get the frequency consistent.

Number of Participants: 10 to 15
Audience: Elementary to High School
Duration: 10-20 minutes
Difficulty: Level 1

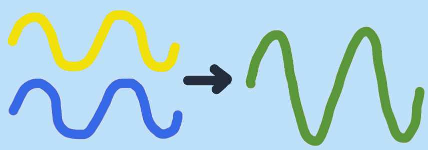
MATERIALS REQUIRED

- Demo A:
    - Construction paper or cardstock
    - Paperclips or wire (2 lengths)
    - Plastic straws
    - Pushpin
    - Marker
- Demo B:
    - Rope or telephone wire
- Demo C:
    - Students!

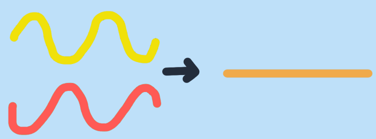
VOCABULARY

Waves: a disturbance or change in physical quantity that transports energy or information from one point to the next

Wavelength: the distance between two peaks of a wave
Superposition: two waves combine when they overlap in space
Phase: location or timing of a point within the cycle of a repetitive wave
Phase shift: the difference in the location or timing of two points in a wave
Constructive interference: when two waves that are in phase add together resulting in a larger amplitude



Destructive interference: when two waves that are out of phase add together resulting in a smaller amplitude

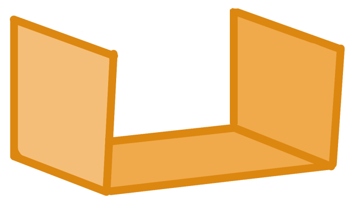


ADDITIONAL RESOURCES
This demo pairs well with *Dragonfly Colours: Thin-Film Interference* and *Dragonfly Sight: UV Light and Electromagnetic Waves* from SPS SOCK 2024. *Transverse and Longitudinal Waves* from the SPS Demonstrations website is another supplement.

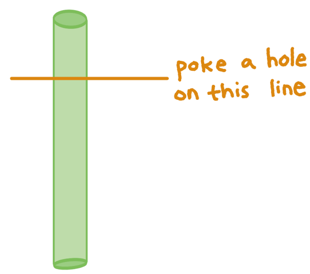
Some additional videos are:
- ‘Flight’ section of Dragonfly Biology
- Video on Electric Ornithopters

Current literature for presenters:
- Flight of the dragonflies and damselflies (Bomphrey et al., 2016)
- Aerodynamic characteristics along the wing span of a dragonfly *Pantala flavescens* (Hefler et al., 2018).

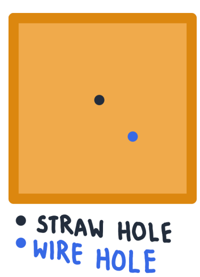
Setup:
Demo A: What is a Wave?
1. Fold a piece of cardstock in half lengthwise (hot dog). Fold each short end of the “hot dog” in about 7 cm. Your paper should look like a very blocky U-shape.
    a. Thin cardboard may be used in place of cardstock.



2. Cut straws into 3-inch pieces.
3. Lining all the straws up, use a marker to draw a line 3/4 (approximately 2.5 inches) of the way up each segment of straw. Using a pushpin, make a hole in each straw along the line you drew–make sure you push the pin in one side and out the other.
    a. Wiggle the pushpin around to make the hole a little bigger.
    b. This demo works best if the hole is perpendicular to the straw.



4. Cut a piece of wire a little bit longer than the length of your cardstock.
    a. If wire is unavailable, an unfolded paper clip may be used.
5. Thread all the straw segments onto the wire.
6. Mark points on the vertical ends of your cardstock as seen below. Make sure that the straw hole is high up enough that straws will not touch the bottom of the cardstock.



7. Poke the ends of your straw wire through the straw holes. Bend the ends of the wire and tape them to the cardstock to secure the wire.
8. Cut a length of wire 1.5 times the length of your cardstock. Wrap it around a thick pen to create a corkscrew.
    a. Markers are a good thing to wrap the wire around!
9. Put one end through the wire hole. Bend a little bit at one end to secure it. The other end is your handle.
10. Ensure the longer part of the straws are on top of your wave wire.
    a. You may need to stretch your corkscrew out so that the straw pieces can lay perpendicular to it.
11. Turn the handle to make your wave propagate.

12. It is possible to repeat steps 1-11 and build waves that can be stacked on one another. If this is done, fold over the vertical ends of the cardstock to form a base that can be stacked on.

Demo B: Wave Superposition

1. Wave: Have one person shake a rope up and down from one end.
2. Constructive interference: Have two people shake a rope up and down, one person at each end. Have them sync their shakes so the waves add together.
3. Destructive interference: Have two people shake a rope up and down, one person at each end. Have them sync their shakes so the waves cancel in the middle.
    a. This video demonstrates the idea.

Demo C: Phase differences

1. Have students get into pairs and flap their arms.
2. Ask them to flap their arms in-phase.
3. Ask them to try and flap with phase-shifts of 90-degrees: when one person's arms are up, the other person's arms are out to their side (perpendicular).
4. Up the stakes! Turn this into a competition! How synced up can students be? Which pair is flapping the most in-phase? Can they flap faster and still be in-phase? Have students turn so they cannot see their partner. Can they flap in-phase? At a 90-degree phase-shift?

Physics and Explanation:

Elementary (ages 5-10):

A **wave** is the form energy takes when it travels. Some examples of waves are ocean waves, sound waves, light waves, and radio waves. When a wave moves in a specific direction, the word we use for this is **propagation**.

> *Have Demo A set up already. Turn the handle and show how a wave moves. Ask students what kind of energy different kinds of waves transmit. Ask students to point out the direction the wave is moving.*

We describe waves with many words. A **wavelength** is the distance between the two closest matching points on a wave - think about the peak of one ocean wave to the peak of the one following it. The **frequency** is how stretched or squished the wave is. Think about a slinky that you stretch–how many coils are in a certain length? Another way we talk about waves is **amplitude**, or how 'tall' a wave gets.

> *Draw waves of different frequencies, wavelengths, and amplitudes. Do step 1 of Demo B. Have students shake the rope at different speeds and strengths to demonstrate different frequencies and amplitudes.*

Waves can be added together. We call this **superposition**. The shape of the final wave depends on how the two waves line up. If the two waves are exactly the same, the wave will get two times bigger.

Draw two in-phase waves and the resulting wave when they are added. Do step 2 of Demo B.

If the two waves don't match up or are exactly opposite, they cancel out. It is like you are subtracting one wave from the other.

Draw two out-of-phase waves and the resulting wave when they are added. Do step 3 of Demo B.

Dragonflies' front and back wings beat in wave patterns that don't match up completely. This means that the back wings can catch the air the front wings push down, which makes them go faster!

Do Demo C. Play on the humour and game part of this. Ramp up the competition!

- What is a wave?
- Waves can add together.
- Waves can match up or be unaligned.

Middle School (ages 11-13) and general public:

A **wave** is a disturbance or change in something that transports energy or information. Some examples of waves are ocean waves, sound waves, light waves, and radio waves. A wave propagates, or travels, in a specific direction. A **wavelength** is the distance between two closest matching points on a wave - think about the peak of one ocean wave to the peak of the one following it. We describe waves with **frequency**, the number of waves that pass a point in a certain amount of time. Another way we talk about waves is **amplitude**, or how 'tall' a wave gets.

Have Demo A set up already. Turn the handle and show how a wave moves. Ask participants to point out a wavelength and the direction the wave is propagating in. Do step 1 of Demo B. Demonstrate different frequencies and amplitudes.

A **phase** is the location or timing of a point within the cycle of a repetitive wave. When you have two or more waves, they can be **in phase** or **out-of-phase**. In-phase waves line up exactly, and out-of-phase waves do not. When waves are out-of-phase, we describe them with a **phase shift**, how much they are shifted away from one another. Phase shifts are measured in degrees or radians. A phase shift of 90 degrees means one wave is 'leading' the other. A phase shift of 180 degrees makes two identical waves mirror images of one another. Where one wave peaks, the other is at a trough. Dragonfly's front and back set of wings beats at a phase shift of 90 degrees or 180 degrees for maximum efficiency. This gives the back wings a 'boost' of air. Out-of-phase flapping is used for steady flight and hovering. Dragonflies can modify the phase of their wing strokes to control how much force they are creating–the wings flapping **in phase** creates the most vertical force. So, flapping in phase is used for takeoff.

Draw some waves representing each phase shift. Ask participants to vote on what each phase shift is. If presenters have more than one setup for Demo A, it can be used to *demonstrate phase shifts. Do Demo C. Play on the humour and game part of this. Ramp up the competition!*

When more than one wave crosses a point, they get added together. We call this **superposition**. Superposition changes the amplitude of the final wave. If two waves are **in phase**, where they match up completely, then **constructive interference** occurs. The resulting amplitude of the wave increases, but the wavelength stays constant. It is the sum of the two in-phase waves.

Do step 2 of Demo B.

If two waves are out-of-phase, where the peaks and troughs don't match up, then we see **destructive interference**. The resulting amplitude is smaller. It is the difference of the two out-of-phase waves. If the two out-of-phase waves line up exactly oppositely, we don't see any wave in the places they intersect.

Do step 3 of Demo B.

- What is a wave?
- What is wave superposition?
- What are constructive and destructive interference?

High School (ages 14+):

A **wave** is a disturbance or change in physical quantity that transports energy or information from one point to the next point. Some examples of waves are ocean waves, sound waves, light waves, and radio waves. A wave propagates, or travels, in a specific direction. A **wavelength** is the distance between the two closest matching points on a wave - think about the peak of one ocean wave to the peak of the one following it. We describe waves with **frequency**, the number of waves that pass a point in a certain amount of time. Another way we talk about waves is **amplitude**, the distance between the peak of a wave and its equilibrium point.

Have students build Demo A. Ask participants to turn the handle and show how a wave moves. Ask students to point out a wavelength, and in what direction the wave is propagating. If Demo A is done in pairs or groups, different groups may make waves of different amplitudes and frequencies. Ask them to make comparisons between each others' waves. Do step 1 of Demo B. Demonstrate different frequencies and amplitudes.

A **phase** is the location or timing of a point within the cycle of a repetitive wave. When you have two or more waves, they can be **in-phase** or **out-of-phase**. When waves are out-of-phase, we describe them with a **phase shift**. We measure phase shifts in degrees or radians. A phase shift of 90 degrees means one wave is 'leading' the other. A phase shift of 180 degrees makes two identical waves mirror images of one another. Where one wave peaks, the other is at a trough. Dragonflies can modify the phase of their wing strokes to control how much force they are creating–the wings flapping in phase creates the most vertical force. Dragonfly's front and back set of wings beats at a phase shift of 90 degrees or 180 degrees for maximum efficiency. The phase shift gives the back wings a 'boost' of air in a mechanism called 'counter-flapping'. When the forewings flap, they create a leading-edge vortex that the hindwing anticipates and catches. This means that the hindwing captures the energy that is ‘wasted’ by the forewing, decreasing the energy the dragonfly uses and increasing its lift. The out-of-phase mechanism is used for steady flight and hovering. Dragonflies can modify the phase of their wing strokes to control how much force they are creating–the wings flapping in phase creates the most vertical force. So, flapping in phase is used for takeoff.

> *Draw some waves representing each phase shift. Ask students to vote on what each phase shift is. Students may use their Demo As to visualise phase shifts in small groups. Do Demo C. Play on the humour and game part of this. Ramp up the competition!*

When multiple waves cross a point simultaneously, they get added together. This is a principle called **superposition**. There are two conditions for superposition. First, the superimposed waves need to be the same type of wave. Electromagnetic waves and mechanical waves cannot be in superposition. Second, the medium the waves travelling in must behave linearly–when you double the force on a particle, the displacement of the particle is also doubled. When two waves are **coherent**, they have the same frequency and constant phase difference, and the resulting superimposed wave is another wave with the same frequency. Superposition changes the amplitude of the final wave. **Constructive interference** occurs when two waves are **in phase**–where they line up completely. The resulting amplitude of the wave is larger. It is the sum of the two in-phase waves.

> *Do step 2 of Demo B.*

We see **destructive interference** when two waves are out-of-phase, where the peaks and troughs don’t match up. The resulting amplitude is smaller than the original amplitudes of the waves. It is the difference of the two out-of-phase waves. If the two out-of-phase waves line up exactly oppositely, we don’t see any wave in the places they intersect.

> *Do step 3 of Demo B.*

- What is wave superposition?
- What are the conditions needed for wave superposition?
- What are constructive and destructive interference?