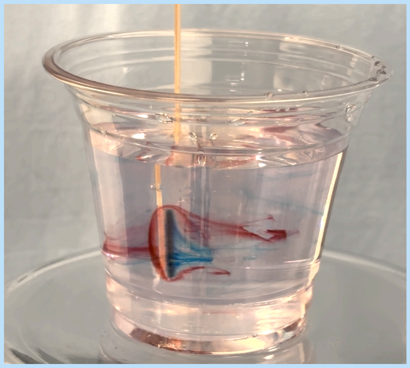
Dragonfly Flight: Vortices

SPS SOCK 2024

This demonstration allows participants to view the vortex that turning wings can create. The discussion is centred on fluid dynamics of insect flight, particularly dragonfly flight.




PRESENTER BRIEF

This demonstration requires some background knowledge on aerodynamics and fluid dynamics.

Number of Participants: 5
Audience: Middle to High School
Duration: 30 minutes
Difficulty: Level 2

MATERIALS REQUIRED

- Large plastic cup (clear)
- Wooden coffee stirrers
- Glycerin
- Syringe
- Tongue depressors
- Food dye
- Double sided tape
- Tape

VOCABULARY

Vortex: whirling fluid or air
Lift: a force from the interaction of fluid and an object, perpendicular to the direction the flow is moving in; lift often points upwards
Wake: an area of disturbed flow downstream of an object moving through a fluid
Pressure: force exerted on an area by something in contact with it; in terms of wings, the force exerted by air particles on the wing
Leading edge vortex: a type of airflow over the surface of a wing that can help create lift
Aerodynamics: the study moving air and how it interacts with solid objects
Phase: location or timing of a point within the cycle of a repetitive wave
Fluid dynamics: the study of how liquids and gases move and interact with things

ADDITIONAL RESOURCES

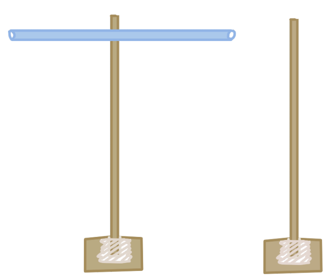
This demo pairs well with *Dragonfly Flight: Waves and Wing Movement* from SPS SOCK 2024.

Some additional resources are:
- Visual of flight fluid dynamics
- APS demonstration: Vortex topology of a flapping wing
- Dragonfly flight in slow motion
- University of Virginia Flow Simulation Research Group Video

Current literature for presenters:
- Flow visualization and unsteady aerodynamics in the flight of the hawkmoth, *Manduca sexta* (Willmott et al., 1997)
- Aerodynamic interference depends on stroke plane spacing and wing aspect ratio in damselfly model wings (Lehmann and Wehmann, 2020)
- Flight of the dragonflies and damselflies (Bomphrey et al., 2016)
- Aerodynamic Performance of a Dragonfly-Inspired Tandem Wing System for a Biomimetic Micro Air Vehicle (Salami et al., 2022)

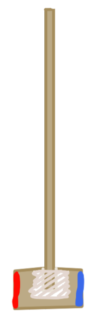
Setup:

Making paddles:
1. Cut the wooden tongue depressor into 1.5 inch long parts.
2. Cut a small amount of double-sided tape and use it to stick the coffee stirrer onto the centre of the piece of tongue depressor. Secure with tape.
3. Two paddles may be connected by cutting slits in a straw and pushing the coffee stirrers through the slits.
    a. A handle may be added to one paddle in the same fashion, or by taping another coffee stirrer perpendicular to it.



Setup:
1. Fill a plastic cup 3/4 of the way with glycerin.
2. There are two ways of adding food dye to the paddle:
    a. Remove the stopper of the syringe. Put a few drops of food dye into the syringe. Stick the paddle into the glycerin. Use the syringe to put dye onto the short edges of the paddle while it is in the glycerin.
        i. This method ensures that all the food dye in the glycerin is moving with the vortex.

b. Add a drop of food dye (or less) along the short edges before it is put into the glycerin.
    i. This method requires less finagling, but may leave trails of food dye in the glycerin.



Demo:

1. Turn the paddle(s) with dye on it in a circle when it is in the glycerin.
2. Use different colours of food dye on one paddle, or different colours of food dye on multiple paddles. To show how multiple vortices may interact, or how a vortex will interact with multiple wings.
3. Turn the paddle(s) in different directions.

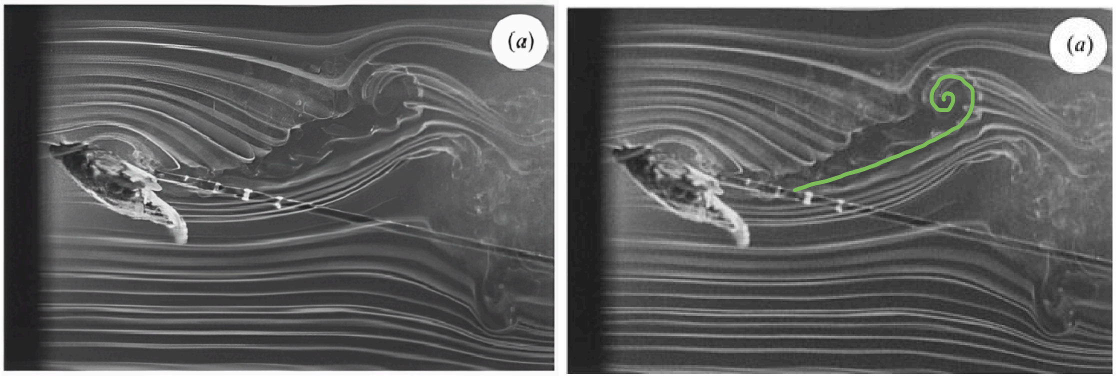
Physics and Explanation:

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

Flying insects don't follow the same aerodynamic laws as airplanes. Using these aerodynamic laws, some scientists have tried to show that bees cannot fly. However, we see bees, dragonflies, butterflies, and moths zip around daily. So how do they do it? Many years ago, some researchers used smoke to visualise how air moved around insects. This was **fluid dynamics** research, looking at how liquids and gases move and interact with things. They discovered something we now call leading-edge vortices.

The airflow on top of an insect wing does not flow smoothly around it like it would around the wing of an airplane. Instead, the air creates a circle on top of the wing. The air rotates inside this circle, creating a **vortex**. The airflow rotates at the front of the wing, which is why it is called a **leading edge vortex**. In the middle of the vortex, airflow is rotating very fast, creating an area of low **pressure** at the top of the wing. The area under the wing has higher pressure than the area above the wing. This pressure difference lifts off the wing.

Look at the image below. Can students point out the leading edge vortex? Where is the centre of the vortex? Can they see the rotation? For presenters: this figure is from 'Flow Visualization and Unsteady Aerodynamics in the Flight of the Hawkmoth, Manduca sexta'.



In dragonflies, we don't just see **fluid dynamics** in studying how flapping wings interact with the surrounding air but also because of how the wings interact with each other. Because dragonflies have four wings, airflow over the back wings is influenced by how the front wings move the air around them.

Whether or not the wings beat up and down in sync or out of sync also impacts how the air flows over them. The current theory is that the back wings expect the leading edge vortex the front wings create. When the front wings flap, they leave that vortex or **wake** behind in the air. When the front and back wings are out of sync, the back wings rotate in a way to intersect and capture the wake, which gives it an extra lift. We call this 'wake capture' or 'wing–wake interaction', and let the back wings capture the wasted energy from the front wings. This allows dragonflies to have very efficient flight. However, the wings need to be at that correct phase difference for it to occur.

Do the demonstration. Have students experiment with different paddle sizes and multiple colours of food dye. How does this change the interaction of the vortices? Ask students to write down a hypothesis for how each modification will impact the vortex interactions. Are their hypotheses correct?

- The principles that govern how insects fly are different to how planes fly.
- Leading edge vortices create lift that helps insects fly.
- The two sets of dragonfly wings interact with each other and the air.

High School (ages 14+):

Flying insects don't follow the same aerodynamic laws as airplanes. Using those aerodynamic laws, some scientists have tried to show that bees cannot fly. However, we see bees, dragonflies, butterflies, and moths zip around daily. So how do they do it? Many years ago, some researchers visualised how air moved around insects. They put moths in a wind tunnel and filled it with smoke to observe how the moths' wings changed how the air flowed around them. This was **fluid dynamics** research, looking at how liquids and gases move and interact with things. They discovered something we now call leading-edge vortices.

The airflow on top of an insect wing does not flow smoothly around it like it would around the wing of an airplane. Instead, the air moves into a circle on top of the wing. The air rotates inside this circle, creating a **vortex**. The airflow rotates at the front of the wing, which is why it is called a **leading edge vortex**. In the middle of the vortex, airflow is rotating very fast, creating an area of low **pressure** at the top of the wing. The area under the wing is comparatively high-pressure. This means the pressure on the bottom of the wing pushes up harder than the pressure on the top pushes down. This imbalance of forces lifts off the wing, allowing the insect to fly.

> *Look at the image in the general public explanation above. Can students point out the leading edge vortex? Where is the centre of the vortex? Can they see the rotation? For presenters: this figure is from 'Flow Visualization and Unsteady Aerodynamics in the Flight of the Hawkmoth, Manduca sexta'.*

In dragonflies, we don't just see **fluid dynamics** in studying how oscillating wings interact with the surrounding air but also because of how the wings interact with each other. Because dragonflies have four wings, airflow over the back wings is influenced by how the front wings move the air around them. The phase difference of the wings, whether or not they beat up and down in sync or out of sync, also impacts how the air flows over them. The current theory is that the back wings expect the leading edge vortex the front wings create. When the front wings flap, they leave that vortex or **wake** behind in the air. When the front and back wings are out of sync, the back wings rotate in a certain way to intersect and capture the wake, which occurs most efficiently at a phase difference of 90 degrees. This phenomenon, called 'wake capture' or 'wing–wake interaction', lets the back wings capture the wasted energy from the front wings and gives the insect extra lift. This allows dragonflies to have very efficient flight. However, the wings need to be at that correct phase difference for it to occur.

> *Do the demonstration. Can students describe the movement of the vortices? Have students experiment with different paddle sizes, more than one paddle, and multiple colours of food dye. How does this change the interaction of the vortices? Ask students to write down a hypothesis for how each modification will impact the vortex interactions. Are their hypotheses correct?*

- Leading edge vortices create lift that helps insects fly.
- When dragonfly wings beat at the correct phase difference, wake-capture (or wing–wake interaction) gives the dragonfly extra lift.