Flapping Wings

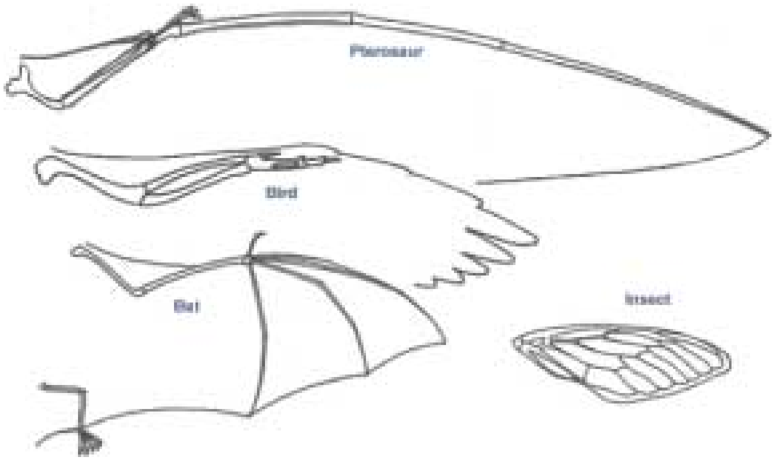
A Guide For Teachers

Flapping wing models called ornithopters can be a great learning activity for students. Building an ornithopter from kit instructions is a unique language lesson that teaches students to read for information and understanding. They'll also learn math, science, and technology skills through this hands-on experience. Students can carry out their own inquiry-based experiments comparing the ornithopter with real birds.

How it Flies

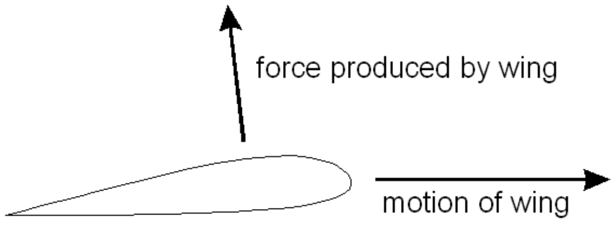
The first thing anyone asks when they see an ornithopter fly is, “How does it work?”. We’ve all wondered the same thing about birds too at one time or another. Since the ornithopter flies like a bird, we can answer both questions at the same time.

All flying creatures, and ornithopters too, have a stiff structure that forms the leading edge or front part of the wing. Birds have their wing bones at the leading edge. For insects, the veins of the wing are concentrated there. Ornithopters have a stiff spar at the leading edge. The rest of the wing is more flexible. It needs to be flexible so the wing can change shape as it flaps.



Wings of different animals all have a rigid structure at the front. The rest of the wing is more flexible.

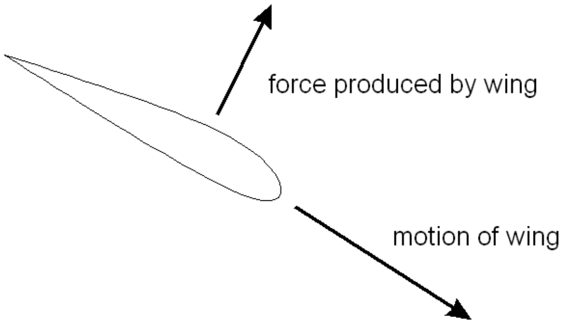
An airplane wing produces lift by moving forward through the air. This force, called lift, is what keeps the airplane from falling to the ground. The special shape of the wing, combined with the slight upward angle of the wing, causes air to be deflected downward. There is more pressure on the bottom of the wing than there is on the top. This difference in pressure produces lift.



Airplane wing in forward flight produces lift.

Notice that the force produced is not perfectly straight up. There is some “drag” which tries to hold the airplane back. It is counteracted by the propeller.

Birds flap their wings up and down. This motion is added to the forward motion of the bird’s body, so really the wings move diagonally. They move down and forward during the downstroke, and they move up and forward during the upstroke.

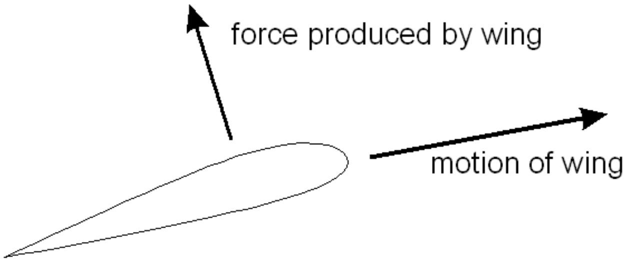


Bird wing in downstroke produces lift and thrust.

The downstroke is what keeps the bird going. The wing acts just like an airplane wing, but since it’s moving at an angle, the force it produces is at an angle too. The wing produces lift, to keep the bird up in the air, and it also produces thrust, to keep the bird moving forward. That’s why birds don’t need propellers.

The outer part of the wing has a lot of downward movement, but the inner part near the bird’s body simply moves forward along with the bird. Since the downward motion is greater toward the wingtips, the wing has to twist so that each part of the wing is aligned correctly with the local movement of the wing.

The upstroke is different from the downstroke, and its function can vary. In general, the upstroke produces lift by relying on the forward motion of the bird through the air. The inner part of the wing, near the body, produces most of the lift. The outer part of the wing, because of its sharp upward motion, can only hinder the bird’s flight. Birds solve this problem by partially folding their wings. Most ornithopters take a less subtle approach: more power!



Bird wing in upstroke produces lift and drag.

There are some common misconceptions about how birds fly. Books and encyclopedias often reiterate this incorrect information. Birds do not move their wings in a rowing motion or push backwards against the air as some people imagine. Some of the tiniest insects fly that way, but it would be inefficient for something as large as a bird. Many books illustrate how a bird's feathers separate to let air through during the upstroke. In reality, this only happens when birds are taking off or landing. The function is not to reduce air resistance, but to allow the feathers to act as individual airfoils, in effect providing some extra flexibility that's needed when the bird is in slow flight. At such times, the wings beat almost horizontally, and the upstroke function is changed. The outer feathers are angled to deflect air downward and produce lift during the upstroke.

Newton's Laws

Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction. This is another way of saying you can't exert a force without something to push against. The concept is easily demonstrated with a simple latex balloon. Blow air into the balloon, but don't tie it off. Then release the balloon. The balloon is made of an elastic material and it wants to contract. Therefore air is forced backward through the nozzle of the balloon. Pushing this air backward also causes the balloon to be pushed forward and it may travel very rapidly across the room.

A wing deflects air downward, much the same as the balloon ejects air. In this case, the equal and opposite reaction is the lift force or difference in air pressure above and below the wing. Therefore the lift produced by the wing can be accounted for by Newton's Third Law of Motion.

Often Bernoulli's Principle is incorrectly used to explain how an airplane wing produces lift. Bernoulli's Principle asserts that the faster airflow over the top of the wing exerts less pressure than the air beneath the wing, causing lift. The problem with Bernoulli's Principle is that it confuses cause and effect. The higher flow velocity above the wing does not "cause" the pressure difference. Rather, the deflection of air causes a partial vacuum above the wing, and the airflow speeds up as it moves into the already-established vacuum. You need the vacuum first to get the accelerated airflow.

Also be wary of any explanation that requires the wing to have a curved upper surface and flat bottom. Airplanes can fly perfectly well with symmetrical airfoils (curved on the bottom as well as on top). They can also fly upside-down.

Bernoulli’s Principle is more an observation of a phenomenon than an explanation of cause and effect. It was observed that higher velocity fluids tended to exert less pressure against surfaces they were flowing parallel to. The actual reason why this works in that the air molecules don’t collide with the surface as much when they are all traveling in one direction. So it really comes down to Newton’s Laws. Since Bernoulli’s Principle is so easily misunderstood and often explained incorrectly, it should not be taught in the primary grades. Newton’s Law is much simpler and easier for kids to grasp.

Learning Points for Each Kit

The Ornithopter Zone model kits are useful for teaching about bird flight. Building any of these kits will help your students develop many important skills. For example, building a kit from instructions will expand their ability to read for information and understanding. The hands-on project will greatly increase their ability to understand mechanical systems. You should always start with the Freebird kit, because it is the easiest to build. (Be prepared so that you can provide any needed assistance as students build the kits.) The other kits are more challenging, but they may be quite useful at the level of high school physics or above. Here are some specific learning points for each kit.

Freebird

This kit is the simplest demonstration of how birds fly. As the wing moves up and down, the simple structure changes shape. This maintains the correct angle of attack even as the wing moves up and down. The flexing in response to aerodynamic forces is called aeroelasticity.

There is a more subtle lesson here also. The Freebird’s simple crank imparts an asymmetric motion to the wings, which can prevent the Freebird from flying straight. We add weight to one wingtip to correct this problem. Why does this work? Because of inertia! When weight is added to a wing, the wing wants to flap through a smaller arc. That difference in motion between the two wings is what gives us the necessary steering force to compensate for the asymmetric motion imparted by the crank.

Funbird

Funbird is very similar to Freebird, but it has a staggered crank that imparts a more symmetrical wing motion. This should reduce the need for any weighting of wingtips. Funbird also teaches about Center of Gravity or balance point and how this affects the stability of an aircraft. Your students may notice that the Freebird wants to stall a little, especially toward the end of a flight. The Funbird is less likely to do this, because it has some extra weight up front. Students should also experiment by varying the length of the connecting rods (simply by adding some new holes to them). Lengthening the connecting rods should raise the thrust line of the model, causing it to nose dive or require more up angle in the tail. Shortening the connecting rods will cause the model to stall. (To compensate, you might flatten the tail angle, but the tail has to be bent up a little bit in order to maintain stability.)

Luna

Luna differs from the other kits in that the load on the wings is balanced. In the other kits, the rubber band must overcome the lift force on the wings in order to flap the wings downward. In the Luna, the left and right wings balance each other, so the amount of torque or force required to flap the wings is much less.
Luna also has a lighter wing loading. (Wing loading is the ratio of weight to wing area.) With a lower wing loading, it can fly much slower than the other kits and still produce enough lift to support its weight. There is a simple equation for this: Lift is proportional to velocity squared times wing area. If the Luna had twice the wing area of a Freebird and had the same weight, how much slower would it fly?

In both cases lift equals weight, so we can make the following computation:

$$v_f^2 \times A_f = v_l^2 \times 2A_f$$

$$v_f^2 = v_l^2 \times 2$$

$$v_f = \sqrt{v_l^2 \times 2}$$

$$v_f = v_l \times \sqrt{2}$$

where v = velocity, A = wing area, and subscripts f and l indicate Freebird and Luna.

Notice this does not take into account the ability of flapping wings to produce lift with no forward motion. Therefore the Luna may fly even slower than your prediction.

Seabird

The Seabird has a different wing structure from the other kits. This allows the angle of attack to change more linearly in response to variation in the lift force (air pressure gradient) on the wing. The wing span is much greater also. Can your students guess why the Seabird has a smaller size crank than the Funbird or Freebird kits? The smaller crank exerts a greater force at the connecting rod, allowing the same size rubber band to overcome a greater resistance. The wings flap through a smaller angle, but since they are longer, the actual up and down motion at the wingtip should be about the same.

Ornithopter Contest

An ornithopter contest is a great way to motivate your students while helping them learn important MST concepts. You know the benefits of an investigative, problem-centered approach to science education. This is it. Students can compete with relatively simple designs like The Ornithopter Zone’s Freebird kit. They can add their own modifications to improve flight times, or they can come up with their own designs.

A school gym is the perfect setting for such a contest. Students must learn to make their birds fly in a circle to avoid hitting the walls. Drafts in the room will make this difficult. It may be helpful to close the doors and turn off any fans that are blowing. Students should have time for practice flights so they can develop their models and technique. Students should work in teams, with two to four students on each team. Suggested contest rules appear at the end of this packet.

Books

Here we feature some books that address the subject of ornithopters. We've heard from teachers who are using these books successfully as part of their instruction. Flapping wing flight is sure to capture the attention and fire the imagination of students.

Our Neighbor is a Strange, Strange Man
by Tres Seymour, pictures by Walter Lyon Krudop, grades K-4

This book relates the true story of Melville Murrell, whose 1876 ornithopter flight preceeded the airplane flights of the Wright Brothers. The narrator is a young boy in the isolated Tennessee town that was Murrell's home. Echoing popular sentiment, the boy doubts Murrell until his invention takes flight.

Freak the Mighty
by Rodman Philbrick, grades 6 & up

Freak is a handicapped boy genius who builds ornithopters. Max is a big, slow kid. Neither of them fits in, but they are empowered by each other's strengths. This is the touching story of their friendship. English teachers using this book often give their students the option of building an ornithopter for the assignment. Students develop important language skills while researching how to build an ornithopter.

Kits & Supplies

For more ornithopter kits, visit The Ornithopter Zone online store, www.ornithopter.org/store. We can also be reached by phone at (800) 445-4215, or by mail at The Ornithopter Zone, 582 Laurelton Road, Rochester NY 14609 USA.

Project ideas

Reading Assignment: English teachers at the elementary or middle school level often assign one of the books listed below. The notion of flapping wing flight adds interest to these stories and adds a multiple intelligences component to the lesson. Many teachers give the option of building an ornithopter instead of a written assignment. Students develop important language skills while researching how to build an ornithopter.

Compare with Real Birds: Students can investigate how the ornithopters compare with real birds. This could involve some library or internet research to find out how birds fly. The students will examine the ornithopter to compare and contrast it with birds. They may also weigh the ornithopter and measure its wings to compare with published values for birds. Required materials: Freebird ornithopter, ruler, scale or balance.

Flapping Rate: Students can calculate how many times a second the ornithopter beats its wings. They simply count how many times they wind up the rubber band and divide that by the number of seconds the wings flap. Teaches scientific measurement skills and math applications. Required materials: Freebird ornithopter, stopwatch.

Compare Flapping Rate with Real Birds: How does the flapping rate compare with a real bird? Students can design experiements to determine which factors affect the flapping rate of a bird or ornithopter. For example, they could vary the size of the wings to test the hypothesis that larger wings won't need to flap as quickly. Materials required: Freebird kits, 1/8x1/8 inch balsa wood sticks, tissue paper, stopwatch.

Optimize the Design: As an engineering design project, students can find ways of improving the ornithopter's flight. The Freebird kit can be modified by making new wings of different size or shape. Students can also try adding curved ribs or bracing the wing to make it less flexible. Carefully remove the original wing, or start with a fresh kit, making changes as you go. Visit your hobby shop or craft supply store for additional balsa wood and tissue paper.

Simulation and Modeling: Students can use the FlapDesign software on our web site to simulate the ornithopter flapping mechanism. They can investigate how changing the dimensions of the mechanism will affect the movement of the wings. Which dimensions give the most symmetrical flapping? Can students find ways to make the ornithopter turn left or right? dive or perform loops? Students can generate hypotheses and test them by modifying the actual Freebird kits. Required materials: computer with internet access, Freebird ornithopter kits.

Students can work in pairs to build the Freebird kit. Building the kit requires scissors, a hobby knife, needle-nose pliers, straight pins, white glue, and epoxy or CA glue available at your local hobby shop. Students should work on cardboard covered with wax paper or plastic wrap. With adequate supervision, the kit has been built successfully by 6th grade students. Allow about three one-hour sessions, depending on age.

Flying Bird Contest Rules

1. The goal of this contest is to construct a mechanical flying bird, which is called an “ornithopter”. The birds will be timed to see which one can fly the longest.

2. Each bird must be powered by a rubber band.

3. Each bird must have a monoplane configuration. That means only one pair of flapping wings. One on the left. One on the right. Any stabilizer or lifting surface other than the flapping wings must be located aft of the rear motor hook.

4. The structure must be made entirely from wood and paper, except as follows. Metal or plastic may be used in the flapping mechanism, wing hinges, and motor hooks. Joints may be reinforced with tissue paper soaked in glue. Materials such as carbon fiber, boron, and kevlar are not allowed.

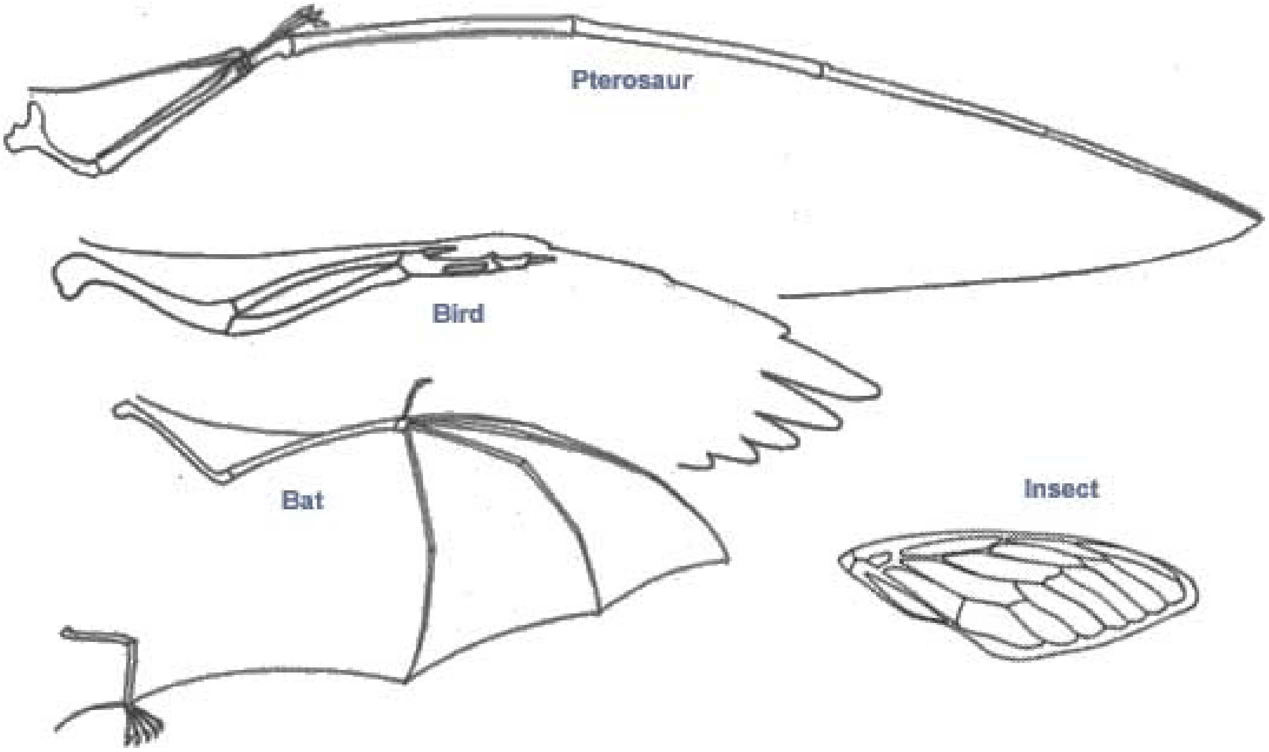
5. The motor stick must consist of a single piece of solid wood. The tail boom, if present, must also consist of a single piece of solid wood.

6. Models may be hand-launched. A stopwatch will be used to time each flight. The timing should begin at launch and should end when the model touches the floor. If the flight ends prematurely because of hitting an obstacle, the time shall stand. However, if the bird gets caught on an obstacle for more than ten seconds, the flight shall be redone.

7. Each team is allowed three timed flights. The best one counts as the score.

Bonus:

1. If the ornithopter is decorated in a manner that makes it look more like a real bird, ten seconds will be added to the flight time.


Pterosaur
Bird
Bat
Insect