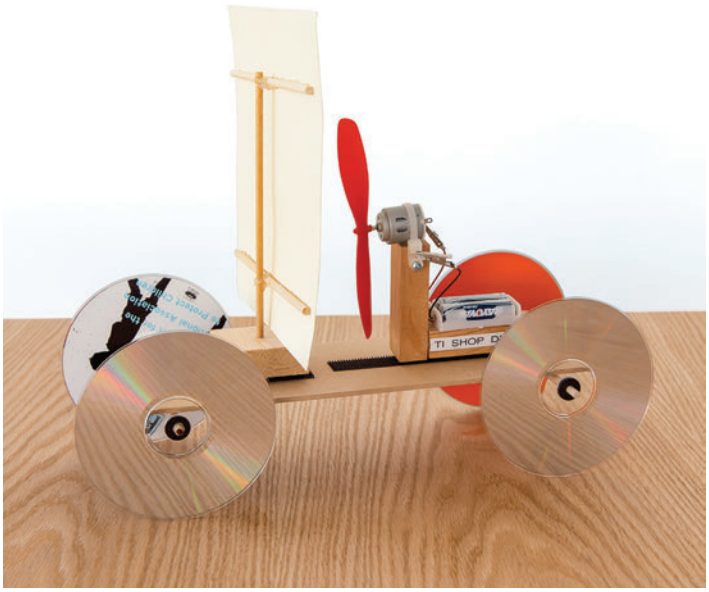


Fan Cart

Can a fan save your sailboat from the doldrums?

If a sailboat is stranded because there is no wind, is it possible to set up a fan on deck and blow wind into the sail to make the boat move? You can explore this classic physics problem using simple materials by building a low-friction cart with a removable motor and sail. The fan cart provides an elegant demonstration of action-reaction pairs described in Newton's Third Law, and can also be used to demonstrate other aspects of force and motion.

Tools and Materials

- Two plastic drinking straws
- Scissors
- Hot-glue gun and glue sticks
- Masonite platform, 4 x 12 inches (10 x 30 cm)
- Four beveled faucet washers, 1/4L (19/32" O.D.)
- Four CDs for the wheels
- Two wooden dowels, 3/16 x 6 inches (0.5 x 15 cm), for the axles

- Three wooden dowels, 3/16 x 7 inches (0.5 x 18 cm), for the mast and spars
- Manila file folder, cut to 8 x 8 inches (20 x 20 cm), for the sail
- Wood block, 2 x 2 x 3/4 inches (5 x 5 x 2 cm)
- Electric drill and bits: 3/16 inch (0.5 cm), 1/8 inch (0.3 cm), and 5/64 inch (0.2 cm)
- Cable tie with mounting head for screw, 7-1/2 or 8 inches (19 or 20 cm)
- DC hobby motor, 1.5 volt
- Two wood blocks, 1 x 3 x 3/4 inches (2.5 x 7.5 x 2 cm)
- Two-blade 6-inch (15-cm) propeller
- Phillips pan-head sheet-metal screw, 8 x 3/4 inches (20 x 2 cm)
- Phillips screwdriver
- Wire strippers
- Battery holder for two AA batteries
- Two mini alligator clips
- Needle-nose pliers
- Two AA batteries
- Sticky-back Velcro, about 9 inches (23 cm)
- Ruler

Assembly

1. Cut both drinking straws to 5 inches (13 cm) long. Then hot-glue the straws to the Masonite platform about 1 inch (2.5 cm) from each end to serve as bushings for the axle (see photo below). Note that the hot glue can melt or distort the plastic straws, so it's best put the glue on the Masonite rather than on the straws. Be sure the straws are as straight as possible. If they curve, the axle may rub against them, increasing friction.

2. Carefully insert the 6-inch (15-cm) wooden-dowel axles into the straws and then assemble the washers and CD wheels as shown in the photos below. When finished, the axle/wheel assemblies should turn freely in the straw bushings. This can be tricky, but perseverance should ultimately prevail! When you're done, set aside to build the mast and sail.

3. To build the mast-and-sail assembly, hot-glue the spars (two of the three 7-inch [18-cm] dowels) to the sail (the manila file folder). Then glue the mast (the remaining 7-inch [18-cm] dowel) to the spars, leaving about 1 inch (2.5 cm) sticking out below the sail. Drill a 3/16-inch (0.5-cm) hole in the center of the large, 2-inch-square (5-cm-square) wood block and insert the sail assembly. When you're done, set aside to build the motor assembly.

4. To build the motor assembly, place the cable tie around the motor and tighten. Cut off the excess tie. Use the 1/8-inch (0.3-cm) drill bit to drill a pilot hole for the sheet-metal screw 3/8 inch (1 cm) down from the top of one of the small wood blocks on a narrow, 3/4-inch (2-cm), face of the block. Screw the cable tie/motor unit to the wood block. Next, insert the propeller onto the motor shaft. If necessary, enlarge the hole in the propeller so it will slip relatively easily onto the motor shaft, while still staying tight enough to remain firmly in place. The size of the drill bit used will depend on the shaft size of the motor used. (Two mm is a common shaft size for this type of motor, and a 5/64-inch drill bit is the best standard bit size to use, but sometimes the propeller may slip. A #48 AWG [American Wire Gauge] drill bit is a better choice if available.)

5. Hot-glue the remaining small wood block to the motor assembly. Set aside to build the battery assembly.

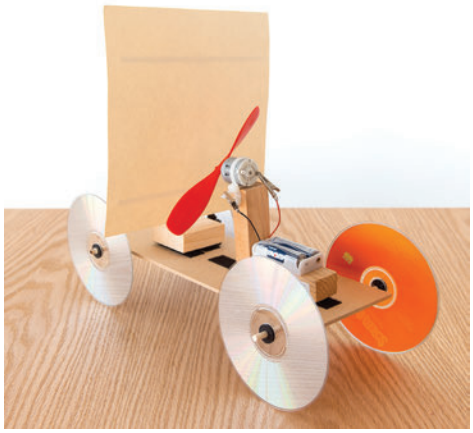
6. To build the battery assembly, use wire strippers to strip about an inch of the plastic insulation from the two battery-holder wires. Use needle-nose pliers to attach alligator clips to the wires.

7. Use hot glue to attach the battery holder to the horizontal wood block (see Step 5) of the motor assembly.

8. Place batteries in the battery holder. CAUTION: Once the batteries are in place, be sure the alligator clip leads do not touch each other. This will cause a short circuit that may cause the batteries to become dangerously hot. When the cart is not in use, you can prevent a short circuit by leaving

one of the clips attached to its motor contact and the other attached to the short, cut-off end of the plastic cable tie.

9. Cut two 2-inch (5-cm) pieces of Velcro, and attach one side (hook strip or loop strip) of each to the bottom of the sail assembly and the others to the cart. You should now be able to easily attach and remove the sail assembly. Cut a 5-inch (13-cm) piece of Velcro. Separate the hook and loop strips, and attach one strip to the cart. Trim the other strip down to 3 inches (7.5 cm) and attach it to the motor assembly. Note: using a 5-inch strip on the cart allows some flexibility in adjusting the position of the motor assembly on the cart.



To Do and Notice

Investigation 1: Attach the sail to the cart, then attach the fan so it blows air toward the sail. Turn on the fan by attaching the battery clip leads to the motor, and observe what happens. (Note: If the air is blowing the wrong way, reverse the motor direction by switching the alligator clip connections.)

Investigation 2: Leave the sail in place, but remove the fan assembly and turn it around (or leave the fan assembly in place and reverse the electrical connections to the motor) so the fan blows air away from the sail. Turn on the fan and observe what happens.

Investigation 3: Remove the fan assembly and hold it in your hand while it blows air toward the sail. Observe what happens.

Investigation 4: Replace the fan assembly so it blows air toward the sail, then remove the whole sail assembly. Turn on the fan and observe what happens.

Investigation 5: Return to the original situation, with the fan and sail both attached to the cart, and the fan blowing air toward the sail. Now hold a file folder or stiff piece of paper between the fan and the sail (but not touching either one) and observe what happens.

What's Going On?

Here is a summary of the results to be expected for the investigations above:

1. Cart doesn't move.

2. Cart goes forward.
3. Cart goes forward.
4. Cart goes backward.
5. Initially the cart doesn't move, but when the file folder or paper is in place, the cart moves backward.

The behavior of the cart is a classic example of Newton's Third Law: For every action, there is an equal and opposite reaction.

Investigation 1: The fan pushes the air forward and the air pushes the fan backward. (A crucial thing to keep in mind is that action and reaction forces, often called an action-reaction pair, do not act on the same object.) If this were all that was happening, the cart would move backward: The fan is being pushed backward, and since it's attached to the cart, the cart is also pushed backward. But the sail is set in place, so there is a second action-reaction pair, with the air pushing forward on the sail, and the sail pushing backward on the air. In this situation, there ends up being two forces exerted on the cart: the air pushing backward on the fan, and the air pushing forward on the sail. These two forces balance each other, and the cart doesn't move.

Try to identify the action-reaction pairs in Investigations 2, 3, 4 and 5, and use them to predict why the cart behaves as it does. Compare your expectations and results with the information offered in the discussions below.

Investigation 2: With the air direction reversed (either by physically reversing the fan or by reversing the electrical connections to the fan), the fan pushes the air backward and the air pushes the fan forward. Since the fan is attached to the cart, the cart moves forward.

Investigation 3: The fan pushes the air forward and the air pushes the fan backward. But because the fan is held in your hand and is not attached to the cart, there is no effect on the cart for this action-reaction pair. The air pushes the sail forward and the sail pushes the air backward. Since only the sail is attached to the cart, the cart moves forward.

Investigation 4: The fan pushes the air forward, and the air pushes the fan backward. Since the fan is attached to the cart, the cart is pushed backward.

Investigation 5: Initially, the cart is in the same configuration as in Investigation 1, so it doesn't move. However, when a barrier is inserted between the fan and the sail (without touching either one), the first action-reaction pair is still the same as in Investigation 1: The fan pushes the air forward, and the air pushes the fan backward. In the second action-reaction pair, the air pushes the file folder forward, and the file folder pushes the air backward. But the only force in the two reaction pairs that acts on the cart itself is the force on the fan, which is connected to the cart, so the cart moves backward.