Fan Cart

A physics classic

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? This is a classic physics problem which you can explore here by using simple materials to build a low-friction cart with a removable motor and a removable sail. The fan cart provides a particularly elegant application of action-reaction pairs in Newton's Third Law, and can also be used to demonstrate other aspects of force and motion.

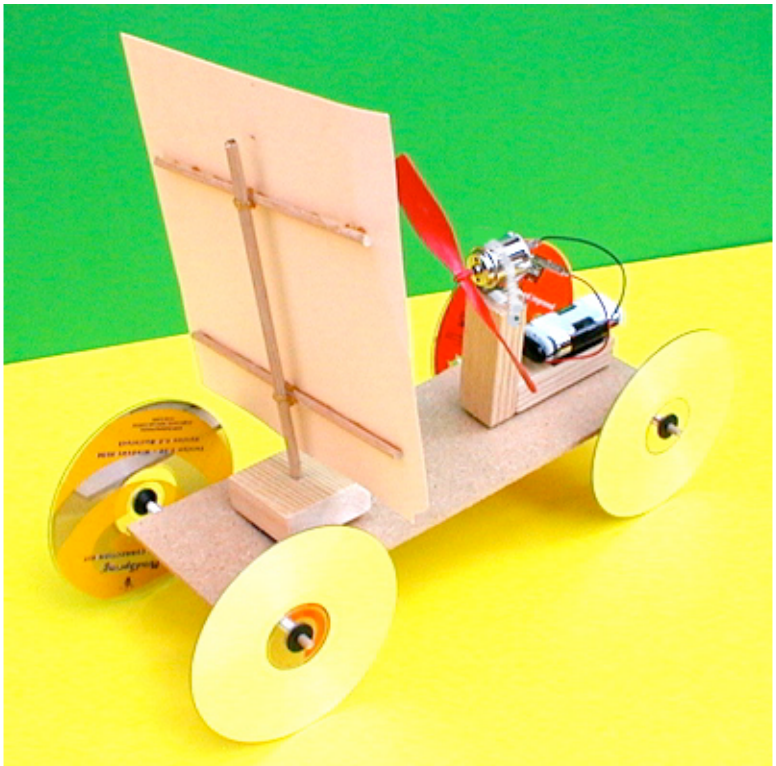

Figure 1

Materials

masonite platform, 4 in x 12 in
2 wood dowels, 3/16 in, 6 in long, for axles
3 wood dowels, 3/16 in, 7 in long, for mast & spars
wood block, 2 in x 2 in x 3/4 in thick
2 wood blocks, 1 in x 3 in x 3/4 in thick
2 drinking straws, plastic, cut to 5 in long
4 CD's
4 faucet washers, 1/4L, beveled (19/32 in O.D.)
sheet metal screw, 8 x 3/4 in, pan head, Phillips
cable tie with mounting head for screw, 7 ½ in or 8 in
dc electric motor, 1.5-6 volt -- e.g. Kelvin 850647
propeller, 2-blade, 6 inch, -- e.g. Kelvin 850889
battery holder for 2 AA batteries -- e.g. Kelvin 220090
2 mini alligator clips -- e.g. Kelvin 310008
2 AA batteries
manila file folder, cut to 8 in x 8 in
Velcro, sticky-back, about 5 in
hot glue gun
hot glue sticks
electric drill
3/16 in drill bit
1/8 in drill bit
5/64 in drill bit
screwdriver, Phillips
wire stripper

Materials for Optional Drip Timer

500 mL plastic water bottle with the bottom half cut off
adjustable "sport top" for water bottle
cable tie with screw mount
sheet metal screw, 8 x 3/4 in, pan head, Phillips
wood block
Velcro, sticky-back, about 3 in

Don Rathjen....Exploratorium Teacher Institute....Pier 15, San Francisco, CA 94111…..drathjen@exploratorium.edu
drathjen@exploratorium.edu

Assembly

1. Hot glue the straws to the masonite platform about 1 in from each end to serve as bushings for the axles. See Figure 2.
NOTE: The hot glue can tend to melt or distort the plastic straws. It seems to work better to put the hot glue on the masonite and then press the straws in place rather than putting the hot glue directly on the straws and then putting them in place on the masonite.

2. Assemble the washers, CD wheels and axles as shown in Figures 2 and 3. When finished, the axle/wheel assemblies should turn freely in the straw bushings.
NOTE: You can do this in whatever way works best for you, but here's a suggested sequence:

   1. put the washers in place in all four CD holes
   2. slide a washer/CD onto one end of each axle
   3. put the axles into the straws
   4. slide a CD/washer onto the other end of each axle

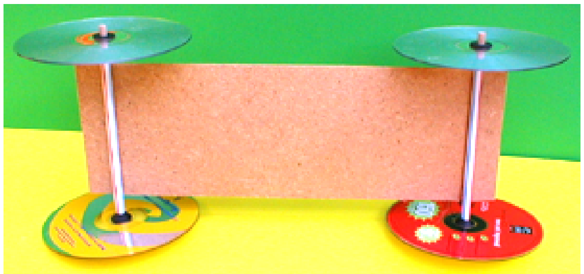
Figure 2

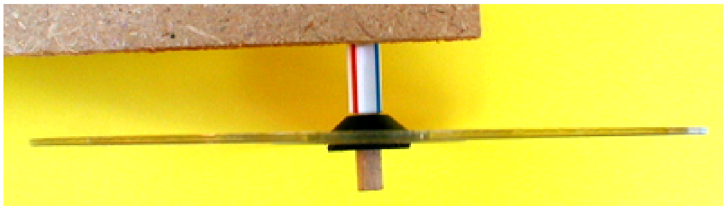
Figure 3

3. Build the mast and sail assembly. See Figure 4.
• Hot glue the spars to the sail and the mast to the spars.
• Drill a 3/16 in hole in the center of the 2 in x 2 in block for the mast.

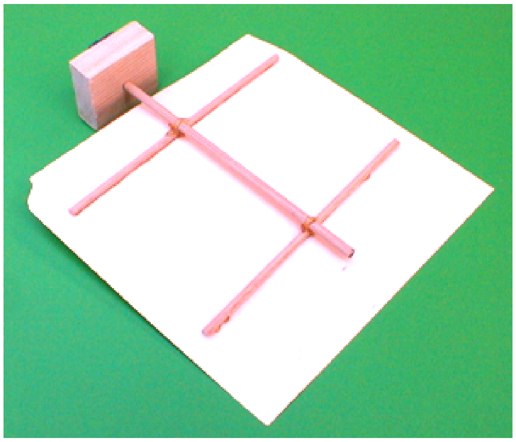
Figure 4

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drathjen@exploratorium.edu

4. Build the motor assembly. See Figures 5 and 6.
• Place the cable tie around the motor and tighten; then cut off the excess.
• Use the 1/8 in drill bit to drill a pilot hole for the screw 3/8 in down from the top of one of the 1 in x 3 x 3/4 in wood blocks on a narrow (3/4 in) face of the block.
• Screw the cable tie/motor unit to the wood block.
• Hot glue the two wood blocks together as shown in Figure 5.
• If necessary, enlarge the hole in the propeller so that it will then slip relatively easily onto the motor shaft, yet will be tight enough to remain firmly in place. The size of the drill bit used will depend on the size of the shaft of the motor used. For the motor specified in the Materials section, a 5/64 in drill bit works well.


Figure 5

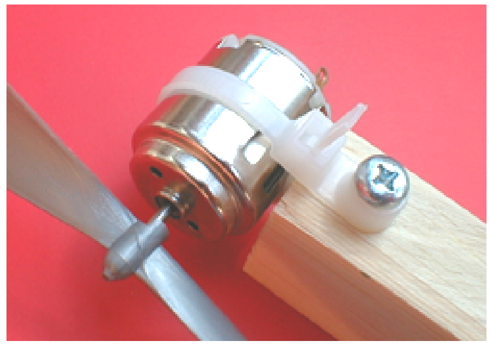
Figure 6

5. Attach alligator clips to the two battery holder wires.
• Use a wire stripper to strip about an inch of the plastic insulation from each wire. If the wire stripper is one that requires you to set the wire gage number, use #24.
• Figures 7a, 7b, 7c and 7d show a sequence for using needle-nose pliers to securely attach an alligator clip to a wire without using solder.


Figure 7a
Stick bare end of wire down through hole.


Figure 7b
Bend bare end back and upward, between tabs.


Figure 7c

Bend near tab down to fasten bare wire against insulated wire.


Figure 7d

Bend far tab down tightly over near tab.

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drathjen@exploratorium.edu

6. Use hot glue to attach the battery holder to the horizontal wood block of the motor assembly. For location see Figure 1 and note the bottom arrow in Figure 8.

7. 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 one attached to the short cut-off end of the plastic cable tie.

8. Attach the sail assembly and the motor assembly to the cart. Use a 2 in piece of Velcro for the sail and a 3 in piece of Velcro for the motor assembly. See Figure 8 and Figure 1.

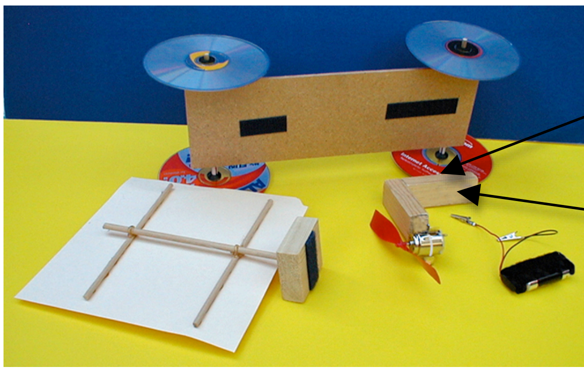

Figure 8

To Do and Notice

1. Attach the sail to the cart, and attach the fan to the cart so that it will blow air toward the sail when it is running. Turn on the fan, and observe what happens. (The motor direction can be reversed by reversing the alligator clip connections to the motor.)
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 that the fan will blow air away from the sail when it is running. Turn on the fan, and observe what happens.
3. Remove the fan assembly, and hold it in your hand while it blows air toward the sail. Observe what happens.
4. Replace the fan assembly so that it will blow air toward the sail when it is running, but then remove the whole sail assembly. Turn on the fan, and observe what happens.
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 insert a file folder or a 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 situations 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.

In case 1, the fan pushes the air forward, and the air pushes the fan backward. (A crucial thing to keep in mind is that the action and reaction forces -- often called an action-reaction pair -- do not act on the same object.) If

Don Rathjen....Exploratorium Teacher Institute....Pier 15, San Francisco, CA 94111…..drathjen@exploratorium.edu
drathjen@exploratorium.edu

this was 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 would be pushed backward also. In fact, this is exactly what does happen in case 4, when the sail is not present. But in the present case, the sail is 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. So in this case there end up being two forces exerted on the cart, i.e., 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 cases 2, 3, 4 and 5 (actually, case 4 has already been done in the preceding discussion) and use them to predict why the cart behaves as it does. Check yourself by reading the discussions of Cases 2, 3 and 5 below.

Case 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.

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

Case 5: Initially the cart is in the same configuration as Case 1, so it doesn't move. When the file folder is inserted between the fan and the sail without touching either one, then the first action-reaction pair is still the same as in Case 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 is acts on the cart itself is the force on the fan, which is connected to the cart. So the cart moves backward.

Don Rathjen....Exploratorium Teacher Institute....Pier 15, San Francisco, CA 94111…..drathjen@exploratorium.edu
drathjen@exploratorium.edu

Going Further

You can use a Drip Timer to make a visual record of the motion of a Fan Cart. This information can be used to tell the story of the motion of the Fan Cart and to investigate its displacement, velocity and acceleration.

Figure 8 shows a version of the drip timer and Figure 9 shows it in place on the cart. You can make one like this or design your own. Following are the materials used in the one shown (also shown as Optional materials in original Materials section):

500 mL plastic water bottle with the bottom half cut off
adjustable "sport top" for water bottle
cable tie with screw mount
sheet metal screw, 8 x 3/4 in, pan head, Phillips
wood block
Velcro, sticky-back, about 3 in

Figure 8

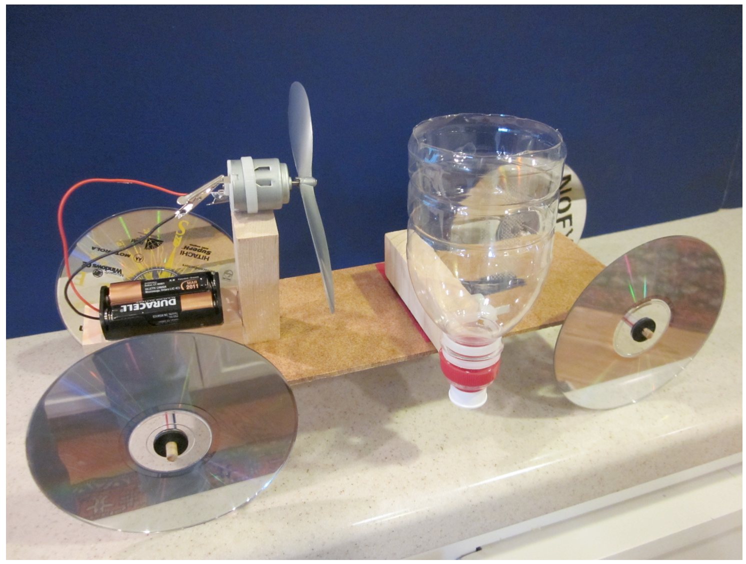

Figure 9

To collect data, fill the timer about 1/2 to 2/3 full of water and adjust the sport top to produce a constant drip rate which will provide a record of motion similar to the one shown in Figures 10 and 11 as the cart travels along pieces of paper which have been taped together to form a suitably long strip. The circles indicate the positions of water drops (for better visibility colored water can be used if compatible with clean-up considerations). In this case the cart was traveling from right to left. In terms of the qualitative story of the cart's motion, notice that at the beginning the drip marks are close together but become farther apart as the cart travels. The time between successive drip marks is constant no matter what the speed, so the distance between marks actually represents the speed. The larger the distance between drip marks, the greater the speed, so we can tell that the cart is speeding up as it travels from right to left. If this same record had been made by a cart traveling from left to right, we can tell that the cart was slowing down. If the drip rate is determined and the distances between drip marks are measured, the displacement, speed and acceleration of the cart can be dealt with quantitatively. In Figures 10 and 11 For example, if the distance between two drip marks is 12 centimeters and the time between drips is 0.6 seconds, the average speed during that interval is 20 cm/s.

Figure 10

Credit

This version of the Fan Cart has evolved over the years from a snack write-up originally shared by Kevin Doyle during the Summer 2000 Institute.

Don Rathjen....Exploratorium Teacher Institute....Pier 15, San Francisco, CA 94111…..drathjen@exploratorium.edu
drathjen@exploratorium.edu