4 Sail with the Wind

Purpose

To investigate the relationship between the components of the force that propels a sailboat

Required Equipment/Supplies

dynamics cart fitted with an aluminum or cardboard sail
protractor
electric fan
ruler pulley
mass hangers
set of slotted masses
string

Discussion

In this experiment, you will use a small model sailboat and an electric fan. The physics of sailing involves vectors—quantities that have both magnitude and direction. Such directed quantities include force, velocity, acceleration, and momentum. In this lab, you will be concerned with force vectors.

In Figure A, a crate is being pulled across a floor. The vector *F* represents the applied force. This force causes motion in the horizontal direction, and it also tends to lift the crate from the floor. The vector can be "resolved" into two vectors—one horizontal and the other vertical. The horizontal and vertical vectors are *components* of the original vector. The components form two sides of a rectangle. The vector *F* is the diagonal of this rectangle. When a vector is represented as the diagonal of a rectangle, its components are the two sides of the rectangle.

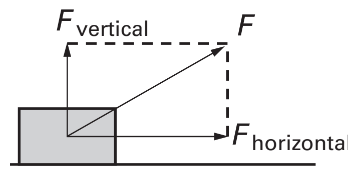

Fig. A

Whatever the direction of wind impact on a sail, the direction of the resulting force is always perpendicular to the sail surface. The magnitude of the force is smallest when the wind blows parallel to the sail—when it goes right on by without making any impact. The force is largest when the sail is perpendicular to the wind—when the wind makes full impact. Even if the wind hits the sail at another angle, the resulting force is always directed *perpendicular* to the sail.

The keel of a sailboat is a sort of fin on the bottom of the boat. It helps prevent the boat from moving sideways in the water. The wind force on the sail can be resolved into two components. One component, *K* (for *keel*), is parallel to the keel. The other component, *T* (for *tip*), is perpendicular to the keel, as shown in Figure B. Only the component *K* contributes to the motion of the boat. The component *T* tends to move the boat sideways and tip it over.

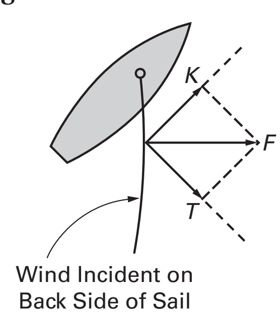

Fig. B

Any boat with a sail can sail downwind, that is, in the same direction as the wind. As the boat goes faster, the wind force on the sail decreases. If the boat is going as fast as the wind, then the sail simply sags. The wind force becomes zero. The fastest speed downwind is the speed of the wind.

A boat pointed directly into the wind with its sail at right angles to the keel is blown straight backward. No boat can sail *directly* into the wind. But a boat can *angle* into the wind so that a component of force *K* points in the forward direction. The procedure of going upwind is called *tacking*.

CAUTION: In the following procedure, you will be working with an electric fan. *Do not let hair or fingers get in the blades of the fan.*

Procedure

Try to sail the boat directly upwind.

Step 1: Position the cart with its wheels (the keel) parallel to the wind from the fan. Position the sail perpendicular to the wheels. Start the fan blowing on the *front* of the cart with the wind parallel to the wheels.

1. What happens to the cart?

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Sail the boat directly downwind.

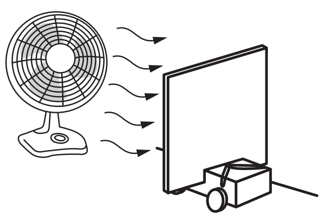

Fig. C

Step 2: Direct the wind from *behind* the cart and parallel to the wheels, keeping the sail perpendicular to the wheels, as shown in Figure C.

2. How does the cart move?

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Sail the boat at an angle.

Step 3: Reposition the sail at a 45° angle to the wheels. Direct the wind behind, parallel to the wheels.

3. What happens to the cart?

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Step 4: Use a ruler to draw a vector that represents the wind force perpendicular to the sail. Remember that the *length* of the vector you draw represents the size of the force. Split the vector into its T and K components. Label the forces and each component on the diagram.

Change the wind direction.

Step 5: Repeat Step 3 with the fan perpendicular to the wheels. Make a vector diagram for this case.

Change the wind direction.

Step 6: Repeat Step 3 but direct the wind at a 60° angle to the wheels from the front, as shown in Figure D.

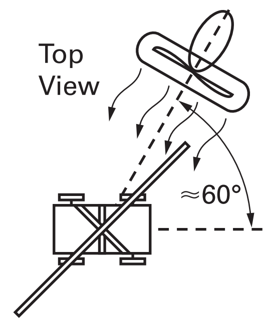

Fig. D

4. Does the cart sail against or with the wind?

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Draw a vector representing the wind force, and split it into its T and K components.

Step 7: Set up a pulley on the edge of the table, as shown in Figure E. Attach one end of a piece of lightweight string to the cart and thread the other end over the pulley. Attach a mass hanger to the string. Set the sail perpendicular to the direction of the cart. Place the fan directly between the pulley and the cart so that the full force of the wind strikes the sail at 90°. Holding the cart, turn the fan on its highest speed setting. The wind force depends on how close the fan is to the sail. Place the fan close to the sail. *Slowly* add very small masses to the mass hanger. Continue adding them until the weight of the masses (including the mass hanger) just balances the wind force on the cart. The wind force is balanced when adding the smallest mass you have causes the cart to move toward the pulley and removing the smallest mass causes the cart to move away from the pulley. Record the mass required to balance the cart.

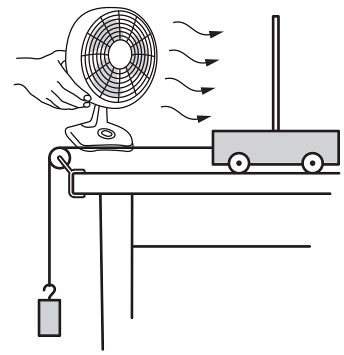

Fig. E

mass = _______________

Calculate the weight of this mass, using the approximation that a mass of 1 kg has a weight of 10 N.

weight = _______________

5. What is the amount of wind force acting on the sail in this configuration?

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Step 8: Repeat Step 7, but this time orient the sail at a 45° angle to the wind. Record the mass and calculate the weight required to balance the cart.

mass = ________________

weight = ________________

6. What is the amount of wind force acting on the sail in this configuration?

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Analysis

7. Which orientation of the sail with respect to the wind provided the greatest wind force?

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8. When the sail is oriented at 45° to the wind, is the wind force less than half, equal to half, or greater than half the wind force at 90°? Justify your answer with a vector diagram.

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