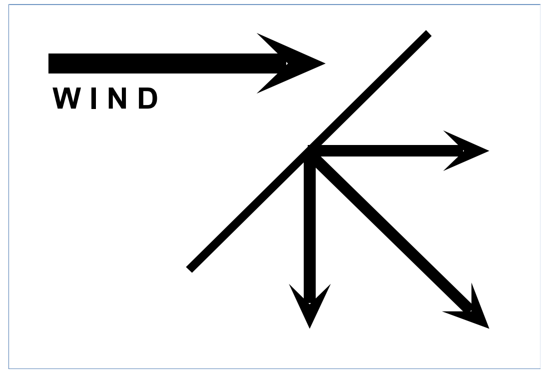
20900 Sail Cart

Purpose:
To investigate forces and their components as applied to wind driven sails and sailboats.



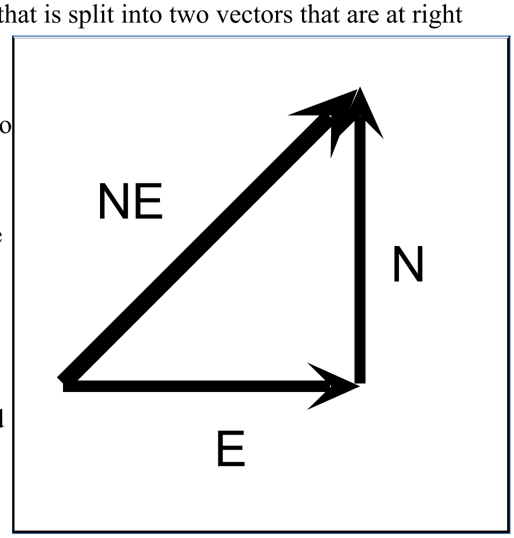
Required Accessories:
Portable Fan
Weight hanger and weights
Pulley with table mount
Light string or braided fishing line

Assembly:
To mount the sail on the cart, remove the wingnut, slip the sail over the screw on the cart, and replace the wingnut. To adjust the angle of the sail, loosen the wingnut, turn the sail to the desired angle, and tighten the wingnut again.

Discussion:
How does a sailboat move through the water on a windy day? If you watch the sailboat, you might see it zig-zag back and forth, tacking as it moves forward into the wind. How does a boat, being pushed by the wind, do this? The sail cart will help you investigate this question.

First, we must realize that there must be a force driving the boat. This force comes from the wind pushing on the sail. To take a simplified view, we will assume this force is perpendicular to the surface of the sail, by setting the sail at 45º. Before going much further, let's look at ways of representing a vector quantity.

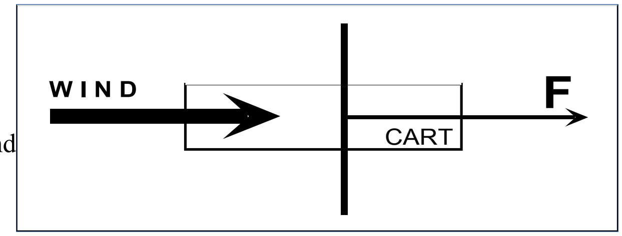
A vector is a form of notation used to represent something that has magnitude and direction. This is not one or the other, but both at all times, and every operation must simultaneously take care of how much is involved (magnitude) and where it is pointing (direction) without loosing anything. Just as we might divide our literature into prose and poetry, we divide our measurables into scalars and vectors. Distance is a scalar, but displacement is a vector. If I travel 3 km from where I am, I might be found any place on a circle of radius 3 km, but if I travel 3 km North, you know just where to find me. Vectors are often pictured as arrows with a length proportional to the magnitude and an orientation that gives the proper direction. Vectors can be added by connecting them in a "head-to-toe" fashion to give a resultant, regardless of where that might take you. The resultant is then drawn from the first starting point to the final end point to give the vector sum. Any vector can be resolved into components, that is split into two vectors that are at right angles to one another. The test to see if they are the proper components is to see if they can be added back together again to give the original vector in both magnitude and direction by connecting them head to toe as described above. In the figure below, a trip to the Northeast is seen to have an Easterly component and a Northerly component.



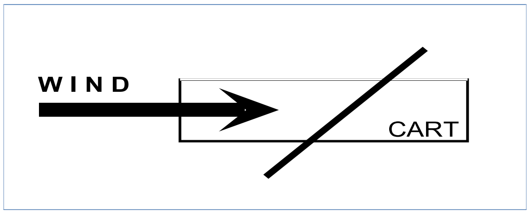
We will use this technique of breaking vectors into components in dealing with the force on the sail. We will have one component along the length of the cart which will be responsible for moving the cart forward (or backward), and one component across at right angles to this, across the width of the cart, which will be responsible for sliding the cart sideways. Because of the friction between the wheels and the tabletop, this force tends to tip the cart to the side rather than slide sideways. It is useful to think of the wind as modeled by many microscopic balls all traveling in the same direction, and bouncing off the sail. If the balls strike the sail at right however, the balls arrive parallel to the surface, they will move right on by, miss the sail, and provide no force on the sail. So, you can see the effect will depend in some way on the angle between wind and sail.

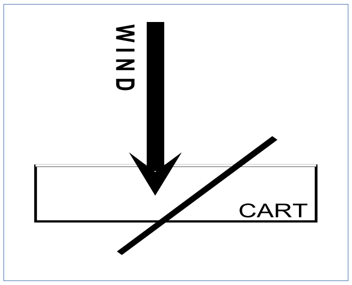
Procedure:

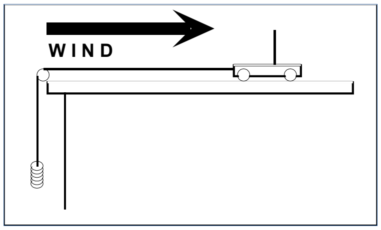
Begin by making a few qualitative observations. First, place the sail cart on a flat table and fasten the sail so that it is perpendicular to the long axis of the cart. Move a portable fan behind the cart so that it will blow a stream of air towards the sail. What happens to the cart? The vector that represents the wind force on the sail is shown.



Now, reposition the sail on the cart so that it makes an angle of 45º with the long axis of the cart. Reset the cart on the table in front of the fan so that it blows the stream of air in each of the ways depicted in the figures below.







What happens to the cart? Does it move as quickly as before? The strength of the wind depends on the size of the fan, the speed of the fan, and how far the fan is positioned from the cart, so keep these constant to make the comparisons. Can you draw a vector that represents the force of the wind on the sail? Can you break this vector into components? Label the force and the components for each of the figures above. How does the force from the side of the cart differ from the force caused by the wind coming from behind the cart? Remember to check your vectors by add them together again.

To measure the actual force of the wind on the sail, balance the force of the wind with the force exerted by weights hanging as in the figure below. Fasten a pulley to the edge of the table. Tie a light string or braided fishline to the cart and tie a weight hanger to the other end. With the line over the pulley, and the sail perpendicular to the length of the cart, place the fan behind the sail and turn it on. While the fan is blowing on the sail, add weights to the hanger until the wind force is balanced and the cart does not move. This condition is satisfied when the smallest weight added to the hanger just makes the cart move backward and the removal of that much makes the cart move forward. Record the total mass (including the hanger) and calculate the force required to balance the force of the wind pushing on the sail. What is the magnitude and direction of the wind force on the sail? Remember that force is a vector whose magnitude is the product of the total mass multiplied by the local acceleration due to gravity, and that force is expressed in Newtons. For example, if $F = ma$, then $W = mg$, and one kilogram “weighs” about 9.8 Newtons.

Repeat this experiment, except with the sail positioned at 45º to the long axis of the cart. What total mass is required now for balance? What is the force required? How does this vector compare with the vector when the sail was positioned at the perpendicular? Is it greater, equal to, or less than before? Can you support your answers using vector diagrams?

Time Allocation:

To prepare this product for an experimental trial should take less than five minutes. Actual experiments will vary with needs of students and the method of instruction, but are easily concluded within one class period.

Feedback:

If you have a question, a comment, or a suggestion that would improve this product, you may call our toll free number.