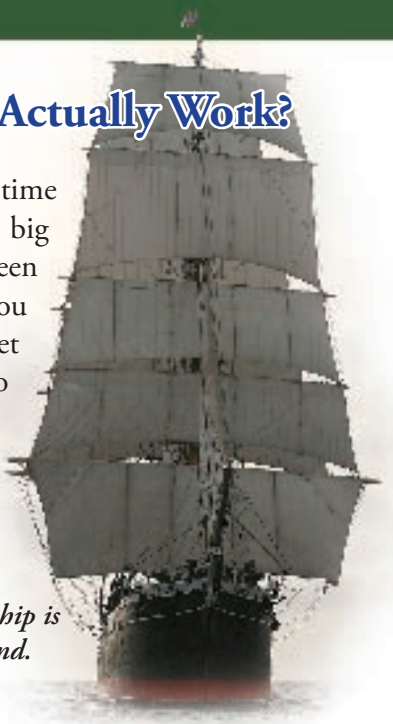
Getting to Windward Under Sail—How Does that Actually Work?

You are planning an ocean voyage. What kind of vessel do you choose? In the time of the Vikings, you would have rowed your ships to windward and used a big square sail to go downwind. In Columbus's day, you could have chosen between a number of small sailing ships, depending on where you intended to go and what you needed to take with you. By 1492, sailors knew that, to go downwind, they could set a big square sail across their ship and let the wind push them where they wanted to go. They also had learned, from the Arab boats they saw during their voyages across the Mediterranean Sea and around Africa, that a *lateen*, or fore-and-aft, sail helped them make progress into the wind. Many early oceanic explorers chose ships with combination rigs—some sails square and some fore-and-aft—to allow them to travel in any direction, no matter where the wind was coming from.

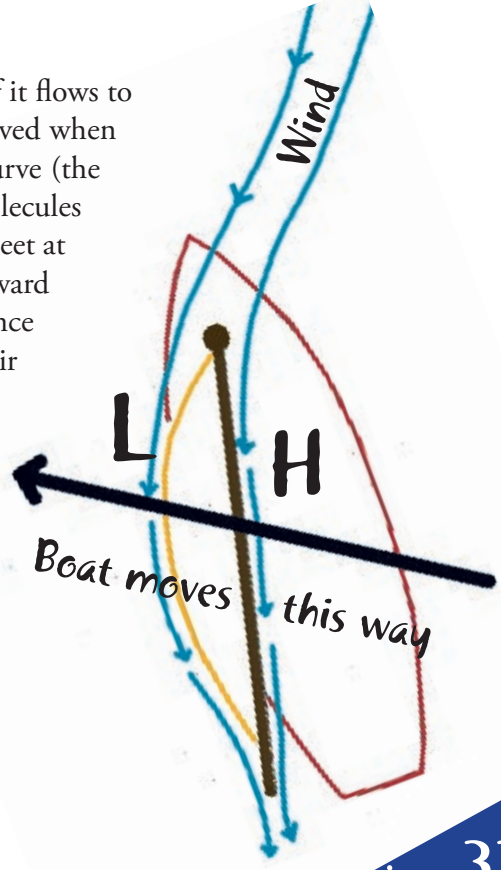


(right) ***This square-rigged ship is getting pushed downwind.***

It's easy to guess how a square sail works to push a ship dead downwind, but how does a sail work to get to windward? Sailing directly upwind is also easy to understand: it's ***impossible***. You just sit there with your sails flapping. Scientists and sailors figured out that certain sail shapes can actually PULL a ship into the wind—not directly, but enough to be able to go toward your windward destination and then tack and keep going, zigzagging, until you get there.

Let's look at how this all works.

When the wind meets the forward edge of a sail, it splits. Some of it flows to one side of the sail and some flows on the other. Because the sail is curved when it's filled with air, the air molecules that travel on the outside of the curve (the *leeward* side of the sail) have a longer distance to travel than the air molecules that cut across the *windward* side. All these air molecules still have to meet at the other end at the same time. So, to do that, the air molecules to leeward have to move faster. This difference in speed causes a difference in air pressure on each side of the sail. *High pressure* (on the windward side) pushes against *low pressure* (on the leeward side), and, on our sail, this creates a force in the direction to leeward.



Why doesn't the boat drift sideways? Well, it does, actually. Sailboats and sailing ships are built with a *keel* (or *centerboard*) underneath the boat. As the wind pushes the boat sideways, the keel is pushed against the water. The water resists this and exerts a force in the opposite direction. The shape of the sail, the underside of the boat, and the keel, and how you position your sails and rudder, work on these opposing forces and cause the boat to sail forward. ⚓