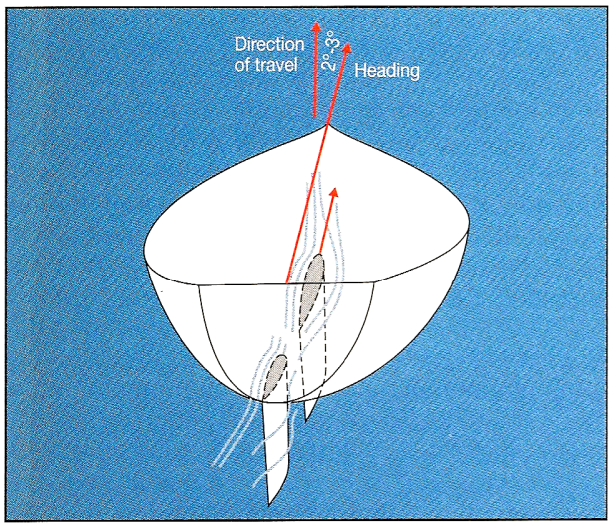
erating and settle down for a long trip to Spain. Boat speed would be 2 knots, wind speed 10 knots, apparent wind speed 8 knots.

Now take the fast boat—an iceboat—in a similar situation. With almost no hull resistance to overcome, the iceboat picks up the same 10 knots of wind from directly astern and, within seconds, the skipper is aware of a rapidly decreasing apparent wind. His boat reaches a balance between the decreasing force of the wind and the increasing resistance of the iceboat at, for example, 9 knots (boat speed 9 knots, wind speed 10 knots, apparent wind speed 1 knot).

Now, 9 knots would be pretty exciting in a Spanish galleon, but in an iceboat, it's not worth chilly feet. So the iceboat skipper turns his boat so that it begins to travel on a line



Since the keel and rudder must be presented to the water at a slight angle of attack (ideally 2° to 3°) in order to create maximum lift, the boat must be steered in one direction—its heading—to travel in a slightly different direction.

perpendicular to the wind. He does this without losing any speed, so his initial speed, after the turn, is still 9 knots. At that instant, the iceboat skipper feels the full force of the 10-knot wind, because he's no longer traveling away from it. He also feels the force of a 9-knot wind, just as if he were on a bicycle pedaling at 9 knots. These two vectors, at right angles to each other, can be added (vector addition is discussed in Chapter 20) with an apparent wind of about 13.5 knots flowing into the iceboat at an angle of about 47 degrees.

The Spanish galleon, still traveling at 2 knots, also turns so that it is sailing on a line perpendicular to the wind. The new wind across its decks is also a vector sum of the 10-knot wind and the 2-knot boat speed. The result is a less-than-impressive 10.3 knots at an angle of about 79 degrees. The galleon responds to this slightly stronger apparent wind (which is still hitting at an angle wide enough for its square sails to make use of) by accelerating. Again, the force on the sails is balanced by the increasing resistance of the hull, and things settle down again—at 2.5 knots.

However, aboard the iceboat, things start to happen. Its highly efficient sail and almost-zero hull resistance respond to the new, stronger wind. It begins to accelerate again. The first one-knot increase in boat speed, to 10 knots, brings a new apparent wind; 14.1 knots, at a new angle of 45 degrees. This angle is still no problem for an iceboat sail so it responds to the new apparent wind strength by gaining another knot. Now the apparent wind is very close to 15 knots and the angle is still comfortable—producing more acceleration.

Where does it all end? Well, this is not perpetual motion (though, in an iceboat, it can often feel that way!). Things start to level off when the apparent wind goes so far forward that the sail begins to point too directly into the wind. It can no longer achieve a useful angle of attack and it luffs. At this point the iceboat is probably experiencing an apparent wind of almost 45 knots and is doing almost 40 knots of boat speed—pretty good for wind strength of 10 knots. In fact, with strong winter winds and cold, dense air, iceboats routinely travel at speeds of more than 50 knots. At that speed, their sails are strapped in tight regardless of what direction the "real" wind is blowing—their apparent wind is far more important, and it's blowing from almost straight ahead.

The effects of apparent wind on most sailboats are far more dramatic than aboard the galleon and far less than aboard the iceboat. Even a heavy racing sloop might increase its speed by 25 percent as a result of a stronger apparent wind. Sailboats that are less limited by their weight can easily double their speed with careful use of apparent wind.

There are some fundamental rules about apparent wind:

- Except when sailing directly downwind, apparent wind will always come from "farther ahead" than the wind does.
- Sailing on any angle ranging from perpendicular to the wind to an angle quite close to the wind, apparent wind will always be greater than the wind.
- As wind strength increases, the angle of the apparent wind moves farther aft; conversely, as wind strength decreases, the apparent wind moves farther forward. A strong gust of wind is usually welcome because it provides more power applied from farther aft.

Heeling

For the most part, boats sail most efficiently in an upright position so that aerodynamic and hydrodynamic lift are converted into forward motion. But the same dynamic forces that pull the boat forward also try to push it over.

The sails, which have their CE at about 40 percent of the height of the mast, and the keel with its corresponding CLR well below the water, both act as levers with the hull in the middle as their fulcrum.

In general, there are two ways to counter these forces and prevent them from pushing the boat over and capsizing it. These are weight and width. Both have disadvantages.