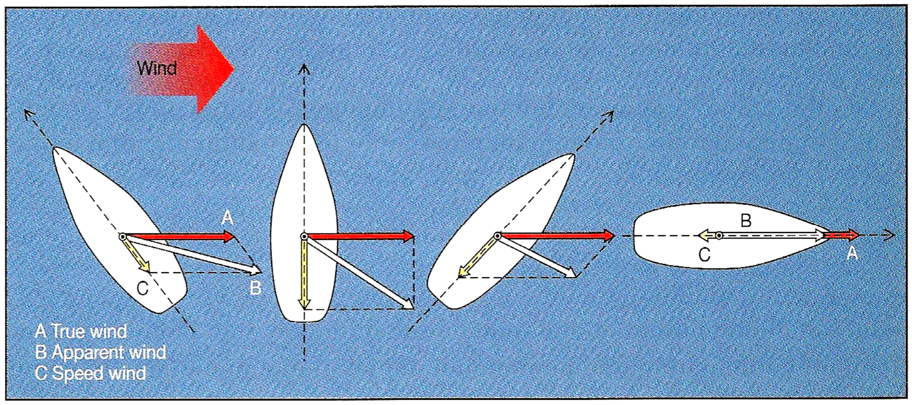
Apparent wind is the direction of the wind as it appears onboard. Both boat speed and the boat's angle to the true wind affect the direction and strength of the apparent wind. In this vector diagram, the narrow red arrow is true wind, the yellow arrow is speed wind, and the white arrow is apparent wind. Apparent wind is greatest when the boat is sailing perpendicular to, or at an angle close to, the wind.



Energy extracted from the wind is partly absorbed in the work of moving weight, especially if that weight begins to move up and down through waves, so any extra weight robs speed. Width makes a hull harder to push through the water (unless the boat is separated into two hulls, or three, that are spread apart).

Most sailboats use both weight and width to stay upright. The width of the hull is the first line of defense because buoyancy begins to provide substantial righting moment (it pushes back) as soon as the hull begins to heel. Fixed ballast gains in importance as the hull heels farther over.

Different sailboat designs rely more heavily on one or the other method. The classic heavy, narrow "meter boats," such as the 12-meter class formerly used in America's Cup competition, were intended to balance at a substantial angle of heel sailing close to the direction of the wind. Designers took advantage of this fact by shaping their hulls in such a way that they would have greater potential speed in their heeled underwater shape than in their upright underwater shape. The basic method is explained below in the discussion of form resistance.

Most recent racing designs such as the J-24 rely more on a wide, shallow hull. With this hull type, crew weight becomes even more important, especially because crew weight can begin to provide righting moment even before the hull begins to heel. That's why the best-sailed dinghies sail through gusts of wind without heeling—their crews move into position in perfect sympathy with the changing aerodynamic forces, converting every increase in power into forward acceleration, rather than heeling.

As the boat begins to heel, several factors combine together to rob it of forward speed. The force created by the sails is now aimed partly downward (instead of parallel to the water), thereby helping to immerse the hull into the water rather than pulling it forward. Less sail area is exposed to the horizontal movement of the wind. A corresponding deterioration takes place underwater where the flow of water across the keel and rudder are compromised. The part of the hull that is underwater becomes asymmetrical, creating turning forces that have to be counteracted.

A more subtle change also takes place. The forces created by sails and keel are no longer acting directly above and directly below the hull—they're both displaced sideways. The effect is similar to what would happen if you were pulling the hull with a towline. When the boat is upright, the towline pulls along the hull's centerline. As the boat heels, the effect is as if the towline were uncleated and made fast again at the gunwale near the widest point of the beam. In this case, you would expect to fight the boat with its rudder to keep it on a straight course. When the boat heels, its propulsion forces operate away from the hull's centerline. That's why boats that are allowed to heel too far under the pull of a spinnaker are so vulnerable to broaching. It also explains why, when a sailboarder leans back into the wind at high speed, he must also move to the tail of his board, holding the sail well aft of the point on which the board pivots when it changes direction.

It's no wonder the Polynesian solution—dividing the hull into two (or three) pieces and placing them far apart—is attractive. With no penalty in weight, a catamaran or trimaran achieves huge righting moment at the slightest angle of heel.

However, that's not the whole story. When stability is achieved entirely by righting moment from hull width (or by spreading the hulls farther apart), righting moment is typically very high at small angles of heel—but decreases steadily to nothing as the boat heels farther over. In one sense, when you need it most, it's all gone.

The righting moment provided by fixed ballast is typically very small as the hull begins to heel, but steadily increases as the hull heels farther; in other words, the boat is initially "tender" and ultimately "stiff." In the extreme case, the mast is almost parallel with the surface of the water and the fixed ballast is held at a similar angle, almost sideways. At this radical stage, righting moment is at a maximum and heeling force at a minimum.

Keep in mind that these examples are highly simplified. Many other factors, such as the wave conditions present when such extreme heeling forces are at work, have to be considered by yacht designers. For example, even though the fixed-ballasted boat may not heel beyond this extreme angle, it may be filling itself with water. Even though the pow-