the underwater string. Yacht designers used to estimate the position of the center of effort by finding the geometric center of the triangles in a sail plan, connecting them, segmenting the connecting line in ratio to the areas of the triangle, then using their experience to estimate how far forward or aft the real balance point might be. The center of lateral resistance was found in a similar fashion. Today, designers still use experience, but it is supplemented by wind tunnel and tank testing of various shapes.

The balancing act

Both centers (called "CE" and "CLR") are constantly changing with boat motion and sail adjustment. Unfortunately, the net effect of lift and drag that the CE represents does not pull the boat straight ahead. Remember that we said the boat would start to move, but not in the desired direction. The force acting at the CE on the sails actually pulls mostly sideways, and the forces acting on the CLR on the hull, keel and rudder, act to windward and slightly aft. These forces are in balance when the boat is traveling in a straight line. When they are out of balance, the boat turns.

Keeping in mind that boats sail fastest when their keel and rudder are presented to the water flow at a slight angle, designers place the sails on the hull in such a way that, if no steering force were applied with the rudder, the boat would turn itself gently toward the direction of the wind (weather helm). When the boat is sailed, a straight-line course is achieved by the gentle application of 2 or 3 degrees of rudder angle in the opposite direction. Balance between CE and CLR is achieved (the boat does not turn), and both underwater foils are presented to the oncoming flow of water at a slight angle of attack—so both foils, keel and rudder, develop a force that pulls the boat to windward. However, you can also have too much of a good thing. An excessive imbalance between CE and CLR, one that requires more than a slight rudder correction, causes the rudder to develop drag commensurate with the greater lift it is being forced to create. The boat decelerates—slower speed means less drive from the sails—and things settle back into the drive-drag equilibrium at a slower constant speed.

In moderate wind (10 to 14 knots), a sailboat that is properly balanced exhibits a "weather helm"—a tendency to turn into the wind. This is counteracted by pulling the tiller slightly to weather (the direction of the wind) or turning the wheel away from the wind. A sailboat that acts in this way is considered safer because in the event of gear failure or lack of attention to the helm, it will round up (head into the wind) rather than fall off into a possibly dangerous jibe. Weather helm should decrease as wind strength abates and many sailboats develop a slight tendency for lee helm in light air.

A "lee helm" is the opposite of weather helm: a tendency for the boat to wander off to leeward. Acceptable in very light winds, it is not desirable in heavier wind. A straight-line course can only be achieved when the rudder is turned to create a force pulling to leeward (so the bow is pushed to windward). This means that no windward lift is being created by the rudder, so all of it has to be created by the keel. The keel then ends up at a more extreme angle of attack to produce this lift, and in the process creates more drag. As a result, everything slows down.

It's worth pointing out that all of these differences in balance are important to the cruising sailor as well as the racer. Though they are difficult to perceive—3 degrees is hard to see and often difficult to feel in the helm—they produce substantial differences on almost all points of sail. The racing sailor may lose a race, but the cruising sailor may make serious errors in navigation by failing to account for large leeway angles that result from excessive imbalance.

Incidentally, keels and rudders can be a lot smaller in area than sails because they operate in a denser medium. In addition, when they are pushed through the water at greater speeds, they can produce sufficient side forces with less area—that's why the crews of fast, planing catamarans often reduce drag by pulling their foils (usually daggerboards) a few inches up at high speeds, even though they are sailing upwind.

Conversely, if there is no speed at all, there is no flow and neither the keel nor the rudder can do its job. A boat that has no way on cannot be steered, which is why "steerageway" is so important. Skippers will often do whatever they can to get a boat settled down and underway so as to create some flow past the keel and rudder before they worry about what precise direction they're going.

Outsailing the wind

For most novice sailors, the idea that a boat can sail faster than the wind is questionable at best. Even the less ambitious claim—that a boat can receive more power from the wind as the boat picks up speed—seems contrary to common sense. After all, there is no source of power other than the wind.

But it's true, and an understanding of apparent wind, the stronger wind partly created by the boat's own speed, is crucial to sailing. Let's look at two extreme examples—a very slow boat and a very fast boat.

The slow boat is a Spanish galleon. It has no separate keel and, by recent standards, inefficient sails. It sails most effectively with the wind behind it, and even then, it doesn't sail very fast. If the galleon were just getting underway and if the wind were exactly on its stern and blowing at 10 knots, the wind felt by someone standing on deck would be 10 knots. As the galleon picked up speed, the wind felt on deck (the apparent wind) would decrease, because the ship would be moving along with it. The effect of the wind on the moving sails would also decrease. At somewhere around 2 knots of vessel speed through the water, the decreasing force created by the sails would exactly balance the increasing resistance of the hull (discussed later) and the galleon would stop accel-