TECHNIQUE, TACTICS AND TECHNOLOGY FOR PERFORMANCE SAILORS

From the Experts

The Wind Tunnel Teaches Key Downwind Trim Lessons

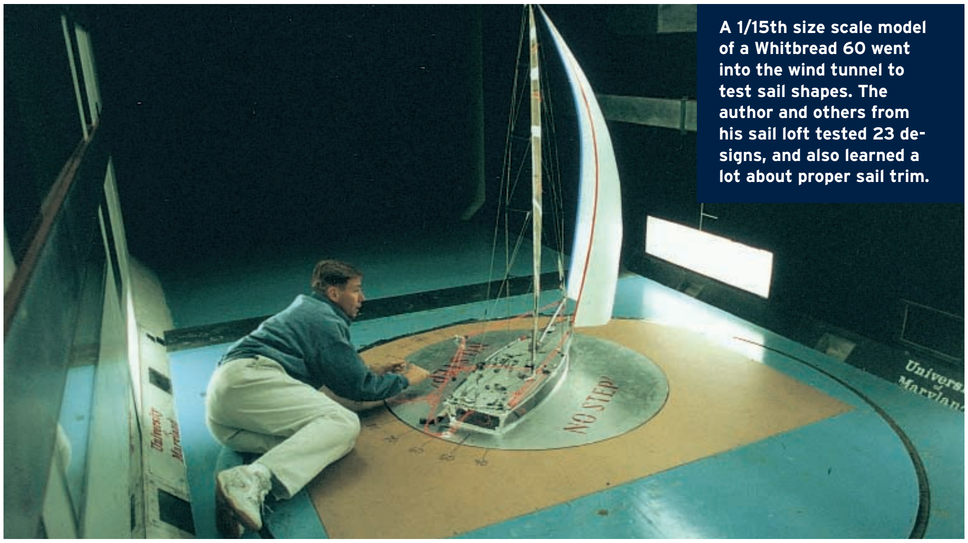
TECHNIQUE BY DAVID FLYNN

"DEADWEIGHT CHECK COMPLETE. TUNNEL clear. Take it up to 25 knots." Shortly after 6:30 a.m., the first light of dawn creeps across the horizon on a cold, early spring morning. But in the windowless control room of the Glenn L. Martin Wind Tunnel, the light glares fluorescent, muted only by the soft green glow from a row of computer screens. Four people are huddled intently in front of the monitors, surrounded by a small mountain of equipment. Coffee cups and half-eaten donuts are perched on boxes surrounded by several miles of wire.

With a resounding clunk, the main tunnel door closes, muffling the growing roar of 25 knots of breeze. On the other side of the floor-to-ceiling windows, a 1/15th size scale model of a Whitbread 60 rotates on a turntable until it reaches the target wind angle for the next test cycle. With a few mouse clicks, trim is adjusted via radio controls linked directly to the computer. Servos whine as the sheet is eased, the pole comes back and up, vang on, mainsheet in…

A string of numbers flashes across another screen. All eyes are on the big readout that displays the "driving force," a number which reduces the forces being measured on six different axes (lift, drag, pitch, yaw, roll, and side force) to the measurement of greatest concern, the force acting in the direction of travel of the yacht. The gathered designers and engineers cheer with the polite enthusiasm of a good golf crowd. The result this time is 110-percent of baseline performance! A new record has been set for this sail design at this angle of attack.

Over and over again for three weeks we repeat the cycle—23 models, tested at every five degrees, and at three different basic trim positions. At one point Chris Mairs, doctoral candidate and test engineer remarks, "This is great. We should be selling sail-trim training sessions."



A 1/15th size scale model of a Whitbread 60 went into the wind tunnel to test sail shapes. The author and others from his sail loft tested 23 designs, and also learned a lot about proper sail trim.

What the Wind Tunnel Can (and Can't) Do

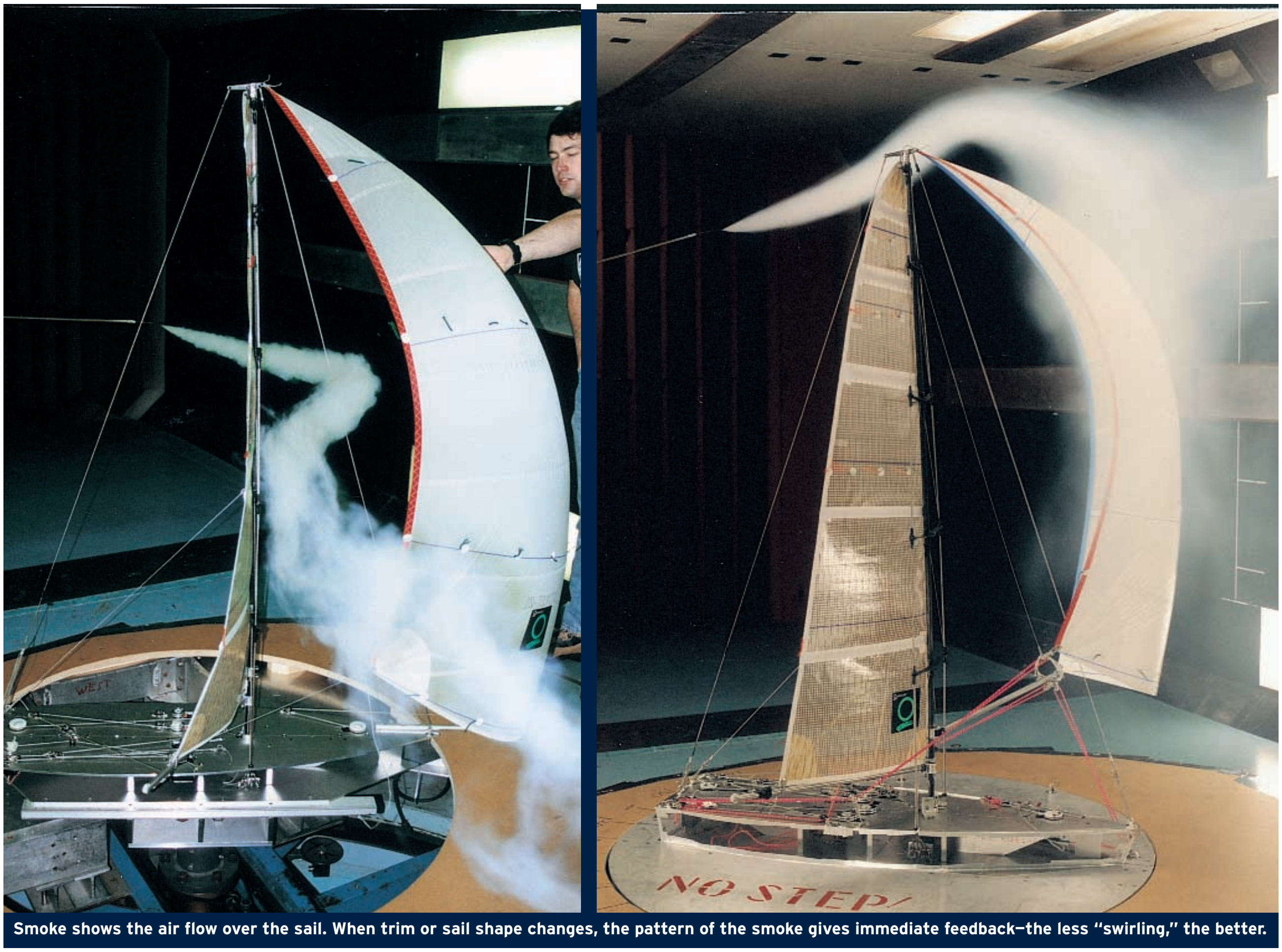
We set out to answer several questions. What does the airflow around a spinnaker really look like? How is flow affected by changes in angle, trim, and sail shape? What is the impact of trim on the effectiveness of a spinnaker? At what angle and velocity does one spinnaker shape become faster than another? The goal was to create faster spinnakers for the Whitbread Race around the world.

Before we chose the wind tunnel, we considered other ways to test spinnakers and trim. First, there is computational fluid dynamics (computer modeling), which can predict the forces via a mathematical model. Second, there is two boat on-the-water testing. Both of these methods have serious drawbacks.

While computer simulations produce great pictures for upwind sails, there is no affordable, general purpose CFD technique that can accurately predict the forces produced by offwind sails. When you tackle the swirling, changing pattern of air around a spinnaker, the math simply gets too complex; more complicated than modeling the flow of water around keels and rudders.

Full-scale two-boat testing might seem like the logical answer: Get out on the water, line them up, and see what works. Sounds simple, but it's not that easy. You need two perfectly matched boats, lots of time, and a steady breeze. Not to mention the expense of building all those full-sized test sails.

Celia Pearson (top), Quantum Sails


Smoke shows the air flow over the sail. When trim or sail shape changes, the pattern of the smoke gives immediate feedback—the less "swirling," the better.

Celia Pearson (right), Quantum Sails

Wind tunnel testing solves these problems, but it has its own drawbacks, which can lead to imperfect results. The first is called "blockage." The walls of the tunnel itself constrain and change the airflow over the model, as does the size of the model relative to the size of the tunnel.

The second drawback is scaling. A model is not the same size as the real thing. An elegant mathematical solution to this problem is found in the "Reynolds" number, which is used in all types of testing where flow of a fluid (like air) is being measured. The Reynolds number synthesizes the velocity and viscosity of the fluid, relative to the size of the object being tested. To make the Reynolds number of a test model and a full-scale sail equal you must either increase the size of the model and/or increase the test velocity of the wind. We chose to increase the velocity, to 25 knots—not a perfect match for full-size scale, but close.

The third problem is what sailors refer to as "twist." In real life, the direction of the wind varies from the top of the mast to deck level, and is never the same from one day to another. But in most wind tunnels (including ours) the airflow is uniform from bottom to top. Again, not perfect, but considering the potential problems of trying to simulate real-life sheer, it seemed a safe compromise.

Design Lessons from the Tunnel

Let's face it, one of the biggest problems when designing a spinnaker is that they are hard to see. Their size makes it almost impossible to get any kind of perspective from on the boat. Even from a powerboat, you only get a snapshot of their actual flying shape.

In the wind tunnel the designer has a bird's eye view. He or she can watch the airstream when smoke is used to highlight the flow. Alter the pole position, or the shape of a particular section, and the smoke dramatically illustrates the effect.

The stable environment of the wind tunnel can also cause you to draw the wrong conclusions. In our testing, flatter entries and flatter overall sections typically provided the most driving force. But on the water, a sail that is flat is also unstable and hard to fly. Real-world conditions call for more stability, particularly in the entry, to make the sail user-friendly and less dependent on ideal trim. The tunnel does indicate, however, that a sail that is too full, too forgiving, and too easy to trim will certainly not be the fastest sail.

INSIDE

Trim Lessons: Aerodynamic Mode

The wind tunnel test makes it clear that we need to think of spinnaker trim in two different modes: the "aerodynamic" and the "barn door" mode. When reaching at angles as far aft as 140 degrees apparent, most of the air flowing over the sail is attached and the sail is "aerodynamic." When smoke is introduced, it's pulled into and around the sail, its path relatively uninterrupted until it gets to the trailing edge of the sail. Our understanding of how upwind sails work—drive resulting from a difference in pressure from one side of the sail to the other—also holds true for spinnakers in this mode.

In this aerodynamic mode, sheet trim is critical. Overtrimming drastically reduces the driving force and increases the side force and drag. The first rule taught to all spinnaker trimmers—ease continually until the luff curls—holds true. In the tunnel, the best driving force numbers were produced when the sail was eased so far that it began shaking violently just before it collapsed. (Remember, testing was done with 25 knots of breeze to get better Reynolds numbers.) Test engineers looked on nervously as the trimmers pushed this edge. Total collapse produced a panicked rush into the tunnel to save the model as it attempted to shake itself to pieces under the force of a flogging spinnaker. A spinnaker "flying on the edge" could easily produce 10- to 15-percent more driving force than the same sail overtrimmed.

If pole height was positioned on the low side of commonly accepted practice, the spinnaker luff became more stable, and hence the whole sail could be eased farther. A lower pole also pulled the shape forward and opened up the back of the sail. This more genoa-like shape reduced side force. Setting the pole 5 or 10 degrees aft of perpendicular to the wind also, as one would suspect, improved forward force. This confirms the advantage of keeping the pole 12 to 18 inches off the headstay on breezy, tight spinnaker reaches when you're trying to sail as high as possible.

Trim Lessons: Barn Door Mode

As the wind angles broadened, the amount of smoke attached to and flowing cleanly off the sail deteriorated. In fact, it became a mess—a randomly swirling pattern more reminiscent of an ink blot test than anything else. By 145 degrees apparent wind angle, we are fully in the "barn door" mode.

At these angles, sheet trim became somewhat less important, while pole position was critical. The best driving force was always produced with the pole farther aft than dictated by the second rule of spinnaker trim—pole perpendicular to the apparent wind. The pole could be set 10 or even 20 degrees aft of square to the wind. This reinforced another tenet of modern spinnaker trim: projected area is the key on a broad reach or run—we want a bigger barn door! Squaring the pole stretches the foot tight, projects area, and gets the sail out from behind the mainsail.

In the tunnel, easing the sheet did help driving force in the barn door mode, but if the sail was eased to the point where the head was allowed to roll out to weather of the vertical line projected up from the pole end, the numbers were not as good as when the trimmer pulled the pole back to the point where it was underneath the curl.

Especially since most of the sails tested were asymmetric spinnakers, it also helped to move the sheet lead twing forward as the pole was brought back at broader angles. This kept the clew from rising up in the air to the point where the sail opened up (twisted) too far, and began to spill air off the back end. The flatter the sail design, the more important the twing.

So next time you're reaching with a chute, try the pole a little lower and the sheet a little looser than you might be used to. And whether reaching or running, try pulling the pole a bit farther aft than you did last season. Finally, don't forget the mainsail—the tunnel showed that if it was over- or undertrimmed, it also had a devastating effect on total power. ✦

David Flynn works for the Quantum Sail Design Group in Annapolis, Md., where he was part of the wind tunnel team. He is a regular trimmer on the 1D48 circuit and at major events around the world.