Design of the *Courageous* Mast

Designers' Forum

By Arvel Gentry

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(Arvel Gentry is a research aerodynamicist at the Douglas Aircraft Co., in Long Beach, Cal., and has long had a special fascination for sailboat aerodynamics, a subject with which he has had extensive practical experience on his successful Ranger 23 "Kittiwake." His non-sailing weekends are spent with such design projects as a sailing performance recorder for the new 79' ketch "Kialoa III" and mast shapes for ocean racers and 12-meters. Here he describes the work behind the mast section on the 1974 America's cup defender. Eds.)

The America's Cup is defended and challenged by men sailing the most advanced boats afloat, and no 12-Meter skipper would want to go to the starting line with anything but the fastest boat and best equipment that designers and builders can produce. Since very small differences in boatspeed can mean the margin between victory and defeat, every part of the boat (hull, rigging, and sails) is reviewed and studied for any possible improvement.

Much was written last summer and fall about hull shape (with the disappointment of the Chance-designed Mariner) and about sails (the Kevlar mainsails and the Hood versus North competition). Although other design features were less spectacular and less obvious, they were nonetheless important. A case in point was the new mast section shapes that appeared on both the challenger, *Southern Cross*, and the defender, *Courageous*. The other 12-Meters had masts with a conventional elliptical mast cross-section shape. Little is known about the origins of the *Southern Cross* mast shape except that it was apparently the result of some wind-tunnel testing. Her mast was a modified D-shape with the round part of the D facing forward.

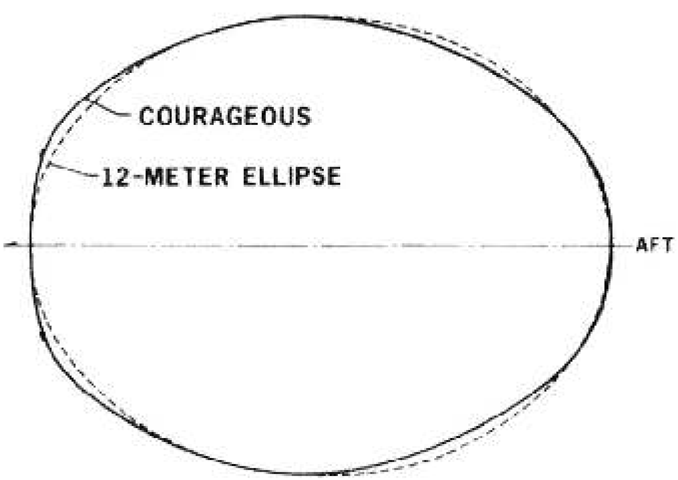

Figure 1. Comparison between section shapes of the standard 12-Meter mast and the new *Courageous* spar. Two plastic transition strips on the new mast delay separation of the air flow.

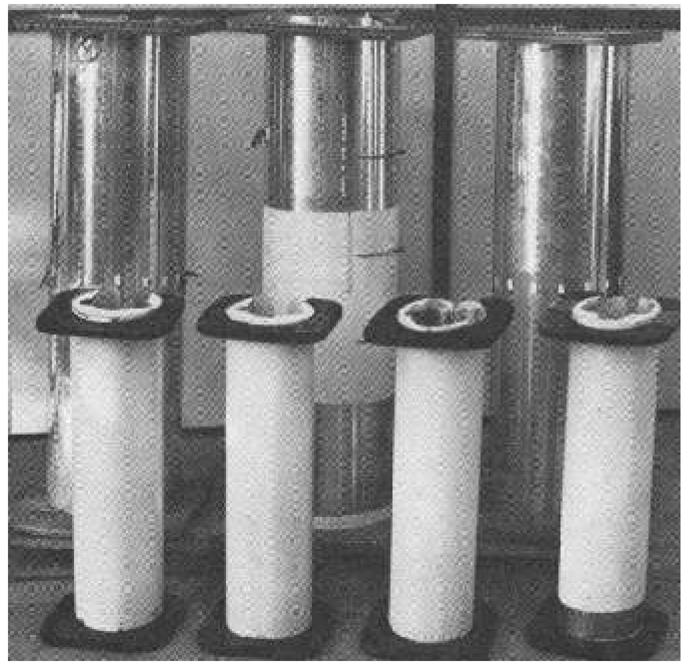

Figure 2. Aluminum shapes used to test new spar designs on the author's Ranger 23 (foreground) and on an Ericson 46 (background). The restrictive 12-Meter rule prohibits any radical developments, as the similarity of these shapes indicates. The background shapes are (left to right) a Bergstrom and Ridder type section, the section eventually selected for *Courageous*, and the 16-year old standard "12-Meter Ellipse" section.

Although not as unusual in shape, the *Courageous* mast was a subtle but significant variation from the conventional elliptical shape with a slightly blunted forward face and with two plastic strips of tiny triangles running up the forward side (Figure 1). The older 12-Meter masts were extrusions from a die originally used on *Columbia* in 1958. To get the desired shape, the *Courageous* mast was formed from flat aluminum plates and welded after forming. Why all this effort for such a relatively small change in shape?

To answer that we must go back to late 1973 in Bill Ficker's home, Newport Beach, Cal. Ficker (who was at that time slated to be skipper of Olin Stephens' new Twelve, *Courageous*) had called together myself, David Pedrick, who was working for Olin, and Bud Gardiner, who had experience in constructing large masts. Ficker wondered if a new mast section shape might lead to improved boat performance.

Being a research aerodynamicist by profession and something of a student of sailing theory, I jumped at the opportunity to pursue this unique problem. I first conducted a series of theoretical studies to gain a basic understanding of how the air flows around the mast and sails. The mast of a 12-Meter forms the leading edge of the mainsail and is important to the driving force of the sail, just as the leading edge is important to the wing of an airplane. However, the presence of the genoa in front of the mainsail and the area of separated flow right behind the mast make the problem difficult to analyze. The point of flow separation on the mast depends upon how the air flows around the mast, and this is strongly influenced by the presence of the genoa and the trim of the mainsail.

Next, I conducted analytical studies of how the airflow and separation changed with different mast shapes. I searched for the shape that gave the least flow separation on the critical lee side of the mast (and, therefore, had more clean undisturbed flow on the mainsail).It was also desirable to have the highest possible velocities over the forward part of the mast (and, therefore, the highest leading edge suction).

But all this was just theory. I had some new ideas, but they somehow had to be tested. The complicated interaction between the genoa and mainsail and the separation behind the mast make accurate and meaningful wind tunnel testing very difficult and expensive. Wind tunnel tests can often be just as misleading as tank tests. Well, why not conduct actual sailing tests of the new mast shapes?

The idea seemed worth trying, so Steve Godshall (crew on my Ranger 23) and I formed several experimental shapes of aluminum and wrapped them around the mast of my boat and went sailing. Two shapes could be tested at a time. In these tests the airflow patterns were indicated by short pieces of ribbon attached to the mast sections and mainsail and by the flow of streams of soap bubbles generated in front of the mast.

When one shape was found to have less flow separation when compared directly with the conventional elliptical shape, it was then subjected to further theoretical study to find out why. Sailing tests were also conducted with a D-section similar to that used on *Southern Cross* and with a section similar to the Bergstrom and Ridder shape. Each time the new shape was compared directly with the conventional 12-Meter ellipse. Figure 2 shows some of the sections tested.

With the help of Ficker and Gardiner, the two best shapes were then tested and compared directly with the elliptical shape under full scale conditions on a Ericson 46. The mast shape that had the least flow separation in the sailing tests was selected for use on *Courageous* by Olin Stephens. The selected shape was not drastically different, but it tested significantly better than the standard 12-Meter elliptical section.

The shape was designed to have its maximum effectiveness with the plastic transition strips precisely positioned on the forward face of the mast. The triangles molded into strips generated tiny swirls of air that change the characteristics of the flow very close to the mast so as to delay the flow separation behind the mast. The optimum position of the strips was found to be different on different mast shapes. It was also found that the optimum mast shape would be significantly different from the *Courageous* mast if the width and thickness proportions of the sections were different from those required under the strict 12-Meter rule.

To better hold the mast to the desired design shape, the mast sections were formed from flat plates and welded in the Southern California area under the guidance of Bud Gardiner. The three 30-foot mast tubes were then shipped to the East Coast where Hood Yacht Systems assembled and completed the outfitting of the mast.

The new mast was not ready for the first set of trial races but went into the boat just before the July observations trials. However, the all-important transition strips on the lower two-thirds of the mast were removed when it was found that the threads in the genoa were damaged by the sharp front edges of the transition strips during tacking maneuvers. New transition strips were manufactured by Gardiner and reinstalled on the mast just before *Courageous'* four-race win streak in the final trials against *Intrepid* (only this time the sharp edges were sanded down so as not to damage the genoa).

How much was all this study and work worth in terms of increased boat seed? No one really knows. So many other changes and improvements were being made at the same time that it was impossible to sort out any incremental effects. However, the full-scale mast section comparison tests conducted with Ficker and Gardiner indicated that there should have been improvement in boatspeed. Skipper Bob Bavier stated the “no one knows how much this affected our boatspeed, but I can't but believe that it improved it, and with the tight racing we were having with *Intrepid* any improvement, however small, was mighty welcome indeed.”

Of course, *Courageous* went on to defeat *Southern Cross* in four straight races, so maybe all of this mast work, and the similar work on other gear, computers, etc., was not really needed. Well, don't bet your deck shoes on it. It's just this kind of all-out effort that has successfully defended the Cup for 123 years.