Sails: The Source of Power

An Introduction to Model Yacht Sails, Part 1

by Rod Carr

The first job of a new skipper is to learn the specific nomenclature that describes the sails. There are a handful of terms, and the quicker they are added to your vocabulary the easier it will be to communicate with your sailmaker and understand the specific techniques described for sail set, trim and tuning.

A suit of sails consists of a mainsail and a jib. The word is "suit", like pants and a jacket, not "suite" which is an expensive multi-room arrangement in a hotel.

Figure 1 provides a profile view of a sloop-rigged mainsail and jib. The names of the corresponding edges of each sail are the same: luff (leading edge), leech (trailing edge) and foot (bottom edge). The names of the corners likewise correspond: head (top forward corner), tack (bottom forward corner) and clew (bottom after corner).

Now, each edge of the sail may or may not be cut straight. Starting from the bow:

Jib luff – if cut concave, the maximum concavity is referred to as jib hollow, or jib luff allowance (JLA). It is usually measured in 1/32" increments, and reported as a 4 or a 6 meaning 4/32" or 6/32" of concavity near the midpoint of the curve. Single panel sails may have no concavity, or they may have some convex JLA to provide the extra cloth needed in the sail to develop camber, the airfoil shape required for good performance. Remember that the jibstay will sag under wind pressure and that the jib luff will be forced to assume that shape.

Jib foot – most jibs are cut with extra cloth outside the straight line drawn between the tack and clew. The amount outside is referred to as foot round, and is usually reported in inches. Most jibs are rigged with "loose feet" meaning that the sail is attached to the jib boom or club at the tack and clew only. If the sail will be attached along the jib club, there will likely be very little foot round.

Jib leech – Class rules typically allow extra cloth to be added to the sail between the straight line distance between the head and clew. This extra cloth is called leech roach and is reported as the maximum distance outside of the straight line. To prevent this extra cloth from folding over, support is added in the form of battens, short lengths of a stiff material attached to the sail, or slipped into pockets that terminate on the after edge of the leech. The number, length and placement of battens are controlled by Class Rules. In general, maximum batten length is about 2.5 x leech roach. Modern sail materials do not require batten support as much as the old cotton sails did, so they are very often eliminated from jibs to prevent the jib leech from being "hard" or flat.

Mainsail luff – Most mainsail luffs are cut with a convex shape, with some amount of extra cloth outside the straight line between head and tack. The amount of extra cloth outside the straight line is called luff round, or Main Luff Allowance (MLA). On a sail with a 67" luff, the MLA is typically ¼", and is reported as such. The extra cloth, when set on a straight mast the extra cloth moves back into the body of the sail increasing its camber or depth. Adjusting the mast by bending it forward in its midsections pulls the extra cloth forward, thereby flattening the sail for higher wind speed condition.

Mainsail foot – Same comments apply as for the jib foot.

Mainsail leech – Same comments as for jib leech. In addition, most mainsails will be constructed with battens, as mainsail leech roaches are usually larger

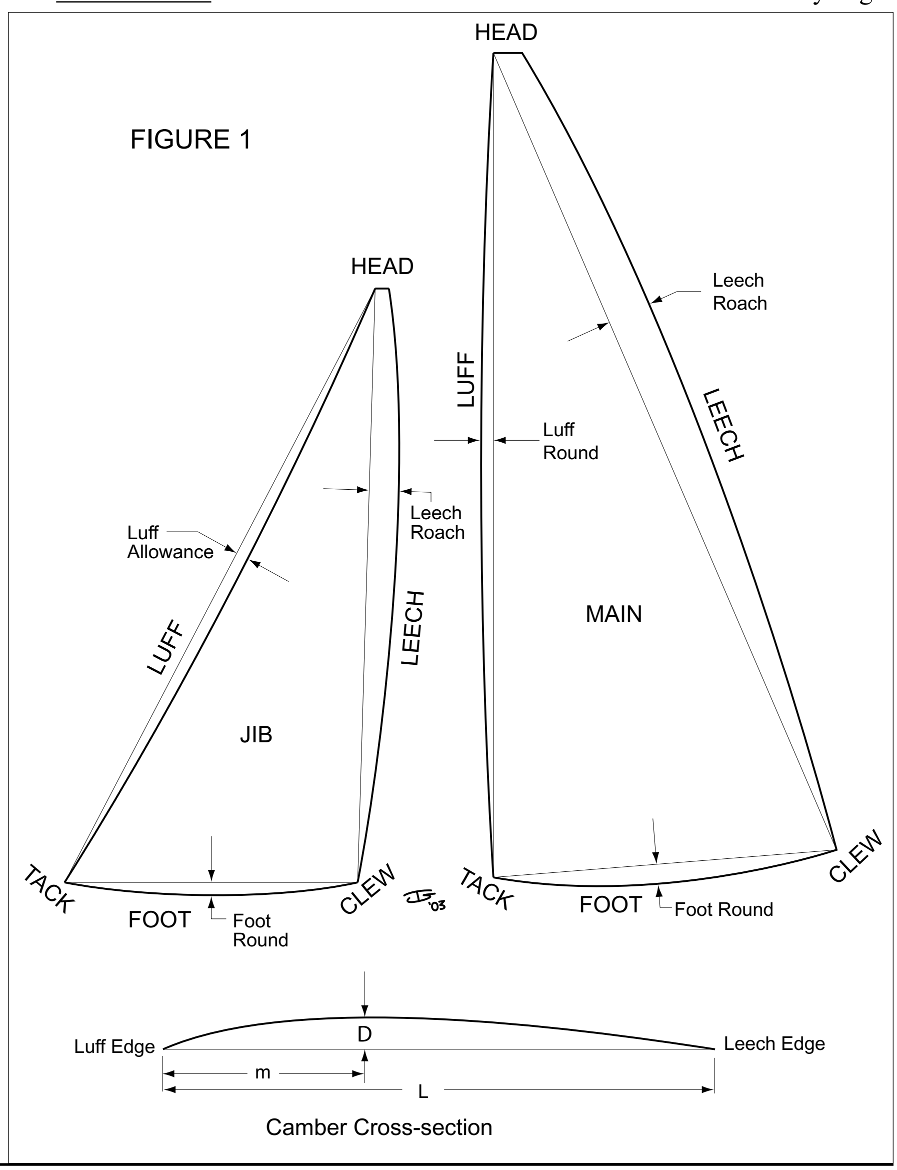

FIGURE 1

Camber Cross-section

than jib leech roaches. Care must be taken that the battens are not so stiff that they flatten the after third of the sail to look like a barn door. Battens on modern sails assist in shaping the after parts of the sail, the cloth is generally stable enough to hold itself fairly well, needing just a bit of help.

Sail Shape

Figure 1B shows a cross section of a sail. The wind blows from right to left. The dimension “L” is the chord across the sail, a straight line from luff to leech. The % camber is found by dividing the maximum depth “D” by the chord “L”. Model yachts sails typically have cambers which vary from 5% for flat sails, to 15% for quite full sails. The position of maximum draft is found by dividing “M” by “L”. Mainsails generally have maximum draft located at 40% to 50% of chord, while jibs can be successful with maximum draft located at 35% to 40%. Sails with maximum draft forward have good acceleration, don’t point particularly well, and have a fairly low top speed potential, generally a good form for light winds. Sails with maximum draft aft have good pointing ability, have a good top end speed capability and are recommended for medium to heavy winds. Draft stripes are often put on model yacht sails to assist in visualizing the shape in the sail when full of wind.

Sail Construction

Sails come in two general varieties of construction; single panel, where the entire sail is one piece of cloth without seams, gores, or cuts in the body of the sail; and paneled, where each sail is made up of panels or strips of cloth, attached edge to edge with tapered seams to induce three dimensional shape in the sail when filled with wind.

Single panel sails of a woven material are typically encountered in the construction of “kit” boats, because single panel sails are much less costly for the kit maker to provide. They are also found in several AMYA racing classes, such as the CR 914 and Soling One Meter where the Class Rules require either kit sails only, or aftermarket single panel sails cut to a specific size. The details of successful set, trim and tuning of single panel sails is an entire subject in itself. Your sailmaker should be able to provide you with guidance if you are purchasing sails of this type from him. At the very least, he should inform you of the JLA and MLA measurements so that you will have a starting point for setting up your initial mast shape, and backstay tension. Single panel sails must be full of air, so that the cloth can stretch under the wind loading and can begin to take on the cambered shape necessary for drive.

Paneled sails are used in the greater proportion of racing classes, and also in scale models that are going to be operated on the water. They provide superior performance because the airfoil shape that produces drive for propelling the hull is built into the sail. Most use a membrane material such as a mylar sandwich with load carrying fibers, or mylar film. These modern materials don’t stretch, so the cambered shape must be built into the sail with tapered seams that hold the panels together.

Sail Attachment

A sail is attached to the spars by each of the three corners and by the luff of the sail to either the mast or the jibstay. (See Figure 2) In the case of the jib, almost all jib luffs are fitted with a hem into which the jibstay slides. This supports the sail along its length

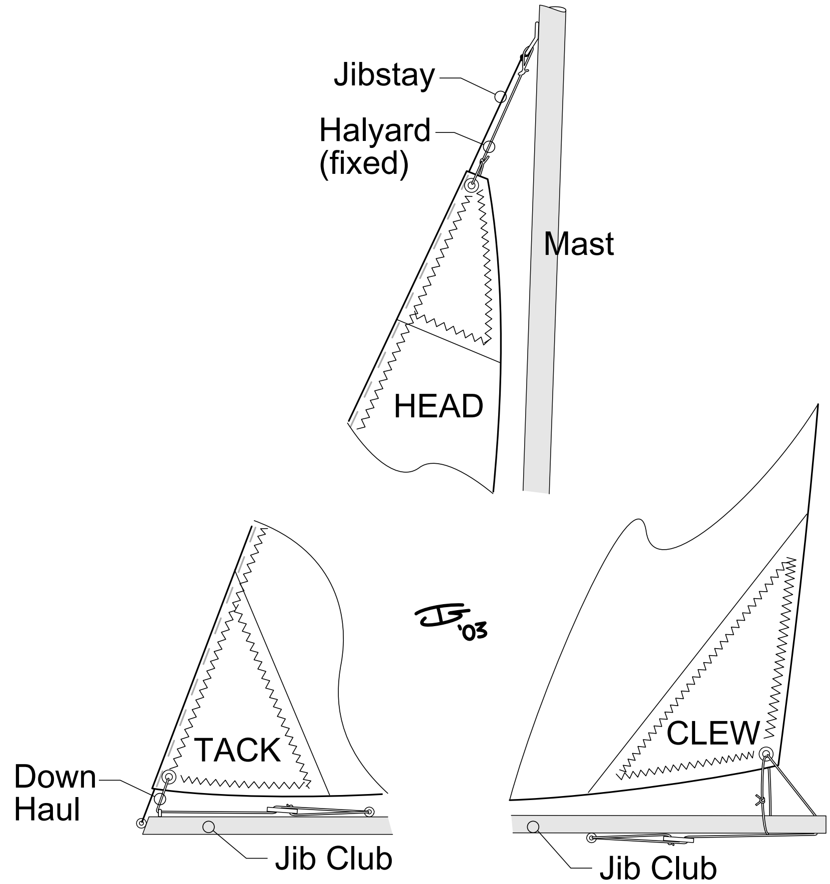

Figure 2
Sail Corner Rigging

and makes for a smooth and clean entry where the wind meets the sail. The luff hem method eliminates scalloping which can happen with the tubes, and it distributes the wind load evenly over the entire luff. Some jibs are mounted using little hollow tubes affixed to the sail that are slid over the jibstay. The sail tubes provide for excellent swiveling as the sail tacks, but produce point loads where they attach to the sail, and this can cause the sail to wear out prematurely.

The head of the jib usually contains a grommet to which is attached a halyard. For ease of adjustment, the halyard is fixed, usually up at the jibstay attachment point. Tension is adjusted on the sail luff by use of a downhaul, which is tied to the tack grommet, led to the jib club, and back about half way down the club to some sort of a tension adjustment like a cleat, 3-hole bowsie, or other device. The clew is constrained in the vertical direction by something as simple as a loop of sheet line tied through the clew grommet and led under and around the club. A second line, called the clew outhaul, leads aft to the end of the jib club, and provides for adjusting the position of the clew along the club, controlling the fullness of the foot and the bottom third of the jib.

The corners of the mainsail are rigged in the same way.

The luff of the mainsail must be mated with the mast, and many methods have been developed over the years. The mast material drives part of the solution, while the size of the boat and/or the class rules under which the boat will sail may provide other opportunities or constraints. Figure 3 shows a series of approaches to this problem, certainly not exhaustive by any means. Smaller classes, such as the 36/600, Victoria, Fairwind, International One Meter and U.S. One Meter, that use round mast materials like aluminum or carbon fiber tube, use the mast loop method (3A) with good success. Aerodynamically it provides the best leading edge, which gets traded off against a shorter sail lifetime since the luff is attached at discrete points. Jackwire methods (3B) work well, with various methods employed for holding the wire to the mast. We show a row of cotter pins set through the mast, with "windows" cut in the sail for clearance. Dress hooks have been used for attachment to the jackwire, but seem typical of only vintage boats these days. Extruded masts like the Bantock "Groovey" and the Ozmun "Goldspar" are amenable to the standard bolt-rope (3C). This method produces generally poor sail shape at the exit to the mast slot, and poor hinging ability in light air. Jackwire methods using mast slides or other attachment methods (3D) produce better hinging and longer sail lifetimes. Mast slugs or beads directly attached to reinforcement patches on the luff are also used (3E).

Sail Setting Assessment

Success in sail setting requires an understanding of the match between the flexible sail and its mounting component. For mainsails, the mast shape must be matched to the shape of the mainsail luff for a good match. For jibs, the jib luff shape needs to be cut so that it harmonizes with the sag in the jibstay which results from wind pressure on the sail.

If your sailmaker doesn't tell you your jib luff allowance, you must measure it. Tape the leading edge of the sail at the head and tack to a flat surface. Make a clew holder by drilling a bunch of holes in an 18" long piece of 2x2 screwed to a plywood base which can be weighted, then put a 4" piece of pointed stiff wire in the appropriate hole to hold the clew. Elevate the clew of the sail until the sail swoops down toward the luff and becomes just tangent where the luff hits the table. Adjust the position of the clew holder by moving it parallel to the luff to adjust for twist in the sail. Moving the holder toward the head will allow the upper leech to sag and twist off. A small amount of twist should exist in the sail. Photo 1 shows a jib which has been set

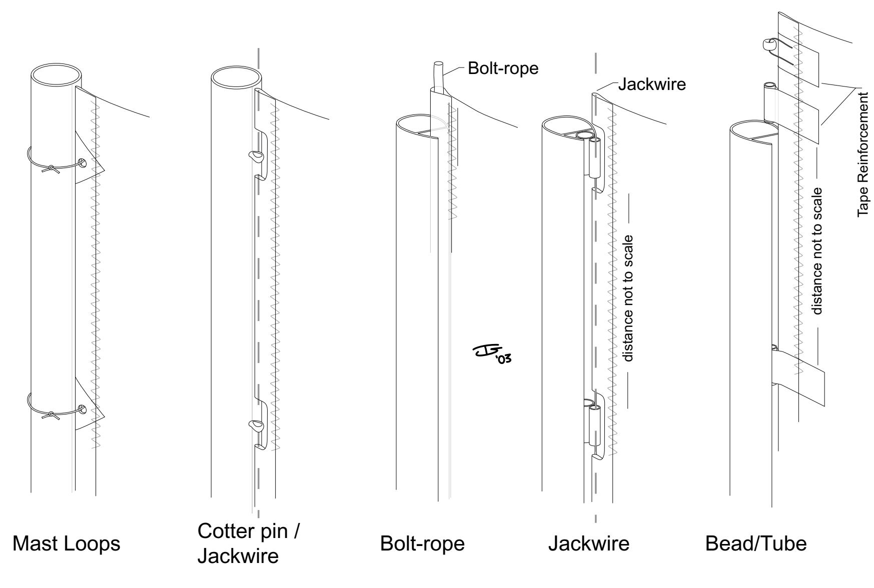

Figure 3: Mast Sail Attachment Methods

up like this. Use a straight edge between the head and tack and measure the distance to the luff in 32nds of an inch, this is the JLA for that sail.

You now know how much the jibstay must sag to exactly match the shape cut in the luff of the sail. The higher the wind blows, the more sag will occur. So in general, model yacht sails are cut with somewhere between 4/32" and 10/32" of JLA. The amount depends on the target wind range and on the length of the luff itself.

While the jib is standing there, observe it for its general characteristics. Where is the point of maximum draft? Is the leading half of the sail smooth and gently rounded? A few pictures taken with a digital camera can be printed out in black and white and measurements made which allow camber, maximum draft, entry angle and so on to be calculated. The shape the sail shows here is caused by gravity, not wind. The weight of the typical sail (1.0 oz/sq yd) can be equated to a wind pressure from a 1 to 1.5 mph wind. So one should expect some changes in shape once the sail is on the boat on the water.

Mainsails are also amenable to inspection by the same method. MLA must be determined for the luff of the mainsail so that a proper mast shape can be matched to the shape of the mainsail luff. Photo 2 shows a sail with the head and tack taped down, and clew elevated. The straight edge along the luff allowed measurement of 3/32" of luff hollow to be determined. This means that a mast match for this sail requires for the center of the mast to be pulled aft by 3/32". As wind speed increases, masts usually bow forward under increased backstay tension. This sail will not respond well to that change in mast shape, so is likely intended for use in only the lightest of airs. We observe that this is a very "draft-forward" sail, so good for acceleration, but with a low top speed capability. Pointing and top speed are not so important in light air, where acceleration after tacks and mark roundings is critical to racing performance. Notice that the leech area is very flat, caused by extremely stiff battens.

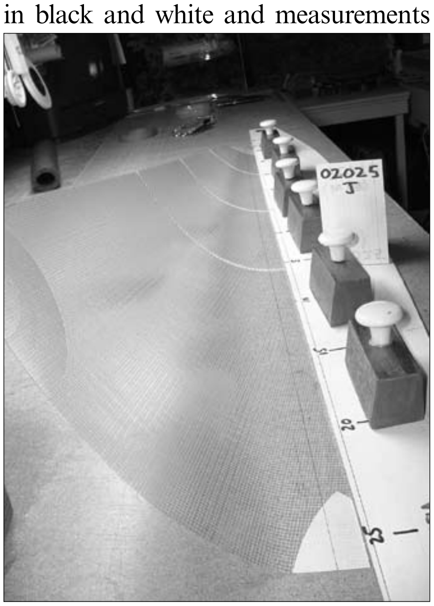

Photo 1: Finding the jib luff allowance.

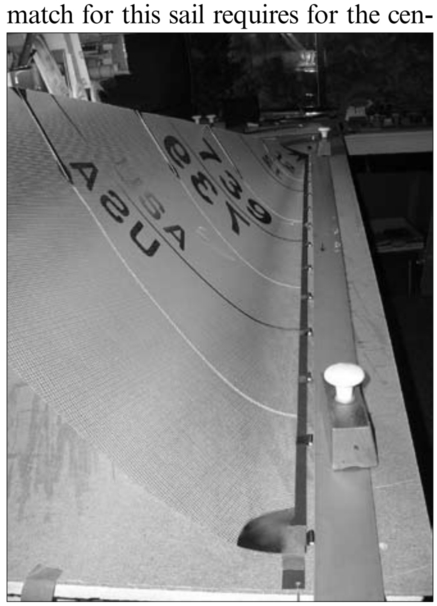
Photo 2: Main luff measurement.

Initial Close Hauled Tuning

With the sails on the boat, and the boat on its side so that you can sight down the mast, the following are good starting points for tuning your new sails for windward performance in light air.

1) Mast shape should be straight for-and-aft. This allows mainsail luff round to give added fullness to the mainsail.

2) Set mainsail sheet so that bottom batten of mainsail is parallel to the main boom.

3) Set main boom vang so that sail twists off aloft until top batten is parallel to the main boom.

4) Adjust jib sheet so that jib boom points just inboard of the side shroud chain plate.

5) Adjust topping lift so that jib twist, when the jib leech is viewed from aft matches the twist set in the mainsail.

Now you are ready to begin a reiterative process searching for optimum performance. Put the boat on the water, check for boat balance. If too much weather helm, the rig may need to be moved forward. If only a little weather helm, you may need to trim the jib in slightly. Sailing with a partner who doesn't make a change while you do will give you a benchmark against which you can gauge improvement.

Further information on tuning can be found in Tuning Guides that some model yacht sailmakers include with their products. You can also delve into books written for people who sail boats that they insist in sitting in! A couple good references are: SAIL POWER by Wallace Ross, (1975) ISBN 0-394-47151-2; and SAIL PERFORMANCE by C.A.Marchaj, (1990) ISBN 0-07-040250-7.

Sails: The Source of Power, Part 2

by Rod Carr

Introduction

Technical discussions of model yacht sails seem to occur only occasionally but when gathered together form a body of knowledge valuable to every R/C skipper. This discussion is the second of a series that began in *Model Yachting* Issue 130, Winter 2003, page 18. This article is posted on the AMYA website <www.modelyacht.org> and can be downloaded from the *Model Yachting* magazine home page at the *Downloads* link, in the *Publication* pull-down menu. Additional material, pointed at the EC-12 class, but with application to any model yacht, will also be found in *Model Yachting* Issue 145. Back issues of these publications may be obtained from AMYA.

Your first step in developing an understanding of your sails is to learn the particular nomenclature that defines the sides, corners, and details of both jib and mainsail. Figure 1 is repeated here for your reference.

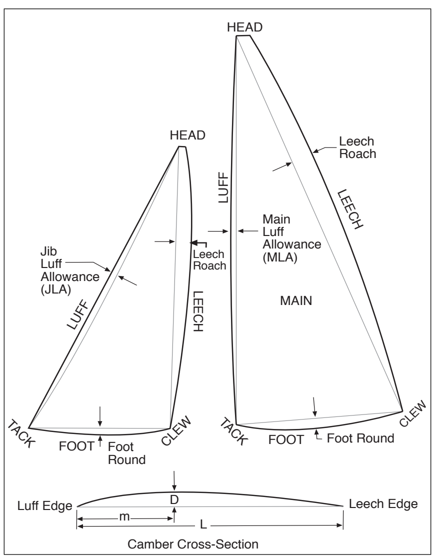

Figure 1

Your second step should be determining the amounts of Jib Luff Allowance (JLA) and main luff allowance (MLA) built into your sails by your sailmaker. If he does not volunteer the information, ask him—Point Blank! If he cannot produce the information, you'll have to measure it yourself or consider a different sail maker. Tape the head and tack of the sail down on a flat surface with the tape holding the sail so that it can "hinge" itself at the surface. Then raise the clew of the sail to the point where the sail sweeps down to the surface and just becomes tangent to the surface at the luff of the sail. The extra fullness built into the sail will show itself as camber, and the departure of the sail luff from a straight line will be a measure of the JLA or the MLA. You must know the MLA to know how much mast bend your mainsail can absorb before a mast "overbend" wrinkle forms between the mid-point of the mast and the clew of the sail. You must know the JLA to start developing a strategy for opposing jibstay sag with adjustable backstay tension.

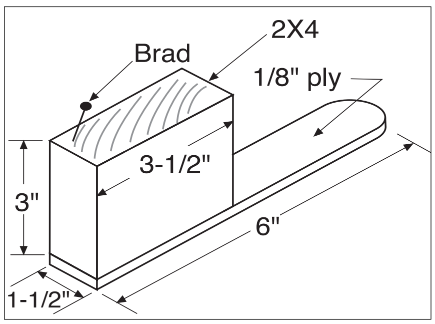

Figure 2

Camber and Draft in Paneled Sails

Your mainsail is the primary power-producing component of the sail plan. Mainsails are usually both the largest and tallest of the sails on a sloop, and thereby have the greatest opportunity to work in the fastest moving air aloft above the water. The shape built into the mainsail must be understood if sail set and sail trim are to be optimized.

So let us first consider the shape of the mainsail when configured for no twist, i.e., the legs of the measured triangle and the three corners of the sail all lie in the same reference plane.

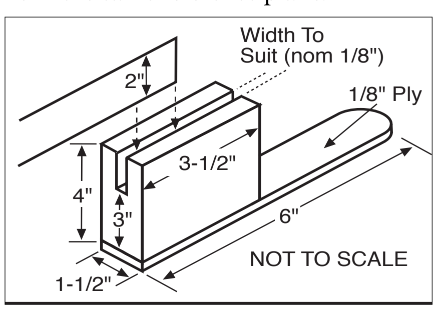

Figure 3

Make three corner-holders as shown in Figure 2. These will establish the reference plane as parallel to and offset 3" from your work surface. The tongue extensions provide places for weights to keep the holders in place while measuring. Make a pair of straight-edge holders as shown in Figure 3. These holders will allow a straight-edge to be held over the sail, perpendicular to the luff, and just touching the luff and leech, representing the chord of the sail at that height.

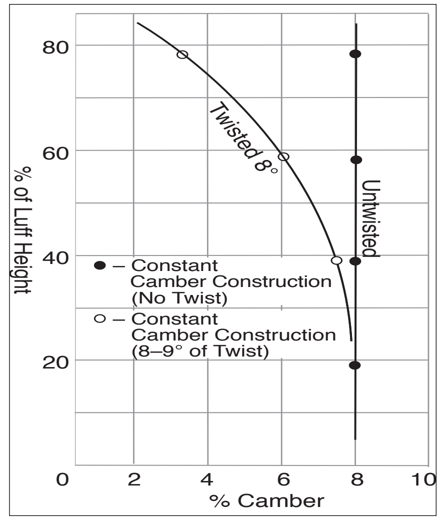

Figure 4

Now with the three corners of the sail held in the same plane, and the straight-edge holders in place, one can measure the chord (L), the depth of draft (D), and the point of maximum draft (m) anywhere along the sail. For convenience, measurements taken at 20%, 40%, 60%, and 80% of the luff height produce sufficient data to describe the sail.

Follow the directions in the first article for calculating percent-camber. Plot the data as shown in Figures 4 and 5. This data will be for an untwisted sail.

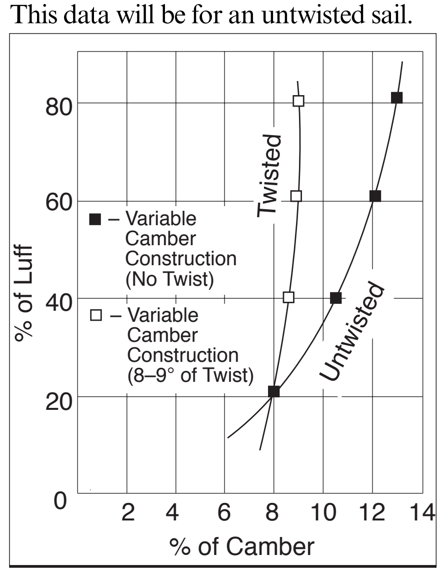

Figure 5

Mainsail Twist

To induce twist into the sail, move the clew holder parallel to the luff, toward the head of the sail. The leech will sag below the reference plane, and the straight edge in the straight-edge holder will no longer touch the leech. This is why we will measure the sail in its untwisted configuration and use that data to assess the cambered shape. One can make an adjustable straight-edge holder to measure cambers in twisted sails, but it is a laborious process. We've done it and will simply present the results later in our discussion of camber as a function of twist.

At the same time twist induces a change in the direction of the sail chord at each station, it also causes the entry angle at the leading edge of the sail to increase from foot to head. Maximum efficiency would seem to demand that the wind seen by the sail should therefore to come from farther aft as one ascends the mast. But more on that later.

There are two kinds of sails being produced today: 1) Constant camber sails that have the broad-seaming in each panel joint the same, producing an untwisted sail in which the camber is constant with height (Figure 4, "Untwisted") and 2) Variable camber sails in which different broad seam configurations in each panel joint make a sail in which camber varies with height (Figure 5, "Untwisted"). Some commercial varieties of this second configuration are labeled High Twist (HT) sails.

If, however, each sail is adjusted so that there is an 8–9 degree twist between the 20% chord and the 80% chord, the plot of camber versus luff height becomes as shown in the "Twisted" plots in Figures 4 and 5. Both sails respond

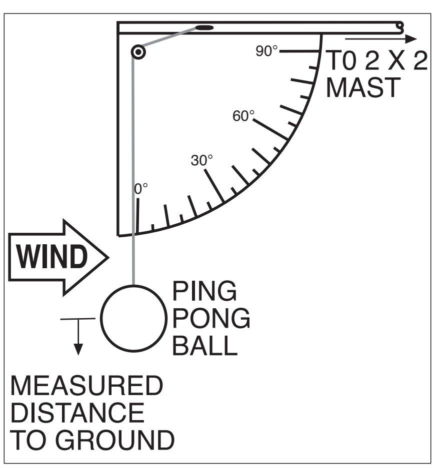

Figure 6

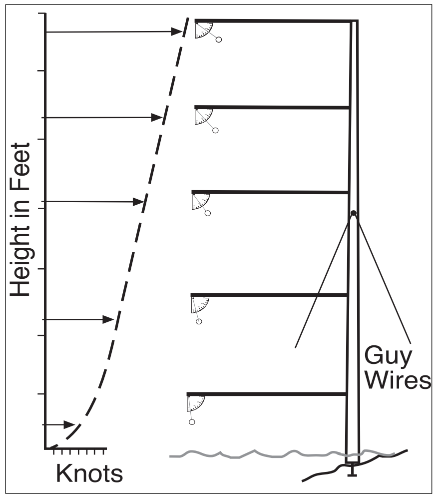

Figure 7

to twist by reducing the camber as one moves up the sail. The constant camber sail sees its head camber reduced almost in half, with the upper seam showing only 5% camber, not a very powerful airfoil to be asked to work in the faster moving air aloft. The HT sail also reduces its head camber, but only down to a 10 – 11% camber, very appropriate for light to medium wind speeds.

So which kind of sail to choose, and why? We need more information about the vertical speed and direction of the wind in which we sail before we can make an informed selection.

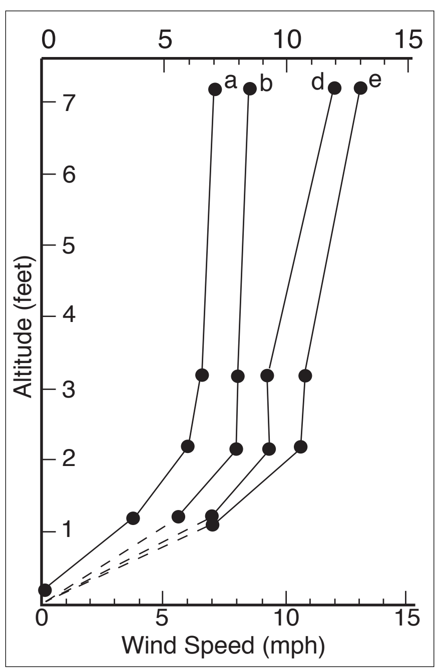

Figure 8

Wind Velocity Gradient

Common sense suggests that immediately next to the water there is an air molecule that is moving, but little. But above the water, say 30' up where the Weather Service or the local TV station has an anemometer whirling away, the free-stream wind speed reported on the evening news occurs. Between these two points there must be a continually changing wind speed, starting at 0 mph at the water surface and increasing to the local wind at height. Model yacht sails are asked to function in the lower 10' of this changeable realm, and the change that close to the water has really been of interest only to R/C skippers and a handful of scientists who study how materials exchange across the air-sea interface.

In the early 1970s, the only published measurements of this change in velocity with height (a velocity gradient) covered an altitude from 6' to about 38'. Model yachtsmen needed to do their own research.

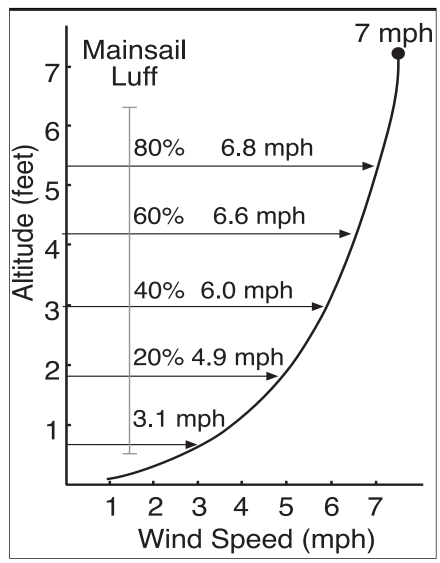

Figure 9

An article I published in the March 1977 issue of *Model Builder* magazine, reports actual measurements taken between the surface and 7' altitude of a Virginia lake. A 7' pole with ping pong ball anemometers mounted at intervals was placed in the lake (Figure 6 and 7). Photographs of the instrument were taken from a distance away that allowed the displacement of the ping pong balls and, hence, the wind speed to be measured. The data clearly showed a transition from the water surface to free-stream wind speed occurring and being generally complete by the time an altitude of 7' was reached for a 2–3 mph wind and by about 4' for a 10 mph wind (Figure 8). In other words, the change in wind speed with height is more rapid when the free-stream wind is faster, certainly logical. Figure 9 shows an idealized plot of velocity gradients for a free-stream wind speed of 7 mph. Data for an EC-12 mainsail luff are shown with wind speeds indicated at various heights.

Apparent Wind: Definition and Distribution with Height

Our sails see not only the wind that blows over the water, but we must account also for the apparent wind that is caused by the boat's movement through the water. If a yacht were given a 1.5 mph shove in still water and still air, a sensor on the boat would register a head wind of 1.5 mph. The boat speed wind must be added to the true wind to give us a direction and speed for the apparent wind, the wind the sails actually feel. Figure 10 shows how to graphically add the two winds together to get the apparent wind vector. "Vector" is a useful term that contains both speed and direction, and is shown as an arrow.

In Figure 10 we see that the apparent wind at the foot of the sail (0% luff height) is 4.2 mph and is felt to be coming from 31 degrees off the starboard bow of the boat. But at the 80% luff height, the wind is stronger, at 8.0 mph, and the direction has come aft by 7 degrees to 38 degrees off the bow. The inescapable conclusion is that the top of the sail must be trimmed farther off the centerline of the boat to avoid being stalled. If the sail is not twisted off, the head will be trimmed too tight, drive will be lost, and additional heeling will result.

So in a nutshell, the increasing wind speed with height produces a progressive change in both the speed and direction of the apparent wind, and an optimized sail must match the direction change, hence the importance of twisting model yacht sails, and maintaining power-producing camber in the upper half of the sails for good performance.

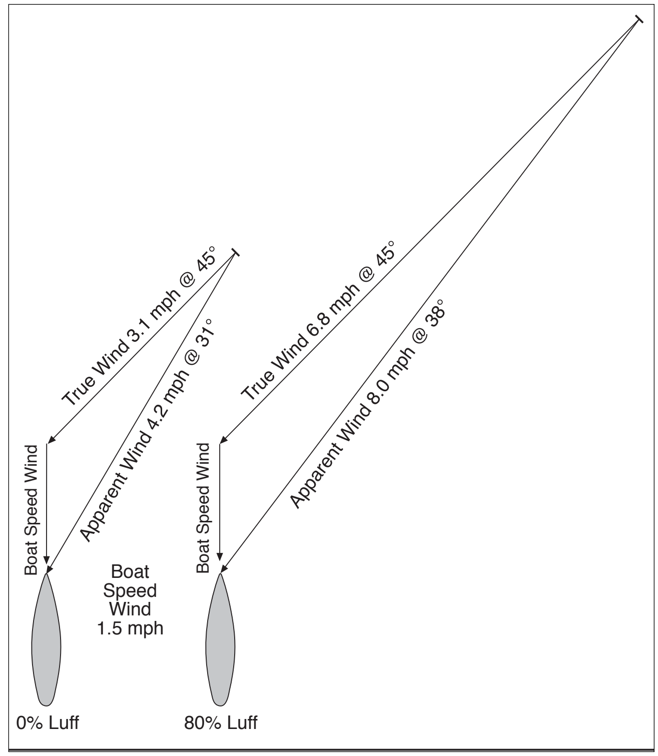

Figure 10