PART 1

by John Marshall

Tuning the Masthead Rig

Most sailors know that proper mast set-up is crucial to a boat's performance, but many regard tuning as an exercise in wizardry, best left to professional riggers. In this two-part article, a revised version of his well-received 1977 series, John Marshall of H.R. Hinckley demystifies the masthead rig, and shows that the concepts and problems involved in tuning are common to both racing and cruising sailors.

The word "tuning" conjures up images of Itzhak Perlman making minute adjustments to his violin strings before launching into the Kreutzer Sonata, or a comparable sailing virtuoso making a quarter-turn adjustment on his lower shrouds before the start of a major race. Fortunately for all of us who are just a little tone-deaf, the mystique of fine-tuning is largely a myth perpetuated at the expense of common sense.

As far as I'm concerned, fine tuning is almost meaningless in terms of serious racing performance, and the major adjustments that have to be made to get a boat going properly have a very straightforward logic to them. Boats that are "out of tune" are generally grossly screwed-up. Boats that are really "hung up" right don't have much magic going for them—just sound application of a few basic principles.

I divide mast tuning into four general areas: 1. **Rake**—adjusting the forward or aft lean or tilt of the spar. 2. **Headstay Sag**—minimizing sag and controlling what there is. 3. **Lateral Tuning**—getting the spar to stand straight athwartships. 4. **Mast Bend**—adjusting and controlling fore and aft bend or curve in the spar.

Fore and Aft Tuning

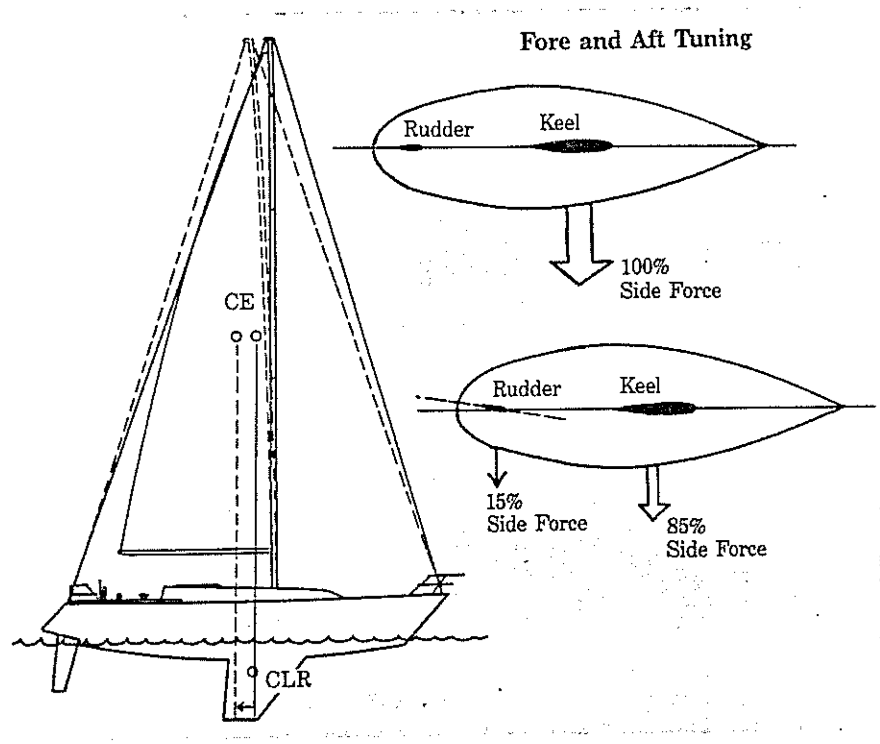
Fore and aft tuning involves two independent factors—rake and bend. Mast rake refers to the amount the masthead is forward or aft of plumb above the mast step, while bend refers to the fore and aft curvature of the spar, whether raked or standing vertically.

Let's consider rake first, since you'll need to adjust the rake before playing bending games. In order to set up a general reference for rake adjustments, level the boat on her design waterline, with a normal sailing load (two-thirds of maximum load, for instance) on the backstay. Then hang a plumb bob on the main halyard and measure the distance at boom level from the bob to the gooseneck. This can serve as your reference.

It's easy to see that the length of the headstay determines the fore and aft position of the masthead, and, hence, the mast rake. In general, adjustments to headstay length should be made if a rake change is desired, but not to correct problems of headstay sag or incorrect mast bend.

Mast rake has a strong influence on helm balance, one of the most important variables in a boat's overall performance. Raking the mast farther aft will increase weather helm (or reduce lee helm); reducing rake by shortening the headstay will reduce weather helm. The side force to windward required to offset sail forces to leeward should be generated by a combination of (1) the hull and keel moving through the water with a leeway angle and (2) the rudder held at a positive angle of attack (weather helm)

In this illustration, when the mast is vertical, side forces generated by keel and sailplan are equal and opposite. The keel produces 100 percent of the side forces in the water, with no rudder load required. When the mast is raked aft, the sailplan's Center of Effort moves aft; this, in turn, requires that the Center of Lateral Resistance also be moved aft—by carrying a weather helm angle. In this example, the rudder carries 15 percent of the total load, the keel 85 percent.



Lee Corbin Scowcroft illustration

to the flow. Sharing the side loading between the fixed keel/hull surface and the moveable rudder reduces the total drag produced. Most naval architects feel that some weather helm is desirable when sailing upwind, but opinion varies on the optimum amount; on many boats it ranges in the three- to five-degree range for upwind sailing.

It would be nice to be able to tune for optimum helm for just one condition—say, upwind in ten knots of air—and find that setting ideal for all conditions. However, the basic balance of the boat changes drastically with heel angle, sail combinations and sail shape, so the best tune for one condition can be dead wrong in another. Let me give some examples of the fundamental balance problems that all boats share.

First of all, weather helm increases with heel angle on virtually all boats. Many hulls develop more side force from their forward sections when heeled. Although this happens with double-enders only to a minimal extent, it's an important factor with boats that are very fine forward and full aft. For virtually all modern designs, the center of lateral resistance shifts forward and the boat tends to rotate into the wind when it is heeled.

When a boat is heeled, its sailplan also generates weather helm. This is because the center of effort of the sailplan is shifted to leeward of the hull by heeling, and, as a result, the forward force of the sailplan, opposing the drag of the hull, produces a rotary "couple" tending to turn the boat into the wind.

Because of these heel effects, it's difficult to get enough weather helm when the boat is upright and sailing upwind in very light air, unless the boat is tuned to have too much helm when heeled. Almost all boats have either no helm or lee helm in these light-air conditions. A racing crew adds helm by using an unusually tight-leeched main and keeping crew weight forward and to leeward. Ideally, when sailing to weather in these conditions, the mast should be raked much farther aft than for heavy air.

In moderate to fresh air, you may have just the opposite problem. If you're sailing with 20 degrees of heel and carrying a No. 1 genoa and unreefed main, you may have excessive weather helm if the main is trimmed normally. Flattening the main, twisting the leech, lowering the traveler and allowing backwind alleviates helm, but also robs total power. Again, the ideal solution would be to change mast rake. In this case, the headstay would be shortened and the backstay eased out to shift the entire sailplan forward. This way, the boat could be balanced without compromising mainsail trim.

Power spinnaker reaching can be an even more severe helm-balance problem. The boat is heeling over, and in addition, the spinnaker's center of effort may be quite a bit farther to leeward and aft than would be the case with a genoa. In this situation, the most extreme forward rake available would be desired.

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If you race in an area where most sailing is in light air, particularly light air to weather, your boat will need more mast rake than boats that do a lot of reaching in areas of predominantly heavy air. Racing boats are usually set up with more helm than cruising boats. While the extra helm can enhance upwind performance, it does require the crew to work harder to keep the helm optimum at all times. The cruising sailor will usually prefer a more neutral balance. The boat is less work to steer, especially on long fresh-air reaches, and more forgiving of imprecise sail trim.

If you have a really good main that can be adjusted and flattened in fresh air, rather than one that becomes a helpless gunny sack in a breeze, you can afford to tune in a little more rake and weather helm for light-air beating. Mainsail shape is extremely important to helm balance, so if you have a new main you'll often require a different combination of rake and bend. In addition to differences in mainsail design, you'll find that a genoa with a bigger overlap (160-170 percent) adds power and heel in lighter air, so that less aft rake is required than if the boat is sailed with a genoa of 150 percent or less.

Your mast rake should be set up for your own conditions and sails, using the experience of others as a reference. You can adjust helm balance for varying conditions by moving crew weight fore and aft (forward adds weather helm, aft relieves it) and to weather or to leeward, by adjusting mainsail shape and trim, and by keeping an eye on heel angle.

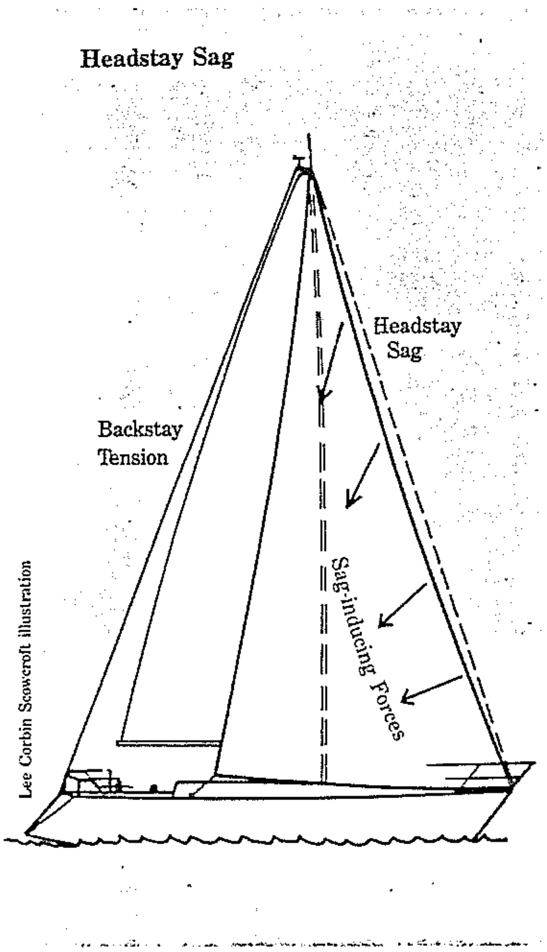
Headstay Sag

Of all the areas of rig tuning, the control of headstay sag seems to generate the most confusion. For instance, you may have a suspicious thought about a comment I passed by you a few paragraphs ago—that headstay length should not be used to adjust headstay sag. Later we'll be digging into the uses, abuses, and methods of mast bend, and I'm sure you'll worry at the assertion that mast bend adjustments have no effect on headstay sag. A widely held misconception is that a rod headstay will sag less than wire. Not necessarily. Since the control of headstay sag is absolutely essential to high performance, it's time to get into it in some detail.

The fundamental engineering concept that governs sag is that when a wire (or string, rope, rod or whatever) is strung between two points and a weight hung from it, the amount of sag is determined purely by the amount of weight and the tension on the wire, not by the strength or elasticity of the wire. On a boat, the headstay is connected to the backstay by the masthead, with the mast serving only to hold the connection aloft. So headstay tension is determined by backstay tension, and is usually indirectly monitored and adjusted via the backstay.

To reduce headstay sag, all you do is tighten the backstay. To increase sag, reduce the tension (in pounds) with which the backstay is pulled. This makes pretty good sense until someone suggests that with a low-stretch headstay (rod rigging, for example) there will be less stretch and less headstay sag. That also sounds pretty good. The resolution to this paradox is that to achieve a given tension in a more elastic system, you have to take up more *inches* of turnbuckle or hydraulic piston. But once you achieve the same *tension* (as measured in pounds by a backstay adjuster dial, for instance), you have the same amount of sag as you would have with a less elastic system under equal tension. Clearly, a good backstay adjuster is essential for controlling headstay sag. In a situation with rapidly changing headstay loads (very rough or gusty conditions), an excessively elastic backstay/headstay can be a problem, since larger and more frequent adjustments will be required to control sag. But while desirable on most boats, fore and aft rod rigging isn't absolutely required.

The same principles apply to sag as



Headstay sag, caused by wind force pulling the jib luff aft and downward, is ultimately determined and offset by backstay tension—not by the material of which the headstay is constructed.

related to headstay length. Shortening or lengthening the headstay would seem to effect headstay sag. Yes, if you don't adjust the backstay at all. But once you readjust the backstay to the original *tension*, you're back to where you started on sag. In other words, over a very wide range of mast rakes (headstay lengths), equal tension on the backstay means equal sag. This, in turn, means that if you have the rake the way you like it and want to adjust sag, you should adjust the backstay tension, not the headstay length.

Now, how about the effect of mast bend on headstay sag? Your sailing expert neighbor asks you if the mast is bent, won't the headstay sag increase? By now you probably smell a rat when we toss up arguments like this. Right! If the backstay *tension* is adjusted to remain constant when bend is changed, the sag will be constant. Obviously, more bend means a slightly shorter mast, and hence, the backstay will indeed need to be shortened to keep the same tension (and sag) you had with less bend. Since you can shorten the backstay with a turnbuckle or pump, you can achieve equally well-controlled sag with a straight or bent mast.

The problem with bend (either fore and aft or lateral) arises when the mast starts pumping (alternately bending more severely and straightening up) rather than maintaining a fixed bend as the boat works over seas or through gusts and lulls. If the spar pumps, we have a situation where headstay sag varies uncontrollably and is usually more than we want. If a spar is unstable and prone to pumping it will behave worst under the extra load of a windy day, producing more bend and sag just when we need it least.

How much headstay sag is correct? One way to look at this question is from the point of view of optimum genoa shape. The answer, in brief, is that for a given genoa, some conditions will require quite a lot of sag and some will require as little as possible. In general, at the light end of its useful range, a genoa will tend to be too flat and will require quite a lot of sag to make it fuller. At the extreme upper end of its range, it may tend to be too full and require minimum sag to stay flat enough. Since headstay sag increases with wind and sail loads, it is a pretty good trick even to keep it constant over a fairly wide range of wind speeds, never mind actually reducing sag as the wind comes up. A good adjuster is essential.

How much tension should be used as a maximum setting? A safe maximum load is a function of rigging, spar and hull strength. In most cases the designer of a boat will specify his rigging sizes in proportion to the righting moment of the boat (its sail-carrying power) and to the spar and hull structure. In this case, it is reasonable to express maximum permissible backstay load as *a percentage of the backstay breaking strength* and assume this will be OK in relation to spar and hull. Most designers use a maximum working load of 30 to 40 percent of the backstay breaking strength to allow a sufficient safety margin throughout the system, especially in cases of shock-load, as when a spinnaker fills suddenly and jerks the rig with unusual force. Obviously, this rule becomes nonsense if you double the size of the backstay or, on the other hand, change to an ultra-thin mast with the same rigging.

Backstay tension is measured in pounds, and some hydraulic pumps and backstay load cells read directly in pounds. If the gauge reads in pounds per square inch, you should calibrate the adjuster in pounds against a rigging dynamometer or the manufacturer's conversion chart.

Lateral Tuning

The first important decision to make is whether to try for a straight spar athwartships or to go for controlled lateral bend. Most one-design classes and many fractional-rigged offshore boats use lateral bend as a basic part of their tuning for heavy air. Fall-off at the tip of the spar and "pop-up" in the center section open the leech, reduce heeling and weather helm, increase twist, reduce aerodynamic loading at the top of the sail, and open the slot between jib and main, thus reducing main backwind and flogging. It's appealing to try to apply the same thinking to offshore masthead rigs. However, most of the mainsail shape control can be achieved in other ways on a masthead rig, and lateral bend can cause many problems of its own. In a masthead rig I feel the problems of sidebend outweigh the benefits, and I prefer a laterally straight spar.

The most important reason for keeping a masthead-rigged spar straight athwartships is that it is much safer that way. On a masthead-rigged boat lateral bend gets more severe as wind loads increase. What looks reasonable in five knots of wind can be out of control in 25. As the spar bends laterally the intersection angle of the upper shroud to the mast gets smaller. As a result, the tension required in the shroud to hold the mast up also increases—rapidly! Along with more tension in the shroud comes more stretch, more side bend, an even smaller intersect angle, and more tension stretch. This process can go to completion—a broken mast—very easily on a light spar with short spreaders and light rigging.

Worse still, as the spar gets out of column, backstay tension begins to pull the top farther to leeward rather than acting directly against the headstay. The genoa leech load starts to pull the spar even farther out of column. You may be tempted to pump the backstay tighter to reduce headstay sag, but as you do so the side bend will just keep increasing.

If you tune for lateral bend you'll also have a very hard time keeping the rig from pumping laterally and keeping the bend controlled in heavy conditions. You'll also find it very hard to get a straight headstay, since lateral bend unloads the backstay-headstay system and headstay sag will vary wildly as the tip falls to leeward in gusts and straightens up in lulls.

Aside from eliminating lateral bend, the other important sideways-tuning consideration is to prevent the spar leaning to leeward as a result of rigging-stretch under load. The more the rig stretches and the farther the rig leans to leeward, the more weather helm the boat will have. This is because the center of effort of the rig moves to leeward of the hull when the spar leans over. As a result, the forward force of the sailplan generates a rotational moment into the wind. Although this effect is small, most boats have too much weather helm in fresh air, and it's important to minimize it any way we can. Racing boats and many cruising boats use rod rigging rather than cable to reduce stretch and side lean. Even with rod rigging, and especially with wire, the upper shrouds must be tuned quite tight.

I feel that on most boats the uppers should be tight enough when the boat is at rest, that when sailing in a moderate breeze (a 20-degree angle of heel is a good rule) the leeward shroud is hand tight–not tight, not sloppy loose. A rig that is too loose will subject rods, terminals and spreaders to unnecessary fatigue as they slat fore and aft on the lee side.

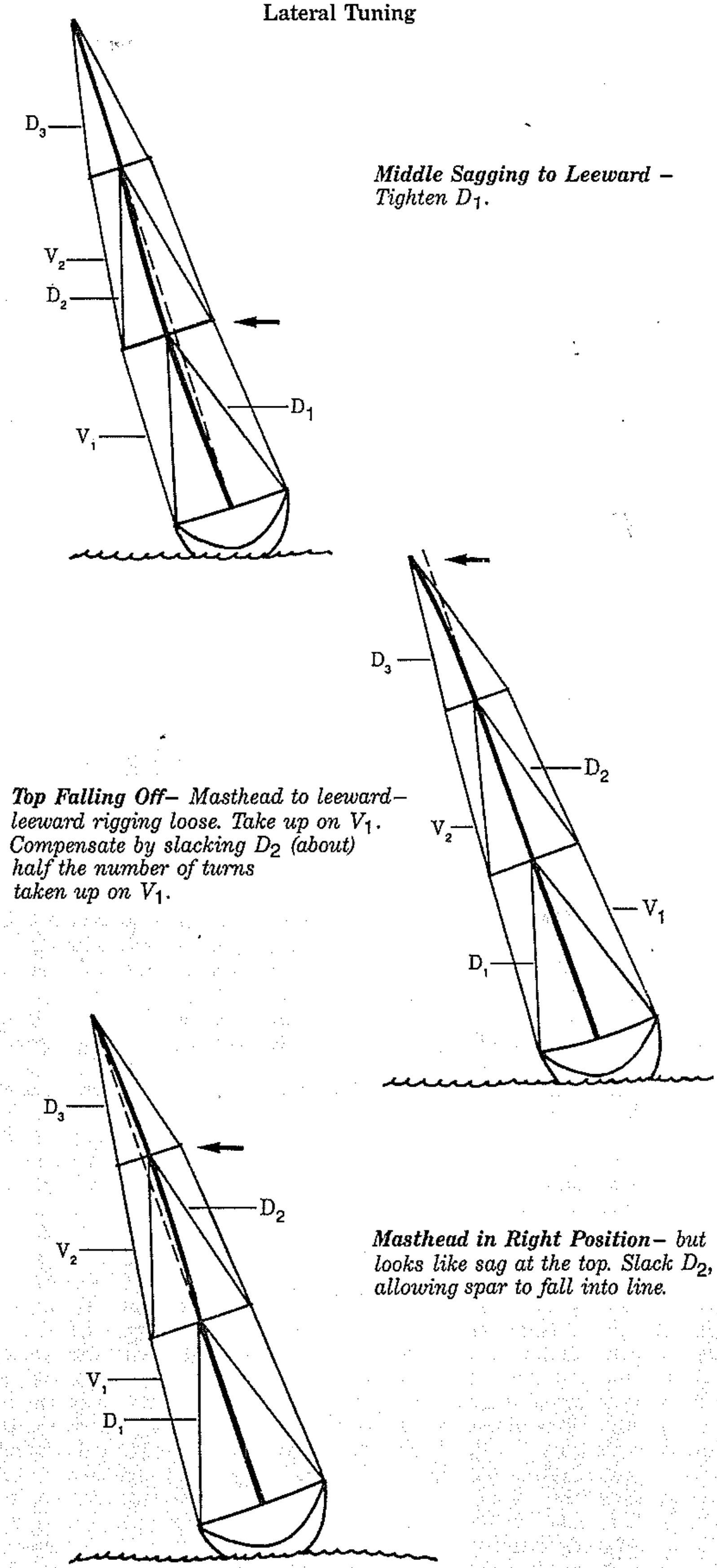
Now we've stated our two goals–a laterally straight spar and no sideways lean. Whether the boat has a single-, double- or multiple-spreader rig, *step one* is to start with the upper shroud system and be sure the spar is centered in the boat. This can be checked in two ways: One is to hoist a steel tape measure on the main halyard (be sure its sheave is on the centerline of the mast) and measure to the gunwale on each side, adjusting the uppers until the masthead is equidistant from both gunwales.

The second way to check lateral straightness, especially on a keel-stepped mast, is to be sure the mast's clearance in the partners is equal on both sides. Remove side wedges or chocks so the spar can find its own position, then adjust the lowers until the distances from the mast section to the edges of the partners on both sides are the same. Measurement from the spar at deck level to both rails is a further check that the partners are centered in the boat and the spar is standing straight up. Since any boat can be a little asymmetrical, there's no foolproof way to get the spar straight up. But combining the masthead check and partners check should give a good answer.

Most modern masts are pretty limber. They tend to bend easily, one way or the other, if not accurately tuned and properly wedged at the parters. Therefore, it's much easier to do the basic lateral positioning with the backstay at fairly low load and the uppers only moderately tight. Doing this minimizes compression on the spar during the process of centering it port and starboard, and makes everything go a lot easier.

When the mast is laterally straight,

Lateral Tuning



Middle Sagging to Leeward *– Tighten D_1.*

Top Falling Off *– Masthead to leeward–leeward rigging loose. Take up on V_1. Compensate by slacking D_2 (about) half the number of turns taken up on V_1.*

Masthead in Right Position *– but looks like sag at the top. Slack D_2, allowing spar to fall into line.*

Lee Corbin Scowcroft illustration

"With the short upper spreaders found on many boats today, rigging loads are very high, and having just the right amount of stretch in each component of the rig is critical."

wedge it securely in the partners with hard rubber mast wedges on both sides. This is very important.

Step two is to get the uppers tight enough. Remember, the goal is to have no slack on the lee upper when sailing heeled at 20 degrees. Tighten equally on both sides, adjusting lowers, as needed, to eliminate buckling and keep the mast straight. If you are sailing, tack back and forth so you can always tighten the slack leeward shroud. If the boat is kept in a slip you can avoid going sailing by heeling the boat over with the spinnaker halyard, first on one side, then the other. This is a very valuable time-saving trick that can be used for the final tuning of the intermediate and lower shrouds as well as the uppers. But be sure that the halyard has a fair-lead block at the masthead. If the lead abeam from the masthead is poor, it's better to hoist a slack line, cleat the halyard, and lead the tail of the line through a block on the dock and back to a deck winch, rather than winching directly on the spinnaker halyard. Again, the goal is to have neither tension nor slack in the lee (down) shroud at about 20 degrees of heel.

Step three is to get the rig straight. With the single spreader rig, the only adjustment is to set the lower shrouds properly. Let's assume, for simplicity, you have a single lower shroud on each side. If the lower is too loose, the spar will sag at the spreader when under load. It's best to start out with the lowers too loose on each side (visible sag at the spreader at 20 degrees of heel) and work back and forth tightening each side until the spar is straight, but shows no sign of the tip dropping off in hard gusts or at higher heel angles. Sighting up the sail track or groove is the best way to eyeball straightness. At the dock the lowers, when correctly tuned, will be a good bit looser than the uppers.

In general, the uppers will stretch more than the lowers under load. So if the rigging is elastic (wire, or small diameter rod), the best tuning in light air will have a little sag at the spreaders, and as the breeze freshens the upper will stretch while the lower holds firm, so that the spar ends up straight.

With fore and aft lower shrouds, exactly the same ideas apply except that the relative load on the forward and aft lowers will influence the fore and aft stiffness or bendiness of the spar. Generally, the forward lower is tighter, while the aft lower acts pretty much as a preventer and bears little load until the breeze is quite fresh. Don't forget to readjust the double lowers if you change the mast rake. Since the lowers will be a good bit looser than the uppers they'll be sloppy on the lee side when you're sailing. A shock cord lashing between them will take out the slack and prevent fatigue.

Multiple-spreader rigs are more complex to tune and generally fussy if poorly tuned, particularly if the spreaders are short and the rigging light. Also, there are more parts to name and get confused. Let's discuss a double-spreader rig, referring to the diagram for terminology. Basically, D is for diagonal, V is for vertical, and a 1 is lower in the rig than a 2.

As with the single-spreader rig, start by centering the spar. Next, get it set up with good firm lateral deck wedges and plenty of tension (the 20-degree test again) on the upper shroud column (V_1, V_2, D_3). Again, heeling the boat at the dock to relieve loads on the low side rigging can save a lot of time compared to sailing and tacking, when a man has to be aloft to adjust rigs with discontinuous rod rigging.

Next, get off the boat and check the spreaders for excessive lift or droop angles. They should be level or slightly lifted, depending on the design of the spreaders and brackets. They should never be drooping. With discontinuous rigging it may be necessary to interchange turns on V_1, V_2, D_3 to get the spreader angles correct and at the same angle on both port and starboard sides of the mast. If the rigging is continuous the spreader ends can be slid up or down the shrouds to adjust their tilt. Once they're finally positioned, be *sure* they can't ever slip.

During the process of setting up the V_1-V_2-D_3 column really tight, you've almost certainly had to make small adjustments to the diagonals to keep the spar fairly straight. Now is the time to get them just right.

Start at the bottom of the rig with the D_1s. They'll need to be a good bit looser than the uppers and just tight enough to prevent sagging at the lower spreader in moderate to fresh air. Be sure to do final adjustment at high load (25- to 35-degree heel angle) since the adjustment is relatively insensitive at low loads.

By far the most important shroud, and the key to tuning the multiple-spreader rig, is the upper intermediate, the D_2 on a double-spreader rig. It has a drastic effect on lateral bend in the upper part of the spar. and if set too tight can lead to dangerous instability. *Be sure* to start tuning with the D_2 too loose, and gradually tighten to eliminate sag at the upper spreader. Probably the most common complaint you'll hear on double- or triple-spreader rigs is, "the top's falling off to leeward—we'll have to tighten the uppers." Nine times out of ten, the problem isn't loose uppers, but that the upper intermediate is too tight, and is pulling the upper spreaders to weather and leaving the tip relatively to leeward. If the V_1 does need tightening, as evidenced by excessive slack in the leeward rigging, you usually will also need to retune the D_2. Fine tuning can be done at the dock, to plus or minus one turn, by heeling the boat over first one way, then the other. To get enough load for the adjustment to be correct, the boat must be heeled 30-35 degrees. With the short upper spreaders found on many boats today, rigging loads are very high, and having just the right amount of stretch in each component of the rig is critical. The most common problem is too much stretch in the upper shroud system (V_2-D_3) compared to too little in the D_2. This situation leads to severe tip fall-off in fresh air, which is impossible to tune out without getting sag at the upper spreader in light air. Changing rigging diameter or type is often the answer.

Lateral Tuning in Summary

1. Position the spar so it's truly vertical in the boat. Use the partners and masthead-to-rail measurements to make sure it's not leaning port or starboard.
2. Set up the uppers to eliminate lean. Use the 20-degree test for adequate tension.
3. Tune the lowers to eliminate side bend. Start too loose and tension to cut out sag. Beware of too-tight intermediates; with double lowers keep in mind that their relative tensions will influence fore and aft bend in the spar. •

Next month, John Marshall will conclude his discussion of masthead rig tuning with a focus on fore and aft mast bend and a summary of tuning tips.

Tuning the Masthead Rig

Last month, John Marshall covered three essential areas of masthead-rig tuning – Rake, Headstay Sag and Lateral Tuning. In his conclusion this month, he tackles the question of Fore and Aft Mast Bend, and provides a summary of tips covering all aspects of spar control.

Adjustable mast bend is vital to getting the correct mainsail shape over the full range of racing conditions and situations, and it's a nice refinement to getting the most out of a fast cruising boat. The main, after all, is expected to have ideal shape in light, medium and heavy air, while beating, reaching and running. Such versatility is hard to achieve, but with proper mast bend control you can help your main master all conditions.

When the mast bends it flattens the mainsail's cross-sectional curvature by extending the sailcloth over a longer luff-to-leech distance. Mast bend adjustment has the greatest effect in the upper two-thirds of the main. This is because, when the mast bends, the change in the luff-to-leech distance is greater (in proportion to the width of the sail) near mid-luff and above where the sail is narrower. Near the foot, the small offset of the luff is insignificant compared to the wide chord length from luff to leech. In this part of the sail, the outhaul and flattening reef are dominant, so overall shape control involves coordinating both. It's very important to realize that bending can make the main flatter, unbending (straightening) or even reverse bending can be used to make a flat sail fuller. Both techniques are in common use in racing from the family level right on up.

There are a number of factors that must be considered in tuning for controlled bend. Some of these are not adjustable while sailing, and, once tuned, are then left set. The most important by far is the relationship between masthead position, deck partners and mast butt position. If the headstay length and backstay tension are set, then the position of the masthead is fixed, and the relative position of deck partners and mast butt will determine whether the mast tends to stand straight or curved.

Suppose, for instance, that the mast is wedged snugly fore and aft at the deck, and is standing straight with backstay set at normal sailing load. Now imagine the mast butt moved aft; the masthead, deck position and mast butt are no longer in a straight line, but lie in a curve. Similarly, if the butt is left in place but additional wedges are forced in behind the spar at deck level, the spar can no longer stand straight and must assume a distinct curve.

On a keel-stepped mast 60 feet long, a one-inch movement of the butt aft, against snugly fixed deck wedges, or a one-inch movement forward at the deck with fixed butt, will produce a bend about four inches deep from deck to hounds, or about a three-inch bend between the tack and head of the mainsail. It's this last measurement that's important to the set of the main. The exact amount of bend produced depends on a complicated interaction of masthead design, spar taper, spreader design and other factors. For our purposes, the key is to at least get a rough feel for the amount of bend to be expected from a given adjustment.

Increased bend combined with increased backstay tension is often useful, since increasing wind generally requires more backstay load to control headstay sag; at the same time, more spar bend is useful in making the main flatter.

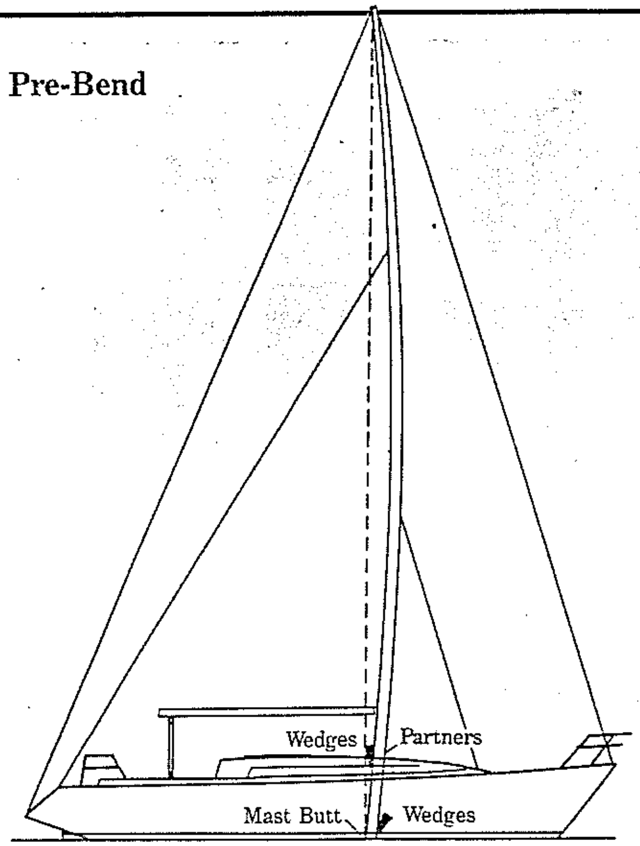
There are times when headstay tension and bend have to be controlled independently rather than together. For instance, very high backstay tension is sometimes required to limit headstay sag with a light, full jib, while at the same time the mast must be kept straight to prevent the main from getting too flat. Likewise, there can be times when we need low backstay tension combined with considerable bend. For these situations, the use of running backstays to limit bend, or a babystay to increase bend, becomes very important.

Another factor that influences bend is the angle at which the butt is cut. If the butt is cut square to the spar and rests uniformly on the step, no bending moments are generated. However, if the butt isn't cut square, the mast will rest on the forward or aft face of the spar and the resulting moment will have a major effect on bend. Shims under the forward or aft face of the spar (producing a non-level step) have the same result.

If the base of the spar is cut to remove material forward, it will tend to rest on the aft corner, compressing the aft face and forcing the forward face to stretch to reach the step. The more compression, from wind load or backstay tension or both, the greater the effect, until the spar is sitting fully flush at the butt. At this point it becomes stable, and bend no longer increases with loading. Since rigging loads (compression) depend in part on side force fed into the shrouds by the wind, the spar automatically bends more in fresher air. Backstay tension, too, adds to compressive loading, and can be used to increase bend.

Again, to get a good feel for how bend is produced when the butt is cut away forward, it may be useful to think of the straight spar resting with its butt flush on the step and the backstay loose. In this case, the spar is leaned forward compared to where the masthead would end up with the backstay tight. Hence, the spar must either rock up to where

Pre-Bend

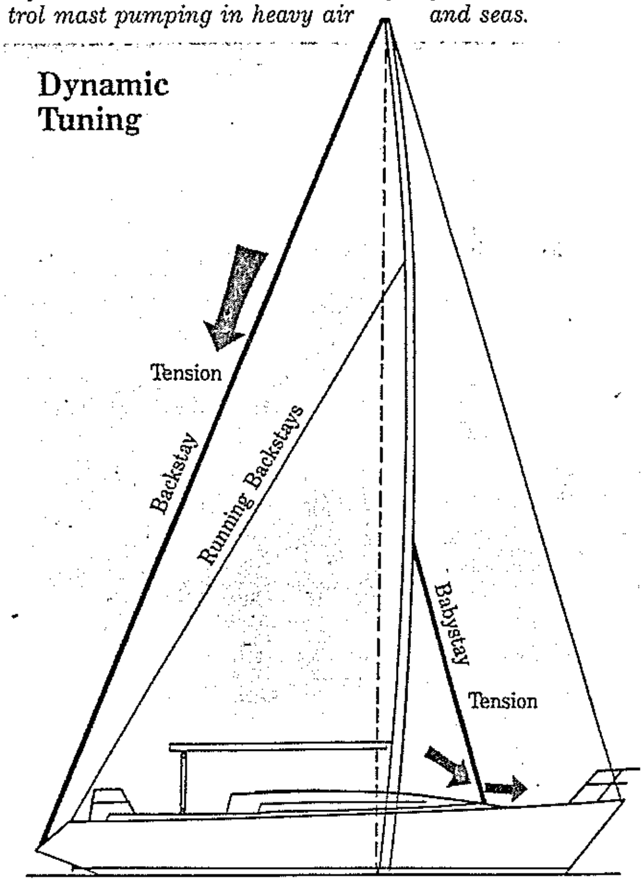


Lee Corlin Seacraft Illustrations

(Left) Pre-bend can be induced by forcing the butt of the mast aft or by forcing the mast forward in the partners. In either case, all other points must be firmly fixed.

(Below) Without pre-bend, a combination of backstay and babystay tension produces fore and aft mast bend, with running backstays acting to limit, reduce or define bend. Both runners and babystay can also control mast pumping in heavy air and seas.

Dynamic Tuning



it is only supported on its aft face, or curve from butt to masthead.

This butt-cut tuning (or butt wedging) is extremely effective on deck-stepped spars, since partner thrust cannot be used to control the spar. It's a particularly elegant technique because the effect increases with rigging load up to the point when the butt sits fully level on the step. With the butt level, higher loads produce no further bend.

Now let's examine the two basic types of lower shrouds that are in general use today—double (fore and aft) lowers and single lowers with a babystay (mid stay). From the point of view of spar control, the babystay rig with running backstays is easier to use and more versatile. With an adjustable babystay, bend can be increased at will, but of course cannot be limited. Since mast *control* is the object, not just mast bend, getting the most out of the babystay rig depends on having the means to *limit* bend.

If the boat has single lowers, a babystay, and running backstays to limit or reverse bend, tune the mast the following way:

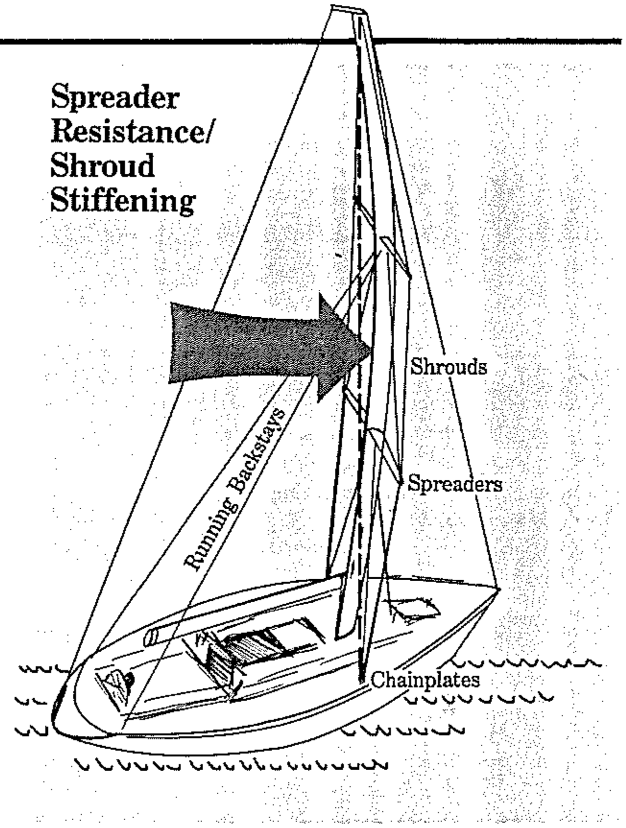
Adjust the partners/step position and cut the butt, if necessary, to provide about one-half to two-thirds the maximum permissible bend at *full* backstay load, and with no babystay or running backstay tension. This can be done at the dock. The mast is thus tuned with "pre-bend" because it bends without using the babystay. The babystay is now used only to achieve maximum bend when needed, and the runners are used to limit or reduce bend and to control pumping. An important advantage of tuning with pre-bend (thus eliminating the need for the babystay in most conditions) is that the boat will tack much faster without the babystay to interfere with the genoa coming across. The babystay can remain detached from the deck in most conditions, and be hooked up in heavy seas to help control pumping, or in very light air upwind to flatten the main.

A tuning effect that is difficult to achieve is a very straight headstay with a full main (straight mast). This would apply at the upper end of the range of the drifter, reacher, light No. 1, or jib topsail/reacher. Here the solution is to use no babystay tension (or just enough to steady the spar), substantial running backstay tension to hold the mast straight, and, of course, a tight permanent backstay to keep the headstay straight. I think runners are so useful, both in this respect and in steadying the spar in rough seas, that I like them on a boat even when they aren't strictly required.

On a babystayed rig without runners, bend control over the entire range is much more difficult. Basically, the best answer is to tune for less bend with maximum backstay tension and no babystay tension. You'll need to go to higher loads on the babystay when more bend is required because you have less built-in bend in the step/partners tuning. This set-up assures an ability to keep the main deep enough, even with a tight backstay, but does force you to use the babystay nearly all the time.

Some compromise is inevitable if there are no runners, and this is particularly true if the lower shrouds are swept aft of the spar at deck level. In

"Mast control, not just mast bend, is the object. Getting the most out of the babystay rig depends on having the means to limit bend."



When a spar with in-line spreaders is bent, the shrouds are restricted by the spreaders from moving to their natural axis of tension (dotted line). The forces pulling aft against the spreaders work to restrict further mast bend and to stiffen the spar. Obviously, strong spreader brackets are a must.

that case, the increased side load in heavy wind tends to straighten the mast since the lower shrouds pull aft quite strongly. Very high babystay loads are required to get enough bend.

Rigs with double lower shrouds rather than a babystay can also be tuned to give good control of mainsail shape. Again, it's fundamental to start with the butt/partners relationship. It must be reasonable for the spar and mainsail that are to be used. Adjust the mast at the butt or the partners to get moderate bend with maximum backstay tension. While adjusting the fore and aft bend be sure that neither lower is loaded up and influencing this basic setting by pulling the spar forward or aft. Next, the relative tensions of the lower shrouds are adjusted. Usually the forward lowers are tighter and the aft lowers looser. The forward lowers provide all the lateral support for the mast, and in addition act to some extent like a babystay by pulling the spar forward as they tighten in fresher breezes. The aft lowers act as preventers and tighten as maximum bend is approached in heavy air. They limit further bend and stabilize the mast. In this rig, direct control is achieved by adjusting the permanent backstay. Acting through the partners/butt tuning, bend increases as backstay tension increases. Indirect control through the lower shroud tuning provides for more bend in heavier air when the forward lower is heavily loaded, less in lighter air when side loads are low.

More built-in bend, adjusted at butt or partners, should be used if runners are available; they can hold the mast straight at high backstay loadings when such an effect is desired.

We've covered the basic "owner-adjustable" factors controlling fore and aft bend. The design of the spreaders and spreader brackets can also have a lot to do with mast control, although it's usually best to leave adjustments in this critical area to a pro. Since spreaders are rigidly mounted on the spar, and not free to swing fore and aft, they'll deflect the shroud forward out of line when the mast is bent. When the shroud is tight it exerts a substantial force aft on the spreaders and through them on the spar. This aft force tends to reduce or limit bend and make the entire spar/spreaders/rigging system act stiffer. Dinghy sailors have used this technique to stiffen lightweight spars for years, and to some extent it has been a basic part of ocean racing and cruising spar design. To take the extreme case, no spar would be safe with completely free-swinging spreaders—the more the spar bent, the farther back the spreaders would swing and the more they would thrust the spar forward, causing it to bend more...Etc.!

Recently, the trend has been toward lighter spars, which rely heavily on the spreaders for stiffening when the spar is bent. Strong rigid spreaders and strong brackets can tremendously increase the strength and stiffness of the whole system.

When the spar is bent, the aft load on the spreader is proportional to the amount the spreader offsets the upper shroud from a straight line, so the exact angle at which the spreader is locked is critical. In some rigs, the spreaders are actually "pre-loaded"—that is, locked forward of in-line; in other rigs, a limited amount of swing is provided so that the spreaders sweep back and lower loads are exerted on spreaders and spreader hardware. In this case, less stiffening is provided to the spar by the spreaders, and more must come from the basic sectional stiffness of the mast.

As many spars bend too much in the lower sections, changing the relative sweep loading on the upper and lower spreaders is one very effective way to adjust the amount of bend in sections of a given spar, and can be of great importance in getting a specific sail/mast combination to work well.

How much bend is desirable? First of all, be sure you establish a *maximum* bend limit. The designer, sparmaker or builder can be very helpful in setting the limit. It will depend on such factors as the spar's wall thickness (thinner-walled spars cannot safely be bent as much), the strength and design of the spreaders and brackets, whether or not aft lowers or runners are part of the rig, the backstay load to be used, and the sea conditions in which you'll be sailing. For most modern masts, a bend, or offset, amounting to three-quarters of the fore/aft dimension of the spar, measured between the mainsail black bands, is a reasonable limit for maximum bend. Some spars are specifically designed to use more.

The desired amount depends first of all on the depth of the main. An excessively deep main needs either a lot of bend or a recut to be any good to windward in fresh air. A very flat main may never need much bend to make it flatter, but will thrive on reverse bend to make it deeper. A mast is always much more stable and less likely to pump if it's tuned with some pre-bend. Hence, an ideal main shouldn't be too flat. The best combination, clearly, is a sail design that's compatible with the spar, and tun-

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ing tools available to adjust the spar. When it comes to mainsail design, matching the sail to the spar is one of the sailmaker's most important jobs.

Looking back at the whole subject of mast tuning, three important factors stand out. First, try to get decent helm balance. Here's where good athwartship tuning, to eliminate lean to leeward, and a good fore and aft rake set-

> "The most important factor is the relationship between masthead position, deck partners and mast butt position."

up are important. Balance will also be influenced strongly by mainsail trim, and mast bend is essential to adjusting main depth, power and leech angle.

Second, try to get good control of headstay sag, so that your genoas will set correctly in a wide range of conditions. Good lateral tuning will keep the spar straight and prevent its buckling or pumping sideways, and keep its tip from dropping off to leeward and unloading the headstay. A good backstay adjuster is mandatory to set headstay tension and adjust it for different conditions.

Third, learn more about controlling moderate amounts of spar bend to get more power from your main in different conditions. The main is a more important sail than most of us think, and good mainsail shape can make a big difference in performance.

Tuning the Masthead Rig in Summary

Rake

1. Use a plumb-bob on the main halyard to measure rake. Measure the maximum available genoa hoist. This information is useful in comparing measurements with other boats of your type.
2. Adjust headstay and backstay length to get the desired rake. Get advice from owners of similar boats; use your own experience with your boat and your predominant local conditions to decide on correct rake. Remember that rake primarily influences helm balance.

Headstay Sag

1. Get a good backstay adjuster suitable to your type boat—calibrate in pounds if possible.
2. Establish a maximum permissible working load and some lower reference settings.

Lateral Tuning

1. Position the spar so that it's truly vertical in the boat—use the partners and masthead-to-rail measurements to check.
2. Set the uppers to eliminate lean. There should be no slack in the leeward uppers at a 20-degree heel if the uppers are tight enough.
3. Tune the lowers to eliminate side bend—start too loose and apply tension to cut sag. Beware the too-tight intermediate shroud; with double lowers keep in mind that their relative tensions wil influence fore and aft bend in the spar

Mast Bend

1. With keel-stepped masts, adjust th step position and/or partner wedges t establish the basic bend desired. Thi should be compatible with your mainsail with average sailing conditions, and wit the way the spar is rigged.
2. With deck-stepped masts, the mas butt may need to be cut or shimmed t adjust bend characteristics.
3. Adjust double lower shrouds to complement desired bend characteristics.
4. Use runners, babystay and permanent backstay to vary bend while sailing. •