Phil Friedman

Build your own mast — Part I

R. W. Wilson writes: "A few years ago ("Backyard Builder", March, 1979) you discussed how cost-efficient masts for cruising yachts could be built of standard industrial extruded 6061-T6 aluminum pipe and tube. Having recently compared the prices on such pipe tubing to that of comparable mast extrusions, I would like to build a pipe mast for my 40 ft jib-headed cutter. However, I have been unable to obtain any information or help with regard to:

1) choosing the right pipe or tubing sections,

2) joining the available 20 ft lengths of pipe or tubing together, or

3) fabricating the masthead, tangs, gooseneck, and other fittings for the mast.

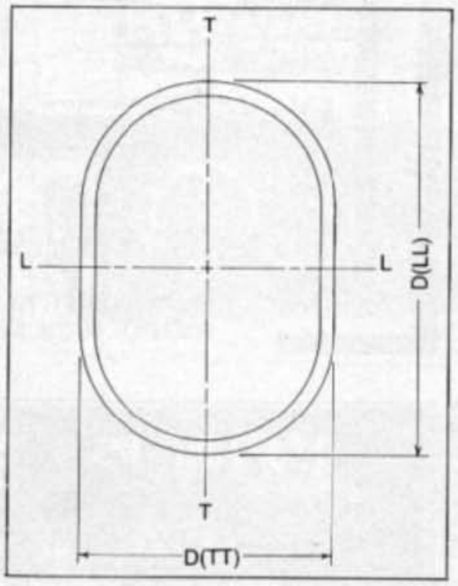
Can you please provide some guidelines on these matters?"

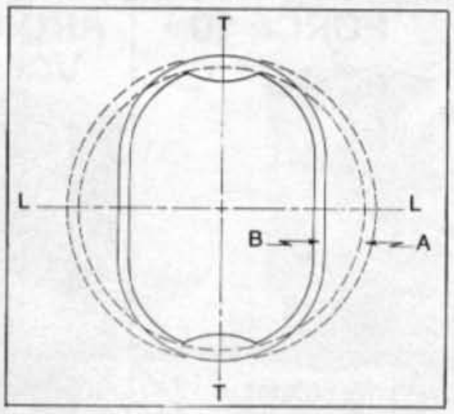
Yes, I can. In the years since the original article was published, I have continued to design and build masts for cruising yachts using extruded 6061-T6 aluminum. As well, I have had occasion to design and build relatively simple, easily-fabricated masthead, tang, gooseneck, and other fittings. I also agree that there is a dearth of good "cookbook" information available to the amateur boatbuilder or refitter. Therefore, a distillation of procedures and techniques that I've developed for building cost-efficient masts and mast fittings follows. Some of these should prove useful not only to the backyard builder, but to the do-it-yourself refitter — and even to some small-shop "pros".

Please be warned, however, that the information supplied is intended only to serve as a general guide. The data which follows should be applied with care and understanding. Keep in mind that general guidelines must be knowledgeably interpreted when applied to specific cases. Unless you have full confidence in your own "engineering sense", consult a competent designer or rigger before proceeding.

Choosing a Section.

As noted in the 1979 article, in non-competitive situations or for vessels whose stability enables them to tolerate the necessary minor increases in weight aloft, an industrial pipe or tubing mast provides a cost-efficient alternative to the more expensive and sophisticated mast extrusions. This is particularly true when a mast is being "home built" and the builder is seeking to minimize cash outlay.





Top: Longitudinal Stiffness I(LL) is measured about neutral axis D(L-L) as is Longitudinal Bending Strength S(LL). Transverse Moment of Inertia I(TT) and Transverse Section Modulus S(TT) are calculated about neutral axis D(TT). Above: Round constant-wall tubing section (A) carries excess stiffness and strength, and hence weight, transversely in relation to sophisticated variable-wall oval mast extrusion (B).

Unfortunately, while industrial pipe and tubing masts are cost-efficient, they are usually not as weight efficient as more sophisticated mast extrusions. This is because the pipe and tubing sections are round with constant-thickness walls. Because most stayed masts are more closely supported athwartship than fore-and-aft — requiring more stiffness and strength longitudinally than transversely — oval, eliptical, pear, and other sophisticated sections have been developed. These section-shapes allow a more efficient disposition of material to meet both longitudinal and transverse stresses. In contrast, utilizing round sections in a modern stayed rig usually means carrying excess transverse stiffness and strength, hence extra weight. However, for relatively stiff, moderate-to-heavy-displacement vessels, the added weight aloft usually presents no significant detriment to safety or performance.

Assuming that you are building or refitting a fairly stiff, moderate-to-heavy-displacement cruising vessel, the safest way to choose a pipe or tubing section is to start with your yacht's original masting and rigging specifications. Provided that these are adequate, converting to specifications for extruded aluminum pipe or structural tubing is relatively straightforward.

If you are building or refitting to a professional design (as well you should be), first check the plan for the original mast specifications. Two sets of figures are important:

1) the specified longitudinal and transverse Moments of Inertia of the mast, usually labelled respectively as I(ll) and I(tt), and

2) the specified longitudinal and transverse Section Moduli of the mast, usually labeled respectively as S(ll) and S(tt). It is also crucial to know the mast material originally specified.

The Moments of Inertia represent the stiffness of a section and result from its geometrical properties. The structural rigidity of a mast (its resistance to deflection) is a product of its Moment of Inertia (I) multiplied by the Young's Modulus (E) (the stiffness rating of the material from which the section is made, or flexural rigidity = EI). The Section Moduli represent the bending strength of a section and also result from its geometrical properties. The structural strength of a mast, (its resistance to destruction) is a product of its Section Modulus (S) multiplied by the strength of the material from which the section is made. Thus, the specifications for Moments of Inertia, Section Moduli, and mast material combine to define the mast's structural properties. If your original mast specifications were adequate, it is a relatively straightforward matter to convert the original mast to one built of industrial extruded pipe or tubing.

Part II will provide tables and guidelines for making the appropriate conversions and for choosing the required industrial extruded aluminum pipe and tubing sections.

Rupert celebrates nautical heritage

The skirl of pipes and the rattle of drums drifted over the ocean one day last June as thousands watched sky divers dropped into Prince Rupert Harbour. Seconds after the last chute hit the water, motors sputtered to life and another bathtub race began. While sailboats ghosted past the water-jousting grounds, the pipes died away, a uniformed brass band struck up a lively tune from the afterdeck of a seiner moving slowly through the fleet.

It was Rupert's annual Seafest.

To those of us who live there, Prince Rupert is a special sort of town. Isolated through most of its history — and clinging to the waterfront rocks with only the muskeg and forest behind — its income, recreation and social intercourse have always been oriented toward the sea. Despite a population of less than 20,000 it has more of a city feel than many centres several times its size yet, like sister communities in southeastern Alaska, Rupert retains the flavour of the frontier.

This year's fun included the usual parades and concerts, beer gardens and bed races, pie throwing contests and arm wrestling matches, loggers' sports and salmon barbecues. The real heart of the celebration, however, was in the waterfront events.

The fleet, decorated with flags and streamers and hung about with merrymakers was as much of a potpourri as possible: trollers, seiners and gillnetters; logging tugs and boomboats; the Coast Guard and the B.C. Lifeboat Society's Lucas inflatable, Rescue 15; fireboats and cargo carriers; speedboats, rowboats and sailboats; even the B.C. Ferries' *Queen of Prince Rupert* was on hand.

Phil Friedman

Build your own mast, Part II

Last month, in response to a reader's query, we were discussing the construction of cost-efficient cruising yacht masts from industrial extruded 6061-T6 aluminum pipe and structural tubing. This month's column continues with tables and guidelines for choosing appropriate pipe and tubing sections.

You will remember that, in choosing an appropriate pipe or tubing section for a mast, the safest way for the amateur to proceed is to start with the original mast design specifications. These specifications define the required structural properties of the mast and, assuming that these specifications are adequate, a pipe or tubing conversion based on them will also be adequate.

Keep in mind, however, that the information supplied is intended only to serve as a general guide. The data and tables which follow have been arranged to be useful to the backyard builder or refitter, provided they are applied with care and understanding. Remember that general guidelines such as these must be knowledgeably interpreted when applied to specific cases. Unless you have full confidence in your own "engineering sense", you should consult a competent designer or rigger before proceeding.

Working from the specified structural properties of the original mast, one can choose the appropriate industrial pipe or tubing sections from tables 1, 2, and 3. Table 1 gives the Moments of Inertia (I), Section Moduli (S), and weight-per-foot of industrial 6061-T6 aluminum schedule 40 pipe and commonly available extruded structural round tubing. Table 2 provides the I, S, and weight-per-foot for round and square section solid spruce and fir masts. Table 3 provides the I, S, and weight-per-foot of box and eliptical section hollow spruce and fir masts.

Converting from Aluminum Extrusion Specs.

If your plans are for an aluminum extrusion, proceed as follows:

A.1) Take the highest Moment of Inertia specified in the plans, usually the longitudinal moment I(LL).

A.2) Using the Moment of Inertia thus obtained, choose a pipe or tubing section having at least that moment.

A.3) If the appropriate Section Modulus (S) is given in your plans, check to see that the section which you have chosen meets or exceeds the required modulus.

If S is not given in your plans, but a recommended section is specified, S may be determined approximately by dividing I by .5 times the appropriate overall diameter, that is, S(LL) = I(LL)/.5 D(LL) and S(LL) = I(TT)/.5 D(LL) (see "Backyard Builder", October, 1983).

TABLE 1

★ Schedule 40 Pipe ★ (Note: All Values are approximate)

Nom. Size (Inches)	Outer Dia. (Inches)	Inner Dia. (Inches)	Wall (Inches)	I	S	Wt./Ft. (Lbs.)
2.50	2.88	2.47	.203	1.52	1.06	2.00
3.00	3.50	3.07	.216	3.00	1.71	2.62
3.50	4.00	3.55	.226	4.75	2.38	3.15
4.00	4.50	4.03	.237	7.18	3.19	3.73
5.00	5.56	5.05	.258	15.06	5.41	5.06
6.00	6.63	6.07	.28	27.95	8.44	6.56
8.00	8.63	7.98	.322	71.99	16.69	9.88
10.00	10.75	10.02	.365	159.63	29.70	14.00
12.00	12.75	12.00	.375	277.42	43.52	17.14

★ Extruded Structural Tube ★ (Note: All Values are approximate)

Nom. Size (Inches)	Outer Dia. (Inches)	Inner Dia. (Inches)	Wall (Inches)	I	S	Wt./Ft. (Lbs.)
2.50	2.50	2.00	.25	1.12	0.90	2.08
3.00	3.00	2.50	.25	2.04	1.36	2.54
3.50	3.50	3.00	.25	3.37	1.92	3.00
4.00	4.00	3.50	.25	5.16	2.58	3.46
4.50	4.50	4.00	.25	7.51	3.34	3.93
5.00	5.00	4.50	.25	10.48	4.19	4.39
6.00	6.00	5.50	.25	18.57	6.19	5.31
8.00	8.00	7.50	.25	45.43	11.36	7.16

The pipe and structural tubing sections listed have been chosen with an eye to keeping the wall-thickness sufficient for maintaining adequate bending strength, hence reserve resistance to destruction once the mast has deflected "out of column" (see "Backyard Builder", November & December, 1980). The sections have also been chosen with wall-thicknesses that allow drilling and tapping for fittings attachment.

The relatively thick-walled schedule 40 pipe and structural tubing sections listed have higher Section Moduli than most mast extrusions with equal Moments of Inertia. Therefore, there is rarely need for concern about loss of bending strength when converting from a mast extrusion to one of these thicker-walled pipe or structural tubing sections. Nevertheless, it is prudent to make a comparative check of Section Moduli just to be certain.

A.4) Calculate the total weight of the pipe or tubing mast (multiply weight-per-foot by length overall) and compare this to the weight of the originally specified mast extrusion.

If your plans specify Moment of Inertia but do not recommend a particular extrusion section, check the weight of the pipe or tubing mast against one which might be built using some of the available mast extrusions. In general, it is best to avoid a mast weight increase of more than 50 percent, unless a thorough stability analysis is made of the vessel involved. Occasionally, though rarely, a mast may have structural requirements which cannot be duplicated using a round pipe or tubing section without an excessive and unacceptable increase in overall weight. But more often, if the weight increase exceeds 50 percent, either you have chosen a pipe or tubing section incorrectly or the originally specified or contemplated extrusion has an uncommonly thin wall — in which latter case, a serious review of the original mast design and specification may be in order.

Converting from Spruce or Douglas Fir specs

If your plans specify a spruce or fir mast, proceed as follows.

B.1) Determine the I for the specified mast from table 2 or 3. Multiply this figure by .14 for spruce or by .18 for fir to obtain the necessary I for a 6061-T6 aluminum extrusion.

B.2) Determine the S for the specified mast from table 2 or 3. Multiply this figure by .05 for spruce or by .06 for fir to obtain the necessary S for a 6061-T6 aluminum extrusion.

If your original mast is not listed exactly, carefully choose a listed wooden section which slightly exceeds the overall dimension of the original. Use the I and S figures from this approximation.

B.3) Using the converted I and S thus obtained, choose a pipe or tubing section meeting which meets or exceeds these specifications.

B.4) Calculate the total weight of the pipe or tubing mast and compare to the total weight of the originally specified spruce or fir mast.

If the original wooden mast was solid, you can generally expect some weight reduction when converting to an aluminum pipe or tubing section. If the original wooden mast was hollow, you may or may not end up with a weight reduction, depending on the original masts's wall thickness and whether or not the original mast was tapered. Naturally, the smaller any weight increase the better. And again, you should take care that any increase does not exceed about 50 percent, unless a detailed stability analysis is done of the vessel involved.

Next month's column will continue by detailing the joining of pipe and tubing sections and some techniques for overall weight reduction.

TABLE 2

* Solid Round Section * (Note: All Values are approximate)

Outer Dia. (Inches)	I	S	Lbs./Ft. (Spruce)	Lbs./Ft. (Fir)
4.00	12.48	6.24	2.3	2.79
4.50	19.99	8.88	2.98	3.53
5.00	30.47	12.19	3.68	4.36
5.50	44.61	16.22	4.45	5.28
6.00	63.18	21.06	5.30	6.28
6.50	87.02	26.78	6.22	7.37
7.00	117.05	33.44	7.22	8.55
7.50	154.25	41.13	8.28	9.82
8.00	199.68	49.52	9.42	11.17
8.50	254.48	59.88	10.64	12.61

* Solid Square Section * (Note: All Values are approximate)

Long. Dim. D(LL) (Inches)	Trans. Dim. D(TT) (Inches)	I	S	Lbs./Ft. (Spruce)	Lbs./Ft. (Fir)
4.00	4.00	21.33	10.67	3.00	3.56
4.50	4.50	34.17	15.19	3.80	4.50
5.00	5.00	52.08	20.83	4.69	5.56
5.50	5.50	76.26	27.73	5.67	6.72
6.00	6.00	108.00	36.00	6.75	8.00
6.50	6.50	148.76	45.77	7.92	9.39
7.00	7.00	200.08	57.17	9.19	10.89
7.50	7.50	263.67	70.31	10.55	12.50
8.00	8.00	341.33	85.33	12.00	14.22
8.50	8.50	435.01	102.35	13.55	16.06

* Solid Rectangular Section * (Note: All Values are approximate)

Long. Dim. D(LL)	Trans. Dim. D(TT)	I(LL)	S(LL)	Lbs./Ft. (Spruce)	Lbs./Ft. (Fir)
4.00	2.67	14.22	7.11	2.00	2.37
4.50	3.00	22.78	10.12	2.53	3.00
5.00	3.33	34.72	13.89	3.13	3.70
5.50	3.67	50.84	18.49	3.78	4.48
6.00	4.00	72.00	24.00	4.50	5.33
6.50	4.33	99.17	30.51	5.28	6.26
7.00	4.67	133.39	38.11	6.13	7.26
7.50	5.00	175.78	46.88	7.03	8.33
8.00	5.33	227.56	56.89	8.00	9.48
8.50	5.67	290.00	68.24	9.03	10.70

TABLE 3

* Hollow Rectangular Sectn. (20% Wall) * (Note: Values are approximate)

Outer Long. Dim. D(TT) (Inches)	Outer Tran. Dim. D(TT) (Inches)	I(LL)	S(LL)	Lbs./Ft. (Spruce)	Lbs./Ft. (Fir)
4.00	2.67	12.33	6.16	1.28	1.52
4.50	3.00	19.75	8.78	1.62	1.92
5.00	3.33	30.10	12.04	2.00	2.37
5.50	3.67	44.07	16.03	2.42	2.87
6.00	4.00	62.42	20.81	2.88	3.41
6.50	4.33	85.97	26.45	3.38	4.01
7.00	4.67	115.64	33.04	3.92	4.65
7.50	5.00	152.39	40.64	4.50	5.33
8.00	5.33	197.27	49.32	5.12	6.07
8.50	5.67	251.41	59.16	5.78	6.85
9.00	6.00	315.99	70.22	6.48	7.68
9.50	6.33	392.28	82.59	7.22	8.56
10.00	6.67	481.62	96.32	8.00	9.48
10.50	7.00	585.41	111.51	8.82	10.45

* Hollow Oval Sectn. (20% Wall) * (Note: Values are approximate)

Outer Long. Dim. D(TT) (Inches)	Outer Tran. Dim. D(TT) (Inches)	I(LL)	S(LL)	Lbs./Ft. (Spruce)	Lbs./Ft. (Fir)
4.00	2.67	3.75	1.87	1.19	1.41
4.50	3.00	6.00	2.67	1.51	1.79
5.00	3.33	9.15	3.66	1.86	2.21
5.50	3.67	13.40	4.87	2.26	2.67
6.00	4.00	18.98	6.33	2.68	3.18
6.50	4.33	26.14	8.04	3.15	3.73
7.00	4.67	35.16	10.05	3.65	4.33
7.50	5.00	46.33	12.36	4.19	4.97
8.00	5.33	59.98	14.99	4.77	5.66
8.50	5.67	76.44	17.99	5.39	6.39
9.00	6.00	96.07	21.35	6.04	7.16
9.50	6.33	119.27	25.11	6.73	7.98
10.00	6.67	146.43	29.29	7.46	8.84
10.50	7.00	177.99	33.90	8.22	9.74

Yanks win 20th Century 21 Contest

In 1962, the Seattle Century 21 World's Fair Organization presented a silver trophy to the International Powerboat Association to recognize the winner of a predicted Log contest which ran from Victoria to Seattle. In 1964 the IPBA set up the Century 21 International Team Contest with six boats from Canada and the same number from the U.S.A., the total percentage error of the lowest four boats in each team to determine the winner.

It was the twentieth annual such event. This year's contest was hosted by Seattle Yacht Club's Henry Island Outstation on Saturday, September 17. The start was off Davison Head near Roche Harbour. The weather was ideal, but the skippers had their hands full trying to make heads or tails of the tide information. Currents that should have been a

Phil Friedman

Mast building, part III

In response to a reader's query, we have been discussing the construction of cost-efficient cruising yacht masts utilizing industrial extruded 6061-T6 aluminum pipe and structural tubing. My last two columns dealt with choosing an appropriate pipe or tubing section. This month's column continues by detailing techniques for joining standard pipe and tubing sections into the longer lengths required for most cruising yacht masts.

Industrial aluminum pipe and structural tubing sections are generally available in 20 ft lengths. Therefore, most masts will require at least one splice. Larger masts will require two splices.

Splicing lengths of pipe or tubing together presents no exceptional problems, nor should the procedure be viewed as unusual. As a matter of fact, although some dedicated mast extrusions are available in 40 ft to 45 ft (or longer) pieces, many sections come only in lengths shorter than 30 ft. Therefore, a larger percentage of "normal" masts contain at least one splice.

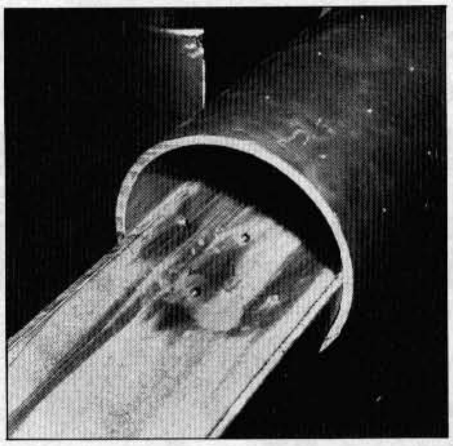
In my shop, we make all our splices in aluminum pipe masts by glueing (yes, Virginia, glueing) and bolting. Welded splices are not used because heat degrades the temper, hence the strength and stiffness, of 6061-T6 alloy. Such degradation might be acceptable if limited to a very small area of a mast wall. However, the strength reduction that results from the full circumferential weld required in a splice is mechanically suspect, in my view.

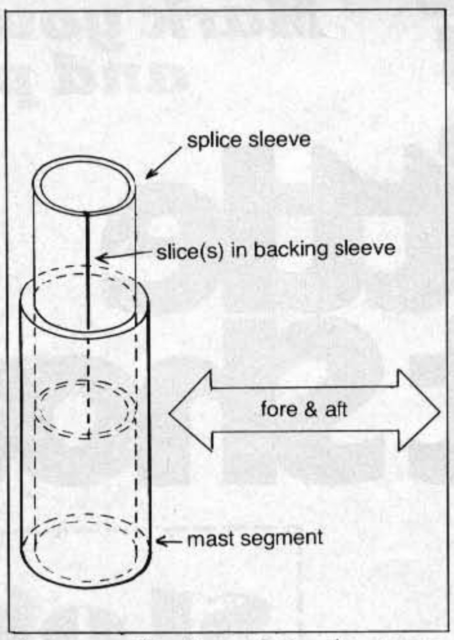
A very strong splice can be made in aluminum pipe or structural tubing by fitting an internal sleeve to back the joint. This sleeve is bolted and glued inside the mast joint, where it keeps the closely butted sections aligned for transmission of primary axial compressive loads and backs the joint for acceptance of subsidiary bending loads.

The backing sleeve should have a wall thickness equal to that of the sections being joined and should extend approximately two mast diameters either side of the joint. For example, the internal backing sleeve for a nominal 5-in. pipe splice should have a .250 wall and should be about 22-in. long.

The backing sleeve can be made by splitting an appropriate length of aluminum pipe or tubing longitudinally using a circular or table saw and a carbide tipped blade. (Be very careful and always wear a protective face shield, not just safety glasses, when sawing aluminum.)

For sections with lighter walls, one or two longitudinal saw passes — made along the same line — will remove enough material to allow the split sleeve to be squeezed into the mast segments that are being joined. Heavier wall sections, however, generally require two longitudinal slices opposed at 180 degrees. This produces a two piece sleeve that is more easily pulled into the correct radius by subsequent bolting. It is not necessary to weld the split sleeve sections; but, since most masts receive less rigging support longitudinally than transversely, it is advisable to arrange the slices in the backing sleeve athwartship.





A strong splice is made in aluminum pipe or tubing (top) by bolting an internal sleeve to back the joint. The backing sleeve (made by splitting a length of pipe longitudinally) is bolted inside the mast joint. Above, diagram of a splice arrangement.

Once the sleeve has been fabricated, the splice should be trial assembled with the sleeve fitted and the mast sections closely butted. The splice assembly should have an easy sliding fit since it will be necessary to disassemble it once before final assembly. If necessary, use a lubricant temporarily to facilitate disassembly after the bolt holes have been drilled and tapped.

With the splice temporarily assembled, drill the mast sections, and drill and tap the sleeve, for ¼-in. flat-head stainless steel machine screws at approximately 3-in. staggered centres, placing no hole closer than 1-in. from the joint or 1-in. from the ends of the backing sleeve (see photographs). This bolt size and spacing is sufficient for most small and medium size cruising yachts to about 45 ft LOA and sections including nominal 6-in. schedule 40 pipe. Above these limits, a change to 5/16-in. or 3/8-in. stainless steel bolts would be in order depending on the size of the vessel in question and the size of the pipe or tubing sections involved.

The bolt holes are drilled and tapped as follows: 1) Drill appropriate tap pilot hole through both mast and sleeve section. 2) Drill out hole in mast section only, to full 1/4-in. diameter and countersink for a flush-fitted, flat-head machine screw. 3) Tap hole in sleeve. This is all done while sections and sleeve are temporarily assembled.

After all holes have been drilled, countersunk, and tapped, disassemble the splice. Clean and degrease the mating surfaces of all parts with appropriate solvent. Roughen these mating surfaces with 120 grit aluminum oxide paper. Clean and degrease again. Then, using a flexible, polyamide-cured epoxy adhesive spread on all mating surfaces, reassemble the splice, carefully tightening all the machine screws. A dab of epoxy adhesive on the bolt threads will act as a locking compound. Mix a bit of filler into some adhesive and fill over the machine screw heads and butt seam. The splice is complete.

While a splice in relatively heavy-walled sections is virtually as strong as the joined segments themselves, it is prudent, where possible, to place all splices in an aluminum mast at, or very close to, the termination points of shrouds or stays. Mast deflection and the resulting bending loads are minimized at these points of rigging attachment. Thus, at these points, the major loads are axial compressive and, since the joined mast segments are tightly butted, these splices do not depend on the integrity of their machine screw fastenings.

Depending on your rig configuration, it may not be possible to place the splices precisely at shroud or stay termination points. If you cannot keep the splices within about 36-in. of such points, you should consider replacing either shrouds or stays. If the required modifications to rigging placement are relatively minor, then you can probably proceed without undue concern. In most conversions, the pipe or structural tubing mast is generally overstrength transversely anyway. However, if major modifications to rigging configuration are required, then professional advice may be in order.

In general, advantageous placement of splices on a two-spreader mast is a breeze, especially if the rig has double headsails and runners. Splice placement on a single-spreader mast taller than about 45 ft above deck is a bit trickier, but still feasible. In the case of more traditional, spreaderless, gaff rigs, placement of splices at rigging termination points may not be feasible at all. In such cases, use slightly oversized sections (subject to weight check, increase S by 10 percent to 15 percent) and increase backing sleeve lengths by 50 percent.

A worthwhile weight reduction may be accomplished in double-spreader masts by pseudo-tapering above the upper spreaders. This is accomplished by fitting a doubled packing sleeve and a smaller section topmast at this point. For masts with sail track, a packing must be fitted under the track along this reduced topmast section in order to keep the track straight. As long as the diameter reduction is made at the spreader, this type of pseudo taper is aesthetically quite acceptable. Unfortunately, it is not generally feasible for single-spreader masts.