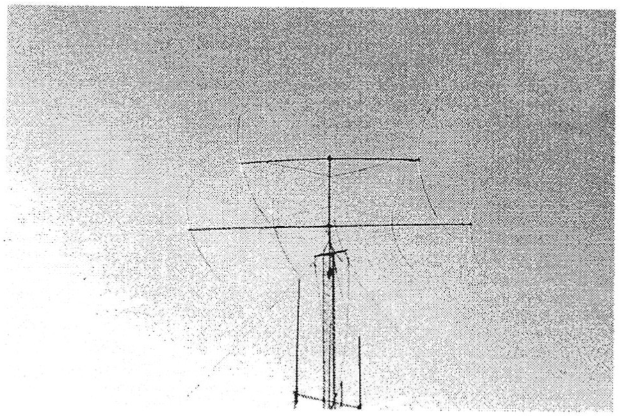
Strengthening the Cushcraft 40-2CD

The 40-2CD is a popular shortened 40-meter Yagi, but it needs reinforcement to survive high winds and icing. This article shows how you can do it.

By Dave Leeson, W6QHS
15300 Soda Springs Rd
Los Gatos, CA 95030



Properly modified, the 40-2CD easily handles 75-mi/h winds commonly found at the author's mountaintop QTH. The lower antenna is a Hy-Gain 205BA 5-element 20-meter monobander that has been modified using similar techniques. *(photo by the author)*

After we lost a series of towers and antennas to the 120 mi/h winter winds at our otherwise wonderful mountaintop site, my wife Barbara, KK6QM, convinced me that there ought to be an engineering solution to our problems. The "engineering solution" started as a weekend project that stretched to several years as I learned more than I ever expected to about designing antennas that would stay up at my QTH. The results of my research are chronicled in a book, *Physical Design of Yagi Antennas*, to be published early next year by the ARRL.[1]

"If it didn't fall down, it wasn't big enough" is an adage hams often apply to Yagis. If this concept were applied to common civil structures like bridges and buildings, this would be a far less safe world. Fortunately, civil structural engineering techniques make it possible to design and build Yagi antennas that can survive and be rotated even in severe weather. This article, based on information in my book, shows what's needed to modify the Cushcraft 40-2CD.

Why I Chose a 40-2CD

The Cushcraft 40-2CD is a widely used 2-element 40-meter Yagi with shortened elements. This antenna has a lot going for it:

- Mechanically, it's a manageable antenna for most hams. With a 22-foot boom and 43-foot elements, it's easily supported on a mast or small tower and can be turned with most amateur rotators.
- Its use of capacitive end loading promotes a higher radiation resistance—and hence a wider bandwidth—than similar antennas that rely only on inductive loading.[2] The antenna can be used on phone *and* CW in most installations.
- As confirmed by successful experiences at many contest and DX stations, the antenna "plays."

I wanted to put up a 40-2CD, but had some doubts that the antenna could survive the wind and icing conditions at my hilltop site. The weaker points of the 40-2CD, from a physical standpoint, are:

- its rather long single-wall-thickness element sections;
- its boom center joint (at the boom-to-mast clamp); and
- its driven-element mounting plate.

I was also concerned with the stability of the electrical connections to the driven element, and I'd heard that corrosion occurs at the screws used for the electrical connections to the loading coils.

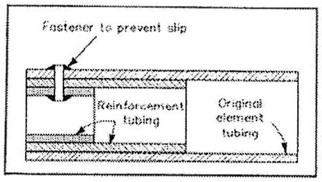


Fig 1—Element sections can be reinforced without changing the material or electrical design by adding internal reinforcement. A snug, mechanically strong fit is ensured by using tubing with 0.058-inch wall thickness and outer diameters that decrease in 1/8-inch steps. Drawings are not to scale.

Reinforcing Antenna Elements and Booms

Using the techniques detailed in *Physical Design of Yagi Antennas*, it is possible to improve the physical strength of the elements and the boom of the 40-2CD without compromising its electrical design. The calculations involved are beyond the scope of this article—they fill many pages of the book. Here's a summary of what I found.

To decide what improvements are needed for antennas installed at a given site, we need answers to the following questions:

1) What are the expected mean and peak-gust wind velocities at your location?

2) What is the wind-survival speed of the antenna as delivered from the manufacturer?

3) How can the antenna elements and boom be strengthened so that the wind-survival speed is equal to or better than the expected wind the antenna will experience?

Experience answered the first question. I knew that 50- to 100-mi/h winds regularly occur at my site and that I could expect mean winds to about 120 mi/h (gusts are 30% higher yet!) at least once a year. See the sidebar, "Determining Expected Wind Speeds."

Mechanical analysis answered the

---

[1] Notes appear on page 42.

Previous
Next

Updated December 23, 1999

K7VC

Determining Expected Wind Speeds

A disadvantage of many excellent radio sites is wind exposure. Wind exposure varies greatly from site to site, and it's a major problem in some areas of the country. The accepted standard in the United States for antenna and tower engineering has been EIA-RS-222-C, published by the Electronic Industries Association (EIA).[1] EIA-RS-222-C is a very interesting document, one that's a big help in deciding just how strong an antenna has to be. Many tower companies include parts of this document in their catalogs. Other relevant standards are the Uniform Building Code (UBC)[2] and the British Standards Institution Code of Basic Data for the Design of Buildings.[3] Both treat wind survival of structures and towers.

EIA's RS-222-C presents a model for expected wind speeds throughout the US. This model is based on 50-year mean recurrence intervals from distribution of extreme fastest-mile winds at 30 feet above the ground. It incorporates a 30% gust factor and includes tables that illustrate the increase of wind with height above ground. (The heights specified—300 feet—are well above those of typical amateur antennas.) The EIA model names three wind zones, as shown in the accompanying table and Fig A. Most of the United States lies within Zone A, the mildest of the three zones. Differences in local topography and surface roughness cause significant site-to-site variations, however.

In 1986, the EIA published a revision of RS-222-C, designated EIA-222-D.[4] In the new document, the wind-zone map of RS-222-C is replaced by a similar basic wind speed map identical to that found in the Uniform Building Code. The newer EIA standard also uses a somewhat different force constant to derive wind pressure on structures, though. The end result is that the new and old EIA standards predict essentially the same wind pressure for a given locale.

Combining concepts from all of these specifications offers a means of accounting for local topographic effects. Fig B gives an estimate of the combined effect of the wind-speed zone and local topography for antennas 70 feet above ground. If you want a more accurate estimate of wind speeds expected in your locale, you can ask your local power utility or radio station for wind statistics for your area. If you're inclined, you can measure your own over an extended period.

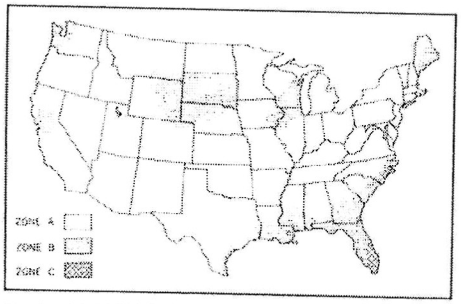


Fig A—EIA RS-222-C wind zones.

EIA RS-222-C Wind Zones

EIA Zone	*Wind Pressure*	*Mean Velocity*	*Gust Velocity*
A	30 lb/ft^3	86.6 mi/h	113 mi/h
B	40 lb/ft^3	100.0 mi/h	130 mi/h
C	50 lb/ft^3	111.8 mi/h	146 mi/h

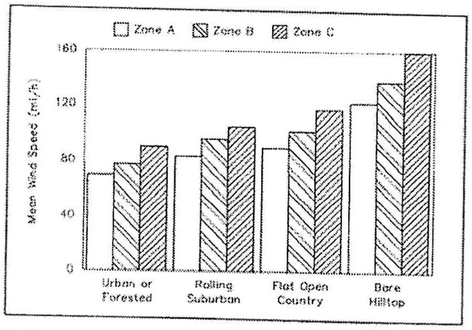


Fig B—Estimate of the combined effect of the wind-speed zone and local topography for antennas 70 feet above ground (RS-222-C).

Ice Loading

High winds aren't the only problem you face in keeping your pride and joy in the air. In many parts of the world, buildup of radial ice on antenna elements is a serious problem. EIA-222-D offers some insights on designing antennas to survive the effects of combined ice loads and high winds. The document specifies ½ inch of ice in the absence of other data. The specification further asserts that there's a low probability that an extreme ice load will occur simultaneously with an extreme wind load. So when designing an antenna to withstand simultaneous wind and ice loading, the wind load factor can be reduced 25% (equivalent to 87% of basic wind speed).[5]

Under icing conditions, an element's effective diameter is the diameter of the tubing plus *twice* the ice thickness. The ice, however, makes no contribution to the strength of the element. This means that the element must not only carry the weight of the radial ice, but it also suffers the penalty of greatly increased wind area! Fortunately, the strengthening required for ice buildup is the same as that required for high wind, so that design for high wind survival generally satisfies the requirements for icing survival.[6]—*W6QHS*

[1] *Structural Standards for Steel Antenna Towers and Antenna Supporting Structures*, EIA Standard RS-222-C (Washington: Electronic Industries Association, 1976).

[2] *Uniform Building Code*, "Wind Design" (Whittier, CA: International Conference of Building Officials, 1988), Section 2311, p 137.

[3] *Code of Basic Data for the Design of Buildings*, "Wind Loads" (London: British Standards Institution, 1972, amended 1988), CP3, Chapter V, part 2.

[4] *Structural Standards for Steel Antenna Towers and Antenna Supporting Structures*, EIA Standard EIA-222-D (Washington: Electronic Industries Association, November 1986).

[5] *Structural Standards for Steel Antenna Towers and Antenna Supporting Structures*, EIA Standard EIA-222-D, Appendix A, 2.1.2 C, p 27; and Appendix A, 2.3.15 A, p 28.

[6] See Appendix F, "Ice Formation on Structures," of EIA Standard EIA-222-D (p 47).

second. Cushcraft rates the antenna for "a steady 80 mi/h wind," which doesn't seem to consider the 30% peak-gust factor found in tower and building standards. My calculations indicate that the 40-2CD could survive mean wind speeds of 71 mi/h, and its use in my windy location requires a stronger mechanical design. I calculated that the 40-2CD's elements can be reinforced to survive 118 mi/h, and the boom can be easily improved to survive the same wind speed.

The answer to the third question is not so simple. A physical force causing bending or rotation is called a *torque* or

Previous

Next

Updated December 23, 1999

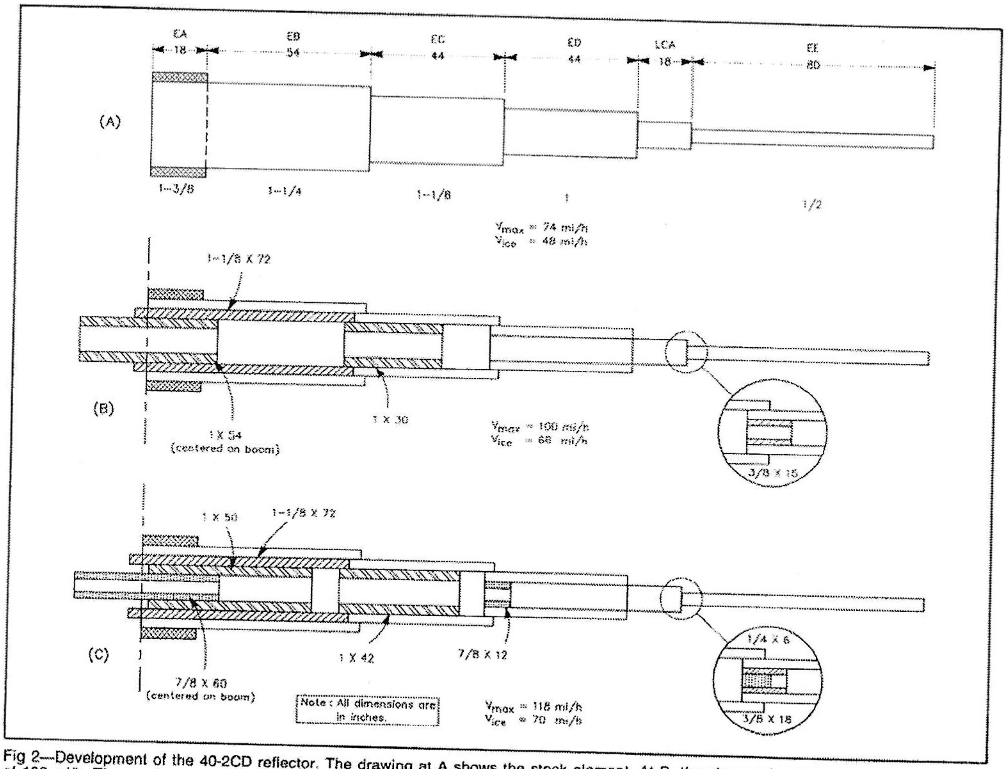


Fig 2—Development of the 40-2CD reflector. The drawing at A shows the stock element. At B, the element is reinforced to survive winds of 100 mi/h. The maximum reinforcement possible—safe to 118 mi/h—is shown at C.

moment. The survival of a tubular structure is determined by its ability to withstand the bending moment that results from wind pressure. Structural bending strength of a hollow cylinder is determined by the *yield strength* of the material it's made from and by a parameter called the *section modulus* of the shape. Section modulus is determined by the outer and inner diameters of the cylinder. The ability of a cylindrical Yagi element or boom to survive bending is affected by wind pressure, ice loading, length, material strength, and section modulus.

If you don't want to change the antenna's electrical design or structural material, the only variable left to alter is the section modulus. This can be accomplished by changing the element's inner diameter. You can do this by reinforcing the tubing at points needing greater bending strength. As shown in Fig 1, additional pieces of tubing are added inside the antenna element at weak points—usually the inner end of a structural section of the element, such as the element-to-boom attachment point and at element joints. A fastener, typically a stainless-steel machine screw in a tapped hole or an all-aluminum or all-stainless-steel pop rivet, is required to be sure that the reinforcing sections do not slip out of position.

Reinforced 40-2CD Elements

I used a computer spreadsheet to perform the strengthening calculations. The resulting development of the 40-2CD elements is shown in Figs 2 (reflector) and 3 (driven element). Only half of each element is shown.

Construction of the stock elements is shown in Figs 2A and 3A. In the element assembly instructions, Cushcraft identifies each element section by two or three letters (EA, EB and so on). I use the Cushcraft nomenclature throughout this article for ease of reference.

The number above each element section is the length that the section protrudes from the previous section to correspond to the dimensions shown in Cushcraft's assembly manual. The number below is the section outside diameter (OD). All dimensions are in inches. For example, section EB is 72 inches long—18 inches inside section EA plus 54 inches protruding—by 1¼ inches OD. Cushcraft usually specifies a 4-inch overlap at each joint except at the element center and element tip, so section EC is a total of 48 inches long (44 inches plus 4 inches inside EB).

Wind survival speed (v_{max}) for the stock reflector is 74 mi/h; for the driven element, v_{max} is 71 mi/h. The survival speed with ½ inch of radial ice (v_{ice}) is 48 mi/h for the stock reflector and 47 mi/h for the stock driven element.

100 mi/h Elements

Figs 2B and 3B show the internal reinforcement necessary to increase v_{max} to approximately 100 mi/h (and increase v_{ice} significantly as well). The dimensions of the additional tubing required is shown in italic type. The details sound a bit complicated, but the concept is simple: Add one or more layers of new tubing inside the stock Cushcraft tubing.[3] The new tubing is the next size down (1/8 inch smaller OD). Wall thickness of 0.058 inch ensures a snug fit between the telescoping pieces. To prevent

Previous

Next

K7VC

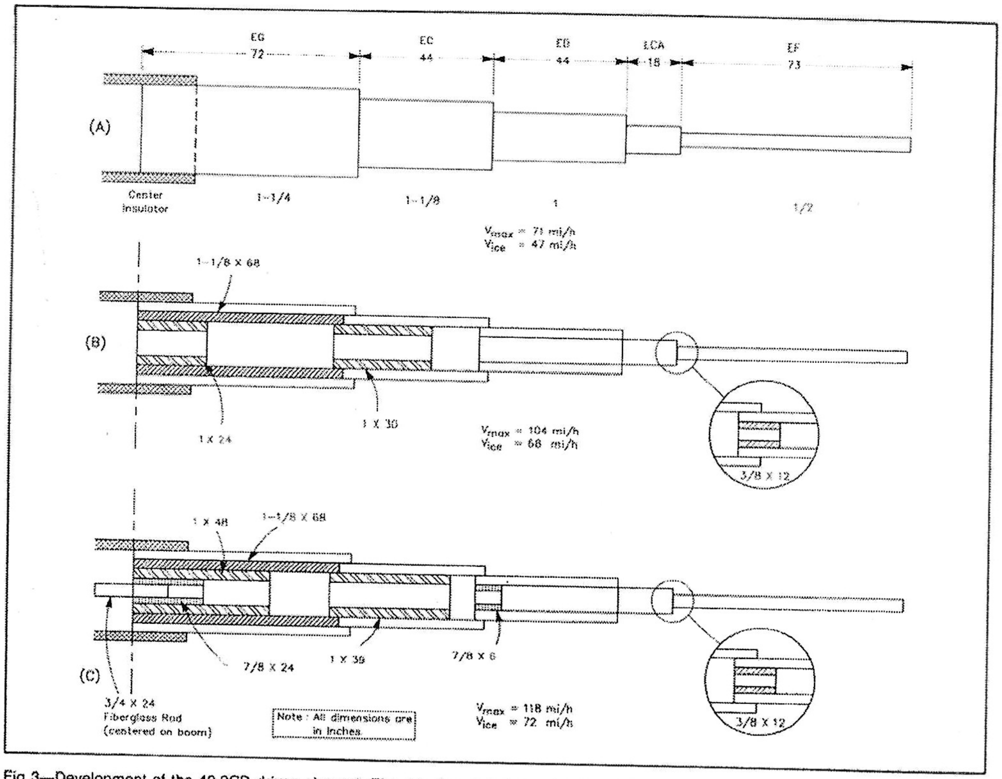


Fig 3—Development of the 40-2CD driven element. The drawing at A shows the stock element. At B, the element is reinforced to survive winds of 104 mi/h. The maximum reinforcement possible—safe to 118 mi/h—is shown at C.

seizing, completely deburr the new tubing and lightly lubricate the reinforcing sections with grease or another lubricant.

The reflector (Fig 2B) is strengthened by sliding a 1-1/8 × 0.058 × 72-inch tube[4] into one of the 1-1/4-inch EB sections. The added tube is located so that it is 4 inches under flush with the outer end (to leave room to insert the next outboard section, EC, which telescopes 4 inches into section EB). The EB section on the opposite side of the boom is reinforced with a 1-1/8 × 0.058 × 64-inch tube. Why not use a 68-inch-long tube inside each EB section? The element is stronger if the joints in the EB sections and the reinforcing tubing are offset. The 1-1/8-inch tubes are further reinforced with a 1 × 54-inch tube centered in the element (27 inches on each side of the boom).

The next step is to reinforce the joint between sections EB and EC by adding a 1 × 0.058 × 30-inch tube to overlap the joint. This tube is located to extend 28 inches inside section EC and 2 inches inside the 1-1/8-inch tube added to reinforce section EB. Finally, tip section EE is reinforced by an internal tube 3/8 × 0.058 × 15 inches. The driven element (Fig 3B) is reinforced in a similar manner, although the dimensions are slightly different. Although these steps are complex to describe, the resulting long-lasting antenna is worth the effort.

118 mi/h Elements

Figs 2C and 3C show the maximum reinforcement practical without changing the external element dimensions. This reinforcement increases v_{max} to 118 mi/h for both elements and increases v_{ice} by another 4 mi/h.

The maximum reinforcement builds on the modifications for 100 mi/h wind survival. As in the 100 mi/h element, the reflector (Fig 2C) is strengthened by sliding a 1-1/8 × 72-inch tube into one of the 1-1/4-inch EB sections and a 1-1/8 × 64-inch piece into the other EB section. This tubing is located as before so that joints in the EB sections and the reinforcing tubing are offset.

The 1-1/8-inch tubes are further reinforced by two pieces of 1-inch tubing. One piece is 50 inches long, the other 58. They are located so that the joint is 8 inches under flush with the boom end of the 1-1/8 × 72-inch tube. In other words, there are 54 inches of 1-inch tubing on each side of the boom. The joint is offset 4 inches from the element center on the opposite side of the boom (and 8 inches away from) the joint in the 1-1/8-inch tubing. Inside the 1-inch tubing is a 7/8 × 60-inch tube centered on the element (30 inches inside each element half).

The 1-inch reinforcement tube for the EC-ED joint grows to 42 inches. A 7/8 × 12-inch tube is added to the joint between sections ED and EC. At the element tip, the 3/8-inch OD reinforcement tube is increased to 18 inches, and an additional 1/4 × 6-inch tube is telescoped inside.

The driven element (Fig 3C) gets similar treatment. For maximum reinforcement, a fiberglass rod, 3/4 × 24 inches, is inserted into each driven element half to bridge the center insulator. At assembly into the

Previous

Next

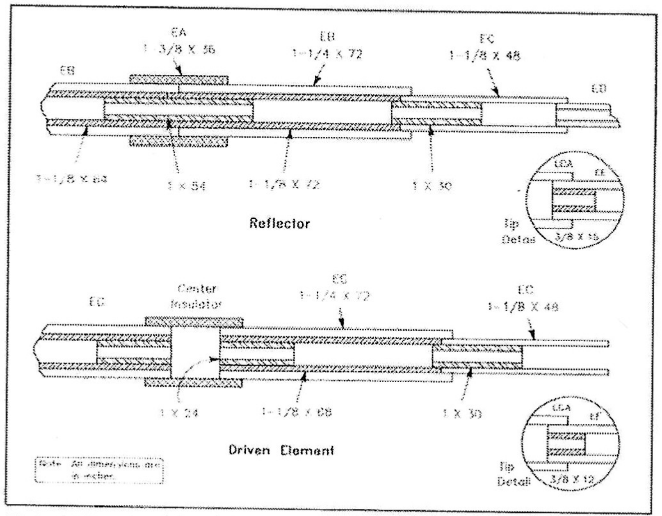


Fig 4—Another view of the reinforcement required to reinforce 40-2CD elements to survive 100-mi/h winds.

center insulator, the fiberglass rod is inserted half into each side of the driven element center sections—make sure to deburr completely before it gets stuck in the wrong place! Spacing between driven-element halves at the center inside the black Cushcraft insulator is 2 inches.

Each joint of the reinforced elements (either version) is held with the supplied all-stainless hose clamps and with at least one 1/8-inch diameter pop rivet. The rivet holes can be filled with silicone caulk for weatherproofing.

In view of the complexity of the reinforcement requirements, different views of the element-construction details are shown in Fig 4 for 100 mi/h reinforcement and Fig 5 for maximum reinforcement. In these figures, actual dimensions of the stock tubing are shown above each element, and dimensions of the added tubing are shown below. When complete, the new elements are quite strong and much heavier than the stock elements.

Strengthening the Boom

The boom has a joint right at its center, between the two **U** bolts that attach the boom to the boom-to-mast plate. As it comes from the factory, the boom joint is reinforced by insert BC, a 2 × 0.058 × 18-inch tube. The bending moment here is the same as immediately outside the **U** bolts, and the insert is the only support.

I calculated the stock boom's wind survival speed to be 86 mi/h, with the center joint confirmed as the weakest point. It's a simple matter to increase the boom's wind-survival speed to 101 mi/h. First, replace insert BC with a 2 × 0.058 × 36-inch length of 6061-T6 or 6063-T832 tubing. Then add a 1-7/8 × 0.058 × 12-inch center reinforcement of the same material. For maximum reinforcement (v_{max} 117 mi/h), replace insert BC with a 2 × 0.058 × 84-inch tube. Then add a 1-7/8 × 0.058 × 12-inch center reinforcement. See Fig 6.

In either case, it's a good idea to reinforce the boom joint with a solid 1-3/4 × 12-inch wood dowel or fiberglass rod. This prevents the boom-to-mast-plate **U** bolts from crushing the boom tubing. Reinforce the stock boom tips with 1-7/8 × 0.058 × 6-inch tubing and a 6-inch length of 1-3/4-inch solid dowel inside to prevent crushing by the element-mounting **U** bolts.

On the stock antenna, each of the joints between sections BA and BB is pinned with a single #8 machine screw to prevent twisting. I recommend securing each joint with two 1/4- × 2-1/2-inch stainless bolts at right angles to each other, spaced 1-1/2 inches apart. The holes provided by the manufacturer for the #8 machine screws can be drilled out to 1/4 inch to make a light-drive fit. Use stainless-steel elastic stop nuts.

Boom-to-Element Mounting

No amount of tightening the element clamp **U** bolts will prevent the elements from rotating on the boom, so I bolted the element-to-boom plates to the boom. The boom-to-driven-element clamp must be increased in thickness, either by obtaining a second one from the manufacturer or by drilling out a 1/8-inch (for 100 mi/h) or 1/4-inch (for 118 mi/h) plate to double with the original.

I mounted the boom to a dummy mast and used bubble levels to get the element plates horizontal. After mounting the elements using the supplied **U** bolts, drill each plate for two 1/4-inch stainless bolts to go through the boom. Drill the boom, using the plate as a template, first on top and then on the bottom. The 1/4-inch bolts are centered 0.781 inch in from each edge of the plate, and the bolt heads are at the plate end under the elements. The reflector re-

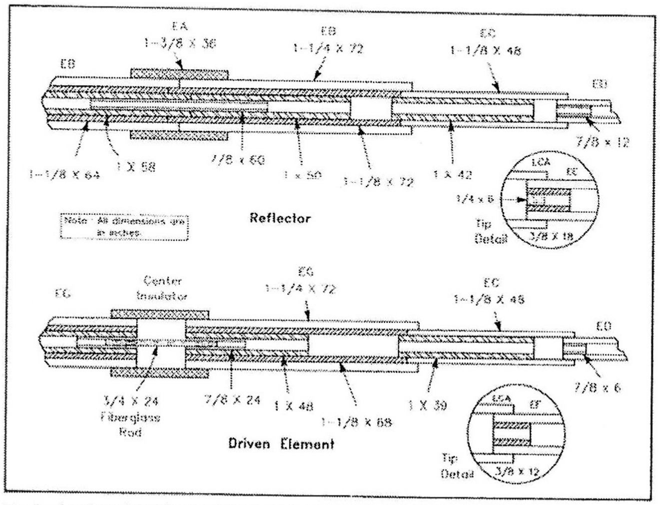


Fig 5—Another view of the reinforcement required to reinforce 40-2CD elements to survive 118-mi/h winds.

Previous

Next

Updated December 23, 1999

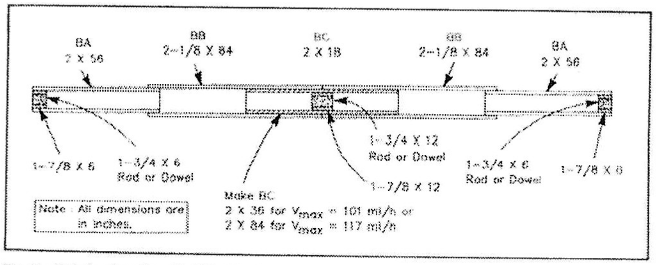


Fig 6—Reinforcing the 40-2CD boom.

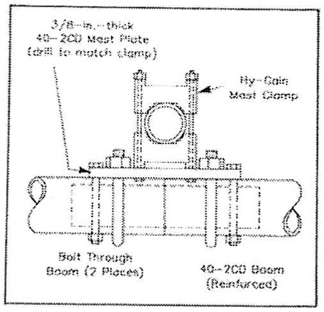


Fig 7—Modifications to the boom-to-mast mounting arrangement.

quires two 1/4 × 2-1/2-inch stainless bolts and stop nuts, and the driven element requires two 1/4- × 3-inch stainless bolts and stop nuts. Last, rivet the inner boom reinforcement to the outer section, two 1/8-inch diameter pop rivets on each side, so that the reinforcing sections help resist rotation of the through bolts.

Boom-to-Mast Plate

I also modified the boom-to-mast mounting arrangement. The stock 1/4-inch-thick boom-to-mast plate deforms if the **U** bolts are tightened snugly, so it is helpful to make a 3/8-inch-thick plate with the same hole pattern. I added a hole centered in the top of the plate to hoist the antenna and to measure the weight balance during construction.

While I was at it, I replaced the stock boom-to-mast **U** bolts with the convenient and strong Hy-Gain #102734 cast mast clamp. See Fig 7. Used on a 2-inch mast, the Hy-Gain clamp requires four 5/16- × 4-1/2-inch bolts and two 5/16- × 2-1/2-inch bolts. Because of the stress here, I use Grade 5 plated bolts with elastic stop nuts in preference to the nuts and bolts supplied by Hy-Gain. The standard bolts are threaded over their full length and are inconveniently long for a 2-inch mast.

The boom-center joint needs to be pinned like the BB-BA joints. Replace the #8 machine screws with 1/4- × 2-1/2-inch stainless-steel bolts. The mast plate is attached to the boom with two of the **U** bolts supplied, but without the supplied **V** blocks. I also drilled the plate and boom for two 5/16- × 3-inch through bolts with elastic stop nuts. These bolts also pin the boom.

Boom Struts

The last boom modification involves Cushcraft's boom-support tubes (boom struts). Locate the straps for the boom struts along the boom as recommended in the assembly manual and then secure them with two rivets. The strut joints are fastened with hose clamps; rivet them as well. I planned to place my 40-2CD at the very top of the mast, so I attached the struts to the mast below the boom, rather than above it. (The reinforced boom is strong enough to support itself without boom struts.) The boom struts don't provide any lateral support against wind force, so their use is primarily to eliminate vertical deflection.

Other Modifications

Based on my firsthand observation of the stock 40-2CD, I decided that several additional steps were necessary to ensure survival. These are detailed here.

I replaced the loading-coil-terminal plated self-tapping screws with #10-32 × 1-1/4-inch stainless-steel machine screws. I drilled and tapped holes through the aluminum tube and secured the screws with safety nuts. To do this, I had to cut a small circular flap in the heat-shrink tubing covering the loading coils. After replacing the terminal screws, I used large-diameter heat-shrink tubing to cover these openings and to double the covering over the coils. I was not able to measure any change in inductance (12.93 μH), Q (161) or series resistance (3.26 Ω) due to the additional heat-shrink tube. I'm confident now that the connections will not loosen or corrode.

I found it best to assemble the antenna without the loading-coil and capacitance-hat tip sections, which are easy to bend or scar. Until the antenna is being raised, keep the assembled element tips separate and protect the loading coils with rags to prevent tearing the heat-shrink tubing, which would result in water problems. I'm uncertain about the strength of the loading-coil sections, but, as with tribanders, they are quite far from the concentrated moment region of the center sections.

The driven element is held in its 2-inch insulating section by the bolts supplied by Cushcraft, but I made the electrical connection *immediately outboard* of the insulating section using #10-32 pan-head stainless-steel machine screws tapped directly into the element wall and its reinforcing tubing. (The stock electrical connections are made by machine screws that pass through the element tubing and the insulator. The insulating material is in compression; if the insulator deforms, the connection is no longer sound.)

I attached a W2DU ferrite-bead balun to the boom with four long black cable ties. For electrical connection, I used a minimum length of flexible, insulated #12 house wire with crimped spade lugs at each end. The coax is routed along the side of the boom so that it does not add to the antenna's wind resistance or upset torque balance.

Torque Balancing

If the centers of pressure of the elements or the boom are not located at the mast, wind forces from various directions cause a tendency for the antenna to rotate. This rotating moment is called the mast torque. The wind-induced torque about the mast is determined by the areas and locations of the elements, the area and length of the boom and the wind-arrival angle. If we can achieve zero rotating torque at all wind angles, rotator stress is greatly reduced. To achieve zero rotating torque for all wind angles, the moments about the mast resulting from the elements *and* the boom must be zero. With a symmetrical boom, this can be accomplished by moving the elements as an ensemble so their total moment is zero, or by adding a nonconductive torque-compensating element. Despite the area of the insulating tube for the driven element (not present at the reflector), the 40-2CD's torque balance is excellent. No torque balancing element is necessary because of the inherent symmetry and small size of this antenna.

The addition of a bead balun affects the antenna's good torque balance, though. The balun is 1.25 inches in diameter and 12 inches long, so the area is 1.25 × 12 = 15 in^2. The center of the balun is 131.5 − (12/2) = 125.5 inches from the mast, so the balun moment of area is 15 × 125.5 = 1882.5 in^3, or approximately 350 inch-pounds at 100 mi/h.

There are two easy ways to regain torque balance:

- Extend the boom 6.84 inches at the reflector end (since it can't be shortened at the driven-element end).
- Make a dummy balun the same size as

Previous

Next

Table 1

Mechanical Parameters for the 40-2CD

Elements	*Stock*	*Reinforced +*	*Reinforced + +*
Wind Survival Ratings			
v_{max} (mi/h)	71	100	118
v_{ice} (mi/h)	47	66	70
Center joint v_{max} (mi/h)	71	104	135
*Tubing Required**			
Reflector	EA		
	EB	1-1/8 × 72 (64)†	1-1/8 × 72 (64)†
		1 × 54‡	1 × 50 (58)†
			7/8 × 60‡
	EC	1 × 30	1 × 42
	ED		7/8 × 12
	EE	3/8 × 15	3/8 × 18
			1/4 × 6
Driven Element	EG	1-1/8 × 68	1-1/8 × 68
		1 × 24	1 × 48
			7/8 × 24
			3/4 × 24
			fiberglass rod
	EC	1 × 30	1 × 39
	ED		7/8 × 6
	EF	3/8 × 12	3/8 × 12
Driven element mounting plate thickness (in.)	1/4	3/8	1/2
Boom			
v_{max} (mi/h)	96	101	117
Center joint v_{max} (mi/h)	86	117	117
Center joint reinforcement (0.058-in.-wall tubing centered on the joint)	BC	2 × 36 1-7/8 × 12	2 × 84 1-7/8 × 12
Extension to compensate for W2DU bead balun (in.)	None	6.84	6.84

Notes

*0.058-in.-wall tubing required for each element half unless otherwise specified.

†Different lengths are required for each element half. See text.

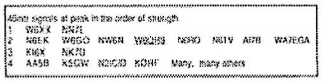
‡This is a single piece centered on the boom.

the W2DU bead balun and mount it at the reflector end of the boom.

Summary

Table 1 compares the unmodified and reinforced versions of the 40-2CD. The improvements make a big difference in the antenna's wind and ice survival. The higher-strength configuration survived at my QTH and performed well right through one of our winter storms. Perhaps Cushcraft would consider offering a reinforcement kit for this excellent antenna to provide certified wind survival.

An indication of the electrical excellence of the 40-2CD is in the comparative report I received from JR1XKU for a QSO in this year's ARRL CW DX Contest. A computer-printed sticker on his QSL card reads as follows:



40m signals at peak in the order of strength

1 W6XX NN7L
2 N6EK W6GO NW6N W6QBS N6RO N61V AI7B WA7EGA
3 KI6X NK7U
4 AA5B K5GW N2IC/0 K0HF Many, many others

Many of the calls in this report are familiar contest winners, and sport full-size three-element or stacked four-element Yagis. Not bad for a small two-element antenna!

Dave Leeson, W6QHS, was first licensed in 1952. With his wife Barbara, KK6QM, he shares an active interest in contesting and DXing from their California mountaintop QTH. Professionally, he holds a PhD in electrical engineering and, since 1968, has been the founding chairman of California Microwave, Inc.

Notes

[1] L. Moxon, *HF Antennas for All Locations* (Potters Bar: Radio Society of Great Britain, 1982), p 28, Fig 3-12.

[2] D. B. Leeson, *Physical Design of Yagi Antennas* (Newington: ARRL, 1992), in preparation. Available in early 1992 from your dealer and the ARRL Bookshelf. The book gives information on modifying a wide range of antennas. The 40-2CD is just one example.

[3] If you live near a metropolitan area, your Yellow Pages should list suppliers of aluminum tubing (try the headings Aluminum, Aluminum Tubing or Tubing) and stainless-steel hardware (try Hardware or Fasteners). Marine supply stores also sell stainless-steel hardware, but often at a premium price. Several *QST* advertisers sell tubing and hardware through the mail.

[4] Throughout this article, I specify tubing as outside diameter × wall thickness × length (in this case, 1-1/8 in. OD × 0.058 in. thick × 72 in. long). Use 6061-T6 or 6063-T832 material.

Previous Next

Technical Correspondence

Conducted By Paul Pagel, N1FB
Associate Technical Editor

MORE ON STRENGTHENING YAGI ELEMENTS

☐ I believe that the November 1991 *QST* article, "Strengthening the Cushcraft 40-2CD," by Dave Leeson, W6QHS, contains a structural practice that might affect the long-term wind rating of the driven element. In this case, improvements are compromised by what appears to be a minor step. The article also contains one particular suggestion for strengthening the driven element that provides an insignificant improvement and should not be used.

Drilling Holes in Elements: Proceed With Caution

Leeson suggests using a machine screw to make electrical contact with the driven element immediately outboard of the element center insulator. He suggests the modification because the method used by the manufacturer has problems. Based on my experience with two 40-2CDs stacked on a 140-foot rotating tower, I agree with the need to use something other than the manufacturer's method of attaching the feed line to the driven element. Dave's suggestion of using a machine screw should not be followed, though: The hole that must be drilled in the element to accept the screw increases stress on the element tube.

How can a small hole cause a problem? You might think that only a very small amount of material has been removed from the element tube, so the stress can only increase a small amount. This is not correct. The hole creates a *stress concentration*, which exposes the tube material near the hole to stress about *three times higher* (and potentially much more than three times higher) than if there was no hole. Fig 1 is from a fracture mechanics course. It shows an equation for the stress at the edge of a hole as a function of the hole shape. For a round hole, A = B, the stress is three times higher than if the hole was not there. Fig 2 shows what is happening to the stress fields in the material.

Does the presence of the hole mean there is going to be a catastrophic failure? Yes and no. When the stress in the area of the hole is high enough, the material will yield. This sets up a situation for the formation of cracks that can grow over a period of time. The problem with a crack is that once it starts, it can grow quickly. A crack is long relative to its width, so the ratio of A/B is very high—resulting in a higher magnification of stresses than seen by the original hole. If the antenna element is subjected to a very high wind, the material near the hole will yield, and cracks will initiate and grow. It's only a matter of time before failure occurs. The higher the loads, the sooner the failure. A modified 40-2CD antenna element would probably last a reasonably long time. Then, at the time of failure, it wouldn't be obvious why the element failed.

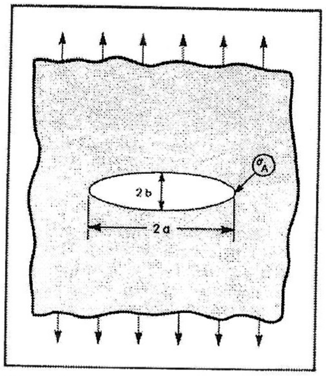


Fig 1—Stress at the edge of a hole is a function of hole shape. For a round hole, where A = B, the stress is three times higher than if the hole was not there. The stress at point σ_A is given by:

$$\sigma_A = \sigma\left(1 + \frac{2a}{b}\right)$$

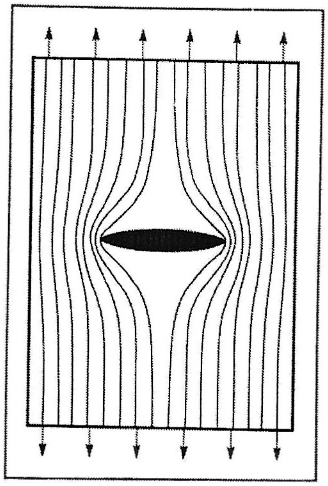


Fig 2—Stress fields in the aluminum are affected by the presence of a hole.

What to do? Don't drill any holes! Don't use screws to attach the feed line to the driven element. The method I recommend is shown in Fig 3. Build a simple clamp to go around the outside of the driven element and install it next to the insulator. The full strength of the tube is now realized, providing there are no other holes.

Elsewhere in his article, Dave suggests using pop rivets or machine screws to secure multiple telescoped layers of tubing within element sections. This should be done with great care. In the case of the feed-line attachment, the hole was drilled in the element at a point where the stress was highest for that section. If you need or want to drill a hole in an element, there is a means to do so without degrading the element's strength: Place the hole in a location where, under the maximum wind load, the material stress (without the hole) is no more than 25% of the tube material's yield stress. Even with a threefold increase in stress caused by a hole, the resulting stress is below the tube's yield level, minimizing the possibility of local yielding and crack initiation.

You can determine the best hole location by performing a detailed stress evaluation of the element sections. A simple rule of thumb is to avoid drilling *any* holes in an element. If you are unable to perform a stress analysis and must drill a hole to secure overlapping telescoping element tubes, place the hole about midway in the overlap length. This puts the hole at the point in the outer element section that is under the lowest stress.

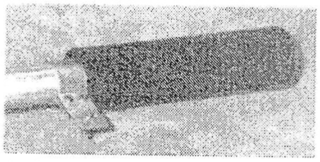


Fig 3—A clamp around the outside of the driven element is one way to attach the feed line without drilling holes.

When an element section is reinforced by adding a tube (or tubes) inside it, there is an easy way to secure them without drilling any holes. Simply use a pointed punch to make a slight dimple in the outer tube that's deep enough to secure the inner tube. Dimple the element tubes in order, starting with the innermost tube, so you can slide the dimpled assembly into the next element section.

Strengthening the Center Insulator

In his article, Leeson suggests installing

Previous

Next

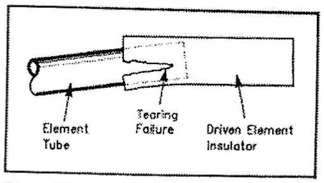


Fig 4—The most probable insulator failure mode is for the element to tear the insulator or pull out a portion of it.

a 0.75-inch-diameter fiberglass rod at the center of the driven element to bridge the center insulator. Presumably, this is done to strengthen the driven element insulator, as it cannot help the element sections. If the insulator-rod composite is treated as a beam, the suggested improvement decreases the stress in the insulator by only 2.3%. (The derivation of this number is available upon request and is not included here due to its length and complexity.) The suggested reinforcement is not only of little value, but does not address the most probable failure mode for the insulator.

The most probable failure mode is for the element to tear the insulator or pull out a portion of it as shown in Fig 4. It is almost impossible to accurately calculate the strength of the insulator, and measuring it would require destructive testing. Even though there is no available information, the tear-out strength of the insulator can be greatly increased by putting a heavy hose clamp at each end of the insulator. Fig 5 shows this method on one end of a center insulator. Adding the clamp accomplishes two things: (1) It preloads the insulating material in compression so it takes a higher load to put the material in tension; (2) It distributes loads to the entire insulator cross section, making it act more like a beam. A rough calculation shows the hose clamp can at least double the tear-out strength of the insulator for a 100% minimum increase in strength. It is recommended that this method be used rather than the 0.75-inch fiberglass rod.

I hope these simple improvements to the material presented in Dave Leeson's article are of use to people interested in strengthening their 40-2CD antennas. *—Dick Weber, K5IU, MSME, PE, Box 44, Prosper, Texas 75078*

Author David B. Leeson, W6QHS, responds:

☐ Dick is correct that holes are stress risers that could lead to fatigue failure in Yagi elements. His viewpoint reflects the concern for metal fatigue that is a way of life for professionals dealing with aircraft wings and race-car engines and other mechanical devices that experience many thousands of cycles of load reversal at full stress. However, several respected antenna manufacturers have long used the same element-section connection approach I advocate without shortening service life. The only Yagi element failures I've identified with fatigue have resulted from resonant flutter of element tips.

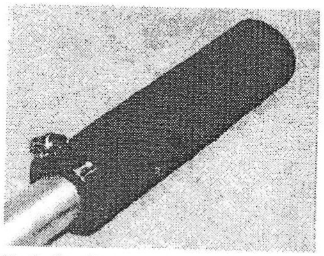


Fig 5—Banding the end of the insulator with a hose clamp minimizes the probability of a tearing failure.

In the case of Yagi elements, the primary hurdle is surviving even one cycle at the peak wind and ice load during the antenna service life. The statistical rather than cyclical nature of peak wind loading raises the question of whether a Yagi element will ever experience the 100,000 full-stress load-reversal cycles that develop fatigue cracking at stress risers.

Even so, it's sound advice not to drill any holes in the inner half of any element or boom section, unless the hole is contained by an externally telescoping reinforcement such as the tip of the next larger section. This favors the use of external clamps to make electrical connection to an insulated driven element, as well as the use of dimples (which can also be stress risers) or adhesives such as silicone to hold internal reinforcements in place.

Fig 6 shows how I'd connect the feed line to an insulated driven element without drilling holes. An all-stainless hose clamp (or two for redundancy) can be used to clamp a thin electrical connecting strap or braid to the element. Although I've had no failures, banding the center insulator with hose clamps is a helpful idea. These clamps can also be used to support the connecting straps.

The choice of strap material, thickness and shape should respect the corrosion potential of dissimilar metals and the tendency for fatigue failure at sharp bends of the strap itself (a problem with the bent-aluminum strap clamp often seen in commercial antenna kits). The connecting wire or strap should be insulated and supported against flexing with black ultraviolet-resistant tie-wraps, and the balun end of a connecting braid can be rolled and crimped in a suitable lug.

Dick also questions the use of a fiberglass rod placed at the driven element center. The fiberglass rod is there to prevent the crush of the element tubing, and is not expected to add strength to the center insulator.

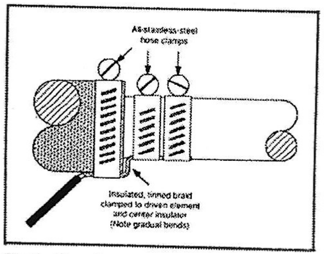


Fig 6—Dave Leeson suggests using hose clamps to connect the feed line to the element, as well as prevent insulator tearing.

Last, here are typographical errors in my book, *Physical Design of Yagi Antennas,* that have been pointed out by readers (the first three by Brian Beezley, K6STI, the last by Bob Wilson, N6TV):

- * Page 8-23, Table 8-3, the second to last entry should be $\ell' = \ell/(f_0'/f_0)$
- * Page 9-4, Table 9-1, the last entry under Hy-Gain should be 0.23, not 0.27.
- * Page 9-14, second sentence from the the bottom: "...element mount totals $X_c = -339\ \Omega$, *not* $-169\ \Omega$
- * Page 11-61, second paragraph, fourth sentence should read: The 15M5 can be constructed on the Hy-Gain 205BA boom," *(not* 204BA boom).

Note: All correspondence addressed to the Technical Correspondence column should bear the name, call sign and complete address of the sender. Please include a daytime telephone number at which you can be reached if necessary.

Keep the author(s) in the communications loop. Whether praising or criticizing a work, copy the author(s) on comments sent to Technical Correspondence.

Previous

Next

Updated December 23, 1999