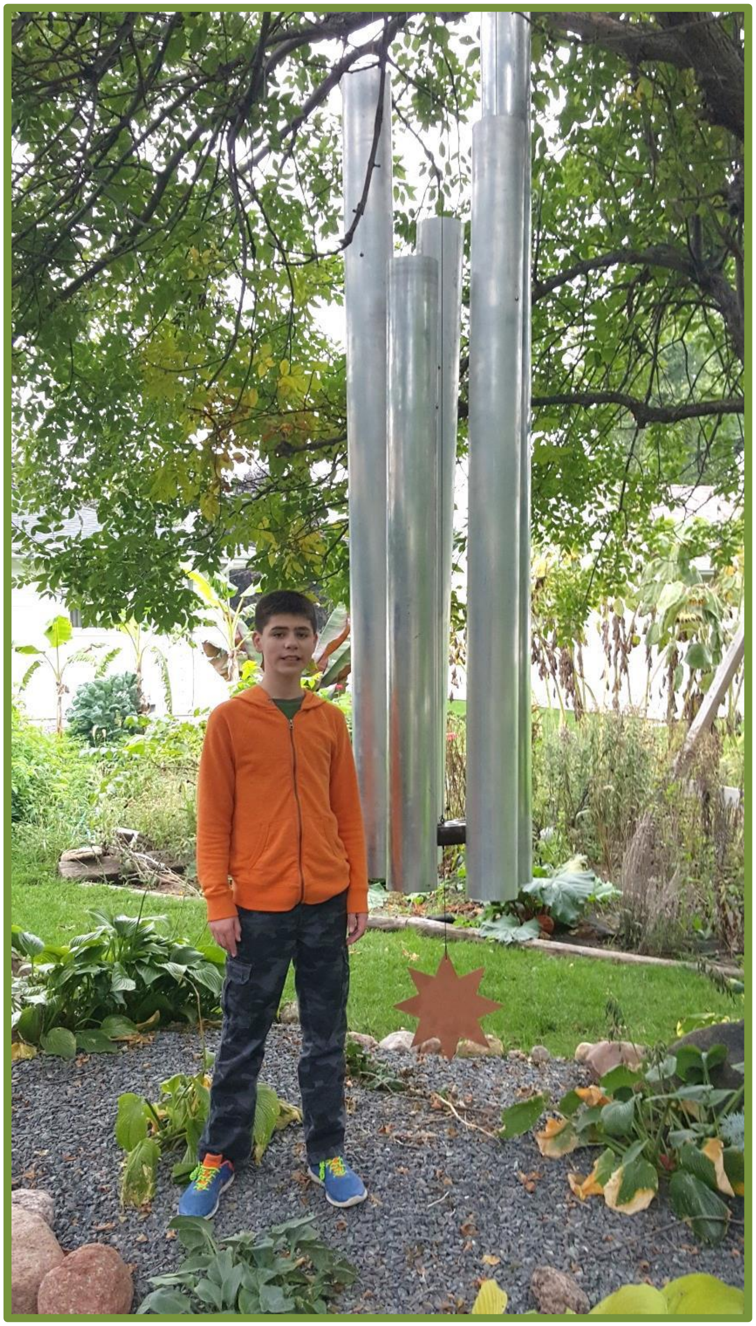
Tubular Bell Chimes
Do-It-Yourself
Compendium



By: Leland L. Hite (Lee)
www.leehite.org/Chimes.htm

Table of Contents

Cover photo by Chris, showing his son who is five-feet, six-inches tall.

Sample Projects

Details for these chime sets are available on the website here. Photos by the builder

Father daughter project by James

1 ½" EMT, by David from Alaska

Aluminum & Brass by Chuck from Columbus

By Kenny Schneider that plays Bach's, Joy of Man's Desiring when struck by a person walking by.

2" Aluminum, Traversed Mercator by Caleb Marhoover

Pictured is a sculptural/musical interpretation of the distance which divides my youth from adulthood. Here, this journey is presented through the linear elevation profile of the terrain which fills that divide.

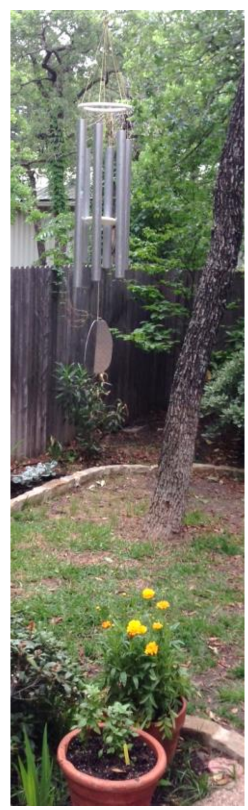
6 inch aluminum by Craig Hewison from the UK

Chimecloud by Lutz Reiter, Marco Dondana and Arnim Jepsen from the Chalmers Institute of Technology Göteborg, Sweden

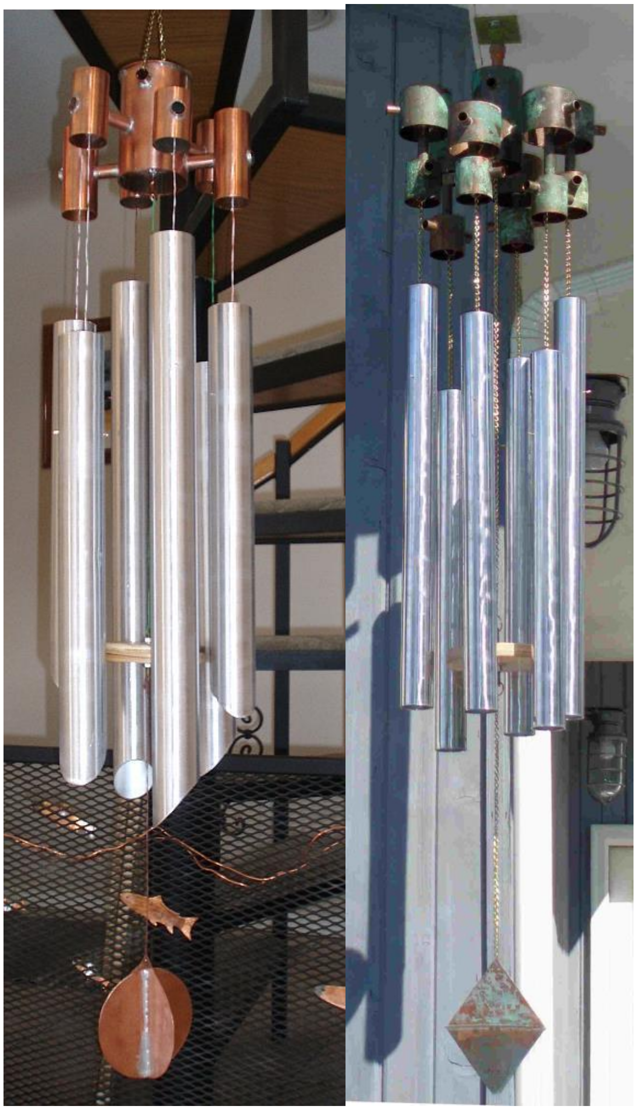
Copper by Dan from Virginia

Cast iron by David

1 inch Copper by: Musician, Travis Oberg, California



Jack Nash, 6 aluminum pipes using the pentatonic scale



Bill Moyer used eight, one-inch copper pipes with a pentatonic scale tuning beginning at A3, for these artistic arrangements.

Tides by Margaret Noble

Tides was to be a series of dynamic public art concerts with large-scale sculptural kites, tuned wind chimes and performances by experimental choral singers. Formally dressed in black, choral performers were to improvise with varying bell note melodies driven by the kite lines they would fly.

2-inch Aluminum
C-9 Chord by Ken

Windless Chimes by Sontag Creations

2 ½” Aluminum
By Neal

Bill Moyer used eight, one-inch copper pipes with a pentatonic scale tuning beginning at A3, for this artistic arrangement

One inch aluminum
By Paul Stoops

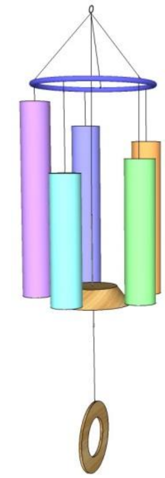
Merle Walther, 1 ½" painted EMT, 3" wooden ball striker & Moose wind catcher

Copper by Michael

Tomáš Jarošek from the Czech Republic developed a special tuning for this chime set. See website for details

Aluminum by Duc Billy from Viet Nam

6-inch diameter x 13-feet long aluminum by Chris (Cover Photo)



Introduction: Providing you with easy options for making good choices when designing and building tubular-bell wind chimes from tubes, pipes, or rods, is our number one goal. Rather than building to a fixed set of plans, the following information allows you to customize a chime set specific to your personality and style.

A variety of best practices, patterns and calculators are provided to accommodate your particular skill level, construction resources, and your budget. Avoid some of the common mistakes and you can easily design and build an attractive and great sounding set of tubular bell chimes.

Background As my good neighbor pointed out when faced with the challenge of designing a new state-of-the-art toaster, first determine what makes toast, toast; rather than dried bread, before designing a great toaster. Clearly my question should have been, what makes a chime, a good chime, rather than what musical notes should be selected when designing a set of wind chimes. I had originally asked that question in 2001 when buildg chime sets for my daughters for use as Christmas presents. I had no idea what I was getting into when I asked that question.

While I would not consider myself an expert by any definition, the findings here can be valued for the understanding of tubular bells. My experience with this project has evolved over time and is presented to help you design and build a great set of tubular bell chimes.

Forward This compendium is a work inprogress so if you spot something that is not clear, needs clarification or correction, please let me know. eMail

Additional resources to this compendium are available for download from the website leehite.org/Chimes.htm and they include:

1. Precalculated dimenions for the complete note range from C1 thru C9 (tubes total = 75, rods = 90)
2. DIY calculators for the complete note range from C1 thru C9, for the pentatonic scale, and for the C9 chord that determine the correct length and hang point for tubes or rods unrestricted at both ends.
3. Look-up tables for stand size tubing.
4. Standard Music Scale with overtones
5. Look-up table for material properties.
6. An embedded Top Support Disk Calculator allows you to determine the correct layout based on your chime diameter, striker diameter and the clearance between the striker and the chime tube..
7. An embedded location calculator for points on a circle can be usedfor layout of the top support disk holes or radial star strikers)
8. Chime-set support disk and striker patterns for a 3-chime set thru an 8-chime set, including patterns for either a traditional circular striker or the new radial star striker.
9. Wind sail/wind catcher patterns.
10. Stand alone support disk calculator with points an a circle calculator

Material type = Aluminum, Brass, Cast Iron, Copper, Steel (EMT thin-wall conduit), Stainless Steel and Titanium.

All dimensions are calculate based on the tubing OD (outside diameter) and ID (inside diameter) measured in inches, and for specific metals. Results are dispalyed in both english and metric units.

The DIY calculator uses nominal values for metal properties. However, if you know the exact metal density and the exact modulus of elasticity, you can enter that data for your specific metal in the data section of the DIY Excel calculator.

The Build Plan You can anticipate just a few decisions before you're ready to begin construction. There is a lot of information in this document and on the website, but don't let it overwhelm you. Most of the information provides choices for making a design decision.

Step 1: Select the number of chimes (typically 3 to 8) for your set and the musical notes. It is helpful to understand the limitations for effective note selection as discussed in the section on the bell-like chime. Keep in mind the physical size for the set. Whether you use pre-calculated dimensions or one of the DIY calculators, observe the length for the longest chime as a guide for overall size. Remember to include extra length for the wind sail that hangs below the chimes.

Step 2: Select the metal for the chime tube.

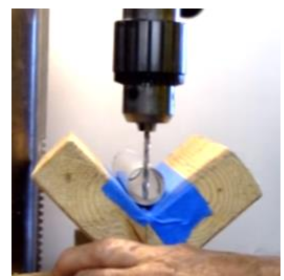
Step 3: Cut each chime to the length provided by the pre-calculated table or the DIY calculator. Cut slightly long (about 1/8") to allow for smoothing and de-burring the ends to final dimensions.

Step 4: Smooth the ends to remove sharp edges and to provide a professional appearance. Place an old towel or cloth on a table to protect the chime from scratches. Roll the chime back & forth as you file or sand the ends smooth. Slightly chamfer or round the outer edge.

If you're new to cutting metal and looking for an easy method, I use an abrasive metal cutting saw blade in a radial arm saw. This works equally well with a cut-off saw, aka chop-saw. The blade pictured right is under $5.00 at Home Depot. The traditional tubing cutter or hacksaw works well also.

Step 5: Drill the support holes at the hang-point location provided by the pre-calculated table or the DIY calculator. De-burr the support holes in preparation for your support line.

Using a V-Block, center the block before drilling by lowering the drill bit to the bottom of the vee and then clamp the block to the drill table.



How to drill the tubes without a drill press or V-Block: Using card stock or a manila folder, cut a strip about ½" by 8", then wrap around the tube and tape it, so that you now have what looks like a "Cigar Band". Lay it on a table and flatten it so a crease forms on both sides. Example: say that the instructions asks for a hole 10 ½" from the end of the tube. Slide the "Cigar Band" down the tube to the 10 ½". Position one crease at your mark and then rotate the tube over to the second crease and mark that location. Now you have drilling marks exactly opposite each other.

Step 6: Select the method or style for the top support disk or ring and select the material to be used.

Step 7: Select the top support disk cutout pattern for your specific tubing size and number of chimes in the set. Download the support disk & striker patterns PDF from the website and just print the page specific to your tubing size and number of chimes in the set. You may need to print two copies, one for the support pattern and holes location, and one for the striker pattern.

Step 8: Select a circular striker, a radial star striker, or a striker-keeper, all are included in the patterns from step 7.

Step 9: Select and print a pattern for the wind sail from selections in Patterns for Wind Sails/Catchers PDF available on the website, or design your own.

Step 10: Weather protect the top support disk or ring, the striker and the sail with a UV protective finish. Decorate the chime tube as desired. A few suggestions here:

Step 11: Select the line, cord or chain for supporting both the chime tube and the top support disk or ring.

Step 12: Select the style for hanging the chime tubes, i.e. top aligned, center aligned or bottom aligned. Bottom aligned is best because it allows the striker to easily contact the end edge of all chimes, the ideal strike location. Top aligned may have a more aesthetic appeal and on occasion some like center alignment. All three locations work well when you keep the striker away from the center dead zone.

Step 13: Select the sequence for locating the chimes on the support disk or ring.

Step 14: Attach the support line or chain to the chime using a simple jig you can make here. Utilized an appropriately sized darning needle for threading line through the top support holes and tubes during assembly.

Step 15: In your workshop, temporally hang the support disk or ring just above eye level. Depending on your chime alignment selection (top, bottom or center) hang each chime according to both the alignment requirement and the chime sequence diagram.

Step 16: Hang the striker according to the alignment diagram and avoid striking exact dead center for any chime. All three locations work well when you keep the striker away from the center dead zone for the first overtone. Don't worry about killing the first overtone with center placement. The first overtone dead zone is very narrow and is easily overcome with a slightly off-center strike.

Tubes, Pipes or Rods

What's the difference between a pipe and a tube, the way it's measured and the applications it's being used for. Pipes are passageways. Tubes are structural. For the purpose of tubular chimes we consider them the same. The important parameter is the outside diameter, the inside diameter and the type of metal.

On the other hand, a rod is a solid metal cylinder that can produce a very diferent sound compared to a tube. The DIY calculators on this website can predicted the resonant frequency for a circular rod and the hang point location. If you want to design and build a chime set using rods rather than tubes all you have to do is set the inside diameter to zero and enter the outside diameter and type of metal into the DIY calculator.

If you are trying to decide between using a tube or a rod as the chime element, one important difference is the sustain time of the musical note. Typically a rod will have a much longer sustain time and in some environments this maybe desirable, and annoying in others.

Another difference is the length is shorter for a rod than a tube to strike the same note, for the same metal. For example, a 1" steel rod for middle C, (C4) is 26 1/4" while 32 7/8" is the length for 1" steel EMT. In addition to smooth surfaced metal rods, I have tested threaded steel rod and steel rebar. The threaded rod sounded okay but the rebar was awesome. Because of the hardness, rebar exhibited a wonderful sustain time which helped to hold on to the overtones. It was a delightful sound. I did not test the accuracy of the DIY calculator but I suspect it will be close. I would suggest selecting your notes based on steel rod, and while the notes probably will not be accurate, the ratio among the notes should remain the same.

Two additional issues to consider are the weight and loudness difference. Rods typically have a relative small diameter offering a smaller sound radiating surface producing a quieter chime, but on occasion the longer sustain time can offset the reduced loudness and sound quite acceptable.

An important issue to consider is the weight difference. The longer sustain time using a rod may offset the increased support weight requirement.

Resources

Metal Tubing Metal Rods Metal Tanks	Always try your local building supply store. In addition to visiting the hardware section in these stores investigate tubing used for closet hanging poles, shower curtain poles, chain link fence rails and post. Yard or garage sales can yield surprising results, look for a discarded metal swing set, tubular shelving, etc. With permission look for discarded materials on constructions sites. Try your local metal recycler; they can yield very economical rod and tubing. Online Speedy Metals accepts small quantity orders for tubes or rods. (Aluminum, Brass, Cast Iron, Copper, Steel and Stainless) Titanium Joe (Tubing) You can use either grade 2 being pure titanium, which is softer and less popular, or grade 9 (3AL-2.5V), which is the more popular high strength. The grade 9 numbers represent the percentage of Aluminum and Vanadium. The DIY Calculators work equally well for both grades. Tank bells can be crafted from out-of-service compressed gas/air tanks, scuba diving tanks or fire extinguishers. A most likely source can be your local testing facility for each type of tank. Ask your local fire department, welding shop and scuba diving shop for their recommendation for a testing company. You may be required to provide a letter to the testing company stating that you will cut the tank in pieces and render it unable to hold compressed air or gas.
Metal Hoops & Rings	Try hobby stores for rings or hoops often used for dream catchers, mandellas or macramé. Some are chrome plated steel and others may require paint. Support rings can be cut from an out of service aluminum fire extinguisher using an abrasive metal cutting saw blade in a radial arm saw, a chop saw or a table saw as described in step 3 above.
Eyelets & Grommets	Small eyelets can often be located at your local hobby store in the sewing department or a shoe repair store. You can also use the outer shell of a 1/8 inch or 3/16 inch aluminum pop rivet. Remove the nail-like center and use the rivet. Heat shrink tubing can be found at Radio Shack®.
Metallic Support Line	Thin braided wire or 1/32 to 1/16 inch rust resistant steel cable, or decorative chain that is zinc plated, brass plated, or painted can be located in hardware and home improvement stores. Try a hobby store for small aircraft control line cable.
Non Metallic Support Line	Make sure the line is UV resistant. Choices include fishing line (both braided & monofilament 30 to 50 pound), braided nylon line, braided plumb line, braided Dacron kite line, venetian blind chord, string trimmer weed eater line (.065 inch), awning chord, and braided electrical conduit pull line.

Musical Note Selection: Do you need to select a musical note? Not necessarily unless you are looking for a specific sound. All you really need to do is support the chime tube at the correct location to allow for the best possible sound from that tube.

Say for example, you want a 5-chime set about 24 inches tall not including the sail. The best thing to do is test a 24-inch tube for a pleasing sound. First, look at the pre-calculated tube length tables for your specific metal and chime size, to learn where a 24-inch tube is positioned in the overall scale. As long as the note is above C2 and well below C5 you should be good to go. Tie a slipknot in a string and position it at exactly 22.4% from one end. Multiply the tube length by .224 to locate the support location. Hold the chime with the string at the 22.4% point; strike the chime on the edge of the end with an object that is medium-hard object like a wood mallet, a wood cooking spoon or the hard rubber heel of a shoe. If you're happy with the sound then remove 2-inches from each succeeding chime, 22", 20", 18" and 16" and proceed to step 4 above.

I arbitrarily used a 2-inch removal measurement and suggest not more than 3-inches between any two chimes. You can lengthen rather than shorten each successive chime for an overall increase in height as long as you remain in the suggested range from C2 to C5 for all notes.

On the other hand, if you want a more coordinated sound a traditional and safe choice by many wind chime suppliers has been the pentatonic scale (C D E G & A.). An enhancement to the pentatonic scale is often the C9 Chord (C E G Bb & D) which has a wider note separation for a good sound both close in and at a distance from the chime. With that in mind, we have a DIY calculator for either choice where you select the metal and the tubing size, and the calculator will prove the correct length for each note.

If you're not sure what notes to select and want to experiment, use the Wind Chime Emulation Designer available on the website. **Caution**, the loudspeaker connected to your computer has the ability to play the low notes from C2 to C4, but a chime will not reproduce those sounds.

A Must Read Caution: Ending your project with a successful and pleasing sound is important and setting the right expectations will allow that to happen. Selecting musical notes for a chime is NOT like selecting notes on a piano or other string instrument, or reed instrument. When you strike C2 on a piano that is indeed what you hear, but Not true for a chime cut for C2.

Tuning implies exactness and exact tuning cannot happen when you do not hear the fundamental note for the chime. When a piano key for C2 (65.4 Hz) is struck, you will indeed hear that note, 65.4 Hz. When a C2 chime is struck you will NOT hear 65.2 Hz. In fact, you will not hear the first overtone at 180 Hz and can barely hear the second overtone at 352 Hz. Most prominent will be the third overtone at 582 Hz which, on a piano, sounds like D5, but isn't D5 because the mixing for all the overtones produces a completely new sound. The new sound is melodious, it sounds wonderful, but what note is it? Tuning charts on this site list dimensions for notes ranging from C1 to C9, that imply exactness, which you now understand cannot happen with a chime when you cannot hear the fundamental note. Read more about the missing fundamental and why this happens in the section "The Science of Chiming."

For example, an orchestra grade chime that is physically cut for C2 will actually sound about like C5. To see a visual representation for what a chime is apt to sound like see this chart. On the other hand, will the strike note for a chime sound pleasing and bell-like? Yes, absolutely, because of the large complement of overtones even though the fundamental is missing. Selections from about C2 to C4 sound the most bell-like but will not adequately radiate the fundamental tone.

Unfortunately, this effect complicates note selection if you are trying to strike exact notes below about C5. Above C5 the strike note will actually produce the fundamental and you can expect to hear the note you selected, but less bell-like than the C2 to C4 range. In fact orchestra grade chimes typically begin in the C5 octave.

Unfortunately this effect complicates note selection if you are trying to strike exact notes below about C5. Above about C5 the strike note will actually be the fundamental and you can expect to hear the selected note but the sound will be less bell-like than the C2 to C4 range. In fact, orchestra grade chimes typically begin in the C5 octave.

Available on the website are:

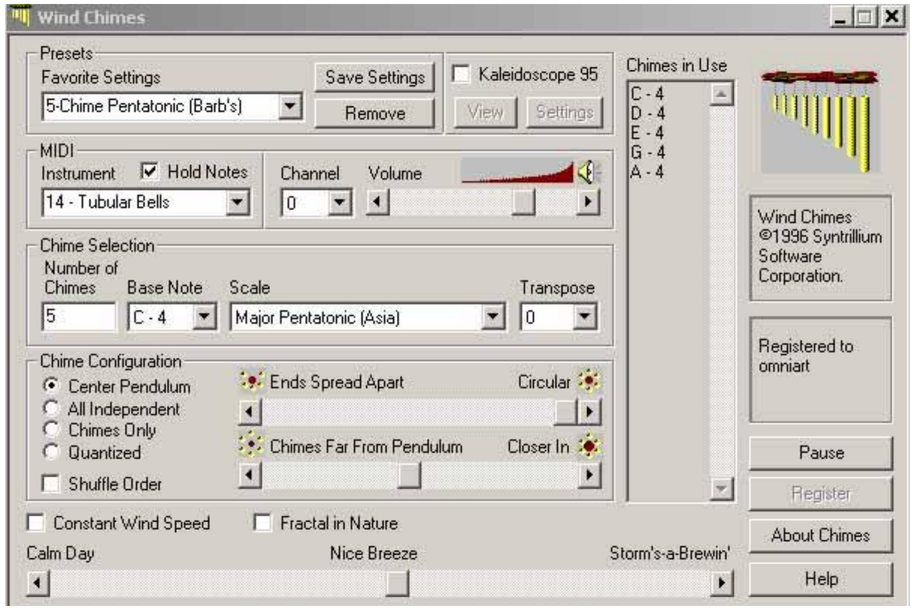
All Notes Wind Chime Calculator, Base A=440 Hz in MS Excel

Pentatonic Scale Calculator Base A=440 Hz, in MS Excel

C9 Chord Calculator Base A=440 Hz in MS Excel

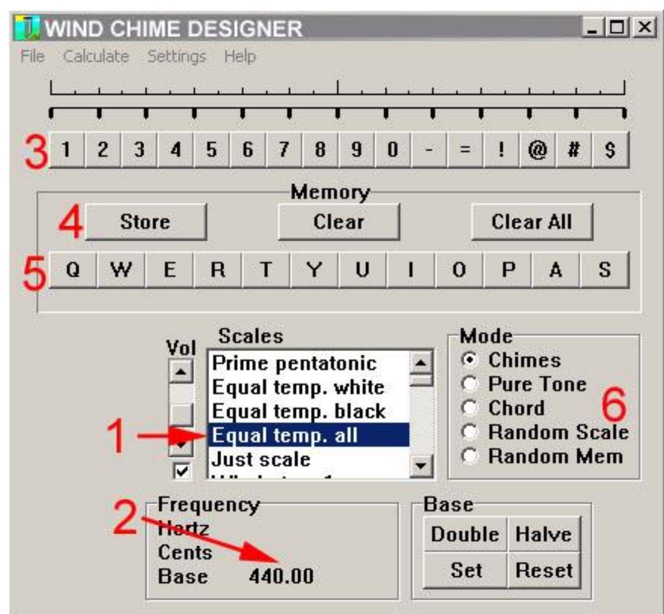
If you're not sure what notes to select and want to experiment, use the software programs from the website that emulate chimes. **Caution,** the loudspeaker connected to your computer has the ability to play the low notes from C2 to C4 but a chime will not reproduce those sounds.

Chime Emulation:



Thanks to a site visitor for providing this excellent emulation program from 1996 by Syntrillium. They are now defunct and we believe the software is considered "freeware". The zip file contains the main program, the registration codes and a help file. Unzip the download and run the wind_chimes_1.01_syntrillium.exe file. The program is quite intuitive; full featured and should be easy to operate. To begin I would suggest you set-up the program as follows: Number of Chimes "5", Transpose to "0", Scale to "New Pentatonic", Base Note "C-4", "Center Pendulum". **Remember**, the loudspeaker connected to your computer has the ability to play the low notes from C2 to C4 but a chime may not radiate those sounds. The program was originally designed to run on DOS 6 using Windows 95, and also runs with Windows NT, W2000, W XP and W7 thru W10.

A well designed freeware called Wind Chime Designer V 2.0, 1997-2006, by Greg Phillips will emulate a chime for notes between A2 (110 Hz) thru B8 (7,902 Hz) in many different scales (82 in all). It will help you determine what notes sound pleasant on a chime and what scale to use. **Remember,** the loudspeaker connected to your computer has the ability to play the low notes from C2 to C4 but a chime will not reproduce those sounds.



Download the Zip file from the website: Wind Chime Designer Software 370 Kb by Greg Phillips (software + Instructions)

1. Using right mouse, save to a folder of your choice
   Internet Explorer, select Save Target As
   Google Chrome, select Save Link As
   Firefox, select Save Link As
   Safari, select Download Linked File
2. Click on wind_chime_designer.zip to unzip the folder. (contains Chime32A.exe, TUNING.DAT, and Wind Chime Designer Instructions)
3. Place all three files in a folder of your choice
4. Click on Wind_Chime_Designer_Instructions PDF
5. Click on Chime32A.exe to run the program.

Strike a Note or Strike a Chord? Over the years much effort, by many well-intentioned people, has been placed on exactly what is the best chord for a set of wind chimes? While a musical chord can be pleasing to the ear, the effort to simultaneously strike all the notes in a chord using the traditional circular shaped striker/clapper has been mostly a waste of time. The striker only contacts one, maybe two, chimes simultaneously. The good news is that with some of our innovative striker designs we can now strike a chord. More on this in the striker section. Also, if you dedicate a striker to each chime tube (internal or external to the chime) that configuration can ring several chimes at nearly the same time and approximate a chord.

When using the traditional round striker it is much better to select notes that have a fair amount of separation allowing the ear to easily discern a variety of notes. Often a traditional choice has been the pentatonic scale (C D E G & A.) This choice can sound pleasant close to the chime set but not so well at a distance. The C9 chord (C E G B^b & D) can be used to widen the note separations for a five-chime set. The problem at a distance is the ear has difficulty discerning the closely spaced notes of the pentatonic scale.

Caution At Distance I often hear the comment, "I have a set of chimes on my deck and they sound great. However, I was over to my neighbor's the other day and the chimes did not sound so good. In fact, they sounded out of tune. Why is this?" The answer lies in the conditions that make up the notes for the chime. As mentioned in the science section, a chime note is a combination of the fundamental strike frequency and the many overtones. Some of the overtones attenuate more rapidly than others at a distance. The original combination of strike frequency and overtones are not the same at a distance. Remember, not always does the fundamental frequency contribute to the note and not always are there many overtones for a given note.

The actual note depends on exactly where in the musical scale the chime is operating. When you have a chime that contains a larger number of overtones that are located in the higher frequencies, and mostly missing the fundamental, you can get this distance effect. High frequency sounds attenuate more quickly in the atmosphere than do the lower frequencies. At a distance you are not hearing the same sound you hear close in. Some of the high frequency sounds can be greatly attenuated or missing. The chime can sound completely different under these conditions. Typically this occurs when you select notes in the lower part of the scale.

If your interest is making the chimes sound good at a distance of say 80-100 feet or more, consider increasing the diameter of the tubing from the traditional sizes ranging from ½" thru 2" up to at least 3" or more: 4" to 6" are better. A set of chimes designed for the C2 to the C3 octave have good acoustic radiation properties close to the set but not so good far away because of this distance effect.

When it comes to size, if you're on the fence between two sets of chimes, and one set has either a thicker wall or a larger diameter, select the tube with more mass, i.e. thicker wall and/or larger diameter.

Choice of Metal: Most often the chime designer considers cost, weight and aesthetics. Your budget may not approve the cost of copper while aluminum may be more favorable than steel because of weight. Chimes from EMT (electrical conduit) are galvanized and resist rust, but not at the support hole or the ends. Rust could be an issue long term for EMT. For the purposes of chime design use the Steel selection in the calculator if you're EMT.

What Metal Sounds Best? After the issues above are properly considered we can move to the question of what metal sounds best for a tubular chime? The short answer is the thicker the wall and the larger the diameter the better they sound, not necessarily the type of metal. However, what sounds best is a personal choice and I have not found a good answer for everyone. Some like a deep rich sound and other like the tinkle tinkle sound. Copper chimes have a different timbre than steel chimes. The best I can advise is to visit a chime shop and test-drive a few chimes of different metals and different sizes.

When it comes to size if you're on the fence between two sets of chimes and one set has either a thicker wall or a larger diameter, select the tube with more mass, i.e. thicker wall and/or larger diameter.

You may hear someone say they like aluminum best or copper best. To better understand the difference in metals let's properly build two 5-tube sets of chimes using the C9 chord beginning with the C2 octave. One set from aluminum, 2" OD with a 1/8" wall thickness, and the other set from steel, 2" OD with a 1/8" wall thickness. While each set will have different calculated lengths, they will both strike the same fundamental note, but sound completely differently. Why is that?

Contrary to intuition there are only two variables that control the sound of a chime, i.e. the density and elasticity of the metal. Those two variables control the specific length dimensions to achieve a desired note for a given tubing size and wall thickness. From the chart to the right you can see that aluminum has the lowest density and the lowest modulus of elasticity (deforms easier than the others), while copper has the highest density but is only midrange for elasticity.

But what does all of this have to do with what metal sounds best? The differences among metals cause a difference in timbre for the same note.

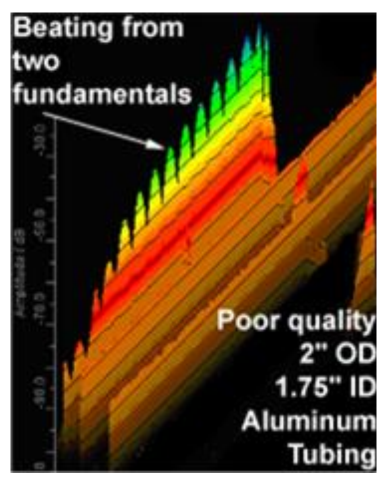
On occasion you may hear someone say they like aluminum chimes best. That likely occurs because the lower modulus of elasticity for aluminum requires less strike energy for resonant activation and, for a given input of strike energy, the aluminum chime can be louder and have an increased sustain time. However, the difference among metals does not make one metal good and another bad. There are no bad sounding chimes when the notes are properly selected, the tubes are properly tuned and properly mounted. It's impossible to have a set of chimes for the same note range made from aluminum sound the same as a set made from steel or any other metal, because of their difference in density and elasticity.

	Elasticity, psi	Density, Lbm / in^3
Aluminum	10,000,000	0.0980
Brass	17,000,000	0.3080
Cast Iron	13,400,000	0.2600
Copper	16,000,000	0.3226
Steel	30,000,000	0.2835
Titanium	14,900,000	0.1630

If you want the smallest possible chime set for a given note range select brass tubing. Opposite to brass, EMT will provide the largest physical set for a given note range. As an example, see the table below organized L to R, smallest to largest for middle C (C4). Also see the section on "proportional dimensions" for considerations of diameter, wall thickness and length.

Length for a one-inch diameter chimes at middle C (C4), smallest to largest.						
Brass .065 wall	Copper M	Cast Iron	Au.065 wall	Titanium .036 wall	Au .035 wall	EMT Steel
26 1/8"	27"	28 7/16"	29 5/16"	29 9/16"	30 7/16"	32 7/8"

Not All Tubing is Created Equal: Some tubing may produce a frequency beating effect when struck. This is often due to variations in the cross section of the tubing from variations and inconsistencies in the manufacturing process. The elasticity and the density of the tubing will be different depending on where the tube is struck. The tube can produce two closely spaced fundamental frequencies and these two frequencies will produce the beating effect. Some people enjoy this type of effect and others may find it annoying. If you want to avoid this wah-wah effect, make sure you acquire high quality tubing – or test a small piece before buying in bulk. While some tubing may be considered poor quality for musical requirements, it can be acceptable for structural needs. The problem with tubing that exhibits this effect is that it makes precise tuning more difficult. On the website you can hear this beating sound, for the tube shown to below.



Beating between two fundamental frequencies causing the wah-wah sound effect

If you know the exact material density and modulus of elasticity, enter those parameters into the DIY Calculator on the data page, when using the DIY calculator.

I want to emphasize that good tuning will certainly help to accurately produce the appropriate overtones for the selected note, particularly for the higher note ranges.

Standard Tubing Dimensions see standard dimension tables in Appendix E.

Aluminum and brass tubing tend to exactly follow their listed ID and OD dimensions.
However, copper tubing does not. Wall thickness for copper pipe varies with the pipe schedule.
The four common copper schedule s are named K (thick-walled), L (medium-walled), M (thin-wall), and DWV (drain/waste/vent - non-pressurized). The printing on the pipe is color coded for identification; **K is Green**, **L is Blue, M is Red,** and **DWV is Yellow.** Both type **M** & type **L** can be found in the plumbing section at home improvement stores like Home Depot, Lowe's and others in the USA.
Commonly available sizes for aluminum, copper, brass, steel and cast iron are also in the DIY wind chime calculator

Chime Dimensions: Select between pre-calculated dimensions or calculate your own dimensions using the DIY Calculator for common metal tubes, pipes and rods.

Pre-calculated Length and Hang Point Dimensions for Tubes & Pipes [English & Metric] PDF

Caution, these values allow you to get close to the desired note (typically within 1%) but if you desire an exact frequency, it is best to cut slightly long and grind to the final length. This is not normally required for wind chimes.

Do not use these calculations for an orchestra or a musical setting because an orchestra will typically tune for A4= 442, 43 or 44 Hz and this chart uses A4=440 Hz. Also, orchestra grade chimes typically do not go below the C5 octave. Manufacturing dimensional tolerances may cause slight inaccuracies in the actual results, not to mention the effects of poor material handling along with slight variations in material properties and impurities. If in doubt, cut slightly long and grind to final values. You might be able measure frequency for verification using any of the free apps for an iPhone, iPad, Android or a software programs like Audacity® See the section "Tuning the Chime"
Read the caution about chromatic tuners and the caution on note selection

Calculate Your Own Dimensions - DIY

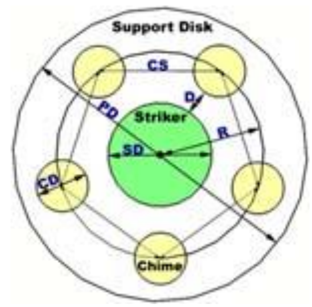
All notes calculator Base A4=440 Hz
Pentatonic scale calculator (C D E G A) Base A4=440 Hz
C9 chord calculator (C E G B^b D) Base A4=440 Hz
All notes calculator Base A4=432 Hz (Old original tuning)

For the purpose of chime design use the steel selection in the calculator if you're using EMT.

Caution, these values allow you to get close to the desired note (typically within 1%) but if you desire an exact frequency, it is best to cut slightly long and grind to the final length. This is not normally required for wind chimes. Do not use these calculations for an orchestra or a musical setting because an orchestra will typically tune for A= 442, 43 or 44 Hz and this chart uses A=440 Hz. Also, orchestra grade chimes typically do not go below the C5 octave. There are manufacturing dimensional tolerances that may cause slight inaccuracies in the actual results not to mention the effects of poor material handling along with slight variations in material properties and impurities. If in doubt, cut slightly long and grind to final values. You can measure frequency for verification using any of the free apps for an iPhone, iPad, Android or a software programs like Audacity® See the section "frequency measurement"

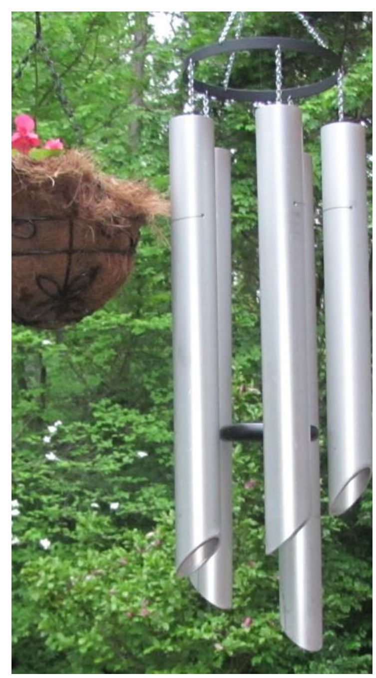
DIY Calculator includes the following features:

- Calculates length and hang point for tubes open at both ends or with end caps by using the ratio calculator.
- Look-up tables for standard size tubing
- Look-up table for material properties
- Standard Music Scale
- All dimensions calculated are based on OD, ID in inches and specific material types
- OD = outside dimension of tubing (inches), ID = inside dimension of tubing (inches)
- Material type = aluminum, brass, cast iron, copper, steel, stainless steel & EMT (thin-wall conduit)
- Note selection by frequency in Hz
- Embedded top support disk calculator
- Embedded points on a circle calculator



The embedded top support disk calculator asks you to decide on the chime diameter **(CD)**, the striker diameter **(SD)** and the clearance between the striker and the chime tube **(D)**. The calculator provides the correct location for placing the chimes **(R)** and **(CS)**, and the diameter of the support disk **(PD).** Instructions for use are included with the calculator. Also included is a Points on a Circle Calculator for use in the layout of a top support disk holes or a radial star striker.

Angle-Cut Tubing: A 45° cut at the bottom or top of the tube can add a nice aesthetic touch; however, the tuning for each chime tube will change considerably from the 90° cut value. The shorter the chime the more the tuning will change. For example, here are the changes for a 5-chime set made from 2 inch OD aluminum with a wall of .115 inch. The set was originally cut for the pentatonic scale (CDEGA) beginning at C6 using 90° cut tubing. After a 45° cut at the bottom end of each tube, the tuning increased from about 5% to 9% depending on length. Unfortunately, the rate of change was not linear, but a value specific to each length of tubing. Tuning increase was C6 =+5.5%, D =+6.6%, E =+7.5%, G =+7.6% and A=+8.8%. This was not surprising because shorting a tube will naturally increase the note frequency.



Additional testing was performed for a number of different diameters and different lengths using aluminum, copper and steel tubing. The results were very consistent. Short thin-walled tubing of any diameter changed the most and long thick-walled tubing of any diameter changed the least. Short tubing (around 20 inches) could increase the tuning by as much as 9 to 10%. Long tubing (35 to 40 inches or more) could change as little as 2%. It was impossible to predict the change other than the trend stated above for short vs. long.

If you want to maintain exact tuning using a 45° cut, cut the tube longer than the value suggested by the DIY calculator or the pre-calculated tables, and trim to final value using your favorite tuning method. If exact tuning is not required or important, cut the tubing to the suggested length by the calculator to pre-calculated chart, and trim the end at 45°.

Tuning the Chime: If you attempt to create exact notes for an orchestra setting, exact tuning is required and the use of an electronic tuning device or a good tuning ear may be necessary. On the other hand, if you desire a good sounding set of chimes but do not need orchestra accuracy, then carefully cut and finish to the length suggested by the pre-calculated table or the DIY calculators listed above.

Frequency measurement; Measuring the exact frequency and musical note of the chime is challenging at best. **Read the caution below!**

There are a host of apps for Chromatic Tuners available for an iPhone, iPad or Android. Site visitor Mathew George uses “gStrings” on his Android, pictured right.

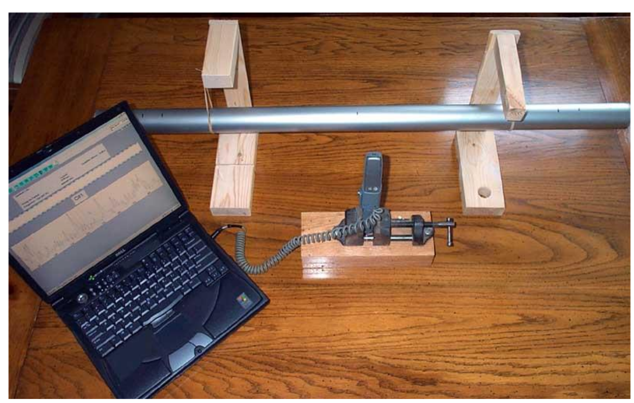
I use the $.99 app “insTuner” on an iPad and freeware Audacity® on a laptop shown below. A few scrap pieces of wood to make two U-brackets, rubber bands and you're in business. Mark the support nodes 22.4% from each end for locating the rubber bands. If you have just a few measurements to make a quick & easy support is a string slipknot positioned at the 22.4% node, pictured right with the iPad.

A word of caution! It can be challenging and often impossible for a chromatic tuner to measure a chime note correctly. Non-linearity of the human ear and a chime's non-harmonic overtones are two reasons.

Chromatic tuners listen and display sound as it is being produced on a linear basis for both amplitude and frequency, but our brain process the same information using *fuzzy logic*. Why is this problem?

Unfortunately, the human ear is no doubt the most non-linear and narrowband sound listening device we know of. Similar to other percussion instruments, chimes do not produce fundamental frequencies and pure harmonic frequencies like string instruments, wind tubes and reed instruments, for which chromatic tuners are intended.

Instead, there are numerous non-harmonic overtones present which (depending on their individual frequency and amplitude) can be predominant to a tuner or analyzer, but make little or no difference to the human ear. A chromatic tuner may display the predominant amplitude and frequency, but that may not be what the ear actually perceives. Because of the brain's "fuzzy logic" characteristic, the many overtones associated with a particular chime fundamental frequency, combine to produce a musical note the brain recognizes, but may not be recognized by a chromatic tuner.



It is difficult to provide an exact recommendation when to use the tuner to measure a chime's note, but in general, I find most any note below C4 difficult to measure, and on occasion, below C5. Long, low frequencies tubes, mostly measure incorrectly because of the "missing fundamental effect" and the preponderance of high amplitude overtones. Thick-walled tank chimes/bells can measure with surprising accuracy because of a single pure tone above C4 that is not cluttered with unimportant sidebands. However, thin-walled tank chimes/bells seem not to do as well and they may be impossible to measure accurately.

In addition, poor quality tubing exhibiting dual fundamentals will cause the chromatic tuner to constantly switch between the two fundamentals, both of which are incorrect. If you are not displaying the note you expected, try moving the chime further away from the tuner to help minimize unimportant frequencies.

If you get a good steady reading that it is not what you expected, the tuner is listening to a predominant overtone, so just ignore that measurement. Using the values for length provided by the tables and DIY calculators on this page will get you very close to the exact note. If the tuner cannot make a believable measurement, use the calculated length for the chime.to the exact note. If the tuner cannot make a believable measurement, use the calculated length for the tube.

A good software solution for FFT spectrum analysis measurement is a freeware program Audacity® used on a Laptop pictured above. A few additional sources are listed in Appendix C. Most any computer microphone will work. In fact, I have used the microphone on a headset used for Skype and it works quite well.

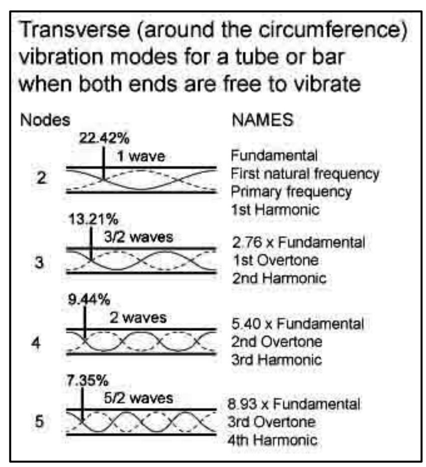
To eliminate the annoying background noise when using a microphone, use an accelerometer. I have good success supporting the chime horizontally at one node by a rubber band and at the other node by a thin wire looped around the chime and attached to an accelerometer.

Chime Mechanical Support: The ideal chime support location to allow for a lengthy sustain time is positioned at either of two locations; at the fundamental frequency node located 22.42% from either end, or at the very end using a string or cable threaded through an end cap.

If sustain time is not a requirement (which makes a tubular chime, bell sounding) such as for orchestra chimes pictured to the right, then support can be through horizontal holes near the end of the tube. A chime supported in this manner effectively reduces most of the sustain time and can be a desirable response for an orchestra chime since the strike note is typically the most important musical contribution with minimal sustain time. I do not recommend this method.



You may see commercial wind chimes supported in this manner, but they cannot support the tradition bell-like sound that you may be expecting. Incorrect support ranks as the number one mistake made by some commercial chimes sets for sale, both on the internet and in stores. They will produce a strike note but lack the rich resonant bell-like sound that results from proper support.

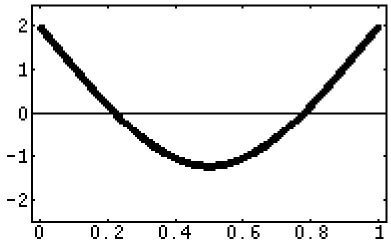


First Support Location for a bell sounding chime uses the traditional fundamental frequency node, which is 22.42% from either end. See the Transverse vibration mode diagram at the right.

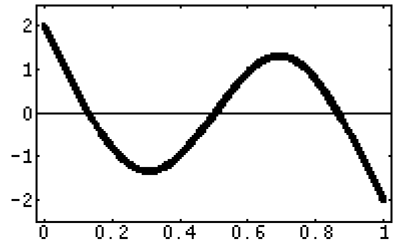
An important objective for a bell-like chime is to preserve the resonance of the chime as long as possible. Accurate placement for the support holes helps to assure the high quality (Q) or hang-time, or sustain time for the chime. A hole size of 1/16" can be drilled directly on the location mark but for larger holes like 1/8", try to place the top of the hole so it aligns with the location mark.

If you're curious about other support locations, it is possible to support the chime at the first, second or third overtone node but not recommended. All charts and calculations in this paper are for the support line to be located at the fundamental frequency node which is 22.42% from either end and is the most optimum location.

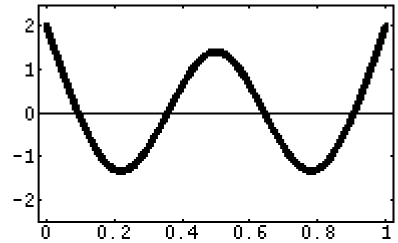
If you happen to have a background in both mechanical vibration and acoustic vibration, it is easy to confuse overtones and harmonics. Overtones = Harmonics -1, or Harmonics = Overtones + 1. This acoustic harmonic relationship has no connection to the radio frequency definition of harmonics. See the diagram below.



1st Fundamental Frequency



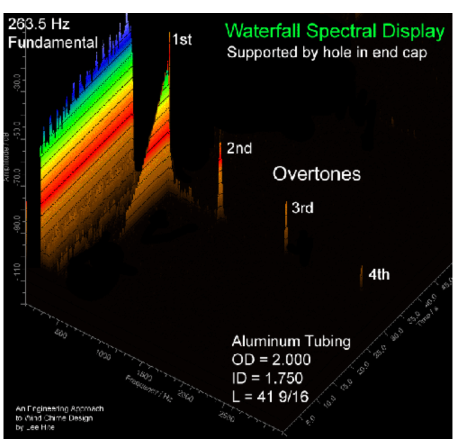
1st Overtone, 2nd Harmonic



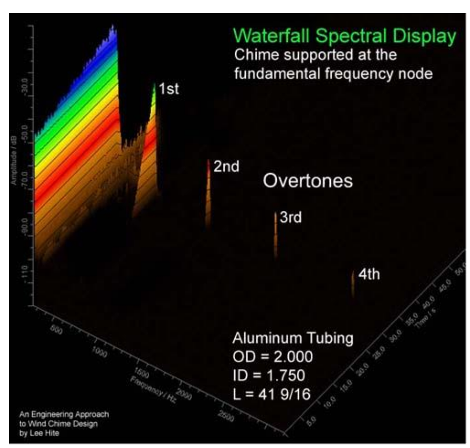
2nd Overtone, 3rd Harmonic

Second Support Location (end cap), is when the chime tube is supported by a cable or cord through a hole in an end cap. It is important to understand that the end cap lowers the fundamental frequency and some associated overtones from values calculated by the DIY calculator or pre-calculated charts. For 1/2" copper tubing type L, the fundamental is lowered by about 3% to 6% from calculated values on this page. For 3/4" type L copper tubing the fundamental is lowered by about 11% to 12%. The good news is that the end cap noticeably increases the duration for the first overtone and the chime has a much more bell-like sound. Look at these two spectral waterfall displays and specifically compare the hang time of the 1st overtone for each. You will notice a considerable increase in sustain time for the end cap supported tube.

Caution: be certain to solder the end caps in place. An unsoldered or loose fitting end cap will completely deaden the resonance. An end cap must contact the entire circumference at the end of the chime to function properly.



Waterfall display for a chime tube supported by a hole in the end cap. Similar to some orchestra chimes.



Waterfall display for a chime tube supported at the traditional fundamental frequency node.

End Support for Rods: It is possible to support a rod at the end and it's fairly easy to accomplish. You might be tempted to inset a screw eye at the end but I can assure you that will completely kill the resonance. Resonance for a tube or rod can easily be stopped by touching the end. The end cap is a special case that allows resonance to exist without seriously reducing the sustain time. But adding a screw eye or any amount of mass to the end can kill the sustain time for a rod. The easy solution that works very well is to drill a small hole in the end of the rod and epoxy a 50# woven fishing line into the hole. First tie a knot at the end prior to inserting the line into the hole. This low mass and flexible connection does not impact the resonance and provides an easy method for connection.

Chime Support Suggestions

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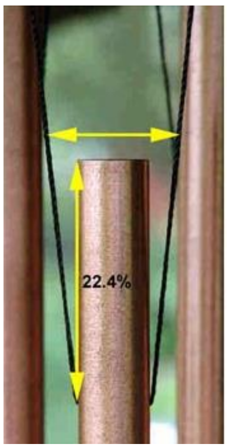
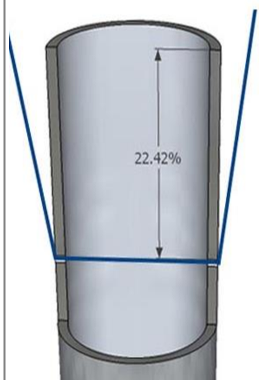
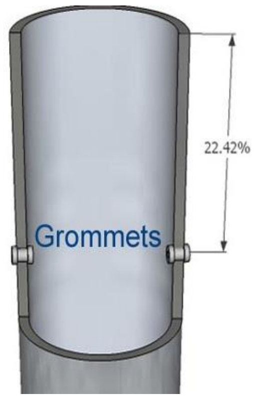
<td></td>
<td></td>
<td></td>
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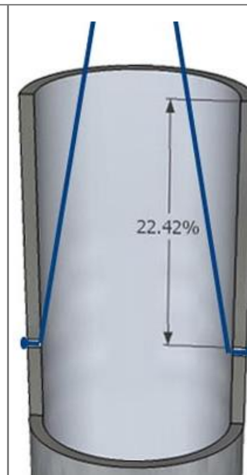
<td></td>
</tr>
<tr>
<td>Method 1
Traditional two-point mount and the most stable in high winds for string supported chimes.</td>
<td>Method 1
Important to de-burr the outside holes</td>
<td>Method 1
Eyelets or grommets help when de-burring is difficult or impossible</td>
<td>Method 2
Knot on the outside allows for one top support point.</td>
<td>Method 2
De-burring the inside support hole is important.</td>
</tr>
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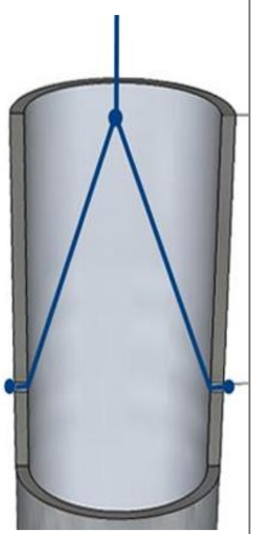
<td></td>
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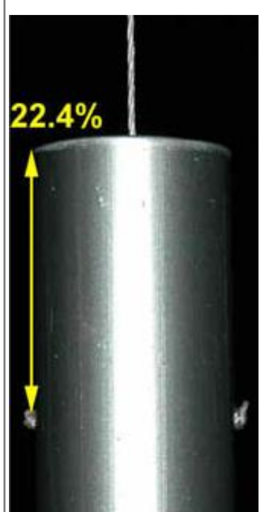
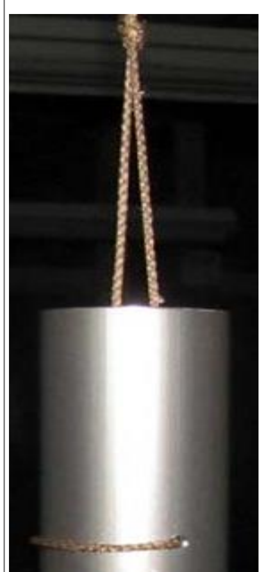
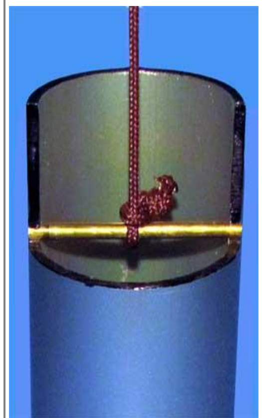
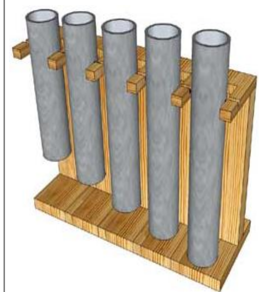
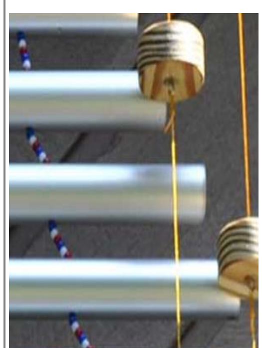
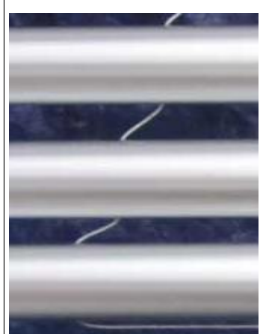
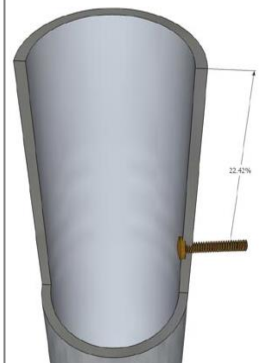
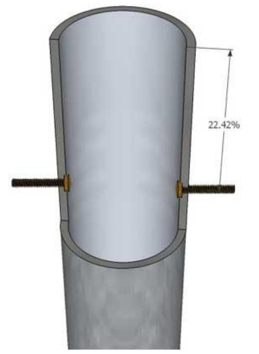
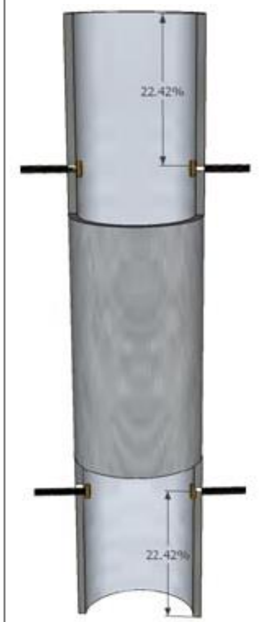
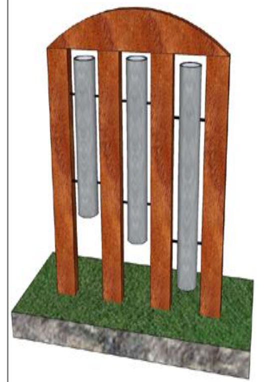
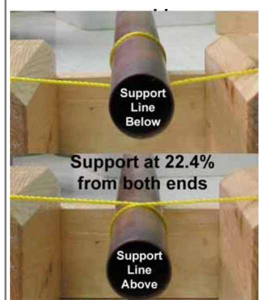
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Method 3
Converts from a two point mount to a single point mount and may be more pleasing to the eye with less visible line.</td>
<td>Method 3
Internal view</td>
<td>Method 3
Side view</td>
<td>Method 4

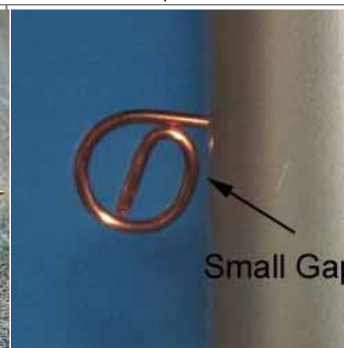
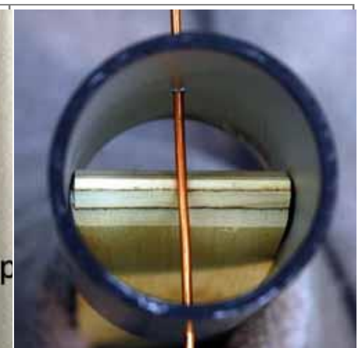
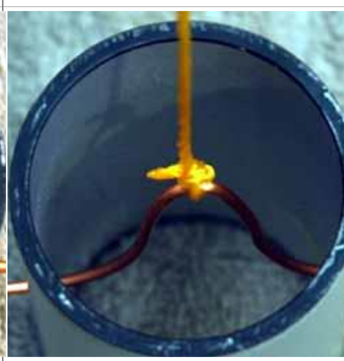
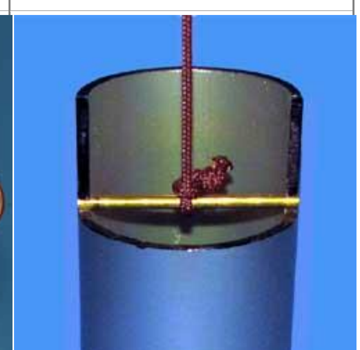
1/2 Wrap.

Both ends feed from the outside to the inside</td>
<td>Method 3
The knot can be tucked inside and out of view</td>
</tr>
</table>

				
Method 4 The half wrap is a convenient connection for a chain mount	**Method 4** Slide the knot out of view for the chain connection	**Method 5** 1/8" metal rod flush cut and de-burred. Held with super glue or flair the ends with a ball-peen hammer.	**Method 5** A small rubber grommet on the outside of the chime for each side prevents buzzing	**Method 5** Can be used to support the concealed striker
				
Method 6 Horizontal cable mount provides a new look	**Method 6** 1/32" or 1/16" steel cable threads thru each hole	**Method 6** Small plastic beads assure even spacing among tubes	**Method 6** Even without the beads the tubes have a tendency to space evenly	**Method 7** End cap support for copper tubing. Must be soldered to function properly

				
Method 8 Rigid mount using 1/8" bolt or larger. Securing nut not shown	**Method 8** Dual rigid mount using 1/8" bolts or larger. Securing nuts not shown	**Method 8** 4-point rigid mount allows maximum support vertically or horizontally	**Method 8** 4-point rigid mount resist abuse in a park or playground setting	**Method 9** Horizontal support using a noninvasive soft chord or line

Forming the inverted V wire pin:
This example uses a #12 copper wire but you can use aluminum, brass or whatever works best.

			
Sharpen and fit a pusher board to the ID of the chime	Insert wire thru both holes leaving sufficient wire to form decorative loops	Form decorative loop on one side only. Adjust the loops to not touch the chime below the hole	Position the pusher board perpendicular to the wire
			
Using moderate pressure to form the inverted V	A slip knot works well to secure the line	Form the second decorative loop. Adjust the loops to not touch the chime below the hole	An inverted V is not absolutely necessary. A solid 1/8" pin glued in place works well.

An alternate inverted V support can be the wire arm from a binder clip shown on the right. Remove the wire arms from the clip, stretch them out a little, and position in place using needle nose pliers, wiggle the arm until the tips pop out of the holes. Be sure to attach your hanger line first. The arms tend to be self-centering. The binder clips are available in different sizes so you can match the clip to the diameter of the pipe. The wire diameter increases with the size of the clip so make sure to check before you drill the pipes.

Support Line: Longevity for a chime set is important and careful attention to the support lines and thru holes should be considered. Rapid wind changes and UV light can quickly deteriorate support lines, not to mention the many freeze/thaw cycles.

Nonmetallic Support Line: Make sure the line is UV resistant. Choices include fishing line (either 80 or 50 pound braided), braided plumb line, braided Dacron kite line, venetian blind chord, string trimmer/weed eater line (.065 inch), awning chord, and braided electrical conduit pull line.

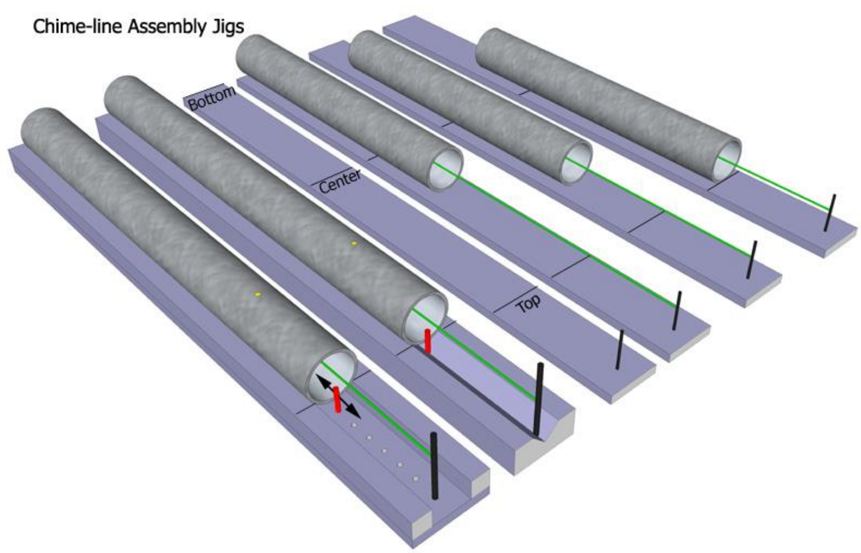
Metallic Support Line: thin wire, decorative chain (zinc plated, brass plated, or painted), 1/32 or /16 inch stainless steel cable (rust resistant), small aircraft control line cable.

De-burring: Depending on where the support line exits the chime, from the inside or outside, one or the other sharp edges of the thru hole require de-burring. First, first remove the burr using a long round file or sandpaper on a stick. Finish the task by using a section of coat hanger wire with a small bend at the far end. Place the wire in a drill and insert the bent end thru the hole. As you rotate the wire, lightly pull back on the drill and the bent wire will bend over any inside burr. Coat hanger wire may be too soft. Instead, use a modified small Allen wrench. Cut off most of the shorter length with a grinder and bend the wrench slightly so the angle is increased from 90 degrees to approximately 105 degrees.

Grommets/Eyelets: are mostly for protecting the outside edge of the thru hole. Rubber, plastic or metal (grommets or eyelets) are encouraged, but small sizes can be a challenge to locate. Small eyelets can often be located at your local hobby store in the sewing department or a shoe repair store. You can also use the outer shell of a 1/8 inch or 3/16 inch aluminum pop rivet. Remove the nail-like center and use the rivet.

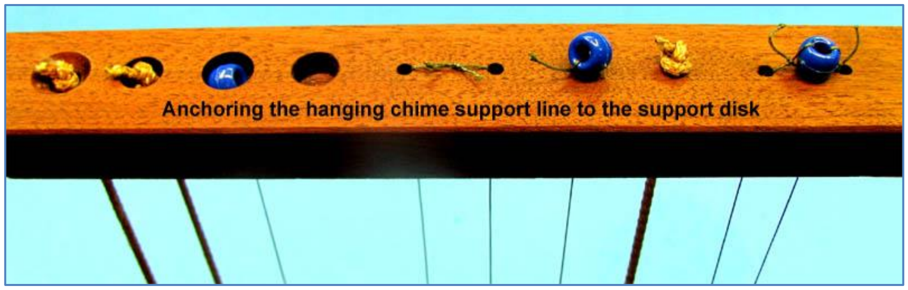
Additional Protection: Use a small section of heat shrink tubing over a nonmetallic support line, where it exits the thru hole from the inside, and it is often difficult to de-burr or chamfer.

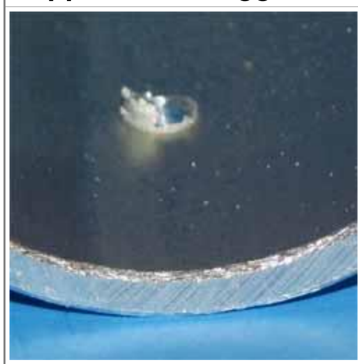
Jig to position the chime for attaching the support line or chain**.** After you have selected the alignment configuration, top, center or bottom, a simple jig can assist the installation of the support line. Below are three possible jigs, a square-grove jig and a v-grove jig, both with red adjustable stops for alignment. A third jig made from a section of cardboard or wood strip works well. Scribe a mark for the bottom, center, or top alignment on the jig.

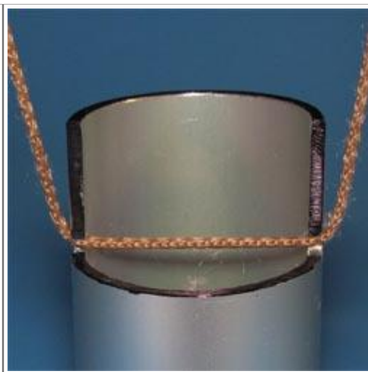
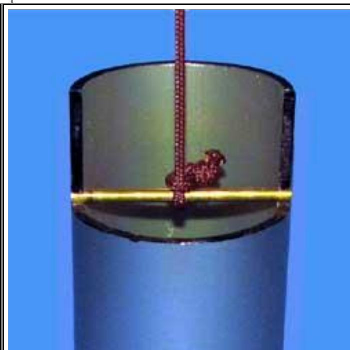
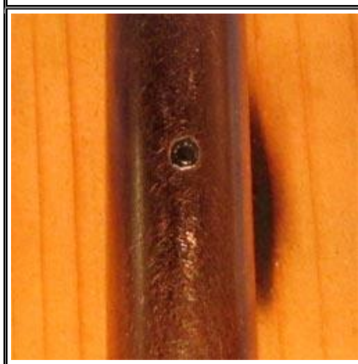
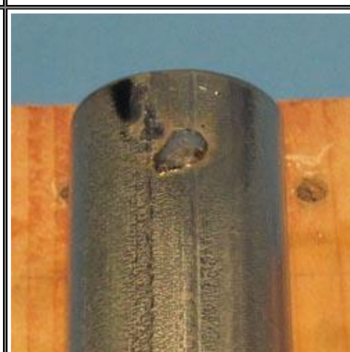
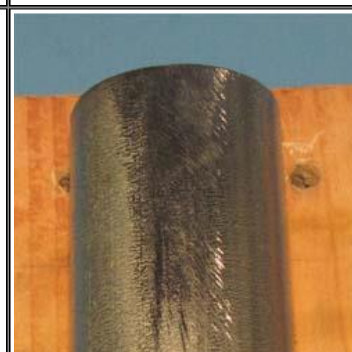


Begin with the longest chime and select an appropriate length for the attachment line from the chime to the support point on the support disk or ring and locate a nail, a pencil mark, or the adjustable post at that location on the jig. Place the longest chime on the template and secure with tape, a clamp or maybe lay a book on it. Stretch the line up to the reference post and tie a loop or a knot or mark with a felt tip pen. Repeat with the remainder of the chime set using the scribed reference mark. For center aligned chimes attach a small section of masking tape to the center of the chime and scribe the chime center location on the tape.

A knot in the support line or wire can be mostly hidden by use of a countersink hole, when using thru holes to anchor line to a solid support disk. Pictured below are a few examples.



Support Line Suggestions			
			
De-burr inside hole using stick & sandpaper	Chamfer outside hole using an oversized drill bit	1/8" & 3/16" aluminum eyelets and a pop rivet	Outside hole with aluminum eyelet
			
Eyelets do not protect the line from the inside edge	1/8" & 3/16" eyelets using the shell from a pop rivet. Use only for thru line.	Heat shrink tubing can protect the line from the sharp inside edge of the hole	Shrinkable tubing in place and operational

			
Good place to use heat shrink tubing	Eyelets required for the outside edge only	#12 copper wire bends easily to form an inverted V	Double support line for an unusually heavy chime
			
Half wrap hides the knot inside the chime	Solid pin eliminates wear and tear on the connection. Epoxy in place.	For copper or brass tubing, fit a 1/8" brass pin into a 1/8" hole and file smooth	Solder or epoxy the pin in place
			
File smooth and finish the tube with either an aged copper look described below or a clear finish	For steel tubing, fit a 1/8" steel or brass pin into a 1/8" hole and file smooth	Solder or epoxy the pin in place	File smooth and finish with a decorative paint

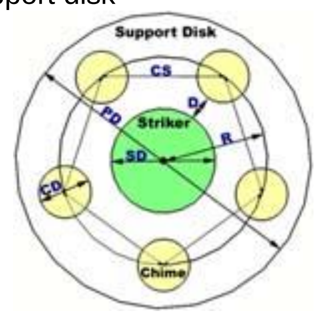
Project Sources: include Home Depot or Lowes for heat shrink tubing, eyelets from the hobby store in the sewing department or a shoe repair store. Grommets can be from a hardware store, the model airplane store or the hobby store.

Chime-Set Support, Ring, Hoop or Disk

Support disk & striker patterns are available in the document to the right. The patterns are for tubing sizes from ½" to 2" in ¼" increments, and for chime sets for 3, 4, 5, 6, 7, & 8 chimes. Generic layout patterns are also included. See Appendix H for a variety of chime support design styles.

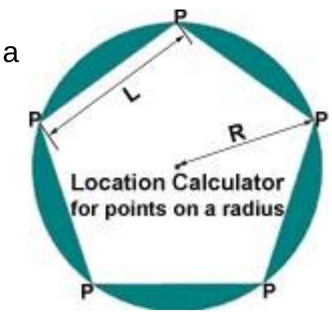
Support Location Calculator and Points on a Circle Calculator 170 K b

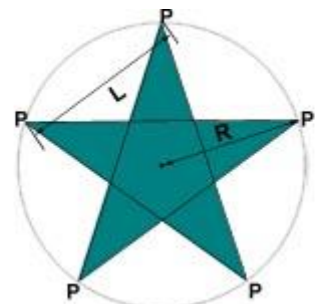
You may wish to calculate your own dimensions for the top support disk using the support disk calculator. You decide the chime diameter **(CD)**, the striker diameter **(SD)** and the clearance between the striker and the chime tube **(D)**. The calculator provides the correct location for placing the chimes on radius **(R)** and the spacing between the chimes **(CS)**, and the diameter of the support disk **(PD).** Instructions for use are included with the calculator.



If you want to avoid using the above calculator, an easy work-around is to select an appropriate generic pattern from the Support disk & striker patterns document, and scribe the accurate location for support holes using the pattern.

Also included is a location calculator for points on a circle. Uses include automatic calculations for locating chimes on a radius, and points used to draw a multisided polygon such as a star striker or support disk arranged as a star, a pentagon, a hexagon or an octagon etc. An easy lookup table is provided for locating 3 to 8 points.



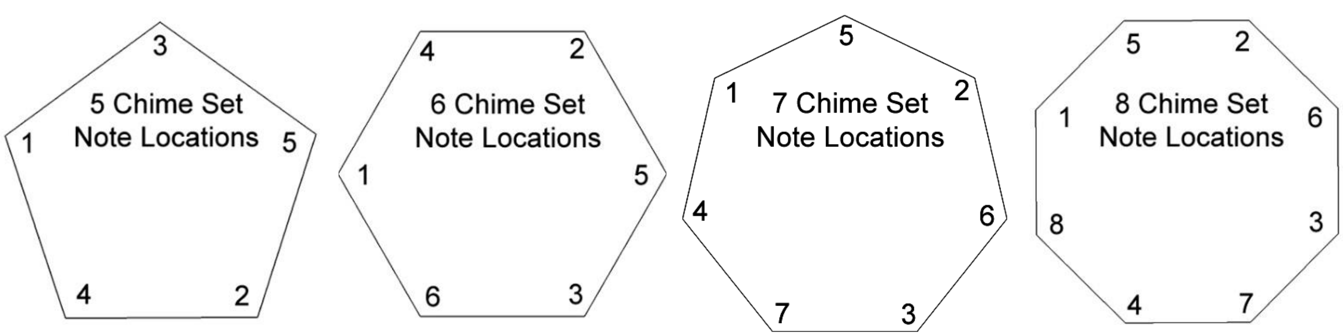


Rather than using a protractor to layout the angles for the shape of your polygon, select the number of points and the radius **(R)** for those points, and the calculator provides you with the distance between points. Adjust a compass to the distance **(L)** and walk the compass around the circle to locate the points.

Chime Location Sequence:

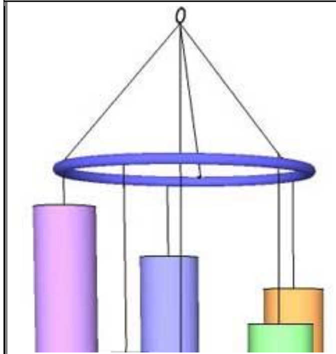
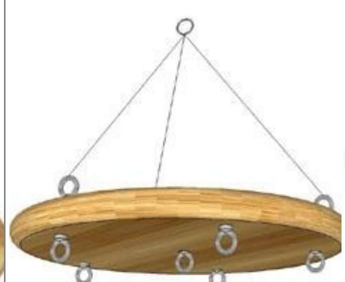
A circular striker will typically strike one chime at a time but can simultaneously strike two chimes. When this happens you can enhance the overall sound by placing widely separated notes next to each other For example, below are location suggestions with chime number 1 as the shortest and moving upwards in length as the location numbers increase.

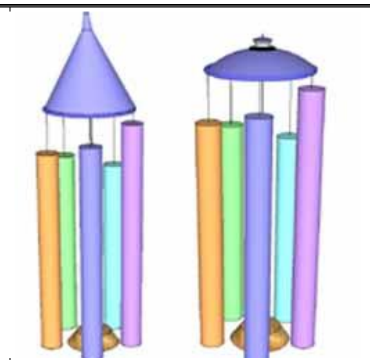
Circular configuration



Inline configuration

1 - 3 - 5 - 2 - 4 1 - 4 - 2 - 5 - 3 - 6 1 - 5 - 2 - 6 -3 - 7 - 4 1 - 5 - 2 - 6 -3 - 7 - 4 - 8

Disk and Ring Support Suggestions			
			
A circular ring or hoop provides an open air and transparent appearance.	Support rings can be cut from an out of service aluminum fire extinguisher. Strip paint and brush with a wire wheel.	Use an abrasive metal cutting saw blade in a radial arm saw, a chop saw or a table saw. Height of 3/8" to 3/4 "works well.	Chain, decorative cord, or braided fishing line can be used with this top support hoop.
			
Use the generic patterns document to mark the 3-point mount location holes and a generic pattern matching your number of chimes.	Chrome plated steel rings and hoops available in a variety of sizes from hobby stores and online	Look in hobby stores for rings or hoops often used for dream catchers, mandellas or macramé	Support disk cut from .075" aluminum with a 3/6" x 3" eye bolt used with the keeper-striker arrangement
			
A single screw eye is an easy connection but more difficult to balance level	Chain or UV resistant cord can be configured for a 3-point or 4-point mount	If the star pattern is used for the striker it can be duplicated for the top support	A solid circular disk offers a wide choice for mounting including screw eyes or thru holes

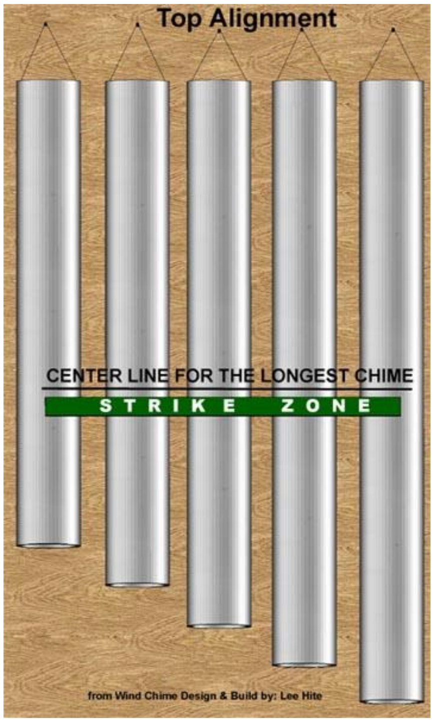
			
You can also use the chime set as a birdhouse.	Bottom view	Pets, sports logo or a favorite hobby can adorn the top of the chime disk.	A decorative hand painted funnel or pan lid adds uniqueness to the set

Striker/Clapper Orchestra chimes, of course, need a human to strike the chime and a rawhide-covered rubber mallet works well. A rawhide-covered baseball or softball can work well for wind chimes but only in a very high wind environment where there is ample strike energy from the sail. An orchestra chime is struck with a lot of gusto but a wind chime often has little strike energy. Typically there is little strike energy from normal winds so preserving and applying that energy is the challenge. Design considerations below include single or multiple strikers, the shape, the weight, the material, the suspension, the motion, and the strike location.

Strike Zone: An important consideration for a bell-like chime is the strike zone. The optimum location is at the very end of the tubular chime because this location will assure that all possible overtones are energized to the maximum. This should not be surprising since orchestra chimes are struck at the end. An easy solution to assuring the strike occurs at the very end of the chime is to use bottom alignment and a tapered striker as shown in striker suggestions.

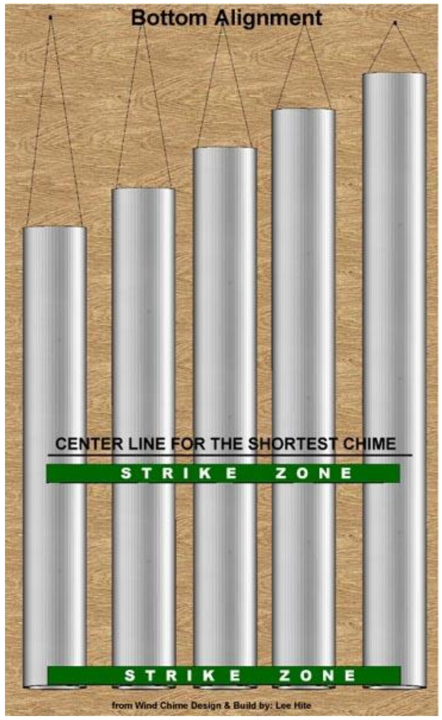
Often you will see the center selected as the strike location for a tubular bell wind chime, perhaps for aesthetic reasons. When the exact center of the chime is struck the odd numbered overtones can fail to energize, and the resulting sound can be very clunky even though the even numbered overtones were well energized. While I recommend striking the end of the chime, there are good aesthetic reasons to align the chimes for a center alignment or a top alignment. The ideal strike zone is about 1 inch from the end, or about an inch below the center line as pictured below. All three locations work okay when you keep the striker away from dead center, which is a dead zone for the first overtone. Don't worry much about killing the first overtone with center placement. The first overtone dead zone is very narrow and easily overcome with a slightly off-center strike.

Strike zone for top, bottom or center alignment



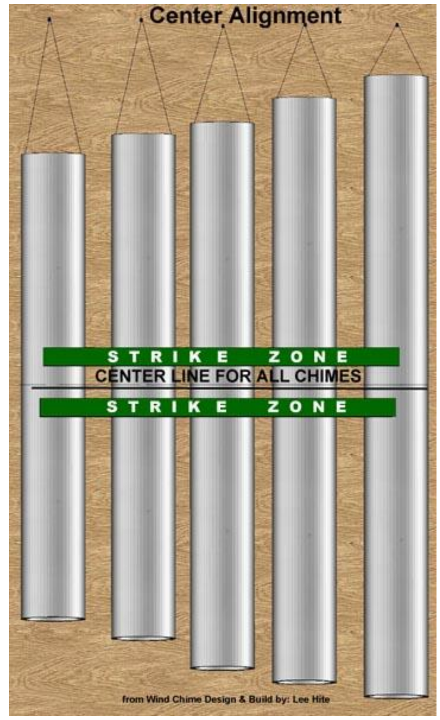
Strike Zone
Top Aligned Chimes

Find the centerline for the longest chime and position the striker slightly below that line, about ½".



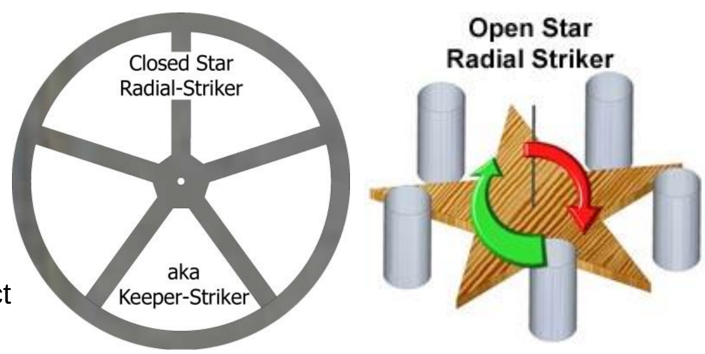
Strike Zone
Bottom Aligned Chimes

Find the centerline for the shortest chime and position the striker slightly below that line about ½", or at the very bottom, the ideal strike zone.



Strike Zone
Center Aligned Chimes

Find the centerline for all chimes and position the striker slightly above or below that line, about ½".



Striker Shape is most often circular because the chimes are located in circle. An alternate shape is the circular traveling radial striker which can be effective for striking a musical chord. The radial striker most often takes the shape of an open star or a closed star, like the keeper-striker pictured here. The striker has a tendency to rotate CW & CCW as it bounces to and from each chime. A circular striker will typically contact one or maybe two chimes simultaneously. However, the star shaped striker can synchronously contact most all of the chimes. The loudness of the chimes struck with a star striker is somewhat reduced compared to the circular striker because the strike energy has been distributed among the various chimes. See a YouTube video HERE

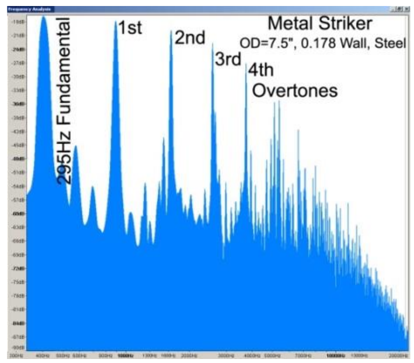
Striker Weight: A heavy striker for large chimes and a lighter weight striker for smaller chimes is a good recommendation most of the time. Depending on your typical wind conditions there may be occasions when you need a lightweight striker for large chimes. Near the seashore winds can be rather strong and you may need to soften the strike with a lightweight striker or switch to a rawhide-covered baseball or softball. Considerable strike energy can be achieved by using an oak disk machined to a knife-edge and loaded with a 1 oz. weight. See striker suggestions below.

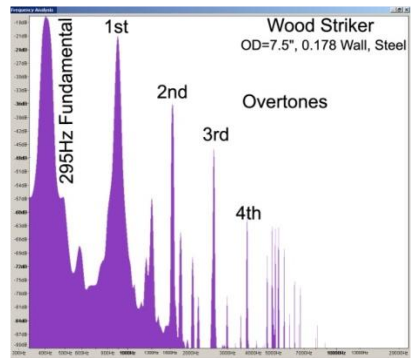
Striker Material: The choice of material depends somewhat on the note selection. If there is good movement from the wind sail, then a circular disk striker (soft sided but heavy) can be used for the larger diameter chimes (say above 2 inches), particularly for lower frequency chimes. Some choices are a hockey puck, redwood, red cedar, treated lumber or a 1/4" nylon cutting board. If the wind is quite strong and gusty, you may need to soften the striker even further by using a rawhide-covered baseball/softball. The rawhide helps to produce a very mellow strike in a strong wind. Smaller diameter higher frequency chimes benefit from a harder wood like white oak, teak or Osage-orange aka hedge-apple. Be sure to coat the striker with a UV resistant coating.

On the other hand, a well performing star-striker should be from a relatively hard material, yet light weight, allowing for a quick response to circular movements. The loudness of chimes struck with a star striker is reduced, compared to the circular striker, because the strike energy has been distributed among the various chimes, and a harder material is required for a strong strike. 1/8 inch soft aluminum, sheet plastic or a 1/4 inch nylon cutting board works well to accomplish both goals.

Keep it Clean: A dirty strike can energize a host of unwanted spurious sideband frequencies as demonstrated by the steel striker in the blue spectrum display to the right.

A most melodious bell sound is achieved with a softer strike that energizes overtones without spurious sidebands, as shown in the purple spectrum display to the far right.

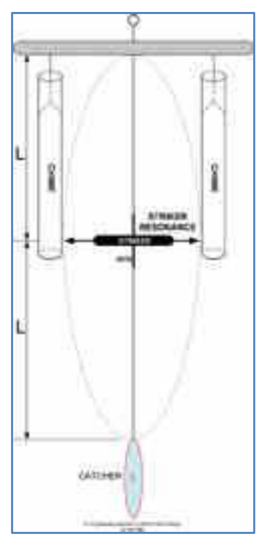




Both strikers produced equal loudness for the fundamental while the steel striker did a better job of energizing overtones (louder) but at the expense of unwanted dirty sidebands. The wood striker (hard maple) produced a most melodious bell sound while the metal strike was harsh and annoying.

Conceal and Carry Chime hides a lead striker on the inside the chime for large diameters chimes, mostly above two inches as pictured left and right. This technique is seldom used unless the chime set is large or becomes annoying, caused by the traditional disk striker in high winds.

Because there is insufficient distance for the striker to gain momentum and strike with gusto, the inside striker could be a good solution to quieting chimes in high winds. If you're looking for a muted sound from a large set, maybe 4 inches and above, this technique is useful. The striker is a lead weight, normally used as a sinker for fishing, and can be any of the following: a cannon ball sinker, a bell sinker, a bank sinker or an egg sinker. Wrap the sinker with about two layers of black electrical tape to prevent the harsh sound from a metal strike yet still provide a strong but muted strike. Support for the striker string or line from can be from the same point you use to support the chime tube.



Striker Suspension A small 1/16-inch brass tube about 5 inches long thru the center of the striker allows for the suspension line to be threaded and used as an axle for the disk. This helps to keep the disk horizontal during rapid and sudden movements from high winds. A stiff wire like coat hanger wire can be used as an axle as shown below in striker suggestions.

Striker Motion: I happen to live in a wooded area with little wind and have struggled to achieve good strike energy with low winds. With that in mind, I set out to improve the low wind performance of the striker.

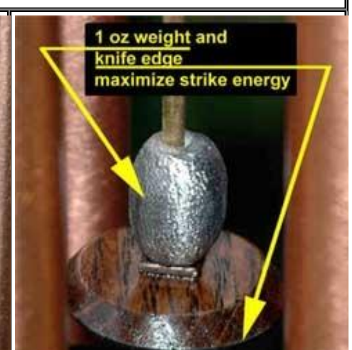
The objective was to maximize striker movement with little input energy from the sail. The easy solution was to resonant the support line that supports both the striker and the sail using the second mode bending principle. This resonance will help to amplify and sustain the motion of the striker with little input energy from the sail. Even though the sail moves in the wind it will act as an anchor for the resonant movement of the striker.

You can easily recognize this movement by using both hands to hold a string vertically and have a second person pluck the center of the string. The natural resonance of the string will cause the center to vibrate. If you position the striker at the exact center between the top and the sail you can achieve this resonance.

It is difficult to provide an exact ratio between the weight of the striker and the weight of the sail. Depending on the actual weight for both, the ratios can be quite different. In general, when you attempt to resonant the striker line, I suggest the striker not exceed the weight of the sail and ideally the striker should be about 1/2 the weight of the sail. I realize that if you use a CD as the sail a lighter weight striker can be difficult to achieve. A heavy striker is difficult to resonant.

On the other hand, for medium to high winds and for a non-resonant mounting, the wind catcher/sail should have a weight less than 25% of the striker.

When resonance is working well you will notice as the sail comes to rest, the striker will continue to bounce off the chimes for a few more strikes, an indication the striker is dissipating the stored energy from resonance. See this Resonant striker video WMV, for a demo. Notice the large movement of the striker compared with little movement from the sail

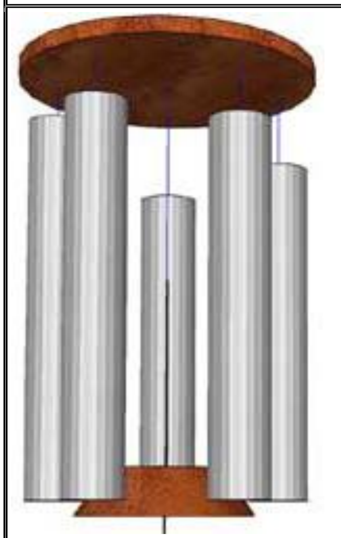
Striker Clapper Suggestions			
			
Straight edge wood disk striker with axle	Knife edge wood disk maximizes strike energy	Knife edge disk striker with weight and axle	Close up for tapered edge wood striker with weight & axle


Bullet nose wood striker with hollow axle or wire axle maximizes strike energy

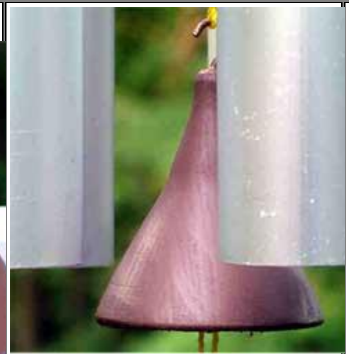

Enameled coat hanger wire works well for an axle


Tapered edge wood striker with axle allows striking the end of the chime edge for maximum strike energy


Typical tapered edge striker with axle for bottom aligned chimes

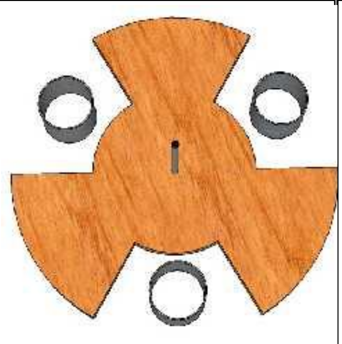

Typical arrangement for a tapered edge striker with an axle for bottom alignment


A sculptured tapered edge striker adds a decorative touch for striking the edge of the chime end.


A sculptured tapered edge striker assures contact with the very end edge of the chime

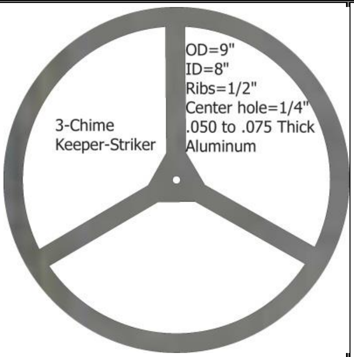
A radial striker rotates on contact with the chime bouncing back and forth effectively striking a chord or most of the chord

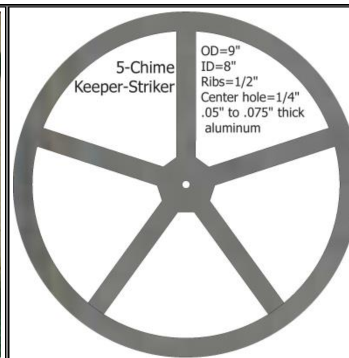

The open star radial striker loudness is reduced compared to the traditional round striker

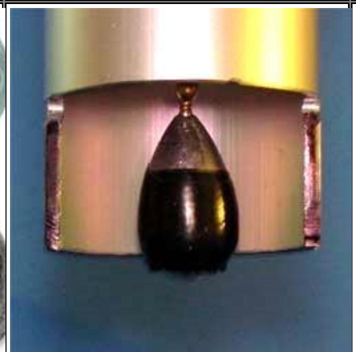

Multipliable configurations exist to achieve a radial strike. This one might be appropriate for someone working in the nuclear business.

The enclosed star radial striker works great for maintaining alignment in high wind conditions and produces a more subtle strike


The enclosed star radial striker can be made from 1/8" sheet plastic, aluminum or other light weight but relative hard material

<table>
<tr>
<td>

3-Chime Keeper-Striker</td>
<td></td>
<td>

5-Chime Keeper-Striker</td>
<td></td>
</tr>
<tr>
<td>
Baseball / Softball good for a mellow strike in a high wind environment</td>
<td>
Conceal & Carry
The chime carries a concealed lead striker inside a 2 inch diameter or larger chime, and provides a unique style with a more subtle strike</td>
<td>
A 2 oz. lead weight wrapped with two layers of black electrical tape provide a strong but muted strike</td>
<td>

A billiard ball or croquet ball are choices for a strong strike on small chimes. Test first for harshness. Can be too strong for some</td>
</tr>
</table>

Wind Sail / Wind Catcher The pessimist complains about the wind, the optimist expects it to change, the realist adjusts the sails. By William Arthur Ward

The objective of the wind sail/catcher is to cause the striker to randomly contact all the chime tubes. Traditional wind sails generally work well and can be configured with a variety of materials, sizes and shapes as shown in the document on the right. Patterns 1.3 Meg, PDF

My dissatisfaction with the traditional wind sail is that single-direction winds have a tendency to cause the sail to swing like a pendulum. That arrangement will swing the sail both to and from the direction of the wind, not allowing the striker to contact adjacent chimes. That affect sounds much like a dingdong, dingdong as the striker hits only two chimes.

As you may know, wind close to the ground can behave differently than winds aloft, and often does not blow horizontally as intuition would suggest. Instead, it is a multidirectional force with an ample amount of wind shear.

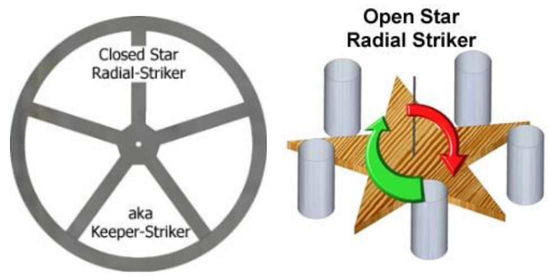
To better understand wind turbulence mixed with single-direction winds watch this 20 sec WMV, Bi-directional wind vane video showing a bi-directional wind vane mounted on my deck. You probably noticed the swirling motion mixed with single-direction winds and the random uphill and downhill movement aka pitch & yaw. Perhaps we can exploit this force to make a better wind sail. Let's take advantage of this turbulence to create a striker movement that is somewhat rotational in nature and does a better job of striking all the chimes.

Solving the Dingdong: The first of several solutions to better capture wind turbulence can be quite simple. Mount the sail at 45° to the horizontal so as to catch the pitch and yaw forces, as pictured on the right. Thread the support line through two small holes next to the center of an old CD disk and tie the knot slightly off-center to create the 45° slope. You may need to glue the line in place for the long term.

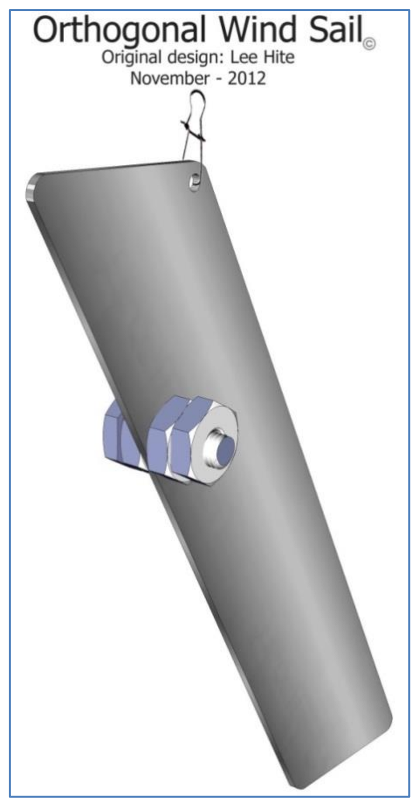
A second solution is to hang the sail perfectly horizontal. Counter intuitive, I agree, but depending on your particular type of wind it can work surprising well, particularly if the chime set is hung from a high deck or beyond the first story of the building and the wind is particularly turbulent.

A third solution is to make sure the top support disk can easily rotate in a circular direction. Hang the top support disk not from a fixed ring or hook but from a single support line as pictured to the right. The very nature of the wind will catch enough of the chimes to rotate the entire set allowing the pendulum motion of the sail to strike more of the chimes.

A fourth solution can be the radial traveling star striker described above. The very nature of the star striker is to quickly rotate CW & CCW from any input motion of the sail, even from straight-line winds, and this motion will easily avoid the dingdong sound.



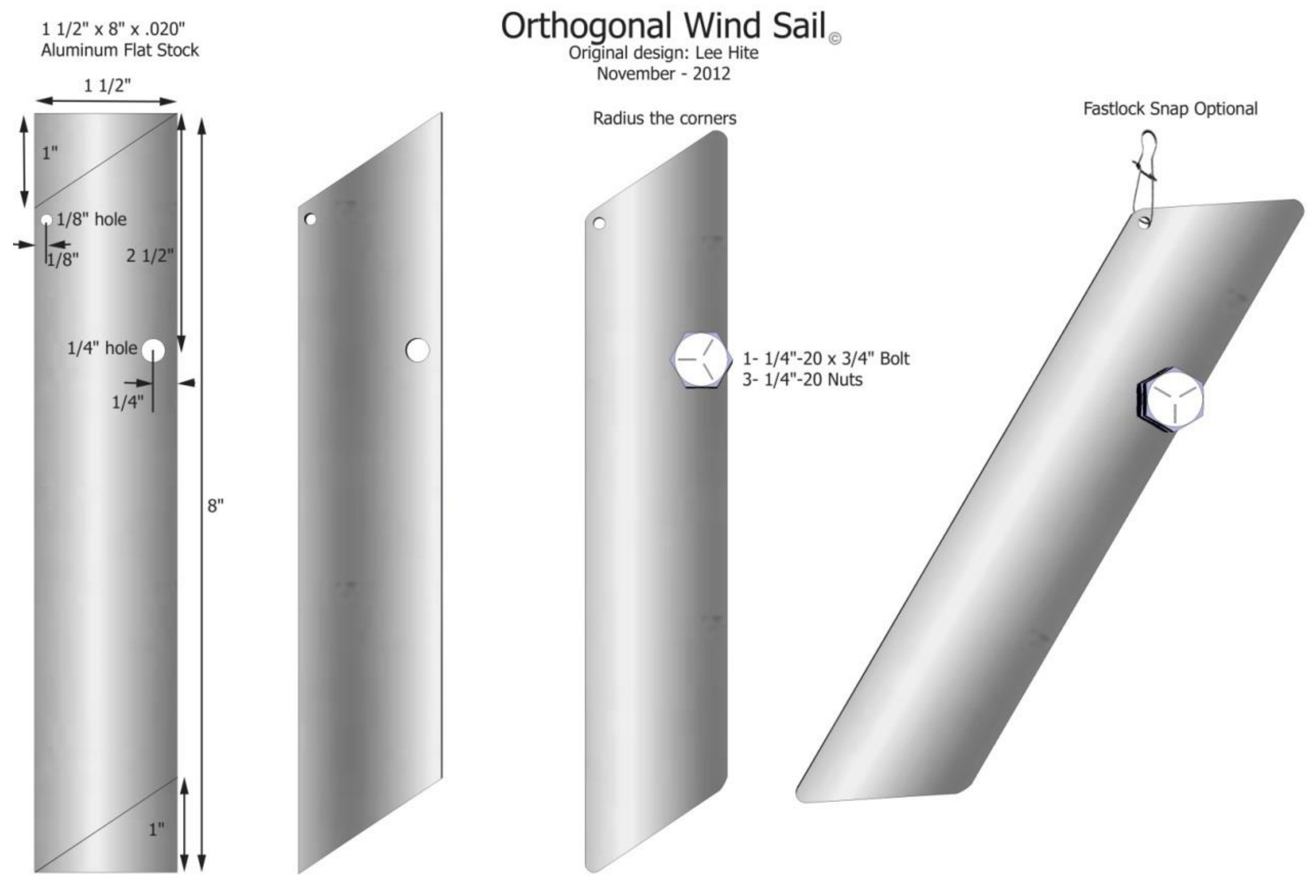
Need More Dingdong: Need More Dingdong? At this point you are most likely saying "WHAT" more dingdong? We just got done solving the dingdong and now you want more! Yes, there is a condition when excessive pendulum movement of the sail is useful and not sufficiently supplied by the tradition wind sail. With the development of the keeper-striker or the radial-striker, both of which are very effective in striking a musical chord, there is a need for a robust movement of the striker. The radial striker produces a more muted sound because the strike energy is simultaneously distributed among all the chimes by moving in a circular motion. Thus the need for a more robust strike.



Jerk, Jolt, Surge & Lurch: We often describe the motion of an object in terms of displacement, velocity, or acceleration. However, an additional motion description seldom used is the rate of change of acceleration. The unit of measurement is often termed jerk but is also known as jolt, surge, or lurch. Jerk supplies the sudden and rapid motion from the wind sail to the rotary keeper-striker.

Introducing Orthogonal Sailing: We have developed a special wind sail to solve the need for more jerk. As mention above, a normal wind sail will mostly swing to and from the direction of the wind; however, the orthogonal sail has the unique ability to fly aggressively at right angles to the wind direction. If the wind is from the North the sail will fly East and West.

The sail has the unique ability to fly aggressively at right angles to the wind direction. If the wind is from the North, the sail will fly East and West, thus the name Orthogonal Wind Sail. The aggressive motion of the sail will eventually exceed its ability to fly, fall into a chaotic state, and stall. Immediately the process repeats and continues to supply considerable energy to the radial striker. The design is simple and easy to build, see below



CAUTION !

The orthogonal sail can be dangerous. Do not hang the chime set where the sail can contact children, adults, or animals. The sail makes no noise and can swing a full 180 degrees in a half circle motion. This quiet operation and wide swing can cause people to be unaware of the danger. The sail is flat thin metal and can easily cut the skin or damage an eye as it swings. BE CAREFUL !

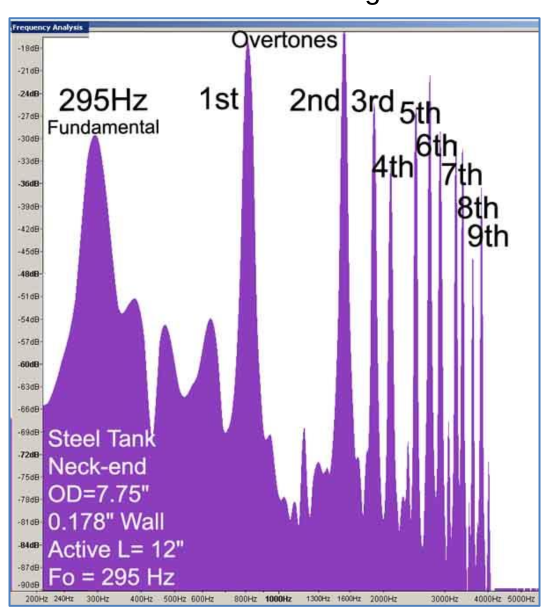
No Sailing Today: Long and large diameter chimes present a considerable surface area to the wind and can move sufficiently to cause a good strike without the need for a wind sail. In addition, the large diameter striker, often associated with a large chime set, can capture adequate wind for a good strike. Depending on the distance between the striker and the chime tube, not all chime sets require a sail. Pictured right are closely spaced chimes that easily contact the striker with low to moderate winds. Because of the short distance between the striker and the chime tube, the strike is not robust but adequate.

The best solution for you will depend on your type of wind. You may need to try a few different sails for success.

Windless Chimes On occasion there may be times when you want a set of chimes in a windless environment, or even outdoors in a low wind environment, like a heavily wood area. Using an electromagnet to repel a high intensity magnet at the end of the striker rod can provide you with endless possibilities. Typically named a chaos engine, this arrangement can produce a random movement for the striker. Powered by either 120 VAC or a 12 VDC solar charged battery, the electromagnet is controlled by a circuit board with an adjustable strike rate. You can design your individual set of windless chimes using components purchased from Sonntag Creations, formerly Newton's Flying Magnets. Below is a short video demonstrating some of the possibilities.

www.youtu.be/LMAQhuHhdMQ

Tank Bells & Chimes Out of service compressed gas/air cylinders, scuba diving tanks or fire extinguishers are often cut and used as a chime or bell. Based on physical measurements can we pre-determine a musical note for these tanks? To the best of my research I have not found a mathematical method for calculating a musical note for these tanks. Both the neck-end and the base-end seriously alter the vibration performance of the cylinder rendering existing formulas useless.



However, once the tank has been cut to your desired length it is easy work to determine the fundamental frequency using an analysis program like Audacity®, . Other choices work well also.

The frequency spectrum does not always follow the traditional overtone pattern for a chime tube and can include a host of additional overtones normally associated with the bell-like sound. See the spectrum diagram to the left.

Energizing all the overtones and avoiding the harsh sound when using a metal striker can be a challenge. A golf ball or baseball can work well but requires a robust strike to properly energize the overtones. I have not had good success using a wood striker unless it's a really robust strike not typically possible with a normal wind sail.

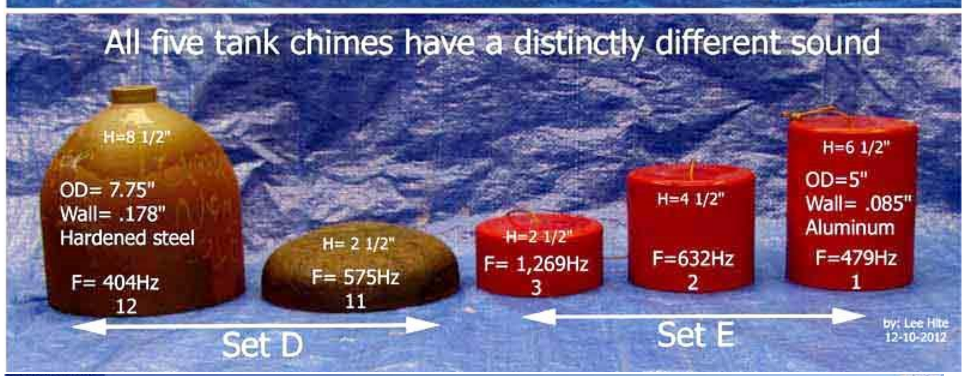
Length Matters, Maybe Not!

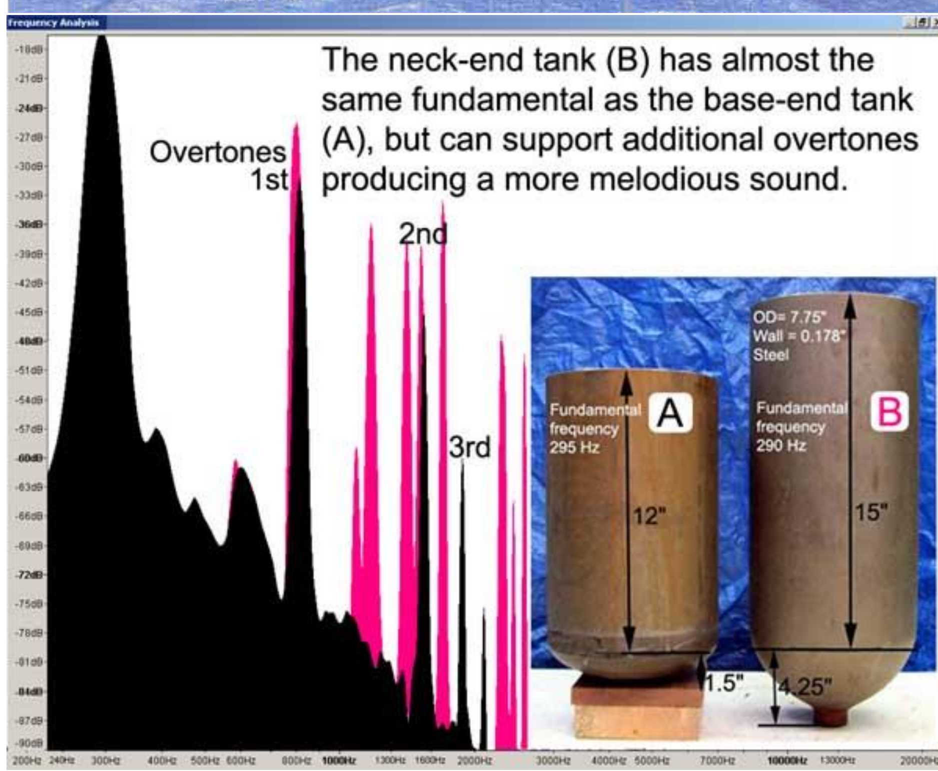
A most perplexing situation can exist for some tank lengths. We tested five sets of tank chimes, sets A, B, C, D, & E pictured to the right. All chimes for sets D and E sounded distinctly different and each had a different height, and a different fundamental frequency and overtone structure; however, not true for sets A, B, and C.

In comparison, each chime in set A sounded exactly the same and had nearly identical fundamental frequencies and nearly identical overtones, but represented three different lengths. The same was true for sets B and C. There was a slight difference in timbre among the bells, but a considerable difference in length for each set.

Set B has both a neck-end and a base-end chime from a compressed-gas cylinder. While both chimes strike almost exactly the same fundamental frequency (295 Hz vs. 290 Hz), they are of different lengths and have a slightly different timbre but sound mostly the same. Tank B was more melodious than tank A, but not a lot. The difference in overtone structure is pictured to the right.

I investigated circular mode resonance which is a function of just material type, OD and wall thickness and not length, as a possible explanation for this effect. Unfortunately the circular mode resonance was considerably lower than the observed resonance and offered no correlation to the actual measurements. The calculated vs. observed resonances were as follows:

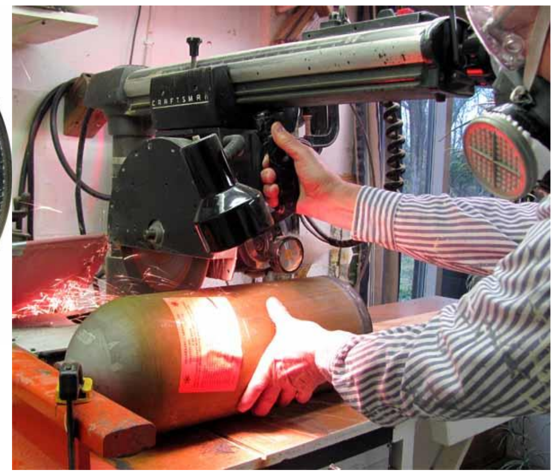




Set A = 35.4 Hz vs. 133 Hz; Set B= 29.7 Hz vs. 290 Hz; Set C= 71.7 Hz vs. 354 Hz. The formula was provided by Chuck from Chuck's Chimes and is: F = (T/(2*D^2))*SQRT(E/Density) where F = frequency, E = modulus of elasticity, D = mean diameter, and T = wall thickness.

I remain a bit perplexed on exactly why length appears to have little effect on the fundamental frequency and the overtones structure, above some critical length point. Clearly this was not a rigorous scientific test, but enough to cause concern and points to a need for further investigation.

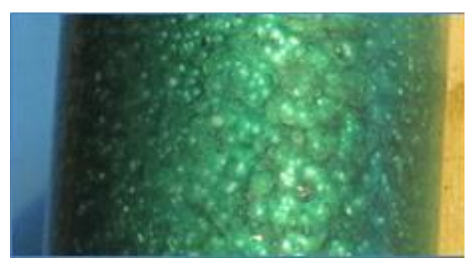
Do not use any formula, table or chart on the website to predict a tanks musical performance.



Cutting Tanks: If you're new to cutting steel or aluminum tanks and looking for an easy method, I use an abrasive metal cutting saw blade in a radial arm saw, and for small diameter tanks it will work equally well with a cut-off saw, aka chop-saw. The blade pictured right is under $5.00 at Home Depot. I was pleasantly surprised how easily the blade cut the hardened steel cylinder. The blade also works well for steel or aluminum tubing and rods. Of course, metal cutting band saws and other resources in a welding shop work well

Safety Caution: All of these tanks are highly regulated by the US Department of Transportation (DOT), or the National Fire Protection Association (NFPA), or by Transport Canada (TC) and others. Make certain the tank is safe for handling, is completely empty (fill with water and empty to assure all gases are exhausted), and is safe for cutting. Wear all recommended safety equipment including eye protection, hearing protection and respiratory protection. The tanks are heavy and can be dangerous when handling, use caution.

Decorating the Chime



Hammered Paint Finish

Lightweight coatings The chime tube can be anodized or decorated with a light weight coating such as a thin coat of spray lacquer, spray polyurethane, spray paint, powder coat, crackle/hammered/textured finish (pictured right) without a noticeable reduction in the sustain time. However, avoid thick heavy coats of latex as they seriously reduce the sustain time and can kill the resonance. I suspect a few hand painted flowers from a heavy paint would work okay

Patina finish on steel: Site visitor and artist, Roger Deweese, has successfully applied a metal dye to produce some amazing patina finishes for his tank bell chimes, pictured right. Read here about the procedure Roger employed.

Patina, the Aged Copper Look: A website visitor sent a procedure to artificially age copper to provide the patina appearance. The procedure works well and pictured on the right are the satisfactory results. I have included the procedure here for your reference. Be patient with this procedure, it can take several days to complete but the results are terrific.

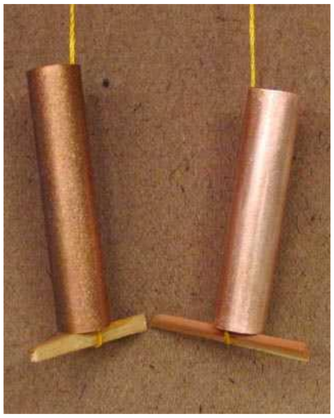
You will need two commonly available chemicals to complete this process. The first is a rust remover that contains phosphoric acid. A couple of sources are Naval Jelly® or Rust Killer™. Secondly, a toilet bowl cleaner that contains either hydrochloric or sulfuric acid. Some choices are Zep® Inc. Toilet Bowl Cleaner, The Works® Toilet Bowl Cleaner, Misty® Bolex 23 Percent Hydrochloric Acid Bowl Cleaner and LIME-A-WAY® Toilet Bowl Cleaner. Read the content labels carefully and look for any brand of rust remover that contains phosphoric acid and a toilet bowl cleaner that has either hydrochloric or sulfuric acid in your local store.

Patina Procedure

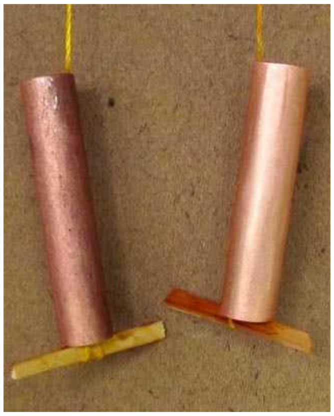
1. Begin by cutting your chime tubes to length and make any length adjustments necessary for tuning. De-burr and remove any sharp edges from both ends and the support hole.
2. Decide how you are going to support the chime, using either end caps or a support line at the 22.42% location. Attach a temporary line to support the chime vertically. This temporary line will get messy and can be discarded at the end of this procedure.
3. Clean the chime using a soapy solution of dishwashing detergent like Dawn™ or equivalent. I also used a fine grade steel wool to lightly scrub the surface. Dry completely.
4. Hang the chime vertically.
5. Soak a small soft paintbrush or dry rag with the rust remover solution and completely coat the chime. Allow to drip-dry. This could take from a few hours to three days depending on your local humidity. This step slightly etches the surface of the copper in preparation for the next chemical step.
6. When the chime is completely dry remove the dried rust remover from the chime using a dry cloth. Do not use water.
7. Soak a small soft paintbrush or dry rag with the toilet bowl solution and completely coat the chime. This could take from a few hours to a few days depending on your local humidity. A second coat will help to improve the patina look. This step causes the bluish green patina to develop in the etched surface and will darken the smooth surfaces.
8. Allow a few days to dry and the chime should ready for handling to install the final support lines.
9. The finished chime may not look like the picture above when newly completed. It can take a few weeks to completely darken and turn green in spots. Re-application of the toilet bowl cleaner may be necessary
10. I have had this patina set of chimes for several years and the patina look gets better every year and holds up well in all kinds of weather.

> These are dangerous chemicals. Wear safety glasses, old clothes, rubber gloves and follow all manufactures safety recommendations. If the chemical gets on your skin wash immediately with a liberal amount of water. Use in a well-ventilated area.

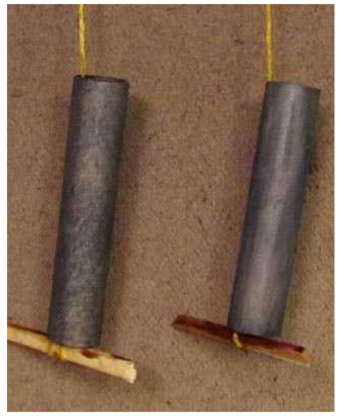
Sequence pictures for completing the patina process above.



Cleaned and ready for the process. The tube on the left has been sanded with 150 grit sand paper while the right hand tube has been cleaned with steel wool



First coat of rust remover applied



Rust remover dried in two days

Dried rust remover wiped with a rag

First coat of toilet bowel cleaner containing hydrochloric acid has been applied. Dried in about two days

Second coat of toilet bowel cleaner dried. At this stage it doesn't look like much has happened but be patient, it gets better with time and weather

After a few weeks in the weather

Left hand picture after about two months. Right hand picture after another coat of toilet bowel cleaner

Sparkling Copper: An easy way to obtain the sparkling copper look is to sand the surface of the copper chime using an orbital sander with about 150 grit sand paper. This will completely expose fresh copper and leave behind orbital scratches on the surface. Coat the sanded chime with a clear spray lacquer or a spray polyurethane to preserve the new copper look. See picture on the right.

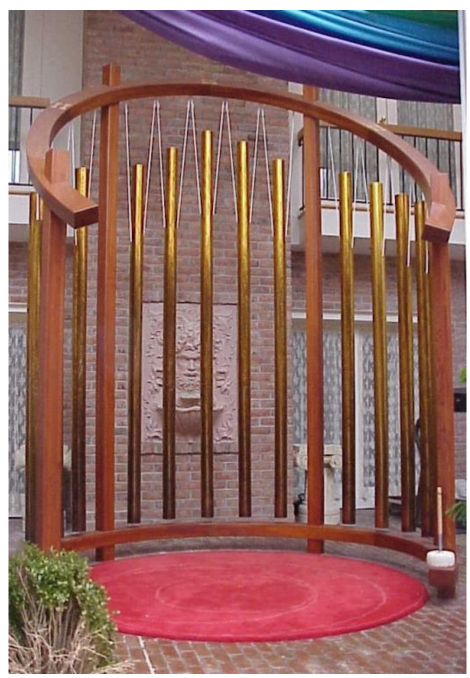
The Science of Chiming

What is a tubular bell chime? Chimes date to prehistoric times for a number of cultures, back nearly 5,000 years. Tubular bells chimes were developed in the 1880's when using regular bells in an orchestra setting became impractical. Tubular bells closely imitate church bells and the practice of using a resonant tube as a bell soon flourished and became the traditional orchestra bell.

Traditional church bells or tubular bells can be characterized by their strike note. That bell-like strike note can be expanded to include the overtone structure, sustain time and loudness. That sounds simple enough, but imbedded in that explanation are two definitions. The first definition is when a chime, properly designed and constructed, can imitate a bell, and the second definition is that a chime may not imitate a bell. Our objective is to assist you to achieve the most bell-like sound as possible.

Compared to a string or brass musical instrument, designing tubular bell chimes present a unique challenge not experienced elsewhere. Although unique, building a great set of tubular bells can be easily understood and implemented. Ending your project with a successful and pleasing sound is important and setting the right expectations will allow that to happen. The information below may help you to better set realistic expectations.

Loudness Limits: One of the largest differences between a chime and other musical instruments is loudness. Loudness depends on the physical size of the chime i.e. the radiating surface area. Compared to a string instrument where a sounding board is used to amplify the vibration of the string, or compared to a brass instrument that is fitted with a flared tube to amplify the loudness, a chime has no amplifying assistance, other than the inherent surface area of the chime tube. Overall, this loudness limitation for a typically sized chime-set will provide serious limitations for the available range of effective note selection.

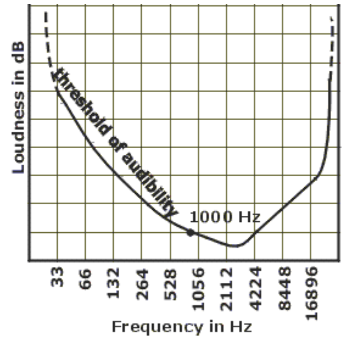


On the other hand, if you move up from a typical chime-set, into the really large mega chimes, then good loudness is easily achieved. For example, shown right is a large chime-set from Sandra Bilotto.

Somewhat of an exception is when the resonant frequency of the tube matches the air column resonance for the tube as described by Chuck from Chuck's Chimes. Assistance from the energized air column adds a small amount of loudness.

On the other hand, if you go beyond the size for a typical chime-set into the really large mega chime, then loudness is easily achieved. As an example, see the two chimes-sets at the right from the website tama-do.com/product/arche.html

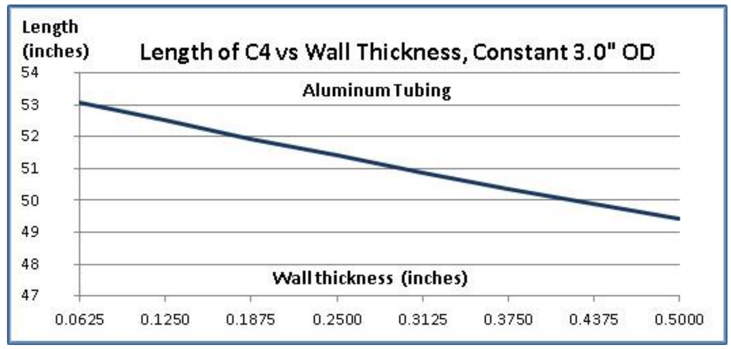
An exception is when the resonant frequency of the tube matches the air column resonance for the tube, as described by Chuck from Chuck's Chimes. Assistance from the energized air column adds a small amount of loudness.



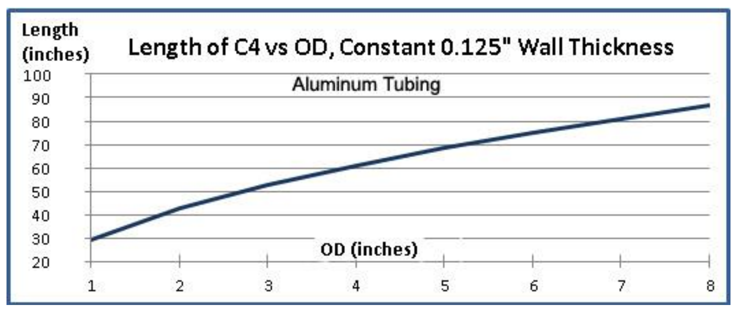
The second limitation for loudness from a tubular chime depends on the location of the selected note on the musical scale, compared to the natural sensitivity of the human ear. Shown right is the loudness sensitivity range vs. frequency for the human ear.

You can see more sensitivity in the range from about 300 Hz to 8 KHz than at other frequencies, and helps to explain why we cannot always hear all the overtones, even if they are present. This loudness limitation will have a direct effect on what notes work best for a chime.

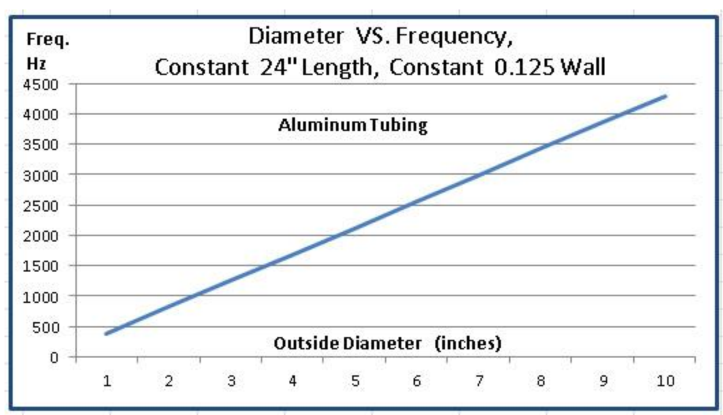
Proportional Dimensions: Increasing the chime diameter increases the radiating surface area and contributes to a louder chime but at a cost. The increased diameter greatly increases the length requirement for a specific note, which is not necessarily bad; it just makes the chime set longer as the chime diameter is increased. See the graph to the right for musical note C4.



On the other hand, increasing the wall thickness has the opposite effect as an increase in diameter. As the wall thickness increases there is a small decrease in the length requirement for any specific note. In addition there will be an increase in sustain time from the increased mass. See the graph below.

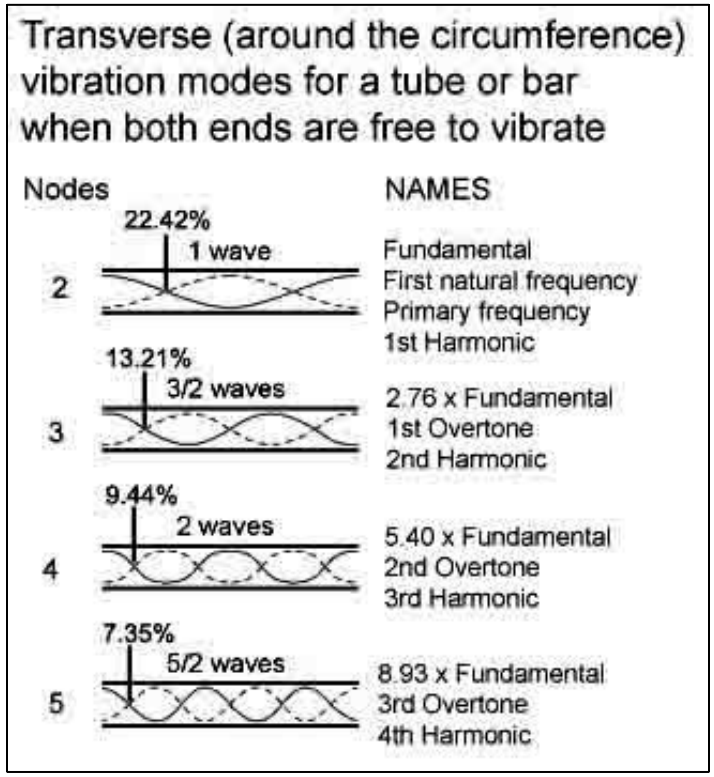


Increasing the outside diameter while keeping the length and wall thickness constant will cause a substantial rise in resonant frequency. See the graph below for Diameter VS. Frequency.



Strike Note vs. Sustaining Note: for a chime, is not an integer harmonic as in string instruments but instead, non-harmonic as in other percussion instruments. When the chime is supported at the fundamental frequency node, see diagram at the right, the higher partials are dampened but the fundamental strike frequency remains. Overtones exist and in a perfect metal where the density and the elasticity are constant, have theoretical multiples of the fundamental multiplied by X 2.76, X 5.40, X 8.93, X 13.34, X 18.64 and X 31.87.

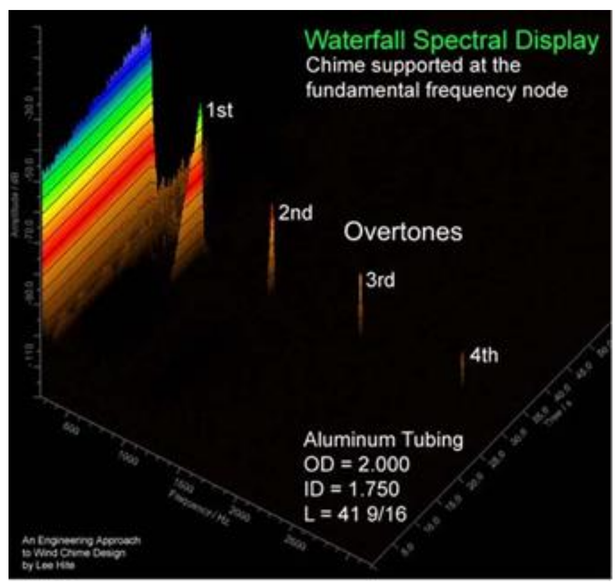
However, in the real world of metal tubing that does not have a consistent density or elasticity, the multiples will drift from the theoretical values either up or down by as much as +2% to -8%.



If we could hear the complete compliment of all overtones for each note of a chime tube, it would be a most wonderful bell-like sound. Unfortunately, not all of the fundamental tones and/or all of the overtones can be adequately radiated as an auditable sound by the chime tube, for all possible lengths of a chime. This condition also limits the available range of notes that have a bell-like sound.

Unfortunately, not all of the fundamental tones and/or all of the overtones can be adequately radiated as an auditable sound by the chime tube for all possible lengths of a chime. This condition also limits the available range of notes that have a bell-like sound.

For example, a chime cut for C2 (65.4 Hz), the fundamental frequency is audibly absent, aka the missing fundamental, along with little audible contribution from the first overtone (180.5 Hz). The remaining overtones combine to produce a perceived musical note. The perceived note does not coincide with any specific overtone and is difficult to measure without a frequency spectrum analyzer or perhaps a good musical ear. The good news is that the brain processes the information present in the overtones to calculate the fundamental frequency, using fuzzy logic.



Waterfall spectral display for a chime supported at the fundamental frequency node

You can see from the display at the right that a chime cut for 272.5 Hz (near C4#), has two characteristics. The first characteristic is the sound when the chime is first struck, the Strike Note. It comprises both the fundamental and the first four overtones, and has that traditional chime sound for a short period of time.

The 1st overtone contributes for about two seconds and rapidly deteriorates. The remaining sound is solely the fundamental strike frequency. Note the long sustain time for the fundamental.

The 2nd, 3rd and 4th overtones are present and contribute to the strike note but attenuate quickly. They have little contribution to the lingering perceived sound, aka sustain time or hang-time

In contrast to the above example, the sound for a chime cut at fundamental C6 (1046.5 Hz) and above is mostly the fundamental and the overtones are audibly absent or mostly absent.

In addition to the many overtones that may be present for a chime we have the difficulty of knowing which overtones are prominent for each note, because of the ear's sensitivity as represented by the equal loudness curve. As you might suspect, the loudness of a particular overtone changes as we move up the scale. For a typical ear sensitivity range of 300 Hz to 3 KHz, see the data audible fundamental and overtones for wind chime notes as a simple example for the range of audible fundamental frequencies and overtones. Obviously this is not the entire audible range of the ear but is presented as a simple example of the limited ability of the ear to hear all the frequencies generated by the overtone structure. In particular, the range of C2 to C3 contain a large number of audible overtones while the range of C5 to C7 contains very few. The note range from C2 thru C4 produce the most melodious sounds, most bell-like, and is easy to build. Precise tuning is not required unless the set is for an orchestra setting.

The Missing Fundamental is when the brain uses "fuzzy logic" to processes the information present in the overtones to calculate the missing fundamental frequency.

To gain a better understanding of the perceived note I examined a set of orchestra grade chimes manufactured by a UK manufacture. The set was 1.5" chrome plated brass with a wall thickness of .0625 inches and ranged from C5 (523.30 Hz) to G6 (1568.00 Hz). The length of C5 was 62 5/8 inches. The fundamental frequency for this length is around 65 Hz, about C2# yet the perceived note is C5 at 523 Hz. The fundamental strike frequency of 65 Hz and the first overtone at 179.4 Hz (65 x 2.76 = 179.4 Hz) are audibly absent, aka the missing fundamental. In fact, even the second overtone at 351 Hz will not be strong in loudness. The remaining overtones (mechanical vibration modes) combined to produce what the ear hears acoustically, which is C5 at 523 Hz, yet there is not a specific fundamental or overtone at that exact frequency.

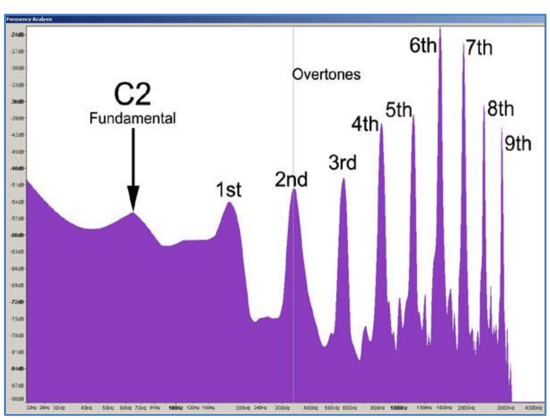
I spoke with the people at a major USA chime manufacture for symphony grade instruments and confirmed that indeed the process of tuning an orchestra grade chime is a complex process and understandably a closely held trade secret. The process involves the accounting for all frequencies from the fundamental (whether present or missing) through the many overtones, by the use of math calculations, acoustic measurements, and the careful grinding of the chime to achieve the correct length for the desired note.

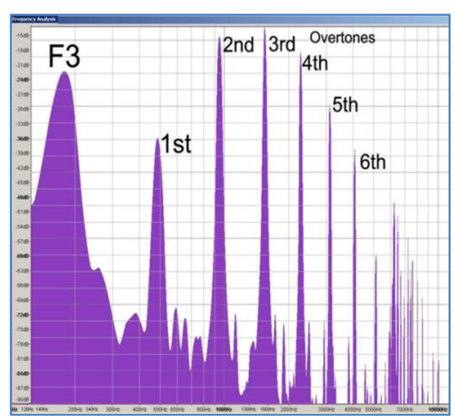
An orchestra chime is not supported by the classical wind chime method using a string through the chime at the first frequency node 22.4%, but instead, is fitted with an end cap that contains a small top hole through which a steel cable supports the chime. From testing I find that the end cap not only enhances the bell-like sound, by increasing the duration of the first overtone, but it also lowers the fundamental frequency by about 4% to 12 % from calculated values, depending on tube material and diameter.

More on this in chime tube mechanical support. Many have spent time investigating the missing fundamental and the perceived note from a chime. Some good sources are: Hyper Physics, Wind Chime Physics, and Wikipedia.

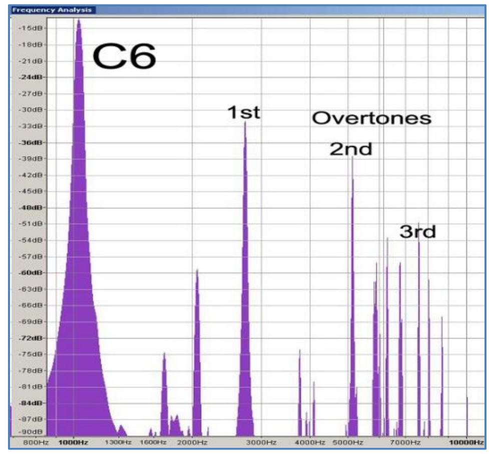
A Bell-like Chime: Using the above characteristics for a chime, I found a limited set of notes that will produce a bell-like sound from a tubular chime. Using the musical scale as a reference, they fall into three categories as follows:

The 1st chime category: (Most bell-like) has a note range from about C2 to the C4 octave. The fundamental strike frequency is present but audibly absent (the missing fundamental) and there are a host of well-pronounced overtones. Often the first overtone can also be inaudible. The perceived sound is not the fundamental strike frequency and not the overtones, but an imaginary note created by the combination of the overtones. To the ear this is a very melodious sound and clearly a bell-like sounding chime. The larger physical size of this chime for this note range causes the loudness to be quite adequate, and

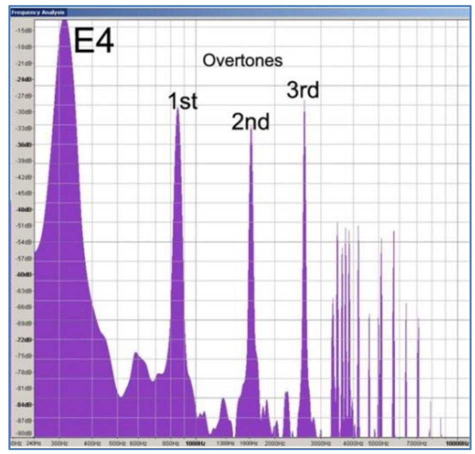




easily supports radiation for the many overtones. Note in the spectrum displays below, as we move up the musical scale the overtone contribution becomes less and less.



The 2nd chime category: (Almost bell-like) has a note range from about C4 through most of the C6 octave. The fundamental strike frequency is mostly audible and some overtones contribute to the perceived sound. The perceived note is not the fundamental strike frequency and not the overtones, but a combination of both that produce a perceived musical note. The sound can be acceptable but may not be the sound you are looking for. This has an almost bell-like sound and can sound fairly good, but not particularly melodious. The loudness is acceptable but not great.



The 3rd chime category: (Non bell-like) has a note range from about C6 through the C8 octave. Not unlike other percussion instruments this category is characterized by an audible fundamental strike frequency (a noticeable pure tone) with overtones mostly absent. Overtones have minimal contribution to the perceived musical note. This note range may not be particularly pleasing to the ear but should not be ignored as a pure tone, and is definitely a non-bell sounding chime. In addition, the loudness is typically low caused by the short length of the chime causing a low radiating surface for the higher notes. The rapid attenuation of high frequencies in the environment causes this note range to quickly diminish at a distance.

Conclusions: Clearly there is more to a chime than I had anticipated and I am sure I have not learned all that there is to know about the physics of a chime. This was originally a Christmas present for my daughters and not a focused research project. I am convinced that it is not necessary to hand tune a set of bell-like chimes designed for musical notes from fundamental C2 through C4 because the formula achieved the desired frequency well within 1 Hz. Tuning to achieve an accuracy closer than 1 Hz was a waste of time. However, for a fundamental note from C5 and up, good tuning is required. Good physical measurements are important to achieve the calculated accuracy.

My favorite design has changed over the years and is currently an end cap supported chime with the striker contacting the tube at the very bottom of the chime using either a tapered striker or a star striker, and having the wind rotate the chime set using a single line support for the support disk. Unfortunately, I know of no formula for calculating the length of a chime tube with an end cap. I begin with a length from standard calculations on this page and then tune by trimming off the length. End caps lower the frequency by as much as 8% to 15%, which requires removal of material to increase the tuning back to the correct vale. Yes, it's a lot of work if you want exact tuning for a tapered end!

On occasion I have added an end cap to the calculated value for an open end tube in order to gain a more bell-like sound, but not adjusted the length to regain accurate tuning. For the most part, it has been difficult to acoustically tell the difference between the un-tuned chime set with an end caps and a set of tuned chimes without end caps. Perhaps I have been lucky or maybe the natural shift caused by the end cap is consistent for all five tubes, and they remain mostly in tune.

Your particular type of wind (single-direction or turbulent) and wind speed will determine the best choice for both the wind sail and for the chime striker. Rotating the chime-set works well to solve the dingdong sound caused from low velocity single directions winds.

Another phenomena we observed, but did not have time to investigate, was the simultaneous production of sound from the natural bending mode of the chime coinciding with the resonance of the air column for the tube. The good news is that another engineer, Chuck at Chuck's Chimes, has done an excellent job detailing this affect, I suggest you give this a look-see. He has excellent information and calculations to accomplish this special effect. www.sites.google.com/site/chuckchimes/home

Originally published 10/01/2012

Appendix A - The math

I am not aware of calculations for a tube closed at one end. i.e. a chime with an end cap.

The bending natural frequency for a tube open at both ends is predicted by Euler's equation where:

$w = (B \times L)^2 \times \sqrt{(E \times I/(rho \times l4))}$

w - frequency radian per second - for frequency in cycles per second (Hz), $f = w/(2 \times \pi)$
E - modulus of elasticity
I - area moment of inertia = $\pi \times d^3 \times t/8$ for a thin wall round tube
d - mean diameter
t - wall thickness
rho = mass per unit length = Area x mass per unit volume = π x d x t x density
L - length of tube

$w = (B \times L)^2 \times (d/l^2) \times \sqrt{(1/8)} \times \sqrt{(E/density)}$

$(B \times L)^2$ - Constants based on the boundary conditions for a wind chime (Free-Free Beam)
$(B \times L)^2 = 22.373$ for the first natural frequency.
$(B \times L)^2 = 61.7$ for the second natural frequency.
$(B \times L)^2 = 121$ for the third natural frequency.
$(B \times L)^2 = 199.859$ for the fourth natural frequency.

To get the units correct you must multiply the values inside the square root by gravity (g).
g = 386.4 in/sec^2 for these units.

For a given material then the frequency of a thin wall tube reduces to f = constant x d / l^2

The formula reduces to:

Area Moment of Inertia = $\pi \times (OD^{\wedge 4} - ID^{\wedge 4})/64$
Area = $\pi \times (OD^{\wedge 2} - ID^{\wedge 2})/4$
K = $\sqrt{}$((Elasticity x Moment x Gravity)/(Area x Density))

Chime Length (inches) = $\sqrt{(22.42 \times K/(2 \times \pi \times f))}$

If you're curious about the circular mode (not considered here) see this
http://paws.kettering.edu/~drussell/Demos/radiation/radiation.html

If you want additional math on the subject here is a paper by Tom Irvine

Appendix B - Music scale with overtones

A=440 Hz displaying the fundamental frequency and the first four overtones for a tube open at both ends

Note	A=440 Freq Hz	1st Overtone X 2.76	2nd Overtone X 5.40	3rd Overtone X 8.93	4th Overtone X 13.34	Note	Freq Hz	1st Overtone X 2.76	2nd Overtone X 5.40	3rd Overtone X 8.93	4th Overtone X 13.34
C0	16.40	45.18	88.56	146.45	218.78	G	392.00	1,079.96	2,116.80	3,500.56	5,229.28
C$^\#$/D^b	17.30	17.30	93.42	154.49	230.78	G$^\#$/A^b	415.30	1,144.15	2,242.62	3,708.63	5,540.10
D	18.40	50.69	99.36	164.31	245.46	A	440.01	1,212.23	2,376.05	3,929.29	5,869.73
D$^\#$/E^b	19.40	53.45	104.76	173.24	258.80	A$^\#$/B^b	466.20	1,284.38	2,517.48	4,163.17	6,219.11
E	20.60	56.75	111.24	183.96	274.80	B	493.91	1,360.72	2,667.11	4,410.62	6,588.76
F	21.80	60.06	117.72	194.67	290.81	**C5**	523.30	1,441.69	2,825.82	4,673.07	6,980.82
F#/G^b	23.10	63.64	124.74	206.28	308.15	C$^\#$/D^b	554.40	1,527.37	2,993.76	4,950.79	7,395.70
G	24.50	67.50	132.30	218.79	326.83	D	587.30	1,618.01	3,171.42	5,244.59	7,834.58
G$^\#$/A^b	26.00	71.63	140.40	232.18	346.84	D$^\#$/E^b	622.30	1,714.44	3,360.42	5,557.14	8,301.48
A	27.50	75.76	148.50	245.58	366.85	E	659.30	1,816.37	3,560.22	5,887.55	8,795.06
A$^\#$/B^b	29.10	80.17	157.14	259.86	388.19	F	698.50	1,924.37	3,771.90	6,237.61	9,317.99
B	30.90	85.13	166.86	275.94	412.21	F#/G^b	740.00	2,038.70	3,996.00	6,608.20	9,871.60
C1	32.70	90.09	176.58	292.01	436.22	G	784.00	2,159.92	4,233.60	7,001.12	10,458.56
C$^\#$/D^b	34.60	95.32	186.84	308.98	461.56	G$^\#$/A^b	830.60	2,288.30	4,485.24	7,417.26	11,080.20
D	36.70	101.11	198.18	327.73	489.58	A	880.00	2,424.40	4,752.00	7,858.40	11,739.20
D$^\#$/E^b	38.90	107.17	210.06	347.38	518.93	A$^\#$/B^b	932.30	2,568.49	5,034.42	8,325.44	12,436.88
E	41.21	113.53	222.53	368.01	549.74	B	987.80	2,721.39	5,334.12	8,821.05	13,177.25
F	43.70	120.39	235.98	390.24	582.96	**C6**	1,046.50	2,883.11	5,651.10	9,345.25	13,960.31
F#/G^b	46.30	127.56	250.02	413.46	617.64	C$^\#$/D^b	1,108.70	3,054.47	5,986.98	9,900.69	14,790.06
G	49.00	135.00	264.60	437.57	653.66	D	1,174.61	3,236.05	6,342.89	10,489.27	15,669.30
G$^\#$/A^b	51.90	142.98	280.26	463.47	692.35	D$^\#$/E^b	1,244.50	3,428.60	6,720.30	11,113.39	16,601.63
A	55.01	151.55	297.05	491.24	733.83	E	1,318.50	3,632.47	7,119.90	11,774.21	17,588.79
A$^\#$/B^b	58.30	160.62	314.82	520.62	777.72	F	1,397.00	3,848.74	7,543.80	12,475.21	18,635.98
B	61.70	169.98	333.18	550.98	823.08	F#/G^b	1,480.00	4,077.40	7,992.00	13,216.40	19,743.20
C2	65.40	180.18	353.16	584.02	872.44	G	1,568.00	4,319.84	8,467.20	14,002.24	20,917.12
C$^\#$/D^b	69.30	190.92	374.22	618.85	924.46	G$^\#$/A^b	1,661.20	4,576.61	8,970.48	14,834.52	22,160.41
D	73.41	202.24	396.41	655.55	979.29	A	1,760.00	4,848.80	9,504.00	15,716.80	23,478.40
D$^\#$/E^b	77.80	214.34	420.12	694.75	1,037.85	A$^\#$/B^b	1,864.60	5,136.97	10,068.84	16,650.88	24,873.76
E	82.40	227.01	444.96	735.83	1,099.22	B	1,975.50	5,442.50	10,667.70	17,641.22	26,353.17
F	87.30	240.51	471.42	779.59	1,164.58	**C7**	2,093.00	5,766.22	11,302.20	18,690.49	27,920.62
F#/G^b	92.50	254.84	499.50	826.03	1,233.95	C$^\#$/D^b	2,217.40	6,108.94	11,973.96	19,801.38	29,580.12
G	98.01	270.02	529.25	875.23	1,307.45	D	2,349.20	6,472.05	12,685.68	20,978.36	31,338.33
G$^\#$/A^b	103.80	285.97	560.52	926.93	1,384.69	D$^\#$/E^b	2,489.01	6,857.22	13,440.65	22,226.86	33,203.39
A	110.00	303.05	594.00	982.30	1,467.40	E	2,637.00	7,264.94	14,239.80	23,548.41	35,177.58
A$^\#$/B^b	116.50	320.96	629.10	1,040.35	1,554.11	F	2,794.00	7,697.47	15,087.60	24,950.42	37,271.96
B	123.50	340.24	666.90	1,102.86	1,647.49	F#/G^b	2,960.00	8,154.80	15,984.00	26,432.80	39,486.40
C3	130.81	360.38	706.37	1,168.13	1,745.01	G	3,136.00	8,639.68	16,934.40	28,004.48	41,834.24
C$^\#$/D^b	138.60	381.84	748.44	1,237.70	1,848.92	G$^\#$/A^b	3,322.41	9,153.24	17,941.01	29,669.12	44,320.95
D	146.80	404.43	792.72	1,310.92	1,958.31	A	3,520.00	9,697.60	19,008.00	31,433.60	46,956.80
D$^\#$/E^b	155.60	428.68	840.24	1,389.51	2,075.70	A$^\#$/B^b	3,729.20	10,273.95	20,137.68	33,301.76	49,747.53
E	164.80	454.02	889.92	1,471.66	2,198.43	B	3,951.00	10,885.01	21,335.40	35,282.43	52,706.34
F	174.61	481.05	942.89	1,559.27	2,329.30	**C8**	4,186.00	11,532.43	22,604.40	37,380.98	55,841.24
F#/G^b	185.00	509.68	999.00	1,652.05	2,467.90	C$^\#$/D^b	4,434.81	12,217.90	23,947.97	39,602.85	59,160.37
G	196.00	539.98	1,058.40	1,750.28	2,614.64	D	4,698.40	12,944.09	25,371.36	41,956.71	62,676.66
G$^\#$/A^b	207.70	572.21	1,121.58	1,854.76	2,770.72	D$^\#$/E^b	4,978.00	13,714.39	26,881.20	44,453.54	66,406.52
A	220.00	606.10	1,188.00	1,964.60	2,934.80	E	5,274.00	14,529.87	28,479.60	47,096.82	70,355.16
A$^\#$/B^b	233.10	642.19	1,258.74	2,081.58	3,109.55	F	5,588.00	15,394.94	30,175.20	49,900.84	74,543.92
B	246.90	680.21	1,333.26	2,204.82	3,293.65	F#/G^b	5,920.00	16,309.60	31,968.00	52,865.60	78,972.80
C4	261.60	720.71	1,412.64	2,336.09	3,489.74	G	6,272.00	17,279.36	33,868.80	56,008.96	83,668.48
C$^\#$/D^b	277.20	763.69	1,496.88	2,475.40	3,697.85	G$^\#$/A^b	6,644.80	18,306.42	35,881.92	59,338.06	88,641.63
D	293.70	809.14	1,585.98	2,622.74	3,917.96	A	7,040.00	19,395.20	38,016.00	62,867.20	93,913.60
D$^\#$/E^b	311.10	857.08	1,679.94	2,778.12	4,150.07	A$^\#$/B^b	7,458.40	20,547.89	40,275.36	66,603.51	99,495.06
E	329.61	908.08	1,779.89	2,943.42	4,397.00	B	7,902.01	21,770.04	42,670.85	70,564.95	105,412.81
F	349.30	962.32	1,886.22	3,119.25	4,659.66	**C9**	8,367.01	23,051.11	45,181.85	74,717.40	111,615.91
F#/G^b	370.00	1,019.35	1,998.00	3,304.10	4,935.80						

Appendix C - Software resources **Read the Caution Here**

Audacity® Laptop freeware, open source, cross-platform software for recording and editing sounds. Good for fundamental and overtone frequency measurements.

DL4YHF's Amateur Radio Software: Audio Spectrum Analyzer (Spectrum Lab) Laptop freeware good for fundamental and overtone frequency measurements.

Tune Lab Pro version 4 Laptop freeware good for fundamental and overtone frequency measurements. At a cost, available for the iPhone, iPad and iPod Touch, Windows laptops, Windows Mobile Pocket PCs, Smartphones, and the Android.

Appendix D - Tubing and rod sources

Always try your local building supply store. In addition to visiting the hardware section in these stores investigate tubing used for closet hanging poles, shower curtain poles, chain link fence rails and post. Yard or garage sales can yield surprising results, look for a discarded metal swing set, tubular shelving, etc. With permission look for discarded materials on constructions sites.

Try your local metal recycler; they can yield very economical rod and tubing.

Tanks bells can be crafted from out-of-service compressed gas/air tanks, scuba diving tanks or fire extinguishers. A most likely source can be your local testing facility for each type of tank. Ask your local fire department, welding shop and scuba diving shop for their recommendation for a testing company. You may be required to provide a letter to the testing company stating that you will cut the tank in pieces and render it unable to hold compressed air or gas.

Online source for metal tubing and rods:

Always try your local building supply store. In addition to visiting the hardware section in these stores investigate tubing used for closet hanging poles, shower curtain poles, chain link fence rails and post. Yard or garage sales can yield surprising results, look for a discarded metal swing set, tubular shelving, etc. With permission look for discarded materials on constructions sites. Try your local metal recycler; they can yield very economical rod and tubing.

Online Speedy Metals accepts small quantity orders for tubes or rods.
(Aluminum, Brass, Cast Iron, Copper, Steel and Stainless)

Titanium Joe (Tubing) You can use either grade 2 being pure titanium, which is softer and less popular, or grade 9 (3AL-2.5V), which is the more popular high strength. The grade 9 numbers represent the percentage of Aluminum and Vanadium. The DIY Calculators work equally well for both grades.

Tank bells can be crafted from out-of-service compressed gas/air tanks, scuba diving tanks or fire extinguishers. A most likely source can be your local testing facility for each type of tank. Ask your local fire department, welding shop and scuba diving shop for their recommendation for a testing company. You may be required to provide a letter to the testing company stating that you will cut the tank in pieces and render it unable to hold compressed air or gas.

Appendix E - Standard Tubing Dimensions

What's the difference between a pipe and a tube? The way it's measured and the applications it's being used for. Pipes are passageways. Tubes are structural.

Aluminum and brass tubing tend to exactly follow their stated ID and OD dimensions while copper tubing does not. Wall thickness for copper pipe varies with the pipe schedule.
The four common schedules are named K (thick-walled), L (medium-walled), M (thin-wall), and DWV (drain/waste/vent - non-pressurized)
The printing on the pipe is color coded for identification;
K is Green, **L is Blue**, **M is Red**, and **DWV is Yellow.**
Both type **M** & **type L** can be found in home plumbing at Home Depot & Low

Aluminum Tubing

Tubing Gauge	**22**	**20**	**18**	**17**	**16**	**14**	**12**
Wall Thickness	0.028	0.035	0.049	0.058	0.065	0.083	0.109

* These sizes are extruded; all other sizes are drawn tubes.

OD inches	**ID inches**	**Wall inches**	**OD inches**	**ID inches**	**Wall inches**	**OD inches**	**ID inches**	**Wall inches**
0.500	0.444	0.028	1.000	0.930	0.035	1.625	1.555	0.035
	0.430	0.035		0.902	0.049		1.509	0.058
	0.402	0.049		0.884	0.058	1.750	1.634	0.058
	0.384	0.058		0.870	0.065		1.584	0.083
	0.370	0.065		0.834	0.083	1.875	1.759	0.508
0.625	0.569	0.028	1.125	1.055	0.035	2.000	1.902	0.049
	0.555	0.035		1.009	0.058		1.870	0.065
	0.527	0.049	1.250	1.180	0.035		1.834	0.083
	0.509	0.058		1.152	0.049		1.750	*0.125
	0.495	0.065		1.134	0.058		1.500	*0.250
0.750	0.680	0.035		1.120	0.065	2.250	2.152	0.049
	0.652	0.049		1.084	0.083		2.120	0.065
	0.634	0.058	1.375	1.305	0.035		2.084	0.083
	0.620	0.065		1.259	0.058	2.500	2.370	0.065
	0.584	0.083	1.500	1.430	0.035		2.334	0.083
0.875	0.805	0.035		1.402	0.049		2.250	*0.125
	0.777	0.049		1.384	0.058		2.000	*0.250
	0.759	0.058		1.370	0.065	3.000	2.870	0.065
	0.745	0.065		1.334	0.083		2.750	*0.125
				1.250	*0.125		2.500	*0.250
				1.000	*0.250			

Brass tubing

Available sizes for Tube Brass

1/2" OD {A} x 0.436" ID {B} x .032" Wall
1/2" OD {A} x 0.370" ID {B} x .065" Wall
5/8" OD {A} x 0.561" ID {B} x .032" Wall
5/8" OD {A} x 0.495" ID {B} x .065" Wall
3/4" OD {A} x 0.686" ID {B} x .032" Wall
3/4" OD {A} x 0.620" ID {B} x .065" Wall
1" OD {A} x 0.870" ID {B} x .065" Wall
1-1/4" OD {A} x 1.120" ID {B} x .065" Wall
1-1/2" OD {A} x 1.370" ID {B} x .065" Wall
1-1/2" OD {A} x 1.250" ID {B} x .125" Wall
1-5/8" OD {A} x 1.375" ID {B} x .125" Wall
1-3/4" OD {A} x 1.620" ID {B} x .065" Wall
2" OD {A} x 1.870" ID {B} x .065" Wall
2-1/4" OD {A} x 2.120" ID {B} x .065" Wall

Available sizes for BRASS TUBE

0.5" OD x 0.03" WALL x 0.44" ID
0.5" OD x 0.042" WALL x 0.416" ID
0.5" OD x 0.065" WALL x 0.37" ID
0.625" OD x 0.029" WALL x 0.567" ID
0.625" OD x 0.065" WALL x 0.495" ID
0.75" OD x 0.029" WALL x 0.692" ID
0.75" OD x 0.04" WALL x 0.67" ID
0.75" OD x 0.065" WALL x 0.62" ID C330 TUBE
0.75" OD x 0.12" WALL x 0.51" ID
0.875" OD x 0.03" WALL x 0.815" ID
0.875" OD x 0.065" WALL x 0.745" ID
1" OD x 0.03" WALL x 0.94" ID
1" OD x 0.065" WALL x 0.87" ID
1.25" OD x 0.04" WALL x 1.17" ID
1.25" OD x 0.065" WALL x 1.12" ID
1.5" OD x 0.04" WALL x 1.42" ID
1.5" OD x 0.065" WALL x 1.37" ID
1.75" OD x 0.065" WALL x 1.62" ID
1.75" OD x 0.12" WALL x 1.51" ID
2" OD x 0.049" WALL x 1.902" ID
2" OD x 0.065" WALL x 1.87" ID
2" OD x 0.109" WALL x 1.782" ID
2" OD x 0.12" WALL x 1.76" ID
2.5" OD x 0.065" WALL x 2.37" ID
3" OD x 0.049" WALL x 2.902" ID
3" OD x 0.065" WALL x 2.87" ID
4" OD x 0.065" WALL x 3.87" ID C330 TUBE

Copper tubing

Wall thickness for copper pipe varies with the pipe schedule.
The four common schedules are named K (thick-walled), L (medium-walled), M (thin-wall), and DWV (drain/waste/vent - non-pressurized)
The printing on the pipe is color coded for identification;
K is Green, **L is Blue**, **M is Red**, and **DWV is Yellow**.
Both type **M** **& type** **L** can be found in home plumbing at Home Depot & Lowe's.

Nominal Pipe Size	Actual O.D.	I.D.				Wall Thickness			
		K	L	M	DWV	K	L	M	DWV
½"	0.625	0.527	0.545	0.569	-	0.049	0.040	0.028	-
5/8"	0.750	0.652	0.666	-	-	0.049	0.042	-	-
¾'	0.875	0.745	0.785	0.811	-	0.065	0.045	0.032	-
1"	1.125	0.995	1.025	1.055	-	0.065	0.050	0.035	-
1 ¼"	1.375	1.245	1.265	1.291	1.295	0.065	0.055	0.042	0.04
1 ½"	1.625	1.481	1.505	1.527	1.541	0.072	0.060	0.049	0.042
2"	2.125	1.959	1.985	2.009	2.041	0.083	0.070	0.058	0.042
2 ½"	2.625	2.435	2.465	2.495	-	0.095	0.080	0.065	-
3"	3.125	2.907	2.945	2.981	3.03	0.109	0.090	0.072	0.045
3 ½'	3.625	3.385	3.425	3.259		0.120	0.100	0.083	
4	4.125	3.857	3.897	3.707		0.134	0.114	0.095	
5	5.125	4.805	4.875	4.657		0.160	0.125	0.109	
6	6.125	5.741	5.845	5.601		0.192	0.140	0.122	

Electrical metallic tubing (EMT) aka thin-wall steel conduit

Electrical Metallic Tubing (EMT)
aka thin-wall steel conduit

EMT (inches)	Actual (OD) (inches)	(ID) (inches)	Wall Thickness	Gauge
3/8"	.577	.493	.042	19
½"	.706	.622	.042	19
¾"	.922	.824	.049	18
1	1.163	1.049	.057	17
1 ¼"	1.510	1.380	.065	16
1 ½"	1.740	1.610	.065	16
2	2.197	2.067	.065	16
2 ½"	2.875	2.731	.072	15
3	3.500	3.356	.072	15
3 ½"	4.000	3.834	.083	14
4	4.500	4.334	.083	14

Iron pipe
Pipe is specified by a nominal dimension which bears little or no resemblance to the actual dimensions of the pipe.

Wrought iron pipe (Schedule 40)
is used for water supply in older houses and is available in either black or galvanized. Joints are made by threading pipe into cast iron fittings.

Nominal Pipe Size inches	O.D.	I.D.	Wall Thickness
1	1.315	1.049	0.133
1.250	1.660	1.380	0.140
1.500	1.900	1.610	0.145
2	2.375	2.067	0.154
2.500	2.875	2.468	0.204

Cast iron pipe is typically used for sewer lines and municipal water.
Available in eight classes, A through H, rated by pressure in increments of 100 feet of head.

Nominal Pipe Size inches	Class A 100 Foot Head 43 psi			Class B 200 Foot Head 86 psi		
	O.D.	**I.D.**	**Wall Thickness**	**O.D.**	**I.D.**	**Wall Thickness**
3	3.800	3.020	0.390	3.960	3.120	0.420
4	4.800	3.960	0.420	5.000	4.100	0.450
6	6.900	6.020	0.440	7.100	6.140	0.480
8	9.050	8.130	0.460	9.050	8.030	0.510
10	11.100	10.100	0.500	11.100	9.960	0.570

Appendix F - Internet Resources/Links

Chuck's Chimes another engineer, Chuck, has an excellent website for chime calculations and information for building a special set of chimes where the chime tube is resonant for both the air column resonance and the metal wall resonance. www.sites.google.com/site/chuckchimes/home

The Sound of Bells This site has pages for bell sounds and tuning in addition to free software that lets you listen to the effects of overtones and allows you to tune your bell or chime using a sound card and microphone. www.hibberts.co.uk/index.htm

The Acoustics of Bells, See chapter 5: The Acoustics of Bells is a nice introduction to bell physics. www.msu.edu/~carillon/batmbook/index.htm

Pitch Perception Psychoacoustics of pitch perception. www.mmk.ei.tum.de/persons/ter/top/pitch.html

The strike note of bells www.mmk.ei.tum.de/persons/ter/top/strikenote.html

Appendix G Credits

Thank you to the many website visitors for your ideas ideas and suggestions included in this document.

Appendix H: Design styles

In-line arrangement with a conceal & carry striker.

Horizontally mounted chimes with individual strikers.

No requirement for the support disk to be horizontal.

Rod chimes use a solid metal ball as the striker. Closely space large diameter chimes can work well without a wind sail

Appendix J: Table for an audible fundamental or lack of and its overtones for chime.

The blue shaded area of the chart represents a frequency range from 300 Hz to 3,000 Hz. This demonstrates a range for audible fundamental frequencies and their overtones beginning at about C2 and moving upward to about C4. Note that the fundamental is mostly inaudible below about C4. The more overtones present the more melodious the strike note. The range of 300 Hz to 3000 Hz was selected as an example for a possible listening range and does not represent the complete audible range.

Octave	Musical Note	Frequency Hz	1st Overtone X 2.76	2nd Overtone X 5.40	3rd Overtone X 8.93	4th Overtone X 13.34	5th Overtone X 18.64	6th Overtone X 31.87
1	C		90	177	292	436	610	1,042
	C#		95	187	309	462	645	1,103
	D	36.70	101	198	328	490	684	1,170
	Eb	38.90	107	210	347	519	725	1,240
	E	41.21	114	223	368	550	768	1,313
	F	43.70	120	236	390	583	815	1,393
	F#	46.30	128	250	413	618	863	1,476
	G	49.00	135	265	438	654	913	1,562
	Ab	51.90	143	280	463	692	967	1,654
	A	55.01	152	297	491	734	1,025	1,753
	Bb	58.30	161	315	521	778	1,087	1,858
	B	61.70	170	333	551	823	1,150	1,966
2	C	65.40	180	353	584	872	1,219	2,084
	C#	69.30	191	374	619	924	1,292	2,209
	D	73.41	202	396	656	979	1,368	2,340
	Eb	77.80	214	420	695	1,038	1,450	2,479
	E	82.40	227	445	736	1,099	1,536	2,626
	F	87.30	241	471	780	1,165	1,627	2,782
	F#	92.50	255	500	826	1,234	1,724	2,948
	G	98.01	270	529	875	1,307	1,827	3,124
	Ab	103.80	286	561	927	1,385	1,935	3,308
	A	110.00	303	594	982	1,467	2,050	3,506
	Bb	116.50	321	629	1,040	1,554	2,172	3,713
	B	123.50	340	667	1,103	1,647	2,302	3,936
3	C	130.81	360	706	1,168	1,745	2,438	4,169
	C#	138.60	382	748	1,238	1,849	2,584	4,417
	D	146.80	404	793	1,311	1,958	2,736	4,679
	Eb	155.60	429	840	1,390	2,076	2,900	4,959
	E	164.80	454	890	1,472	2,198	3,072	5,252
	F	174.61	481	943	1,559	2,329	3,255	5,565
	F#	185.00	510	999	1,652	2,468	3,448	5,896
	G	196.00	540	1,058	1,750	2,615	3,653	6,247
	Ab	207.70	572	1,122	1,855	2,771	3,872	6,619
	A	220.00	606	1,188	1,965	2,935	4,101	7,011
	Bb	233.10	642	1,259	2,082	3,110	4,345	7,429
	B	246.90	680	1,333	2,205	3,294	4,602	7,869
4	C	261.60	721	1,413	2,336	3,490	4,876	8,337
	C#	277.20	764	1,497	2,475	3,698	5,167	8,834
	D	293.70	809	1,586	2,623	3,918	5,475	9,360
	Eb	311.10	857	1,680	2,778	4,150	5,799	9,915
	E	329.61	908	1,780	2,943	4,397	6,144	10,505
	F	349.30	962	1,886	3,119	4,660	6,511	11,132
	F#	370.00	1,019	1,998	3,304	4,936	6,897	11,792
	G	392.00	1,080	2,117	3,501	5,229	7,307	12,493
	Ab	415.30	1,144	2,243	3,709	5,540	7,741	13,236

	A	440.01	1,212	2,376	3,929	5,870	8,202	14,023
	Bb	466.20	1,284	2,517	4,163	6,219	8,690	14,858
	B	493.91	1,361	2,667	4,411	6,589	9,206	15,741
5	C	523.30	1,442	2,826	4,673	6,981	9,754	16,678
	C#	554.40	1,527	2,994	4,951	7,396	10,334	17,669
	D	587.30	1,618	3,171	5,245	7,835	10,947	18,717
	Eb	622.30	1,714	3,360	5,557	8,301	11,600	19,833
	E	659.30	1,816	3,560	5,888	8,795	12,289	21,012
	F	698.50	1,924	3,772	6,238	9,318	13,020	22,261
	F#	740.00	2,039	3,996	6,608	9,872	13,794	23,584
	G	784.00	2,160	4,234	7,001	10,459	14,614	24,986
	Ab	830.60	2,288	4,485	7,417	11,080	15,482	26,471
	A	880.00	2,424	4,752	7,858	11,739	16,403	28,046
	Bb	932.30	2,568	5,034	8,325	12,437	17,378	29,712
	B	987.80	2,721	5,334	8,821	13,177	18,413	31,481
6	C	1,046.50	2,883	5,651	9,345	13,960	19,507	33,352
	C#	1,108.70	3,054	5,987	9,901	14,790	20,666	35,334
	D	1,174.61	3,236	6,343	10,489	15,669	21,895	37,435
	Eb	1,244.50	3,429	6,720	11,113	16,602	23,197	39,662
	E	1,318.50	3,632	7,120	11,774	17,589	24,577	42,021
	F	1,397.00	3,849	7,544	12,475	18,636	26,040	44,522
	F#	1,480.00	4,077	7,992	13,216	19,743	27,587	47,168
	G	1,568.00	4,320	8,467	14,002	20,917	29,228	49,972
	Ab	1,661.20	4,577	8,970	14,835	22,160	30,965	52,942
	A	1,760.00	4,849	9,504	15,717	23,478	32,806	56,091
	Bb	1,864.60	5,137	10,069	16,651	24,874	34,756	59,425
	B	1,975.50	5,443	10,668	17,641	26,353	36,823	62,959
7	C	2,093.00	5,766	11,302	18,690	27,921	39,014	66,704
	C#	2,217.40	6,109	11,974	19,801	29,580	41,332	70,669
	D	2,349.20	6,472	12,686	20,978	31,338	43,789	74,869
	Eb	2,489.01	6,857	13,441	22,227	33,203	46,395	79,325
	E	2,637.00	7,265	14,240	23,548	35,178	49,154	84,041
	F	2,794.00	7,697	15,088	24,950	37,272	52,080	89,045
	F#	2,960.00	8,155	15,984	26,433	39,486	55,174	94,335
	G	3,136.00	8,640	16,934	28,004	41,834	58,455	99,944
	Ab	3,322.41	9,153	17,941	29,669	44,321	61,930	105,885
	A	3,520.00	9,698	19,008	31,434	46,957	65,613	112,182
	Bb	3,729.20	10,274	20,138	33,302	49,748	69,512	118,850
	B	3,951.00	10,885	21,335	35,282	52,706	73,647	125,918
8	C	4,186.00	11,532	22,604	37,381	55,841	78,027	133,408
	C#	4,434.81	12,218	23,948	39,603	59,160	82,665	141,337
	D	4,698.40	12,944	25,371	41,957	62,677	87,578	149,738
	Eb	4,978.00	13,714	26,881	44,454	66,407	92,790	158,649
	E	5,274.00	14,530	28,480	47,097	70,355	98,307	168,082
	F	5,588.00	15,395	30,175	49,901	74,544	104,160	178,090
	F#	5,920.00	16,310	31,968	52,866	78,973	110,349	188,670
	G	6,272.00	17,279	33,869	56,009	83,668	116,910	199,889
	Ab	6,644.80	18,306	35,882	59,338	88,642	123,859	211,770
	A	7,040.00	19,395	38,016	62,867	93,914	131,226	224,365
	Bb	7,458.40	20,548	40,275	66,604	99,495	139,025	237,699
	B	7,902.01	21,770	42,671	70,565	105,413	147,293	251,837

