The Acoustics of Resonators

by Leigh Howard Stevens

Acoustics of Keyboard Percussion Instruments

There is an old joke told by orchestral musicians about harpists.

"***Harp players spend half of their time tuning their harps and the other half playing out of tune.***"

I've written this article with the hope that similar jokes about marimbists never develop. That is not such an easy task, because there is a vast amount of misunderstanding and percussive folklore to overcome. Even today, almost ten years after the (re)introduction of tunable resonators to the marketplace, there is still great confusion about what they are for, what actually happens to the bars and resonators in different weather conditions, what tunable resonators can do to compensate for those conditions, and perhaps even more confusingly, what to do if you don't have tunable resonators.

Generations have passed since the introduction of less-sophisticated features such as slots, handles and knobs for raising and lowering the entire bank of resonators, and yet there is still disagreement over what to do with them.

"Move the bank of resonators into the lower slot for a hot stage . . ."
Article on resonator tuning in Percussive Notes
Vol. 31, Number 2, December, 1992

"In temperatures warmer than 70 degrees . . . raise each bank . . ."

Infomercial on resonator tuning in Percussive Notes

Vol. 32, Number 1, February, 1994

Both experts can't be correct. But, is it possible that *both* are wrong and that the solution to the problem lies elsewhere? Before we referee this match, let's return to the harp/marimba comparison.

To be fair to harpists, (who already hear enough criticism about their rhythm, without having to put up with jokes about their tuning), it is a far more difficult skill to tune a set of harp strings than a set of marimba resonators. You can make a major mistake tuning a resonator or two and it may not spoil a performance for most listeners. Try that with a couple of harp strings and most people in the audience will know something is dreadfully wrong -- at least with the harp -- if not with the harpist. (Sometimes, I have heard, a clever harpist deliberately mistunes a string or two -- to deflect attention from their poor rhythm.)

Fortunately or unfortunately, you can still perform an entire marimba concert with the whole set of resonators out of tune and most marimbists won't notice anything wrong -- unless they happen to be sitting near a chatty acoustician, who might lean over and explain. Perhaps because we do not really "tune" percussion instruments (with the exception of timpani) in the same sense that a harp, violin, or even trumpet is tuned, I believe we do not generally develop as critical a sense of tone as most other instrumentalists. The first music lesson on a violin or trumpet is a struggle to produce a recognizable tone. The issue of "tone" for a percussionist may not even be mentioned until the student has played for many years! How often do you hear percussionists refer to other percussionists in terms of their tone production? A remark like, "Did you hear so-and-so's recital the other night? He's really developing a great tone" is unlikely to be heard in the halls of a music school in reference to a marimbist or percussionist, *but is very common among other* *instrumentalists and singers*. With us, it's usually technique that is commented on, not the beauty of sound.

This lack of sensitivity to the tone of the marimba is really quite natural. Just think about it: in a practice or performance environment without temperature and humidity control, the ring, tone and sustain of the same marimba varies day to day with the weather. Neither teachers nor students have had any particular reason to even notice these changes, *because there wasn't anything that could be done about them anyway!* It has only been recently that players have had the opportunity to even hear the difference between an "in-tune" and "out-of-tune" resonator. Pounding on force-fit permanent resonator caps with a broom handle and hammer (as I did for many years) is not a very quick or even accurate way to "A/B" the effects of sharp and flat caps. Now that the dawn of the tunable resonator is here (again), our days of innocence are numbered. Once your ears get accustomed to the difference that an "in-tune resonator" makes, the lack of proper tuning will drive you just as crazy as listening to a snare drum with a broken head.

<u>The Novice Experiments</u>

I don't know what originally caught my attention, but twenty years ago I began noticing that my marimba sounded radically different depending on the weather. I was not bothered so much by the tuning, as by the tone quality, fullness, response and sustain of the instrument. In my non-air-conditioned practice room at the Eastman School of Music it was obvious that my low-A marimba had short ring and poor tone quality in the hot, humid Rochester summer. Raising the resonators to the higher slot, as recommended by the manufacturer, had almost no effect on this problem and sometimes seemed to make it even worse. At other times, on what I began to call "marimba days", the wood sang.

Not knowing what to do, I tried to improve the sound by tightening and loosening the cord, waxing the bars (OK, it's pretty stupid, but I thought it might keep the humidity from flattening the pitch . . .) and raising and lowering the ranks of resonators. Some days there seemed to be a subtle improvement when I performed one or more of these procedures. But that was the problem, the changes, if any, were subtle. The instrument still sounded like . . . ah . . . well, like a bad xylophone, instead of a good marimba.

At that time I didn't understand marimba acoustics and assumed, as many people still do today, that the bars had gone flat. True enough, the bars probably *had* gone a few cents flat in the hot weather; however, blaming the bars for the terrible tone and short ring is akin to blaming foul sounds coming out of a guitar amplifier on the speaker or electronics, when you haven't tuned the guitar strings in weeks.

I had heard some vintage instruments from the 1930's and 1940's that obviously needed tuning. Many of those bars *still had good ring and a full-bodied tone*. How could that be? Some of those instruments seemed to be very far out-of-tune compared to my instrument on its worst day, yet, the ring and tone seemed relatively unaffected. Clearly, the dead sounds coming out of my marimba in certain weather conditions were not strictly related to the bars being thrown a little out of tune by temperature changes. Something more serious was going on here.

<u>The Introduction of Synthetics</u>

Evidence began to pile up showing that the problem was not with the bars, but with the resonators. When synthetic bar material was first introduced some thought this new material was going to cure all the weather-related sound problems "caused" by the rosewood. Advertising headlines read "unaffected by temperature and humidity" Hooray, Hooray!! So durable, it's "bullet-proof!" As it turns out, this is a more relevant feature today than we could have imagined in the 1970's!

Twenty years later I can think of six different brands/formulas of synthetic bars for sale in the world. But, despite the advertising claims, in hot or cold halls (or -- even more obviously -- on the football field) the tone and projection of these instruments deteriorates almost as quickly as rosewood *because the problem all along was not with the bars, but with the resonators*. An inexperienced player might think that the instrument is still ringing well because his ears are only two feet away from the bars and resonators. The weak but long ring of the fiberglass bar may still be there in hot or cold temperatures, but the characteristic sound of the marimba - a full bodied, gutsy sound made up of the tube and bar ringing together - is lost with the synthetics, just as with a rosewood bar! You don't have to listen in a perfect concert hall setting to hear this: compare the sound of the sideline keyboards in a drum corp on a 70° and 80° day.

I remember the denial and disbelief that originally met my assertion that synthetics were just as subject to deterioration in tone as rosewood -- that the reason marimbas sounded so terrible in hot weather *was not so much that the bars went flat, but that the resonators went sharp*. How could the resonators go *sharp* in hot weather -- don't things expand in heat? Yes, but that is completely overshadowed by the fact that the speed of sound increases at higher temperature. String instruments go flat under the stage lights because the main vibrating thing, the string, expands. Clarinets go sharp because the main vibrating thing, the air column, vibrates faster.

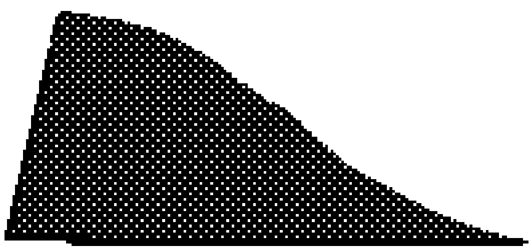
Any acoustic scientist worth his salt could probably have told the manufacturers years ago that the problem that players were hearing in different performance situations was not caused principally by the bars, but by the resonators. Had someone only asked! Even the designers themselves, had they really been passionate about the marimba, could have found out many of the answers. I'm not saying it is easy -- you have to read a half dozen acoustics books to assemble all the pieces of the puzzle, but the information is there in any public library for anyone who is interested. Recently I found a great book that succinctly explained in layman's terms much of why we hear what we do on marimba: it is *Science and Music* by Sir James Jeans (Dover Publications, 1937). Some of what he writes about is so relevant to the design of marimbas and vibes that it merits quoting here.

"We have already seen that any change of temperature alters the speed of sound in air very appreciably . . . It has, however, far less effect on either the dimensions or the elasticity of wood or metal. Thus when the temperature changes, we may almost disregard any change produced in the dimensions of pipes or resonators . . .The only thing that changes appreciably is the column of air in each pipe, and the frequency of its vibrations will change in exactly the same ratio as the speed of sound."

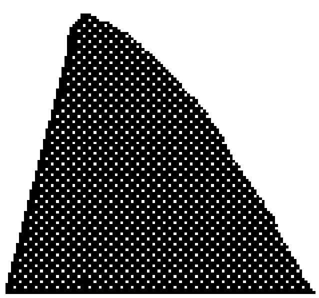
A simple experiment confirms this. Point a blow drier (with the heat switch off) into a resonator and measure the pitch with a strobe tuner. Flip on the heat switch. Within a split second, the strobe spins like the wheels of a criminal's getaway car on TV. You can hear it. Next, remove a rosewood bar from the instrument and measure its pitch with the strobe. Now "blow dry" the bar with the heat on. What happens? Nothing. Well, not exactly nothing, but you've got to really toast the thing to get the strobe to even move. So, the resonator goes up like a rocket and the bar goes down like, well, like the fuel gauge in a four-cylinder car when you drive 55. (Sorry, I've run out of metaphors -- and space. To be continued . . .)

<u>End of Part I</u>

In the first half of this article (PN Vol. X, No. X, p. xx) we discussed the fact that weather conditions affect the tuning of the resonators much more than the bars. In warm weather, for instance, the bars go a little flat, but the resonators go very sharp. Lets look at some pictorial representations of what this does to the sound of a marimba. First of all, when the bar and resonator are in the proper relationship to one another, the tone will be full, rich in fundamental, and the ring of the bar will decay smoothly. The "envelope" (acoustician lingo for the shape of the attack, ring and decay pattern of a sound) might look something like this: (The vertical axis is volume and the horizontal axis is time.)



If the temperature gets too warm, the resonator goes sharp to the bar. This results in the decay time being too short. The envelope might look like this:



If the temperature gets too cool, the resonator will be too flat to the bar. This results in the tone sounding thin and weak. It will lack in volume and fundamental, and the decay time will be long, but most of the after-ring will be too soft to be heard in the audience. The envelope might look like this:

Of course, these are examples only -- and pictorial representations of sound at that. There are as many possible envelopes as there are individual marimba bars and individual sets of circumstances.

Progress

In recent years a few major manufacturers of marimbas have spent many tens of thousands of dollars to develop and patent tunable resonator plugs in an effort to give the player control over these undesirable changes in the response of keyboard percussion instruments. This is not as simple as making some kind of sliding force-fit stop, or a tube within-a-tube, the way you might at first imagine. Once you begin to actually make a prototype, you come up against a very inflexible and discouraging reality. Just like a leaky pad on a woodwind instrument, the slightest pin hole of an air leak around a resonator plug will kill the volume and fullness of tone of that bar.   Almost every simple design you can think of has one or more fatal flaws: they leak, they get stuck, they take too long to change position, they don't seal at the leading edge or tend to camber away from 90° to the side of the tube and therefore lose "focus", they just sound bad for no apparent reason, or, they work and sound great, but they cost $50 each to make! These are some of the reasons why a convenient-to-use, tunable resonator plug that seals perfectly at the leading edge of the cap is so difficult to design and manufacture.

Why are the tunable plugs only put on the bottom octave of most instruments? Most people believe that you don't need tunable resonators on the higher notes because the upper range isn't as affected by the weather. Sir James disagrees:

"Actually small pipes are slightly <u>more</u> affected than large by changes of temperatures." (my emphasis.)

Once you experience for yourself the dramatic improvement in the ring-time of the mid and upper range, and the new-found control over volume and tone, one can't help but feel that having tunable resonators in the low range only, is just a tease.

<u>The Emperor's New Clothes</u>

To return to the opening quotes: One expert says *raise* the bank of resonators for warm weather, one says *lower* it for warm weather. They both can't be right. I have been asked about this issue ("do I raise or lower the resonators for hot weather?") by dozens of college percussion teachers through the years (many of whom, I'm sure, have excellent ears). Why is everyone so confused? The reason the experts can't agree is because moving the whole bank of resonators up and down ***makes such an insignificant difference to the tone of the instrument, nobody can tell what is happening!*** The addition of knobs or levers to position the bank of resonators, instead of just different slots in the resonator bracket, just makes it more convenient to be confused.

Sure it's confusing, because the fact is, moving ***the resonators around does not tune them.*** Waving them in the air or chanting at them doesn't tune them either. You can move the entire rank of resonators to China and they will still be tuned to the same pitches as long as the temperature and humidity are identical that day in China. However, this is not to say that both authors are equally wrong.

Logic would tell you to move the set of resonators lower in warm weather (make the distance between the plug and bar longer and therefore "lower"). But logic doesn't prove out here any more than it does in many other percussive debates. The pitch of the tube is not determined by the distance of the bar to the plug, it is determined by the distance of the *open end to the plug* (or, even more accurately, a little past the open end to the plug). Knowing about this "end correction" - the wave length extending a little beyond the open end - you might be led by logic to think that moving the bars closer to the open end of the tube would "squish it down", (smaller) and that would then make the note sharper. But, in fact, that doesn't happen either. In fact, not much of anything happens.

But a little tiny thing *does* happen that makes moving the resonators *up* in warm weather the better of the two alternatives. There is a very slight (and very esoteric) "proximity effect" that flattens the response of the resonator slightly when something approaches the open end of the tube. Obviously, any improvement is frequently not enough for even an experienced player to hear, and thus, all the confusion. If the player is having difficulty hearing the improvement, how about the audience? It also needs to be pointed out that this "proximity flattening effect" has no parallel for cool temperatures. Move the resonators away from the bar and all you do is "de-couple" them and lose volume.

In any case, the tuning changes that take place in rosewood bars due to temperature and humidity are not uniform. (This is why tuning or retuning them in anything but a temperature and humidity-controlled environment is not totally accurate. There is no such thing as accurate "temperature correction" when it comes to rosewood.) Each bar is unique in its grain, elasticity and hardness. In other words, some bars go flat sooner, later or to a greater or lesser degree than others. Therefore, moving the resonators as a unit, even if it could substantially change the pitch of the tubes, which it can't, will never compensate for the variations in individual bars.

Why, until recently, did the major manufacturers offer only high and low resonator brackets, instead of tunable resonators? After all, some models of marimbas produced in the early part of this century offered crude versions of resonator tuning. I believe it was simply supply and demand: players weren't asking for tunable resonators because they really didn't know what a huge difference they could make. Besides, offering the high and low bracket feature adds only a few dollars to the cost of each instrument. Adding resonators tuners can add a few dollars to the cost of each note.

Will tunable resonators "catch on" and become the norm, rather than the exception? Only time will tell, but I can tell you from personal experience that once you've gotten a taste of being able to customize the sound of your instrument to the hall's acoustics, control the ring and volume of individual bars and completely compensate for temperature, it's hard to go back.

<u>End of part II</u>

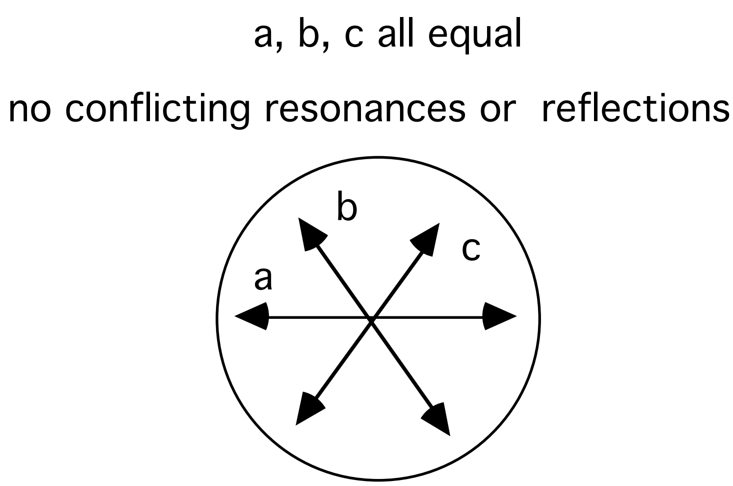
Acoustics of Resonators

Part III

Resonator Shape

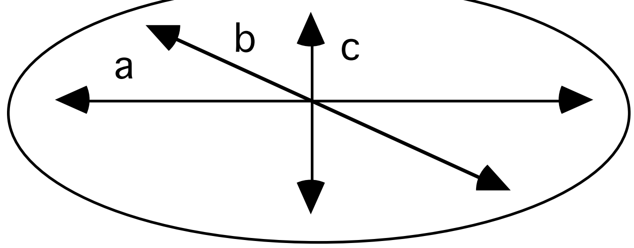
There is no controversy among acousticians about the fact that the shape of a resonator affects the tone. The most perfect resonator is a sphere. All the internal dimensions are the same, so no non-harmonic sounds are reinforced. This is often referred to as a “Helmholtz resonator” after the 19th century acoustician Hermann Ludwig Ferdinand von Helmholtz who developed these highly efficient resonators. But try to imagine using resonators the shape and size of beach balls under each of the low bars of a marimba. Not a good solution for us slat tappers.

Round, tubular resonators are the next best thing, and the fact that they are usually the choice for organ pipes is no surprise. They reinforce only the harmonic components since the only two internal dimensions are the length and diameter of the tube. In other words, all reflective surfaces are equidistant:

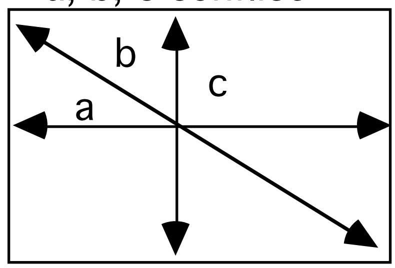


Not so with oval, square or flared resonators:

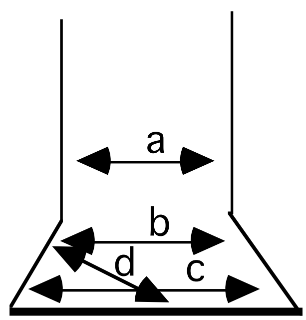
a, b, c all different(confllict)



a, b, c conflict



a, b, c, and d conflict



These shapes reinforce non-related resonances that are products of the uneven internal dimensions.

This is not as serious a problem in the design of an organ pipe, but all marimba, xylophone and vibe bars contain numerous non-harmonic “edge”, “side”, and “end” tones, as well as other “junk pitches” that can not yet be finely controlled in the tuning process. Non-round resonator shapes amplify these shortcomings at the expense of a sweet, round, harmonic tone quality. Oval tubes are particularly problematic as can be quickly ascertained by blowing into them. It is difficult to get a clear pitch out of a large, low range oval tube, but the same blowing effort into a round resonator produces a sweet singing note.

In terms of size, bigger is better, assuming the bar and resonator are the right size for proper "coupling". A larger diameter tube accentuates the fundamental, which is just what is lacking in the low notes of most marimbas. (This is not to discount the importance of the bar width, which is equally important. Do not confuse marimba bars with piano strings where longer is better. To visualize the importance of bar *width* for moving a large quantity of air, would you rather fan yourself with a one inch diameter 6 foot long broom handle or an 8 x 10 inch sheet of paper? Case closed.)

Resonator Material

There is still some controversy over the effect of material on the sound of a resonator. Organ builders have always operated on the seemingly obvious assumption that the material the pipe is made of influences tone, but some scientists have cast doubt on this. The Groves Dictionary of Music and Musicians entry on the *Physics of Music,* has a pertinent comment.

". . . the physicist (must) have a musical ear, or be able to develop one, capable of hearing the overtones, difference tones and particularly summations tones . . . It seemed 'logical' to many people . . . to doubt the existence of what they could not hear."

Sir James Jeans has this to say.

"Organ-builders usually specify the precise nature of the metal or wood of which their pipes are to be built, the reason being that the quality of tone depends on the material of the pipe. For instance, pipes of wood produce a heavier, but also a warmer and more mellow, tone than pipes of metal . . . The same is even more true of orchestral instruments; a silver clarinet

sounds very different from one of wood, just as an orchestral flute sounds different from a penny whistle. If the sound were produced merely by the vibration of a column of air, such differences as these could not arise; the air would vibrate in the same way no matter what material was used to enclose it. The fact that differences of timbre can be heard shews (that's what he said, ed.) that the pipe must itself contribute something to the production of the sound. The pipe has of course its own free vibrations, their frequencies depending naturally on the material of which it is made. Clearly, then, some of these must be reinforced by resonance with the vibrations of the column of air."

I have heard players like Bob Becker and Gordon Stout, who have used brass resonators almost exclusively for many years, claim that there is a distinct difference in the projection of an instrument with brass resonators compared with one that has aluminum resonators. All of this makes perfect intuitive sense as you tap on a brass resonator and compare its "ping" with the "clunk" of aluminum. On the other hand, I have grown suspicious of such instincts when it comes to percussion instruments, since so many of the already disproved myths of tone production also seem to make intuitive "sense."

In my own experiments on testing various materials such as steel, aluminum, plastic and brass there appeared to be clear subjective differences in the sounds of the materials. Sir James says, in reference to violin tone,

"We have seen that the tone of a Stradivarius differs from that of a cheap modern violin mainly in possessing a superabundance of very high harmonics. . ."

Could it be that what we perceive as different and "better" about brass resonators is the very high harmonics of the tubes freely vibrating in resonance to the bar and air column? If this is so, the difference between brass and aluminum might be limited to the very highest audible range -- a subtle color enhancement that not everyone can hear -- just the same as the difference between a real and fake Strad. Whether these differences are measurable on the latest scientific equipment, remains to be seen. Malletech is currently involved in just such a research project.

Part IV

Tuning Your malletech® Resonators

by Leigh Howard Stevens

There is an old joke told by orchestral musicians about harpists. "Harp players spend half of their time tuning their harps and the other half playing out of tune." If every new owner of a malletech® Concert Keyboard reads this instruction sheet carefully, similar jokes about marimbists will never develop.

Aural Illusions

Before we discuss how to adjust the patent pending tuning plugs on your malletech® Concert Keyboard, you should be aware that all keyboard percussion instruments are subject to a few strange acoustical phenomena that occur in certain rooms that can confuse even the most attentive and well-trained ears. You may have already noticed these peculiarities on other instruments. Consider these sounds to be the equivalent of optical illusions ("aural illusions"?).

A typical teaching studio or home music room will have unpredictable effects on an instrument like the marimba. The distance of the resonators to the ceiling, the distance to the side walls, the distance between the side walls and the sound absorbing properties of the all surfaces have a tremendous effect on the tone, decay and volume of each note. Sometimes a note will seem to have very little volume compared to its neighbor (a result of "standing" or "stationary" wave forms), but moving your head two feet one way or another eliminates the problem completely. The first thing to do when you hear something odd is to move the marimba three feet or so to a different location in the room. If the results are the same, stand on the audience side of the keyboard and listen to the same note.

While moving your ears or the marimba around the room will eliminate most of the problems caused by the geometry of a small room, it will do nothing to mitigate the effects of acoustic ceiling tile, carpeting on the floor or mysterious buzzes coming from lighting fixtures, filing cabinets or window panes. Do not expect to produce as powerful tone and resonance in a room covered with sound absorbing materials as you would in a concert hall. The oversized resonators in the low range require a larger than average room to allow the tone of these notes to fully bloom.

The best place to listen to a marimba is, of course, in a good concert hall. Most of the oddities caused by small room acoustics will be eliminated in a good hall. An auditorium with a 2 to 3 second reverberation time and solid reinforcement of all registers is ideal for performance and critical listening. It's too bad that we can not do our daily practice in such an environment!

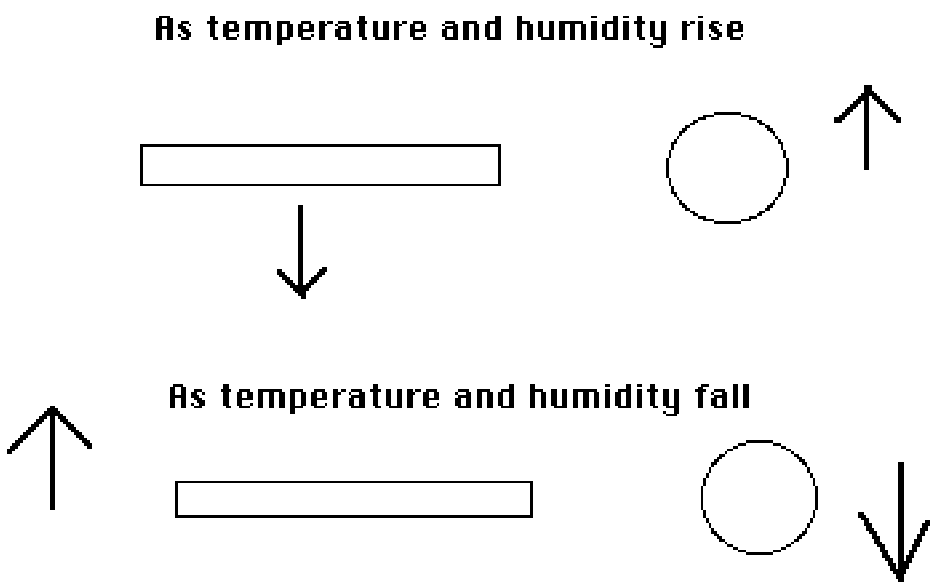
Tuning vs. balancing

To be fair to harpists, we do not really "tune" the marimba in the same sense that a harp, piano or violin is tuned. We are not as concerned with the absolute pitch of the resonator as we are the relationship of the pitch of the resonator to that of the bar. In fact, we do not even tune the resonator exactly to the pitch of the bar: as we will see, the tone is usually the best when the pitch of the resonator appears to be slightly above that of the bar. However, two bars an octave apart, perfectly in tune, can sound slightly out of tune if the resonators are misadjusted.

What we are usually doing when we tune the resonators is balancing the timbre, volume and sustaining qualities of the instrument. Wooden keyboard percussion instruments are particularly finicky in terms of their tone quality. One reason for this is that each marimba bar is unique. The grain of the wood, its density and elasticity, and therefore much of the tone quality are the results of nature. Only the actual tuning (pitch) of the bar is controlled by man.

Weather and pitch

An even more important reason that the tone of a marimba varies more than other instruments is the fact that the two vibrating systems, bar and resonator, do not react to temperature and humidity changes in the same manner. The bars react to high temperature and humidity by expanding and thus going flat. While there is a certain amount of expansion of the resonator tubes in hot weather, this slight flattening of the pitch is overshadowed by another factor. The speed of sound increases as the temperature rises. As a result, a column of air of fixed length sharpens as the temperature rises. A way to visualize this is to imagine that the sound waves are making their round trips through the resonators more quickly -- and so their frequency increases.



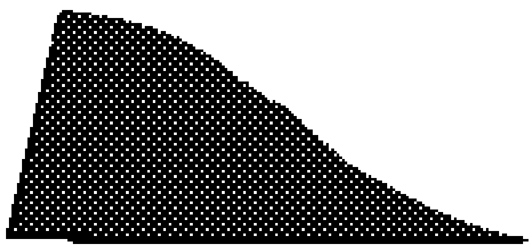
An easy way to remember this is:

"The pitch of the resonator follows the temperature".

Basic envelopes

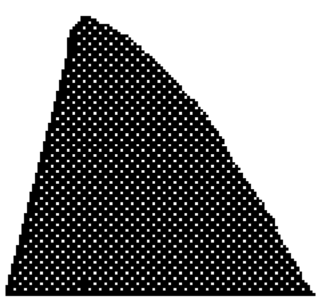
The audible "shape" of the sound (the attack, after-ring and decay time) is called the "envelope" of the sound. This envelope is one of the main things you listen for when adjusting resonators.

When the bar and resonator are in the proper relationship to one another, the tone will be full, rich in fundamental, and the ring of the bar after the attack will decay smoothly. The envelope might look something like:



If the temperature gets too warm, the resonator will be too sharp to the bar. This results in the decay time being too short.

The envelope might look like this:



If the temperature gets too cool, the resonator will be too flat to the bar. This results in the tone sounding thin and weak. It will lack in fundamental, and the decay time will be long, but most of the after-ring will be too soft to be heard in the audience. The envelope might look like this:

Of course, these are examples only -- and pictorial representations of sound at that. There are as many possible envelopes as there are individual marimba bars and individual sets of circumstances. As you gain more experience with tuning resonators you will begin to hear certain categories of symptoms of out of tune resonators. In time, you may even become more sensitive to changes in temperature and be able to predict how the instrument will sound just from your impression of room conditions.

<u>When</u>

malletech® keyboard percussion instruments have their patent-pending tunable plugs pre-set to average positions for "normal" room temperature (72° f) and a moderate humidity level (50%). Most players will not hear any serious deviations in resonator response down to 71° and up to 73°. In other words, malletech® instruments have a 3-degree range in which all but the fussiest players will happy with a medium setting of the resonator tuning plugs. Therefore, if your marimba is kept in an institutional setting where the temperature and humidity are kept constant, there may be little need to adjust the resonator tuners. After you have found the settings that you prefer for the stable conditions in your building, you can tighten them and virtually forget that the tuners are there.

However, if your marimba, like mine, finds itself in Florida on Monday (auditorium at 77 degrees, 75% humidity), North Dakota on Wednesday (auditorium at 68 degrees, 30% humidity), and at home on Friday (where conditions vary with the season and last month's heating or electric bill), you will probably want to spend a few minutes adjusting the resonators after each change of conditions.

Since each bar is unique you may find that certain notes need more or less adjustment than others. Do not assume that your instrument will sound its best when all of the plugs are proportionally positioned. This will rarely, if ever be the case. I find that when spring arrives (and therefore humidity and temperature start to go up in my music studio), one or two notes seem to show the effects of the seasonal change long before the rest of the marimba.

Adjust the tuning of a resonator when you experience one of the following four conditions:

- the envelope of a note is too short
- the envelope of a note is too long
- the overall volume or fundamental response is too soft compared to its neighbors
- the overall volume or fundamental response is too loud compared to its neighbors

How

To move a malletech® Patented Tunable Resonator Plug, unlock it by loosening the wing-screw 1/2 turn or so. Pull or push on the wing screw or on the surface of the plug itself to move the plug to whatever position you want. When moving the plug down, pull steadily on the wing-screw, or push on the top of the plug through the resonator. Re-tighten the wing-screw when you are in a position you want to stay in or listen to carefully. Take note of the following.

a. Depending on the humidity, temperature conditions and exact fit of the plug to the individual tube, certain notes will sound fine with the wing-screw loosened, and others will lose most of their volume. On most notes and under most conditions you will be able to find your preferred position of the plug without tightening the wing-screw. Tightening the wing screw will increase the volume or ring time. The low tubes are most susceptible to volume loss when the plug is in its untightened, unexpanded state.

b. Certain notes may require a pull or push with both hands to move the plug.

c. When putting heavy pressure on the resonators, be sure to hold the resonator rails or support an adjacent tube or two with your knee or other hand.

d. You can help push a plug up or down with a mallet handle or the reference stick.

e. Tighten the wing-screw with your hand -- do not use pliers or other tools.

f. Use the reference stick to quickly adjust the resonators back to the approximate positions for 72°.

g. Use the reference stick to reorient yourself when you "get lost".

Since the volume of air in the lower resonators is greater than that in the upper, the lower notes are less sensitive to the tuners than the upper notes. This means that while a very keen ear may be able to hear a slight character change after moving the plug on the low 'E' 1/8 of an inch, this same change in the midrange will be much more obvious. In the upper range the effect of the resonators is much more subtle. While an adjustment of 1/8 of an inch produces more than a 1/2 step change in pitch in the top few notes, it may still be difficult to hear the exact spot that is best. It is probably wise to gain experience in other ranges before trying to finely adjust the response of the top octave.

A good general rule:

Sharpen the resonator to achieve more volume and flatten the resonator to achieve more length.

The problem with this rule is that the sound of a very sharp resonator is very similar to a flat resonator. If both the temperature and humidity are high (lets say 80° and 95% humidity) and the cap is already in a sharp position, the envelope may be long and the volume weak. Ordinarily, you would shorten the ring and strengthen the volume by sharpening the pitch of the resonator. If you try this standard procedure the problem will not be alleviated. In this set of circumstances, the long, weak ring may be caused by the tube being so very sharp to the bar that it is not really resonating the pitch properly. In this case, flattening the pitch of the resonator quite radically will bring the tube into harmony with the bar, both shortening and strengthening the tone.

I have been tuning resonators for fifteen years now and my ears are still tricked occasionally. This mistake can be avoided if you first check the pitch of the tube by blowing into it. Get your mouth down near the space between the bars and aim your breath into the resonator. Now tap the bar and compare pitches. With practice you may be able to get an accurate idea of the pitch of the tube with this method. (As mentioned earlier, most players find that they prefer the sound produced when the resonator is slightly above the pitch of the bar.) This sharpening of the tube to the bar is progressive - the top octave resonator may sound more than a half step high to the top bar. There is no arguing with personal preference. In the top octave the resonator caps act more like reflectors than real resonators.

Learning experiments

1). Using the reference stick, check to make sure that the lowest 'D' sharp resonator plug is in the "normal" range -- that is, within 1/2 inch or so above or below the line on the stick. If this were a midrange note, normal range would be within 1/4 of an inch or so above or below the line on the stick. In the mid-upper range this would narrow to 1/8 above or below and in the top octave, 1/16 of an inch.

2) Tune the 'C' sharp resonator 1/2 inch flat to its normal position. Compare the sounds. Note that the 'D' sharp has a full tone of normal length and that the 'C' sharp has a very shallow, weak sound of excessive length.

3) Place your hand over about one half of the opening of the 'D' sharp resonator. Instead of the top of the resonator being a circle, half of it is now closed off so it looks like a hemisphere. Listen to the resonator response with your hand blocking part of the opening as just described. Compare the sound to the 'C' sharp, which should still be tuned very flat. The two sounds should have much in common. Both notes will lack volume, fullness and fundamental and will also ring too long for most musical situations (about 3 to 4 seconds -- normal ring time in this range would be about 1 to 2 seconds). Strike the ‘D’sharp and remove your hand right after the stroke. You should hear a crescendo as the pitch of the tube returns to normal while the bar is still ringing. You will hear a slower version of this crescendo when you retune the ‘C’ sharp in the next step.

4) Retune the C sharp by ear -- without using the reference stick. Check the position with the stick.

5) For practice, repeat steps 1-4 with other adjacent notes in other ranges.

6) Mid-term test: de-tune 10 or more resonators. Try not to memorize which ones you changed. Play on the instrument and also check chromatically. When you find a tube you think needs adjustment, do so. When you are done, take off the bars and check each tube with the reference stick to see if you missed any serious de-tunings.

7) Final exam: Before performing in a hot or cold room, take 10 to 15 minutes to adjust resonators to the conditions. If the room gets warmer due to the lights and audience in the first half of the program, you may want to take the time during intermission to make further changes.