AN INTERESTING DULCIMER EXPERIMENT

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Experiments into the Acoustics and Vibrational Behavior of the Appalachian Mountain Dulcimer

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Contents

Chapter 11 Bracing (cont.)

Preface

This book contains summaries of acoustic experiments conducted on the Appalachian Mountain Dulcimer over the years 2008 to 2018. The experimental results were previously posted to the discussion forum of the now non-operational *Everything Dulcimer* website under the thread title of “An Interesting Dulcimer Experiment”.

I had started making dulcimers again in 2001 after a hiatus of about 30 years. A number of instruments were constructed and one or two had tonal characteristics that I just did not like. I reluctantly realized that correcting those deficiencies required knowledge that I did not possess — how should a mountain dulcimer be constructed so as to modify its tone in a certain direction? There were no serious acoustic studies of the instrument that I could find, and current builders, whilst clearly producing well-regarded dulcimers, provided conflicting and unsatisfactory answers to my questions. It ultimately dawned on me that I would have to find out for myself, and that I would have to undertake practical experiments that might possibly reveal ***the way forward.*** I should have known better.

The experiments generally took the form of making a constructional change in a newly built or modified test dulcimer, then taking and analyzing some acoustic measurements and finally the perceptual judging of the structural change on the resultant tone of the instrument. Control comparisons took the form of before and after measurements and listening judgments for a single test instrument, or sometimes comparisons between a small group of simultaneously constructed dulcimers.

There were serious deficiencies in these experimental methodologies. Although experiments were always conducted as carefully as I could, taking into account possible errors and confounding variables, they were not of laboratory standards. The excuse I offer is that I had no idea of what constructional factors influenced tone – I was therefore looking for gross effects, not subtle ones, nor just “statistically significant” ones, so most experimental errors could be tolerated. If I could not discern a clear tonal difference before and after an intervention, the intervention might not be of major significance for tonal modification. The greatest deficiency was in the perceptual judging of any change – there was a judging panel of one - myself. I like to think I am a critical judge of the dulcimer by now, especially my own instruments, but acoustic perceptions are notoriously unreliable, and yours might be different to mine. Take that into account (as with all tonal advice from any luthier).

Also, the experiments deal only with the traditional full-length fretboard configuration of the mountain dulcimer. Results may or may not be applicable to other configurations, such as truncated fretboards with the bridge attached to the top plate. I can't say.

When the *Everything Dulcimer* website ceased operation in 2018, the *Dulcimer Makers* discussion forum disappeared, including my contributions to "An Interesting Dulcimer Experiment", and the comments from many other builders. Fortunately, Jon Leachtenauer, another contributor, had been collecting and collating the experiment summaries over the years and was prepared to undertake the task of re-organizing the information to make it more accessible, and to disseminate it to interested dulcimer makers. Together, Jon and I have edited the on-line discussions to make them more consistent and readable, and in some cases incorporated the essence of other builders' comments. Those builders have remained un-named mainly because of our uncertainties in obtaining informed consent — however, their contribution often shed further light on the matter under discussion. Experience counts for a lot.

The end result is still not a completely coherent record and the reader should be aware that the experiments took place over a ten-year period, during which time knowledge was continually accumulated, some of which contradicted early results. Some content here will no doubt be shown to be incorrect in the future. Collating the experiments into broad subject groups has made searching easier, but has necessarily disrupted the time line of the discussion forum. For this reason, the date of each experiment has been included in the title. I have always tried to indulge in as little speculation as a luthier is able, but the earlier the experiment the lower the knowledge base and the more likely the inclusion of speculation. In addition, the many sound-clips posted to the on-line forum in support of some conclusion, could not be included here, and textual or graphical explanations have been substituted.

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September 2018

Foreword

As an amateur luthier with a science background, I began collecting Richard's postings in the *Dulcimer Makers* forum of *Everything Dulcimer* some ten years ago. After several years, it became evident that in order to be of use to me, I needed to organize the material in, for me, some logical fashion that I could better use. As I was in the process of doing so, the *Everything Dulcimer* web site ceased operation. Along with others, I urged Richard to publish his work so it would be available to the builder community. Richard graciously accepted my offer of help, and we began this effort. It quickly became apparent that a printed paper book of over 400 pages and 300 illustrations would not be economically practical, so we chose a DVD format.

This is not a "how to" book, but rather, in my opinion, a foundation for further research in the construction of Appalachian dulcimers. The book leaves many questions unanswered for others to address. Unlike the guitar and violin community, there is no published body of knowledge spanning years of study. It is my hope that Richard's efforts will encourage others to further his work (and that he will perhaps continue his efforts as long as he can).

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USA

Introduction

I cannot tell you how to make a good mountain dulcimer, no-one can. You will never know, except in a general way, what a new mountain dulcimer will sound like until you string it up for the first time and play it. Even that newly released sound may not be the end of the story – the tone may develop, subtly or significantly, over months and years as glues and finishes harden and wood ages and settles in. Or it may remain the same.

This is not a bad thing for luthiers, new or experienced. If we had an unfailing recipe for making superior mountain dulcimers (or any other instrument), they would be spitting off a production line somewhere, at low cost, and there would be little call for hand-made instruments.

Luthiers as a class, myself included, have a strong tendency to connect their building methods with the sound of their instruments, and claims are often made that particular woods, design, and construction methods or materials will result in a particular sound. Instrument builders love their work, and are proud of their results. Anecdotes abound regarding superior outcomes from particular methods or materials, but hard supporting evidence is almost non-existent. The reasons for this situation are fairly clear – there is no agreed upon definition of a "superior" dulcimer sound, or even a general consensus; the ***sound*** of the instrument is by no means the only factor making an instrument desirable; and people have individual tonal preferences for an instrument. One person's "superior" can be another's "unimpressive".

So is there a working definition of a "superior" instrument? Two that I have seen in Mark French's book *"Engineering the Guitar"* [1]are:

- A luthier can be said to make superior instruments if he or she can consistently command high prices for them.
- A superior instrument is one where the player does not have to work hard to produce the sound he or she is aiming for.

These are player-centric definitions, rather than builder-centric, and as it should be. No mention of wood or construction methods here. In fact, if a list was made of, say, ten

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[1] French, Richard Mark, "Enginerring the Guitar:Theory and Practice", Springer, New York, NY, 2009, ISBN 9781441944962

important factors influencing mountain dulcimer sound, wood species might not even make the list.

None of this is to say that luthiers in general produce poor instruments, they don't — many builders consistently produce fine sounding dulcimers, which are also wooden works of art. The disconnect that sometimes occurs between the rhetoric and the reality can be excused as artistic license and enthusiasm by a passionate builder, and is no worse than in many other areas of advertising. However, the ***connection of the rhetoric to the building proces****s* by a luthier does a disservice to a new builder, standing at the bench, looking at the wood in front of him or her, and searching for guidance as to what to do next. Prescriptive directions of the form "do this, and it will sound like …" are likely to result in disappointment.

In my former occupation as a biomedical engineer, much of my time was involved in the analysis of the human voice, particularly the disordered voice. Many people who relied on their voice for their occupation passed through the Speech lab at my hospital — they had turned up there because something had gone wrong with their voice.

At the other end of the vocal spectrum are the superior or professional voices - singers, actors, and other athletes of the vocal mechanism— and for them, in the 1980's there were a series of conferences at the Julliard School in New York called the *Symposium on the Care of the Professional Voice*. The conference arose out of the recognition that the high-performance voice was poorly understood; that singing teachers, whilst individually competent and sometimes outstanding, were nevertheless speaking a different language from every other singing teacher; and that physical science might offer some hope of bringing uniformity of terminology and method to the understanding and teaching of voice, with benefits to teachers and singers.

Initially, singing teachers raged against the intrusion onto artistic sacred ground by scientists; and scientists decried the lack of rigor and fundamental knowledge of the singing teachers. But after a few years of conferences, the huff and puff died down and it started to dawn on both groups that both were basically correct, and that each needed the other. Physical variables such as frequency and intensity cannot capture the emotional essence of a voice, but unless the object of study is at least basically physically understood, and some attempt at uniform parameters is agreed upon, then productive communication is impossible.

When I left that field, the status was that the arts and sciences were willing to talk to each other. Much research was done and published — pure science, artistic applications of science, and artistic work informed by increasing underlying knowledge. But even with all the research effort, which still continues, there was never any world-wide agreement regarding the meaning of the various terms used to describe voices, and no agreed upon definitions of commonly used voice measurements and assessment methods, or agreement on their value to a teacher or scientist. The trouble is that people were involved.

The musical instrument building and playing community is in precisely the same situation — the friendly tension between "art" and "science"; the multiplicity of meanings for the same commonly used terms; the interpretation of physical phenomena in intuitive ways that mean one thing to the speaker, and something else to the listener; the generally poor performance in transmitting genuinely useful information from the more experienced to the less experienced. This is the situation in which both new and experienced luthiers find themselves in 2018. The ***sound*** of their instruments will be the subject of discussion and analysis, by other builders and by players — both qualitatively and quantitatively. Qualitative descriptions will suffer from misunderstandings and poor communication of meaning; quantitative analyses will be very poor at conveying any artistic or emotional content. The experiments in this document have largely produced quantitative information about how a mountain dulcimer makes sound. They can make no comment on whether the sound is “good” or otherwise. That is for the listener to decide.

For myself, I cannot say that the experiments reported here have led to consistently ***better*** instruments, which was my initial hope. By now I have a fair idea of what I ***like*** in a mountain dulcimer sound, and I think I can recognize a superior one when I hear it. I also know that if an instrument turns out to have that special "something" about the sound, it will not clearly show up in the crude physical measurements I am able to make (loudness, attack, sustain, spectral content, etc.). As well, I understand that my judgments are different from other peoples’ judgments when assessing the quality of the sound, and that those judgments are colored by more than the sound itself — by the playing style, the virtuosity of the player, the context, the appearance of the instrument, the time of day ….. However, the results of experiment ***hav****e* produced some new physical knowledge about mountain dulcimers, and gaining knowledge is never a wasted activity. In a practical sense, the experiments have shown some areas of dulcimer construction to be less important than previously thought by many makers, at least in my estimation. This, in turn, has allowed me to concentrate construction efforts on matters that consistently showed up as being more important to the tonal quality of the dulcimer.

So the purpose of this book is not to tell you how to make a fine mountain dulcimer with a particular tone, but to indicate in a broad way, through experimental results, how a dulcimer might make sound, and to shed some light on the truth or folly of some commonly held beliefs regarding dulcimer building and its influence on tone. There can be no infallibly right, or infallibly wrong ways to make a fine sounding and playing mountain dulcimer, and some of the information presented here will undoubtedly be shown as incorrect as knowledge of the instrument increases. However, this information, gained from ten years of experimentation, may help shorten the pathway to your own realization of fine sounding, long lived, and loved, mountain dulcimers.

When in 2008 I began this series of experiments on various aspects of dulcimer construction and sound production, the results were published on the now defunct *Everything Dulcimer* web site. When that web site closed, some ten years of posts were assembled and preserved in this book. Rather than present them sequentially, they have been organized by general broad topics. For those who may be interested, the dates of the original postings are shown in the topic headings. This will give the reader a small insight into the maturity of my knowledge about the mountain dulcimer at the time of the experiment, and to make allowances accordingly.

Organization

My first experiment (and its post script) is described in Chapter 1. Chapter 2 begins with studies and thoughts on how a dulcimer produces sound. Chapter 3 expands those thoughts with studies on vibration and resonances. Top plate thickness and grooving are discussed in Chapters 4 and 5. The effects of replacing the tops and backs of a dulcimer with different woods and bracings are provided in Chapter 6. Shape and stiffness are covered in Chapter 7 and the influence of fretboard design in Chapter 8 and 9. Bridge design studies are presented in Chapter 10; bracing and side linings are covered in Chapters 11 and 12. A variety of miscellaneous design effects are discussed in Chapter 13, including such things as side ports, sound holes, and sound posts. Chapters 14 through 16 cover factors affecting tone, loudness, and wolf notes. Finally, Chapter 17 discusses the design process, provides some studies of alternative designs including Joellen Lapidus's Princess dulcimer, and provides a summary of various design issues.

Since Australia uses the metric system, most of the measurements provided are in the metric system. However, there are exceptions. String diameter, string height, and string length (VSL) use the conventional measurement in inches. Other measurements were sometimes made in inches simply because of the tool at hand. An appendix is provided showing the conversion between metric and Imperial measures of distance and weight.

Chapter 1
The Beginning

The First Experiment-the Topless Dulcimer-Dec 18, 2008

I had cause to modify an early dulcimer, #13, and took the opportunity to confirm something that I had suspected for a while — that the top plate of a mountain dulcimer is not such a critical component as it is in guitars and violins. At the time there was considerable discussion on the *Everything Dulcimer* website regarding the relative merits of various species of wood for the tops of mountain dulcimers, and how thick they should be, and whether internal bracing was necessary or not. There seemed general agreement amongst dulcimer makers that these things mattered to the ultimate sound of the instrument. However, after having made twenty or so dulcimers, my own observations did not support those conclusions — nothing I did to the tops of my dulcimers seemed to affect the sound very much. So I decided to test some ideas on Dulcimer #13 in an attempt to find out the truth of the matter.

For this initial experiment, I recorded the sound of Dulcimer #13 with the original top — first a short tune, then each individual string, and then the three strings struck simultaneously. A plectrum attached to a wooden pendulum, as shown in Figure 1.1, made the individual and triple string strikes. Trials showed that there was good repeatability for the method, usually within 1dB recorded sound pressure level between strikes.

The top, which was made of Sitka spruce, was then progressively removed, and the recordings repeated. Subsequently, the dulcimer was fitted with an untreated newspaper top, attached with office glue, and after that thin manila folder cardboard. The top bracing was left in place. Figure 1.2 shows top removal stages.

Figure 1.1. Dulcimer #13 – Pendulum String Striker

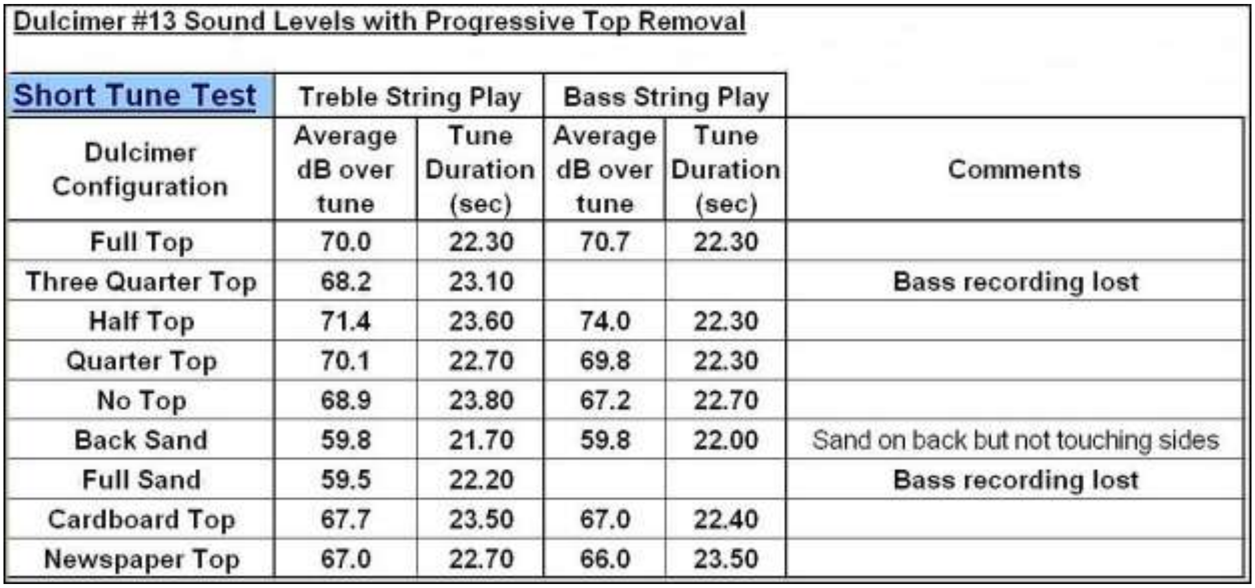
Figure 1.2. Dulcimer #13 - Stages of top removal

Finally, to test whether there was significant sound generated by the fretboard itself, or by the sides, the dulcimer was filled with sand to immobilize the back, and then back and sides, as shown in figure 1.3.

Figure 1.3. Dulcimer #13 – Immobilized back and sides

For the recordings, the instrument was isolated from the bench by 1" soft felt pads and subsequently analyzed by the PRAAT signal processing software package. Sound pressure levels (peak and average) and sustain were measured, as well as listening judgments for tonal changes in the short tune recordings. Three string strikes for each configuration and string were averaged. The results for the short tune recordings are shown in Table 1.1.

Table1.1 Dulcimer #13 Short Tune Sound Level Results



Dulcimer #13 Sound Levels with Progressive Top Removal

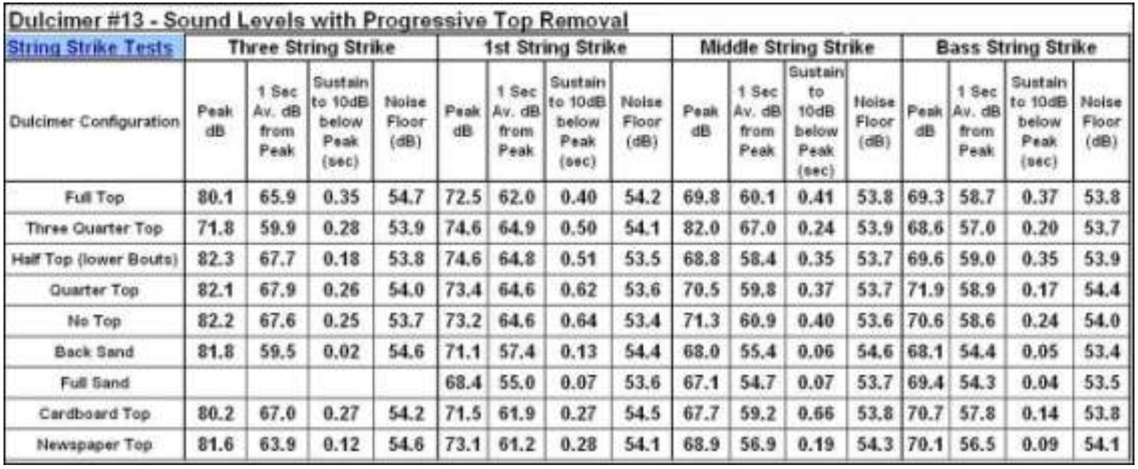
Short Tune Test	Treble String Play		Bass String Play		
Dulcimer Configuration	Average dB over tune	Tune Duration (sec)	Average dB over tune	Tune Duration (sec)	Comments
Full Top	70.0	22.30	70.7	22.30	
Three Quarter Top	68.2	23.10			Bass recording lost
Half Top	71.4	23.60	74.0	22.30	
Quarter Top	70.1	22.70	69.8	22.30	
No Top	68.9	23.80	67.2	22.70	
Back Sand	59.8	21.70	59.8	22.00	Sand on back but not touching sides
Full Sand	59.5	22.20			Bass recording lost
Cardboard Top	67.7	23.50	67.0	22.40	
Newspaper Top	67.0	22.70	66.0	23.50	

The tune (Wildwood Flower) was recorded on the first string, and then the bass string.

There was necessarily some uncontrolled variation between trials, but even so the sound pressure levels are surprisingly similar over all configurations except the sand filled arrangement. Loudness seemed basically unchanged in informal listening. There ***were*** tonal differences between full-top and the various stages of top removal, but all configurations had an acceptable dulcimer sound. The full-top did sound better, in my judgment, than no top, but not substantially so. The results of the sand tests showed about 10dB lower sound levels, which would be perceived as about half as loud as the other configurations, and not much louder than the background levels of about 55dB. This indicates that the fretboard itself was not producing much sound. Nor were the sides, which, even when free to vibrate, may not have been as effectively connected to the strings as they would be when a top was in place. My actual sound preference was for the thin cardboard top!

Results for the single and triple string strikes are shown in Table 1.2.

Table1.2 Dulcimer #13 String Strike Sound Level Results



Dulcimer #13 - Sound Levels with Progressive Top Removal

String Strike Tests	Three String Strike				1st String Strike				Middle String Strike				Bass String Strike			
Dulcimer Configuration	Peak dB	1 Sec Av. dB from Peak	Sustain to 10dB below Peak (sec)	Noise Floor (dB)	Peak dB	1 Sec Av. dB from Peak	Sustain to 10dB below Peak (sec)	Noise Floor (dB)	Peak dB	1 Sec Av. dB from Peak	Sustain to 10dB below Peak (sec)	Noise Floor (dB)	Peak dB	1 Sec Av. dB from Peak	Sustain to 10dB below Peak (sec)	Noise Floor (dB)
Full Top	80.1	65.9	0.35	54.7	72.5	62.0	0.40	54.2	69.8	60.1	0.41	53.8	69.3	58.7	0.37	53.8
Three Quarter Top	71.8	59.9	0.28	53.9	74.6	64.9	0.50	54.1	82.0	67.0	0.24	53.9	68.6	57.0	0.20	53.7
Half Top (lower Bouts)	82.3	67.7	0.18	53.8	74.6	64.8	0.51	53.5	68.8	58.4	0.35	53.7	69.6	59.0	0.35	53.9
Quarter Top	82.1	67.9	0.26	54.0	73.4	64.6	0.62	53.6	70.5	59.8	0.37	53.7	71.9	58.9	0.17	54.4
No Top	82.2	67.6	0.25	53.7	73.2	64.6	0.64	53.4	71.3	60.9	0.40	53.6	70.6	58.6	0.24	54.0
Back Sand	81.8	59.5	0.02	54.6	71.1	57.4	0.13	54.4	68.0	55.4	0.06	54.6	68.1	54.4	0.05	53.4
Full Sand					68.4	55.0	0.07	53.6	67.1	54.7	0.07	53.7	69.4	54.3	0.04	53.5
Cardboard Top	80.2	67.0	0.27	54.2	71.5	61.9	0.27	54.5	67.7	59.2	0.66	53.8	70.7	57.8	0.14	53.8
Newspaper Top	81.6	63.9	0.12	54.6	73.1	61.2	0.28	54.1	68.9	56.9	0.19	54.3	70.1	56.5	0.09	54.1

Overall, there was not a lot of difference in loudness from full top, to no top, to paper top, although there are one or two unexplained anomalies for the ¾ top setup. Again the sand tests showed lower loudness and also a much lower sustain. So in the absence of much sound coming from the fretboard, with the top removed, the dulcimer-like and adequately loud sound must be coming from the back, and possibly also from the sides coupled to the back (with no sand).

This topless dulcimer configuration is not a new thing. A number of European zithers, such as Kanteles and Hummels, often have no back. In this dulcimer case, the back becomes the new top with sound radiating from the vibrating inner surface of the back, and also driving the sides. This is not to say that a mountain dulcimer does not benefit from having a top plate. At least two things, which will affect the tone, are lost without the top plate. The first is the influence of internal air resonances on the sound. These cannot develop in an open dulcimer body, but do contribute part of the total sound in an enclosed instrument. Some air vibration sound emanates from the sound holes and adds to the sound generated by the wood vibrations. The second effect of the enclosed air space is the interaction of the internal air resonances with the wood plates of the dulcimer. Pressure changes inside the instrument will cause the wood plates to vibrate and so to emit sound. This complex interaction between the internal air sound and the wood plate vibrations is what gives an individual instrument its unique sound. Whether the sound is better with or without a top is for the listener to decide. However, general opinion seems to favour having a top plate!

So what has the experiment shown? The removal of the top plate did not markedly reduce the loudness of the instrument. Elements of the sound that are related to air resonances were lost and the tone was modified, but it remained acceptable, as it still does ten years later. The experiment points to the likely possibility that the top plate itself is not the principal driver of the sound, other than the acoustic consequences of enclosing the air cavity. It follows that the parameters of the top plate — wood species, thickness, bracing, etc., are not as important in mountain dulcimers as in other instruments, such as guitars. If this is so, it allows makers more latitude in selecting tops based on aesthetics rather than assumed acoustic qualities, and frees them to concentrate on areas that ***do*** significantly influence the sound. In this case I think the prime candidate is the fretboard. The top plate ***doe****s* vibrate vigorously in a mountain dulcimer, not, however, because of its own intrinsic parameters but under the influence of the glued-on fretboard, which is both more massive than the top plate, and also much stiffer. The fretboard parameters swamp the top plate parameters in controlling the sound of the instrument.

The First Experiment – Postscript-Sep18,2018

The experiment described above was not actually the first that I had undertaken. In 2002, six years before the topless experiment I had made two dulcimers, notionally identical, except that one had a hollow fretboard and the other had an arched fretboard (Figure 1.4).

Figure 1.4. Two identical 2002 dulcimers— hollow fretboard and arched fretboard

The hollow fretboard dulcimer, #14, was given to a friend, who hung it on her wall for sixteen years, where it became a home for wasps nests. The arched fretboard dulcimer, #13, was kept and subsequently used for the topless experiment.

The purpose of making the two was the same as many makers must have done before me — to see if there was a clear tonal difference between an arched fretboard instrument and one with a hollow fretboard. Only informal listening tests were undertaken at the time, but the general consensus was that they both sounded pretty much the same. If the experiment were to be done today I would accept that any tonal difference was no more than would be expected between any two dulcimers of the same shape and size, irrespective of constructional differences. In other words, the fact that one had an arched fretboard and the other a hollow fretboard did ***not*** make them sound characteristically different.

In 2018 the friend returned #14 to me, which, after removal of the wasps, allowed comparison with #13, now with no top. A manila folder cardboard top was again fitted to #13 (Figure 1.5).

As an aside, it is interesting to note the change in color of the New Guinea Rosewood sides, fretboard and scroll in #13 which was exposed to light, and the red of #14 which was in a darkened area for sixteen years. New Guinea Rosewood is a species of Padauk. Many woods show this change of color with light exposure over the years.

Figure 1.5. D#14 hollow and #13 arched fretboard, cardboard top; 2018

Recordings were made of the two – one with a spruce top and the other with a light cardboard top, as well as spectral analysis and vibrational modal studies. The bridge tap spectrum for the two dulcimers is shown in Figure 1.6.

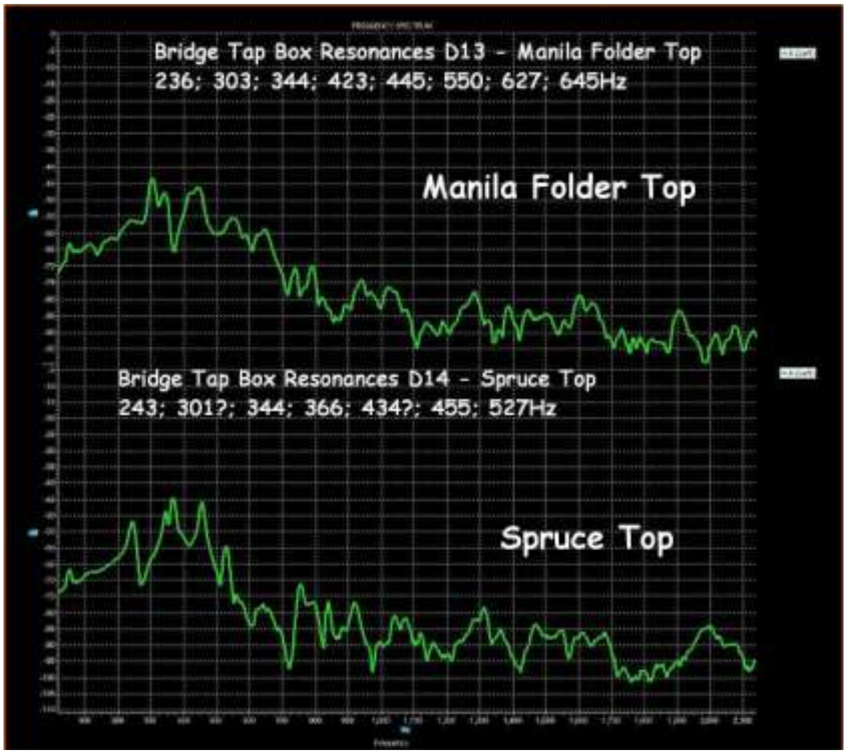


Figure 1.6. Bridge tap spectra — cardboard top and Spruce top

There is a clear resonant structure in the cardboard-top spectrum, although the first air resonance, at 236Hz, is weak, and this probably accounts for the less mellow sound.

The actual vibrations of the cardboard top were not as crisp or clear as the spruce top. An example is shown in Figure 1.7.

Figure 1.7. A vibration mode for manila folder and spruce dulcimer top

Recordings were made of the same tune with various microphones and recording setups. The end result was that there *was* a tonal difference between the two dulcimers, and in blind listening tests I *did* prefer #14, with a spruce top. However, I still liked both of them almost equally.

So at least for my own preferences, a good quality wood top plate is preferred over a paper top, but not significantly so.

Chapter 2
Dulcimer Sound Production

Dulcimer Sound Production Theory-Jan 08, 2009

In the early stages of experimentation, clamping the ends of a mountain dulcimer in order to make some measurements was fundamental to what I wanted to propose as a sound production model for the instrument; i.e., the mountain dulcimer as a vibrating bar. It was almost a make or break requirement. I tried clamping and found it extremely difficult to immobilize the two ends of a dulcimer. In fact, almost impossible. Figure 2.1 is a picture of an attempt to clamp a dulcimer to a large beam. It was clamped nearly to the point of crushing the scroll and end block.

Figure 2.1. Attempt to immobilize the ends of a dulcimer

To my surprise, the dulcimer sounded louder, and better, when clamped to the log—substantially louder and better. More than that, the log itself was vibrating strongly!

Some attempts to explain mountain dulcimers have invoked complex and esoteric mechanisms for sound production, when even the core basics have not yet been explained. As a community, dulcimer luthiers were ahead of ourselves in explaining dulcimer functioning — there was almost no actual evidence, other than unreliable anecdote, to back up any claims. So I made a basic proposal, well ahead of definitive proof; and in due course, experiment showed this to be partially true.

Proposal of a Basic Sound Production Model for Mountain Dulcimers

The production of sound in a mountain dulcimer can be largely explained by treating the instrument as a vibrating bar rather than as a group of vibrating plates.

When the instrument is treated as a complex bar, many things fall into place, at least things that I could get no answers for.

For example, former considerations about how the top and back vibrate resolve into how do they contribute to the overall stiffness of the box/bar structure. Their individual contributions become less relevant. So, whether there is a back, or a top, or both, it doesn't matter — what matters is the stiffness of the structure, and how that translates into bar-like vibrations. Any large surface will vibrate as part of the "bar" and produce sound (think marimba bar, only hollow and more complex in shape). The reason the topless dulcimer did not lose loudness was because the bottom was still vibrating as much as the top formerly was, and the inside of the back became the new "top".

I did not then want to make a full sound production model proposal before doing some more supporting experiments, and as it transpired, a full sound production model was not proposed. But to that point, nearly all of what I knew about the instrument could be better explained if treated as a bar, rather than thinking about which bits were individually vibrating.

That is the ***basic*** proposition. Overlaid on that will be all the subtleties and mysteries that all wooden musical instruments exhibit — air vibrations, air/wood interactions, localized wood resonances, etc., all too complex for the mind to grasp. Mostly, we seem to have been addressing the subtleties, which is fair enough when talking about the distinctions between two dulcimers, and what might be done to produce a characteristic type of sound. But those explanations never made clear to me how the instrument basically works. These experiments are an attempt to provide that underpinning explanation.

Returning to a method of immobilizing the ends of a dulcimer, a proposal was made by another maker to mount the dulcimer on posts set in concrete. This is not a bad idea for solidly mounting an instrument in space, but I needed to make sure the whole instrument can't flex, and flexing is still possible here. Even steel star pickets bolted between the tops of the two posts might allow some flexing.

A free bar needs its end to be unconstrained for it to vibrate; so rigidly fixing the ends should basically kill most of the normal sound of a mountain dulcimer ***if it is acting like a bar***. It might still vibrate like a "string" in that configuration, but it is unlikely to be a normal dulcimer sound in frequency spectrum and amplitude. If sufficiently immobilized, putting a pickup on the ends should show much less vibration than when free. This test would then confirm or disprove the idea of the dulcimer as a vibrating bar.

When I say a bar needs to be free at both ends to vibrate, I mean a free bar, which is the model being proposed. There are other types of bar vibrations where one or both ends are immovable, as in Figure 2.2. Clamping the dulcimer was an attempt to deny it the opportunity to act as a free bar.

One theory has it that a dulcimer acts as a bar fixed at both ends. I cannot subscribe to this explanation for the main reason that the ends of a dulcimer are not fixed at all and are as mobile as any part of the instrument, which adds support for a free bar model. You can tell this by just holding an end whilst strumming – strong vibrations can be felt.

Also, though not relevant to one model or another, the bridge and to a lesser degree the nut, and therefore the string ends, are not really fixed in relation to the body of the instrument. They can move around quite a bit. Not as much in a dulcimer as in a guitar, but still mobile relative to the body (we are talking microns here).

So I’m setting out to prove, or disprove, the proposition that a mountain dulcimer vibrates in the way a free bar would (although in a more complex and less predictable way), as in the free bar pictures in Figure 2.2.

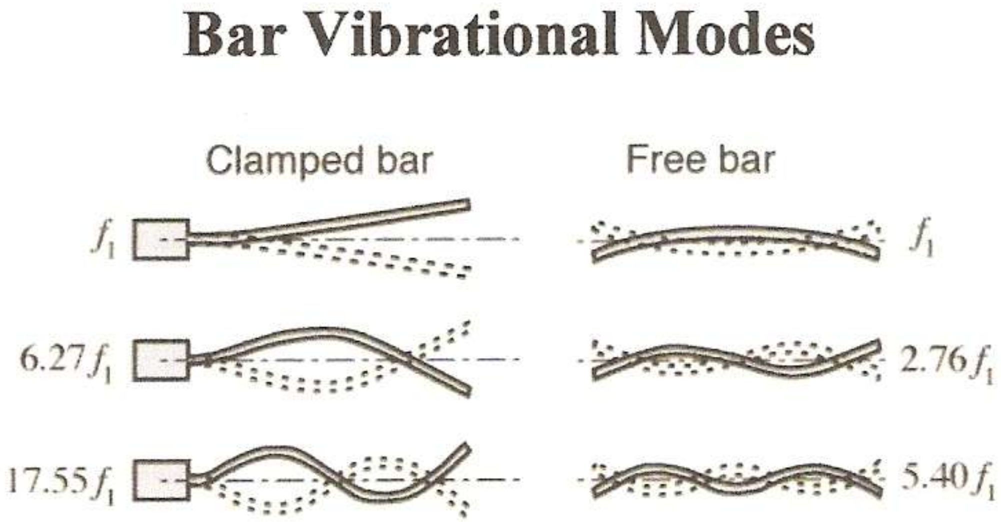


Figure 2.2 Vibrations in free and clamped bars

One test to investigate the box/bar proposition would be to absolutely fix the ends of a real dulcimer so there was no possibility of them moving. That's what I tried unsuccessfully to do with the dulcimer on the beam in Figure 2.1. I could bolt the instrument to the garage floor, but then I couldn't get it on the bench for measurement under standard conditions.

Guitar, violin, mandolin, ukulele, and other instrument makers have access to a basic understanding of how those instruments work, as a sort of ground zero starting point. Mountain dulcimer makers don't — that's what I hope might come out of these experiments.

Approaching the matter from the standpoint of wave dynamics or similar mathematical approaches is too inaccessible and esoteric for most makers, and I'm not convinced it's a workable method anyway. So, in these experiments I'll stick with the familiar and measurable variables of mass, stiffness, frequency, etc. Secondary effects such as the contribution of internal sound reflections and the materials' acoustic transmissibility I'll have to leave to future generations. Those effects are unlikely to be part of a basic model.

However, none of these proposals is proved one way or the other; i.e., the mountain dulcimer as a bar, fixed or free, or as a collection of independent vibrating surfaces, or any combination in between. Some day some light might fall on the matter, but there is no reason to stop building in the meantime, or put off starting. Our lack of knowledge of how the instrument works does not preclude fine instruments being made.

Dulcimer Sound Propagation-Jul 14, 2009

It has been proposed that the sound generated by a dulcimer vibrating is not only radiated outwards, but also propagates within the instrument where it can be reflected from the internal wood structures, and further, that this internally radiated/reflected sound can pass through (mainly) the top of the instrument to the outside, where it is heard as a significant component of the total dulcimer sound.

I hadn't considered this proposition before, (of internal sound audibly passing ***through*** the wood) and haven't heard any luthiers mention it as a component of the sound of an instrument. However, I've come across references that seem to indicate that wood is nearly transparent to sound. In addition, I asked one of Australia's leading luthiers about this and his reply was that there might be something in it (but with a sort of implication that it wasn't of critical importance).

So, I looked into the matter a little, and soon found a wall of information, academic and practical; more than I really want to know about.

But some things are clear:

- when sound impinges on a wood panel through the air; some of it is reflected from the surface; some is absorbed in the wood and the energy lost; some is scattered; and, some is retransmitted as audible sound,
- less dense woods will pass sound more easily than heavy woods (the "Mass Law" of airborne sound transmission loss in a material),
- doubling the thickness of a panel reduces the sound transmission level by about 6dB,
- the sound that passes though is highly filtered; lower frequencies, below about 1kHz, pass more easily than higher frequencies, and
- the stiffness of the wood will influence the sound transmission properties, and the frequency dependence of the absorption can be non-linear.

This is interesting, but I wanted to know what general magnitude of sound transmission through a dulcimer top plate might be expected — is it a significant level; is it a secondary effect; or does it not occur audibly at all at the sound levels of a playing dulcimer?

I did the following crude test to get some idea.

A small loudspeaker was placed in a wooden box made of dulcimer top scraps, about

15cm x 7cm x 7cm. The speaker rested on a soft foam pad and didn't touch the sides of the box; it was connected to a personal computer sound card. A signal analysis computer program (Visual Analyzer 2009) provided a swept sound tone to the speaker over the range of 100Hz to 4000Hz, whilst simultaneously picking up and analyzing the sound from the speaker via a microphone suspended 30cm directly above the box (Figure 2.3). Recordings were made of the un-boxed speaker to have a baseline to compare against (Figure 2.4).

Figure 2.3. Speaker on foam pad

Figure 2.4 Speaker on foam pad in box

Several pieces of wood were used to cover the top of the box to measure the transmission of the sound through them - two samples of Western Red Cedar (2.1mm and 3.6mm); 3.3mm *Acacia Implexa* (density 713kg/m3); and 3.1mm Alpine Ash, a 680kg/m3 eucalypt. The wood samples covered the top of the small box enclosing the speaker (Figure 2.5).

Figure 2.5. Speaker box covered with wood

Multiple trials were performed on each sample, as well as an open, unboxed speaker, and repeatability was very good. Being small and low quality; the output of the speaker was quite ragged, but it was the difference in sound level at various frequencies that was important, so the poor speaker could be accommodated (although not much was happening below 250 Hz).

Sound transmission results from the four samples of wood were quite similar, with the thin Western Red Cedar allowing slightly higher level of sound through. The frequency spectra of the results are shown in Figure 2.6.

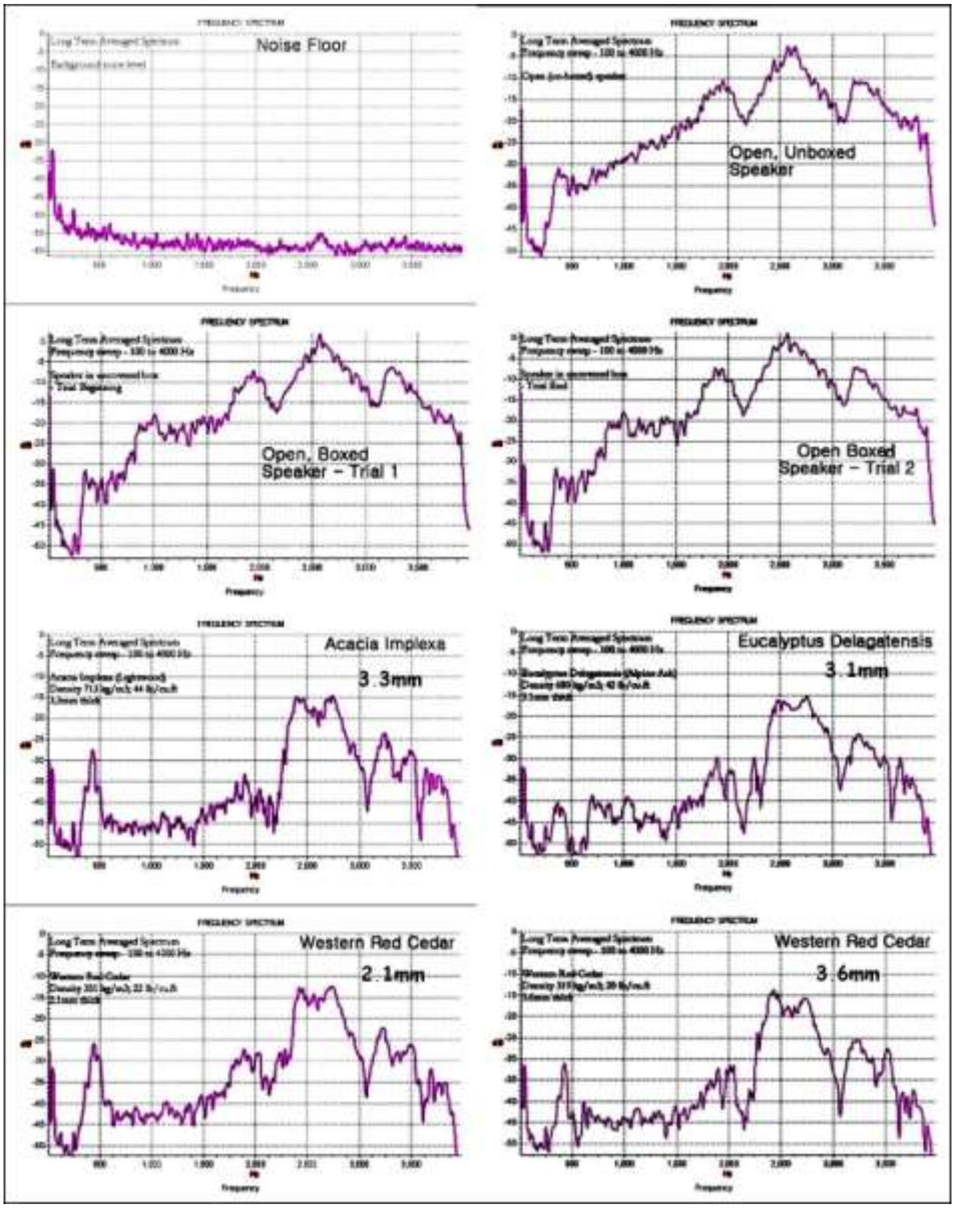


Figure 2.6. Long term averaged swept frequency spectra (100 to 4000Hz) with speaker in or out of box, and with box open, or closed with plates of sample woods

In all cases there was between 5dB and 35dB of sound loss through the wood sample, depending on the frequency. If the chart of the 2.1mm WRC (lower left in Figure 2.6), is smoothed and the sound loss measured compared to the open boxed speaker, the result is shown in Figure 2.7.

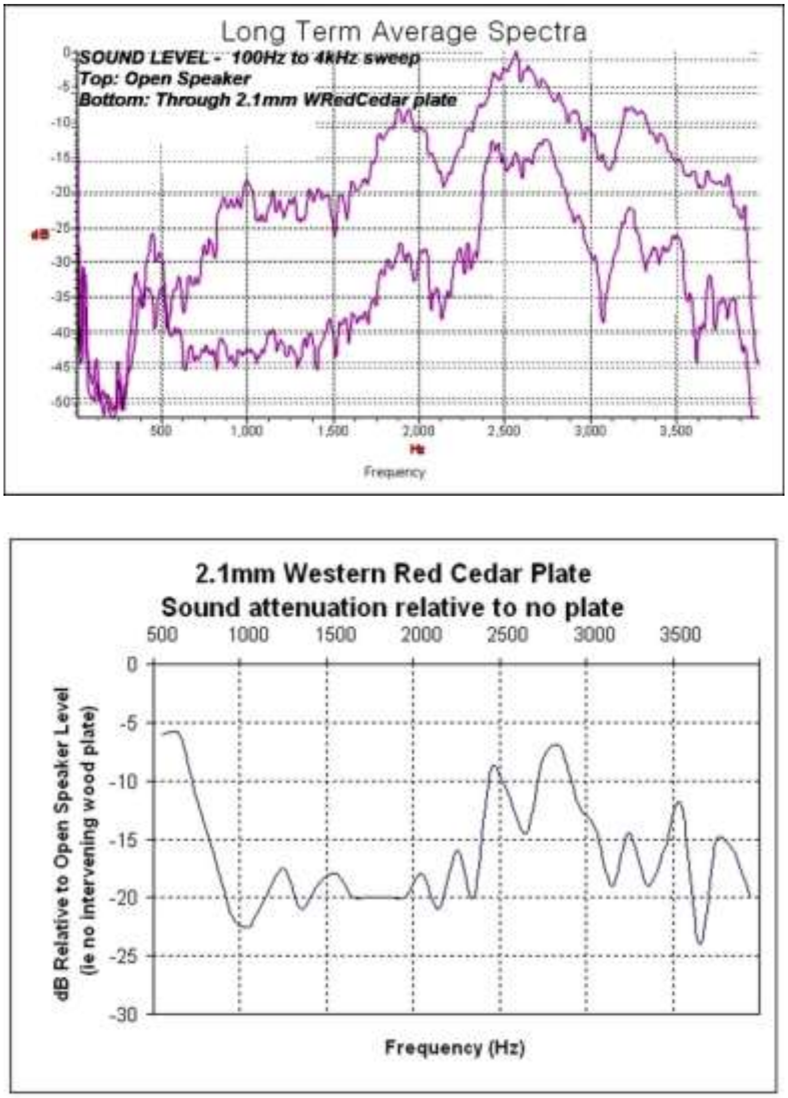


Figure 2.7. Sound transmission loss through 2.1mm Western Red Cedar plate

Experimental uncertainties aside, it appears that typical dulcimer thickness top woods will attenuate sound by an average of about 15dB over a 4kHz range. That’s a significant 30-fold reduction in sound level compared to sound generated directly from the outside surface of the instrument.

Interestingly, the rubber band shown in Figure 2.5, holding the test plate of wood in place, contributed a further 5-10 dB loss in transmission. I moved it to the end of the box, then finally did the tests with the plates just resting on the top of the box (it was sanded flush, and the plates were flat).

The conclusion I draw from this is that there can be some sound transmission through a dulcimer top plate, but that it would have to be considered as a secondary sound contributor compared to directly radiated sound, although some of this “internal” sound could exit the top through the sound holes as well as through the wood.

Dulcimer Sound Production Theory Revised -Mar 11, 2010

My proposition that mountain dulcimers could be treated as a complex vibrating bar, rather than vibrating plates, reported above, cannot be fully supported.

Sound spectral and vibrational experiments show me that only the first bar vibrational mode is present, and is surrounded in frequency by vibrations of the air inside the box, and the wood plates themselves. There seem to be some generalizations that can be made from these vibrational tests.

1. Mountain dulcimers identifiably vibrate at the first bar mode, but not at higher bar modes (at least not that can be easily identified). See Figure 2.8.

Figure 2.8. First bar mode vibration pattern for three dulcimers

The patterns on the dulcimers, when excited by the loudspeakers at about 330Hz, are consistent with the instrument flexing up and down like a xylophone bar, and hence making sound. That region of the sound spectrum does seem important to the quality of the overall sound, so the fact that the dulcimer box is bending like a bar in its lowest mode, is still important, and different from guitars and violins in this regard.

However, if the dulcimer as a box-bar acts anything like a solid bar, then the 2nd and 3rd bar vibration frequencies would be predicted to be about 900Hz and 1800Hz. These higher bar vibrations might still be present, but I have not been able to identify them in vibration studies, possibly because other complex plate vibration modes close by in frequency would mask their appearance.

2. It appears from vibrational tests that the tops and backs of mountain dulcimers vibrate as plates, and that the tops and backs resonate at pretty much the same series of frequencies as shown in Figure 2.9.

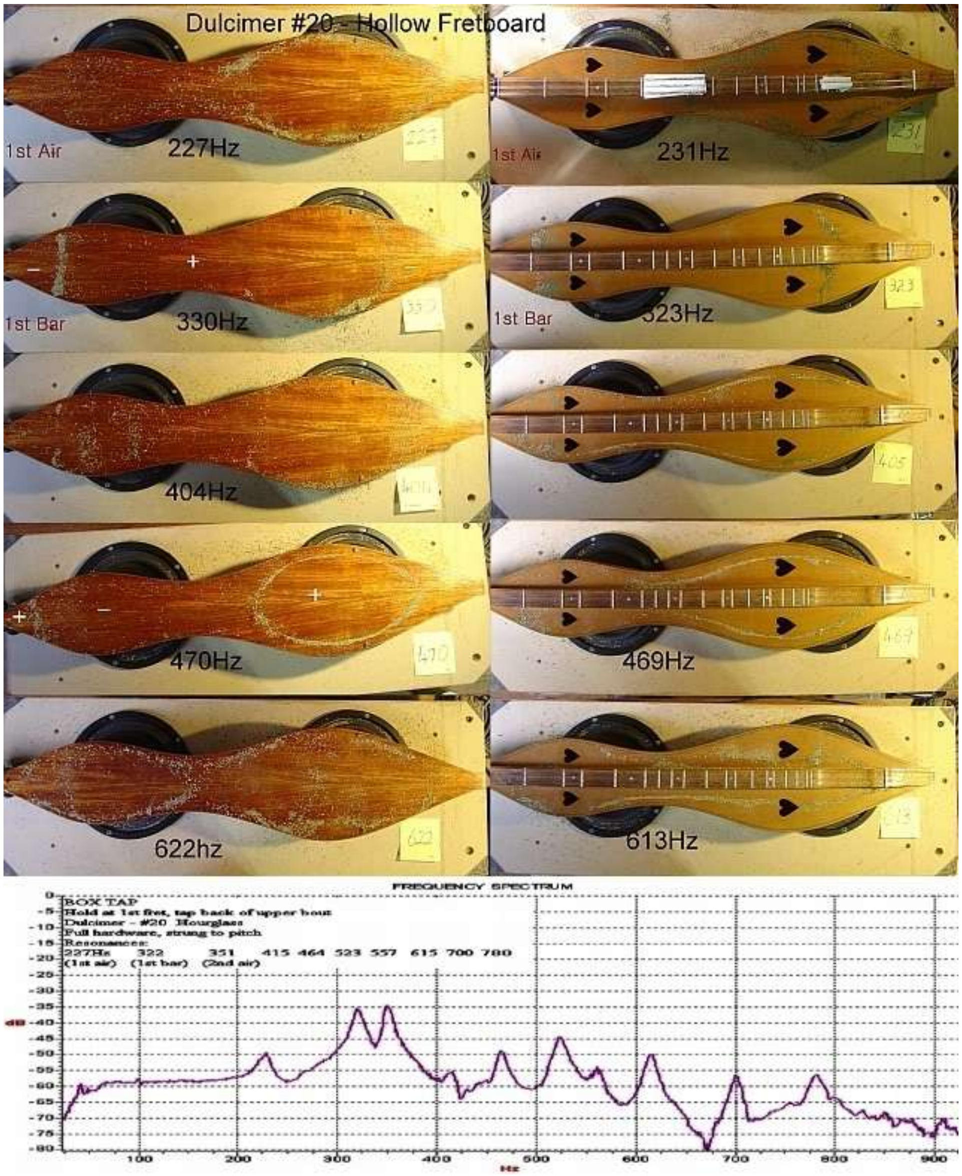


Figure 2.9. Top/back vibration patterns and box-tap spectrogram for hollow fretboard dulcimer

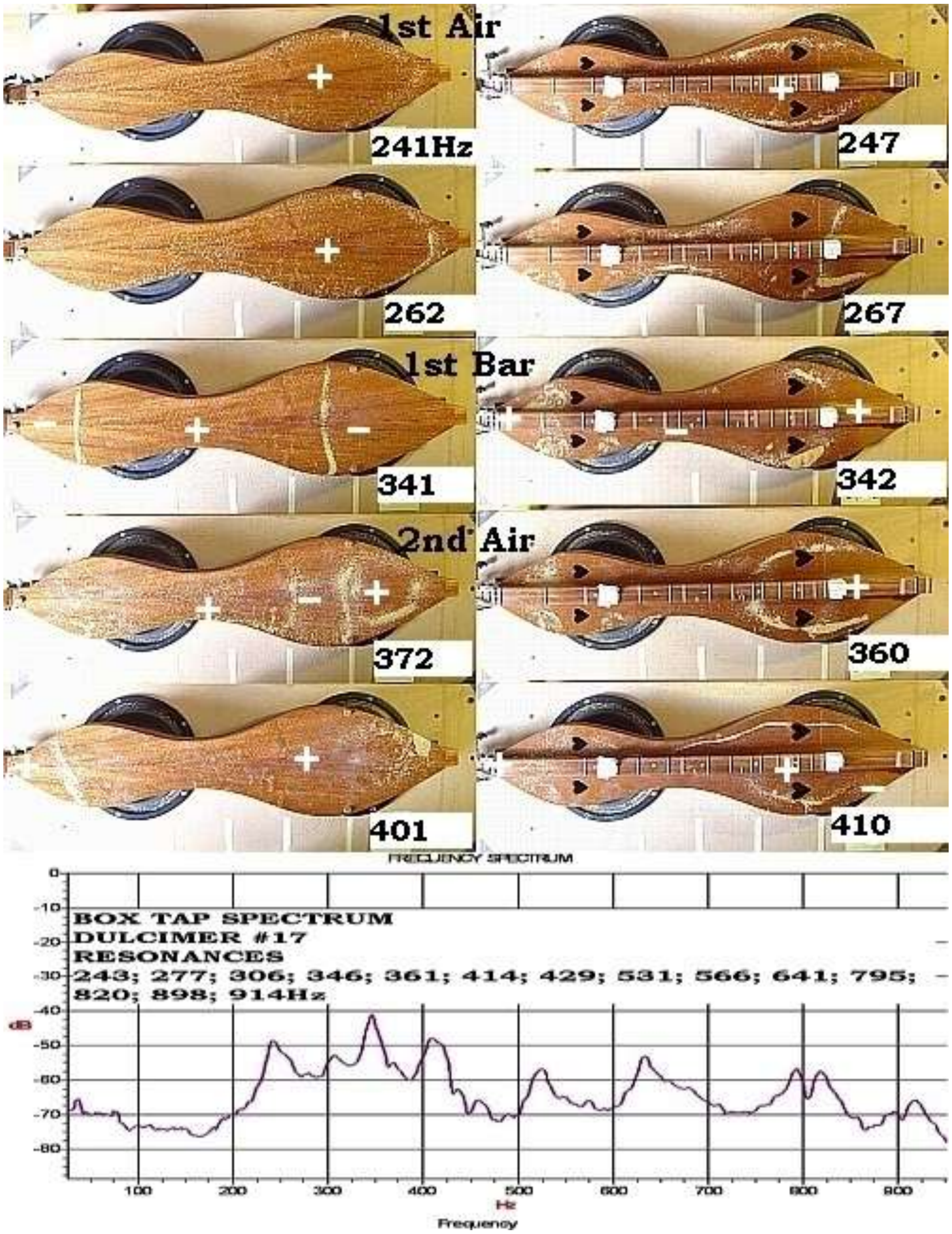


Figure 2.10. Top/back vibration patterns and box-tap spectrogram for arched fretboard dulcimer

Figures 2.9 and 2.10 show only some of the resonances. Of the ten or so resonances below 1000Hz in the top plate, one or two did not have a matching resonance with the back that I could excite with the speakers.

Even though the patterns of the top and back vibrations are different to each other (at the same frequency and in the one dulcimer); the fact that they resonate together at multiple frequencies might indicate that the top and back plates are coupled in some way, either by the air in the box transferring energy from the top to the back, or the energy from the top transferring via the sides to the back. In general, other than the first bar vibration resonance, the tops seem to have a rather simple mode of vibration — just up and down, at multiple frequencies. This is the "trampoline" mode of vibration. Backs can vibrate in more complex ways because they are not so constrained by the mass and stiffness of the fretboard.

3. There might be other modes of vibration not usually considered.

In free tops and on one complete dulcimer, I have seen evidence of a twisting vibration. This is shown as a line of stationary particles along the fretboard at a particular frequency (Figure 2.11).

Figure 2.11. Evidence of twisting vibration

Figure 2.11 shows vibration at a reasonably high frequency, so I wouldn't say it is important acoustically, but it's something I had not expected. It may arise because of an asymmetry of dulcimer construction, either deliberate or accidental. It could be the dulcimer equivalent of the guitar cross-dipole vibration mode, where one side goes up, while the other side goes down. Or, it might be reasonable to think that a dulcimer can vibrate as a bar in a horizontal direction. The isolated fretboards certainly do.

Some support for the “1st bar mode only” comes from vibration studies of three instruments with backs and sides only, with end blocks and tuning hardware, but tops and fretboards not yet glued on. There is a clear bar mode as the lowest vibration resonance (Figure 2.12).

So, mountain dulcimer do vibrate as bars, but also in other complex ways.

Figure 2.12. Back vibration of dulcimer with no top/fretboard, showing a bar vibration mode.

In undertaking these vibration mode studies, the instruments are mounted on soft foam blocks on the speaker box or suspended on rubber bands stretched across the speakers. The distance from the speaker rim is only about 1". There are resonances in the box housing the speakers, but much lower than the dulcimer resonances — it's a heavy box, and it's easy to see if any speaker box resonance coincides with a dulcimer resonance.

The speakers are 12ohms, in parallel, and in phase. I used two speakers to excite the whole instrument. Guitar testers typically use one speaker, held in the hand, and hold it close to the spot on the guitar that is expected to vibrate. I use a 100 Watt amplifier — dulcimers are very stiff and it takes a lot of acoustic energy to get them moving.

Measurement Equipment and Thoughts-Aug 30, 2010

Other than the odd microphone amplifier, I don't have any special equipment for doing spectral analysis or sound pressure level (SPL) measurements. Sound is recorded through the computer sound card and analyzed by signal analysis software. The fact that the room is a normal reverberant one doesn't affect results too much if the microphone is close enough to the sound source — these are not laboratory standard experiments in any case.

I get by with three software items.

1. An ordinary sound recorder software package. I use Audacity, but there are any number freely available. I save the recordings in .wav format for analysis.

2. An off-line signal analysis suite for the recordings made using Audacity. I use PRAAT, which is free at http://www.praat.org. This is a voice oriented research analysis package, and fairly idiosyncratic, but it does a lot of things very nicely and is free. It can record its own sound files, or use .wav files. There is a Mac version. Results and graphs can be saved, but are in Postscript format. Screen Capture is easier, saved as JPEG images.

3. For real-time averaged Fourier spectral analysis, I use Visual Analyzer, which is available free at http://www.SillanumSoft.org. Again it is somewhat idiosyncratic; e.g., you have to save the pictures as "text" files which actually are saved as *filename.txt.wmf*, and are .wmf files. But the software does a lot of useful things in real time. If users are unfamiliar with basic signal processing techniques, things can get completely out of control. However, if the setup is left in a standard configuration things would be OK.

This is about all that's needed to do tap spectra and to analyze the sound coming from an instrument — recorded or in real-time. Most of what happens in a dulcimer (or guitar or violin), that we have any hope of controlling, happens between about 100Hz and 1000Hz. Above that it gets very chaotic (but not in the mathematical sense), and vibration modes tend to run together.

The vibration analysis is essentially just a rig to suspend an instrument over some loudspeakers powered by a 100 watt amplifier and driven by a sine wave generator with a frequency meter accurate to 1Hz. It is a ***very*** noisy business. You would need a sound-proof room to do it in the suburbs or the neighbors would be calling the police.

Like musical instrument making, I think you could expect to spend a year or so just practicing with sounds and analyzing them until you started to get a feel for what you were doing. But even so, it is interesting anyway.

Regarding sound holes, their size and placement, a smaller sound hole will tend to have a radiation field that is omni-directional, and a larger one a sound field that is directed vertically from the hole and doesn't spread out so much. It will depend on the wavelength of the sound relative to the diameter of the hole.

I should also point out that almost none of this information gives any clear guidance on how to make better dulcimers. At most it might give a general indication of the state of things, acoustically, and some hints about how you might approach something. For better or worse, I now don't worry about the top material or its parameters very much, because of the overriding influence of the fretboard in comparison, and I think more closely about what I do with fretboards. In the past I would agonize over the properties of the top, and the quality of the wood, and its thickness, etc., and then mount a fretboard that seemed OK. To my mind that was misdirected thinking - so the studies have directed me to what I now think are more valid areas to produce better results.

The notion of what is "best" is subjective of course. I think I would recognize a superior sounding dulcimer if I heard it, and I'm fairly sure I can recognize a poor sounding one. But I'm a little shaky about whether I could tell if a change made to an instrument produced a better or poorer sound, as opposed to just a "different" sound, especially if the sound change was not substantial. And one sound does not fit all; otherwise we'd all have one dulcimer, and one guitar for all the styles we played.

In terms of the environment in which a dulcimer is made, I once made two spruce-topped dulcimers during a week of rain and high humidity (didn't know any better at the time). Both had heart-shaped sound holes and both tops split at the point of the heart when the weather dried out. This points to the critical necessity of doing all cross-grain gluing when the humidity is about 45%

Stresses in a structure can focus at sharp discontinuities. Does this mean that the internal glue joins between the tops/sides and braces should be rounded? Probably not. The right-angle that brace edges form against the top and back probably do focus stresses there, but that's how everyone has always done it, so the components must be amply strong enough to cope with normal stresses.

If I can, I like to do the same measurement on as many instruments as are available before I feel confident I'm looking at a general finding. The making of mountain dulcimers might now be fairly mature, but our detailed understanding of them isn't, and may never be, so I'm happy if I can come to any gross conclusions. For instance, there is always jitter in the frequencies of sequential tap resonance spectra, and I don't know if that's significant acoustically, or is a result of changes in the weather, or if it's just measurement variation or something else. But overall, the tap spectrum of an individual instrument stays remarkably stable over months or years in terms of general spectral profile and position of the resonances. But even the gross aspects of an instruments’ tap spectrum can be difficult to interpret, let alone any jitter around the mean, so we have a long way to go before we need to wrestle too much with the errors in experimental measurements. However, I always keep in mind the magnitude of the errors I might be dealing with, and draw conclusions accordingly.

Value of experiments- Jan 09, 2016

For me personally, experimenting has not lead to consistently “superior” instruments. By this stage I have a fair idea of what I like in a mountain dulcimer sound, and I think I can recognize a superior one when I hear one. But I never know until I string up a new instrument what it will sound like, except in a very general way. And I know that if an instrument turns out to have that extra "something" about the sound, it will not clearly show up in the crude measurements that I can make (loudness, attack, sustain, spectral content etc).

For the rest of the world, I have no idea what any one individual might consider a superior instrument — no one does. That is one of the problems with mountain dulcimer comparisons — there is no consensus about good, bad or excellent. So making measurements and doing experiments can not help much when there is no target to aim for - other than the most general of descriptors such as bright or mellow - and even those very general terms are unreliable; one persons' "bright" can be another person’s "mellow".

So, the experiments I do cannot provide a recipe for making superior instruments. But by gaining information about how a mountain dulcimer produces sound, the scene is better set for makers to concentrate more on matters that might affect the sound and worry less about things that have been shown to affect the sound less. For example, before I started experimenting, I did not know that in one vibration mode dulcimers vibrate like a xylophone bar—but they do, and it informs my thinking about where to put the three feet on the bottom so I don't damp out that vibration when played on a table. Also I no longer stress out about top bracing, string break angle, top wood species, hollow or arched fretboard types, sound ports and sound posts, etc., etc. I know the answer to these things now, to my satisfaction, which, unfortunately, I didn't before because of the variety of different answers from a variety of luthiers.

In a general sense, there are no right answers, and no wrong answers, just different answers. The same applies to dulcimer sounds, no better or worse, just different. One person will like one different sound better, and another will like a different sound better.

Chapter Three

Dulcimer Resonances and Vibratory Behavior

Dulcimer Vibration Patterns-Feb 05, 2009

It would be good to discover and catalog characteristic vibration patterns of the mountain dulcimer, both in the free top assembly, and the completed instrument. But first, consider this (which is relevant to any method that measures the vibration at a single point on the dulcimer surface).

1. The vibration pattern will be complex over the whole of the instrument body, so readings at a matrix of measuring points would need to be taken on the top, back, sides and end blocks, for example.

Figure 3.1. Example of a dulcimer free top vibration pattern

2. The vibration at each point will be frequency dependent, so multiple sets of readings would be needed over a range of excitation frequencies. In practice, readings are usually taken at identifiable resonant frequencies at which the largest vibrations occur, and which shape the sound timbre. There might be between five and ten of these below about 2000Hz.

3. The vibration patterns measured on a dulcimer may be unique to that instrument; i.e., not representative of dulcimers in general. So, a number of instruments, of the same basic design, should really be measured to confirm that the vibration patterns are characteristic of that design, and not just one instrument. For every different design there are likely to be a different set of vibration patterns (or modes).
We're starting to get to a serious investment in measuring time here, and unfortunately

I think the likelihood of a generalized outcome is low.

In the guitar and violin world some progress has been made in the science/art of “free plate tuning”, which is essentially a hard-measurement extension of tap tuning of top and back plates for those luthiers who don’t have the 20 years left to learn that method, or who like to see pretty pictures of plates vibrating. An isolated top or bottom is excited into vibration by a nearby loudspeaker; sawdust or something similar (dried oregano leaves from the kitchen) is sprinkled onto the plate; and the loudspeaker frequency is varied until the sawdust jumps into patterns of nodes and antinodes. Several vibration resonant modes might be examined for frequency and the shapes of the patterns. The plate thickness or bracing can then be varied and the measurements repeated until the desired patterns and frequencies are achieved. ***Then*** the plates are assembled into the instrument with the hope that the changes in vibration modes, caused by gluing the free top and back plates to the sides, will result in a more favorable instrument. It seems as much an art as a science to me. However, for violins and several types of guitar, there are now known general patterns that at least serve as a starting point for free plate tuning, and end results can be good.

There’s nothing like that for mountain dulcimers, so I’ve measured the free plate resonant modes of the tops and bottoms of the last twenty or so instruments I’ve made in the hope that some common patterns might emerge. No such luck. What I’ve found is:

1. The free plate vibration modes of an unbraced top and back, without fretboard mounted, have some similarity to violin back plate vibration modes and are fairly repeatable across different plates and for both tops and backs; i.e., provided the plate is the same shape, the vibration patterns are basically the same, but the mode frequencies depend on the plate density and stiffness. The top and back plate vibration pattern from two different dulcimers - no bracing or fretboard, just the thin plates, are shown in Figure 3.2

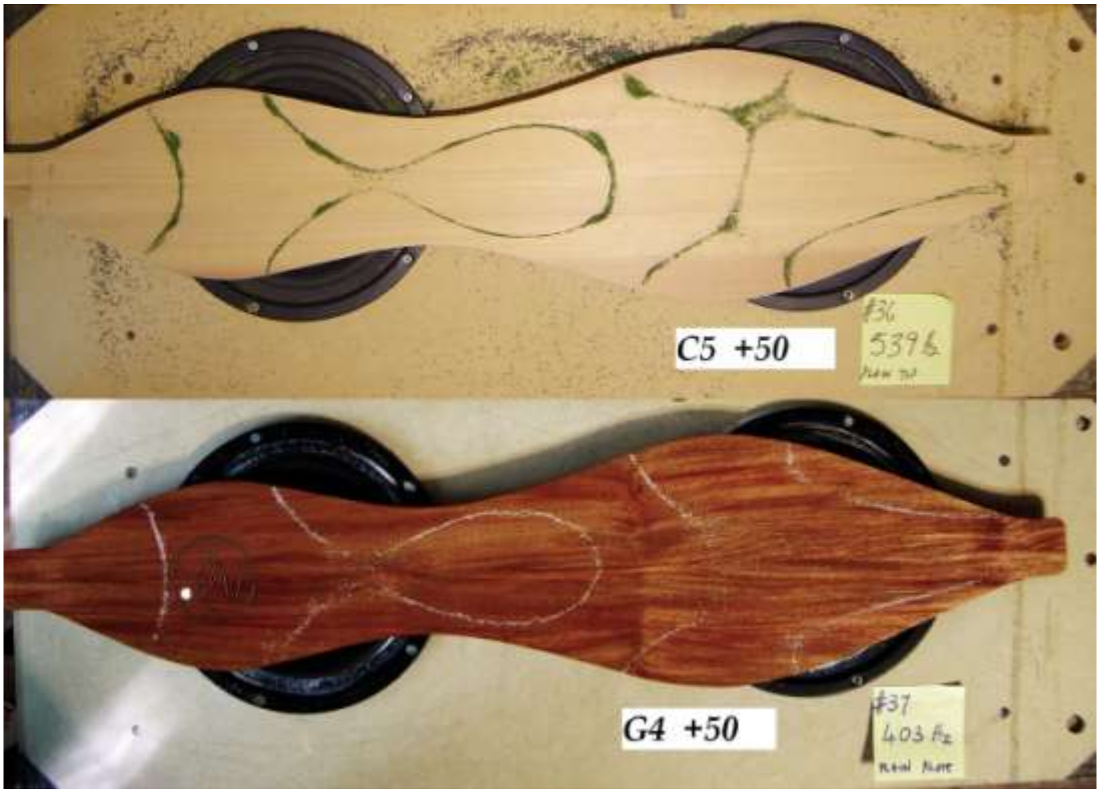


Figure 3.2. Examples of vibration patterns for unbraced dulcimer plates

2. When braces and fretboard are added the vibration modes change completely in patterns and frequency (Figure 3.3). The patterns can be heavily influenced by the position of the braces, but not always. (Keep in mind this is in the free top assembly, not the assembled instrument.)

3. The vibration mode patterns and frequencies are different for each bracing pattern. Shaping the top braces may lower the resonant modes by only about ½ semitone, because the top bracing is completely overshadowed by the stiffness of the fretboard. Adding back braces may eliminate some of the lower vibration modes and may raise the resonant frequencies by roughly one octave over the unbraced back, and shaping the back braces has more of an effect than on the top, but still small.

Figure 3.3. Examples of vibration patterns for braced dulcimer tops

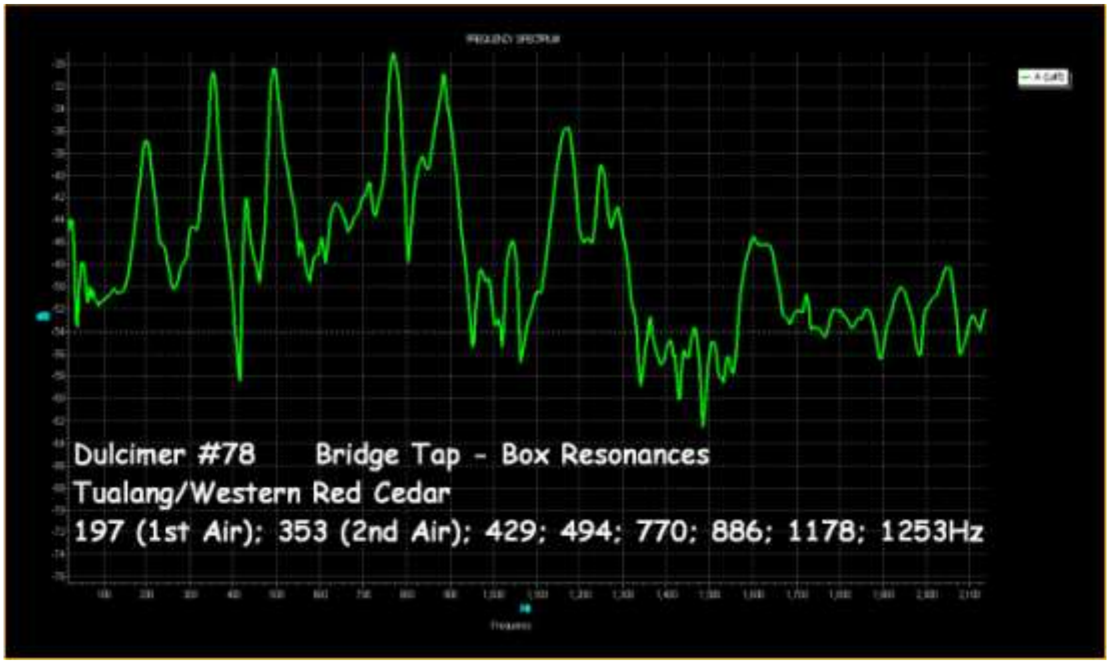
Overall, I haven't discovered any generalized vibration patterns for the free top and back plates, or data to link the free plate vibration modes with the completed instrument resonances, or any correlation between different bracing patterns or vibration patterns and subjective auditory results.

I think this means that in the mountain dulcimer world the variety of instrument shapes, building methods, and design details probably preclude the assembly of a set of standardized top and back vibration patterns in the free top.

I don't do free plate measurements anymore because it hasn't helped me produce what I think are better sounding dulcimers. It might be a helpful method if I froze the design and spent the next decade making only that style, and systematically studied each one as I made it, and then applied some standardized listening test or hard measurements correlated with known listening preferences. But then it might not.

The same vibration method can be applied to the completed instrument – at least to the top and back because they're generally flat. I've only done a little of that because changes can't really be made after the instrument is finished, and also, I don't know a method of correlating the vibration patterns with the sound quality.

In place of loudspeaker drive modal analysis, I measure the acoustic resonant properties of the box and the enclosed air by tapping with a small rubber hammer (a pencil eraser on a stick), and sweeping sound inside with a small loud speaker and analyzing the frequency spectra of the resultant sounds (Figure 3.4). These end up more generalized, over all designs and construction methods, and between makers — but still no identifiable correlation between resonant peaks in the sound spectra and quality of sound of the instrument. What is known is that each resonant peak in the tap spectrum represents at least some part of the dulcimer that is vibrating at that frequency, but ***which*** part cannot be determined from the spectrum alone. I continue to do these measurements on each instrument because it's easy to do (just a microphone, a lap top and a knuckle is all that's needed). One day some general insight might dawn on me if I do enough dulcimers.



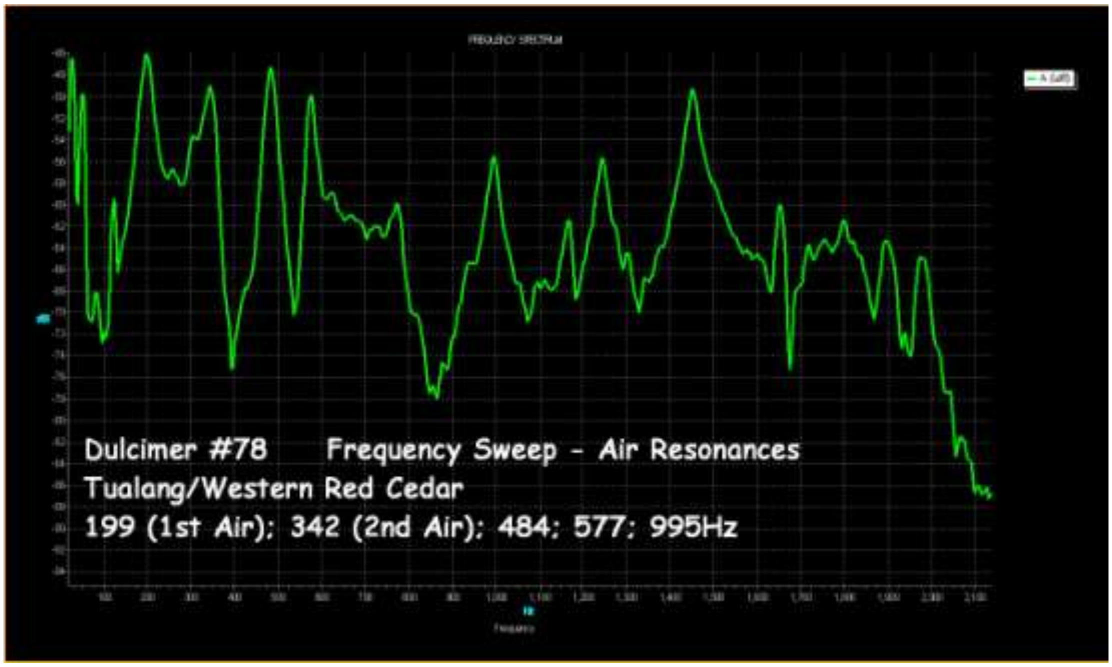


Figure 3.4. Example of bridge tap and air cavity spectra of completed dulcimer

First and Second Air Resonances -Apr 22, 2009

I always measure the first and second air resonances of the dulcimers I make.
I do this in two ways - firstly by blowing across the sound hole with the barrel of a ball point pen and analyzing the resultant "rum jug" tones; and secondly by inserting a small

loudspeaker inside the instrument and sweeping the frequency from 50 to 800Hz and recording/analyzing with a microphone at the other sound hole. The results are the same; but if you blow really hard the frequency of the tone can vary a bit, and the upper bout sound hole will jump from the first air resonance tone to the second as you blow harder. Sometimes the shape of the sound holes won't allow the air blowing technique and I rely on the speaker method.

I also repeat the exercise with the instrument held firmly on my lap, arms wrapped around the sides and forearm pushing down on the fretboard. This is to try to stiffen the overall sound box and get closer to the Helmholtz resonant frequency which requires a rigid sound box. The result is always an increase in the first and second air resonance frequencies, which is expected.

But one dulcimer I made did something I hadn't noticed before. It had a very strong air-blow note, but if I touched, even lightly, the middle of the back at the lower bout whilst blowing, the tone stopped. So I made some quick measurements on three instruments I had nearby to see how much the back was vibrating under the influence of the air vibrations within the box; i.e., air-box resonance coupling.

The instruments were mounted upside down on the bench with cork blocks at the nut and bridge (strings tuned but damped). A workshop air compressor was used to initiate the loudest sound hole tone across a lower bout hole, and sawdust sprinkled on the back to see the patterns. Brace locations are marked with paper strips. These are completed dulcimers; all had prominent "rum jug" tones. The results were:

Dulcimer No.4. Made in 1970; Plywood, 4mm, no braces, not very stiff box, quiet and sweet sound. Weight 2.52lb, 1st air 208Hz; Helmholtz frequency 233Hz (constrained back, sides, and fretboard). Many air resonances set the back into vibration. The ring at the edge of both bouts shows that both are vibrating strongly in the simplest vibration mode.

Figure 3.5. Dulcimer No. 4 vibration pattern

Dulcimer No.42. Fairly stiff Tasmanian Blackwood box, loud and woody sound. Weight 2.6lb, 1st air 201Hz, Helmholtz frequency 223Hz. It is just possible to make out a rough ring on the lower bout indicating it is vibrating. Touching the middle of the ring stopped the sound.

Figure 3.6. Dulcimer No. 42 Vibration Pattern

Dulcimer No.38. Very stiff *Acacia Implexa* (Lightwood) box, loud and bright sound. Weight 3.2lb, the heaviest I've made to date. 1st air 218Hz, Helmholtz 219Hz.

Figure 3.7. Dulcimer No. 38 vibration pattern

Hard to see here, but there is no sawdust pattern produced by the air resonance coupling to the wood; i.e., the air vibration has not set the wood into vibration.

I'm not sure what to make of these observations, but some comments are:

1. The loudness increased as the box stiffness increased #04 < #42 < #38 (but #04 has the bridge on the end-block, the other two about 4" in, so it's not a fair fight).

2. A light/flexible box (#04) encourages air/wood resonance coupling; #38 was so stiff there was no observable air/wood interaction; and at some point as box-stiffness

increases, the coupling of air resonances with the wood ceases, and can easily be quenched by touching (#42).

3. The back of the very stiff box, #38, still vibrated under the influence of the strings, as did the other two.

4. The stiff box of #38 did not reduce loudness very much when played on the lap. The flexible box of #04 was highly damped when played on the lap; #42 was intermediate, but closer to #38; i.e., slight knee damping. Although these are subjective listening evaluations on my part, this might imply that it's the wood vibration coupled to box air vibrations that are mainly lost when playing on the knee, rather than wood vibrations proper, and that stiffer boxes can reduce the effect. Increased stiffness and weight per se doesn't necessarily reduce loudness. Nor does increased stiffness necessarily increase weight by much.

5. The first air resonance will move in frequency in a less stiff box when the instrument is played on the knee. This will not only reduce loudness because of the loss of wood/air back vibration, but will change the tone of the instrument because of the shift in frequency of part of the sound emanating from the sound holes (i.e., the sound resulting from the first air resonance).

Top and Back Vibration Modes-May 23, 2010

Lately, I've been looking at the way finished dulcimers vibrate — the vibration modes of the top and back, to see if there might be any standard patterns, having basically given up on such testing of the free tops and backs before gluing up. I've only tested dulcimers of two different shapes (but three different bracing patterns), so there's a lot more to be done, but it does seem like there might be generally standard modal patterns. Those who want to see more detailed pictures of the vibration modes below 1000Hz of five dulcimers can see them in the following illustrations.

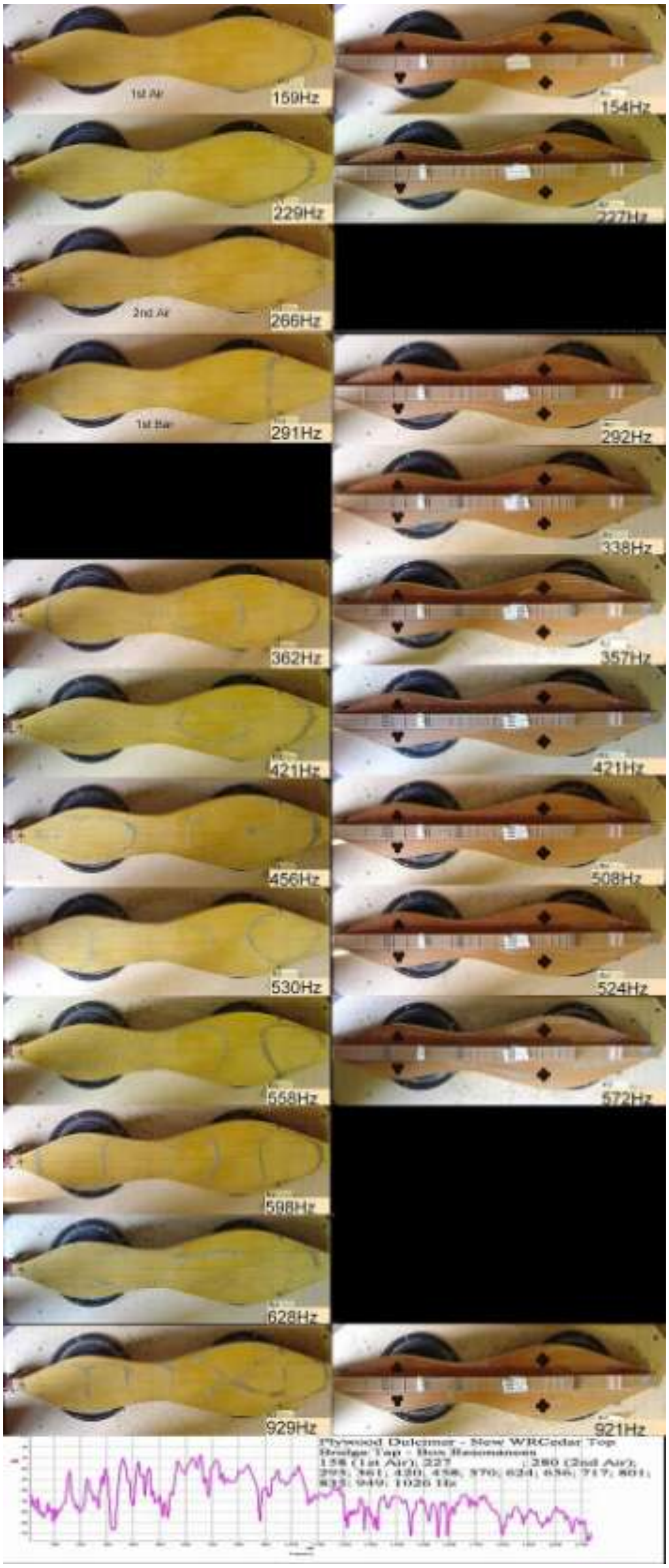


Figure 3.8. Vibratory pattern of plywood back/red cedar top

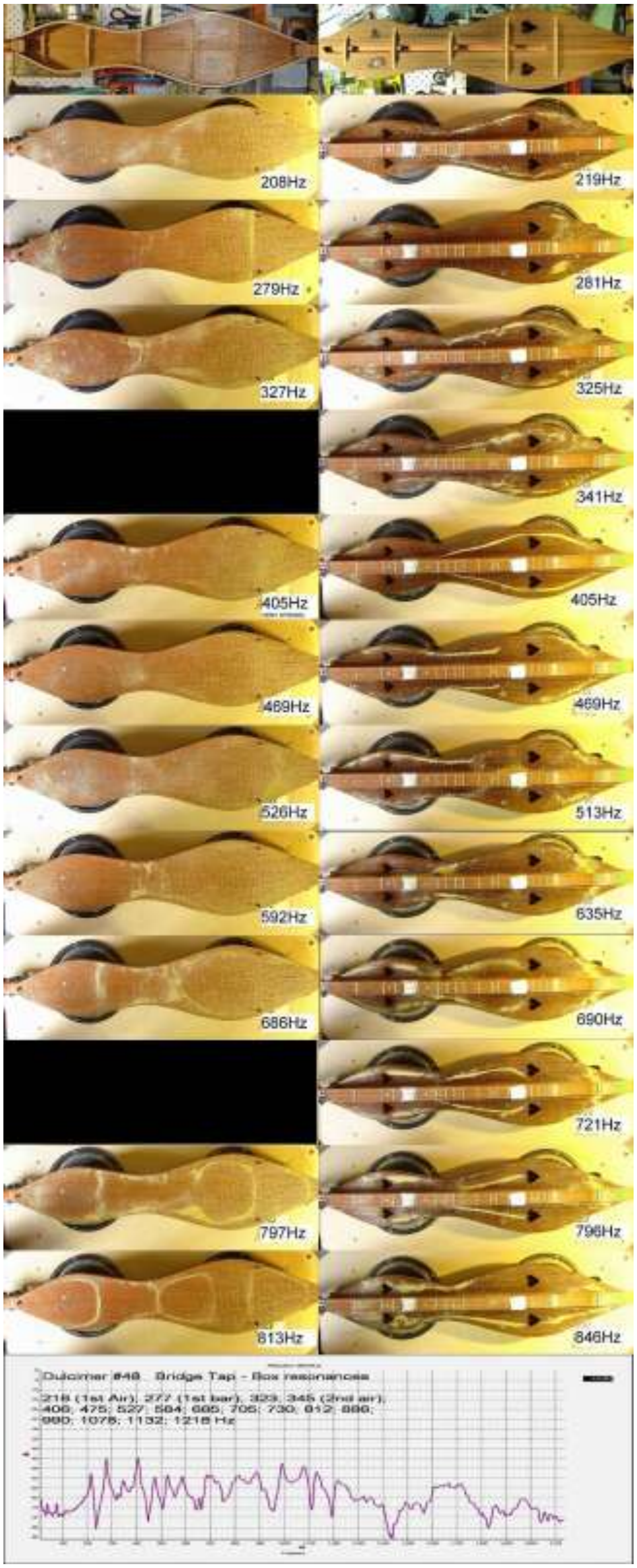


Figure 3.9. Vibratory pattern of Western Red Cedar/ Seraya dulcimer

Figure 3.10. Vibratory pattern of dulcimer # 20 Western Red Cedar/ New Guinea Rosewood

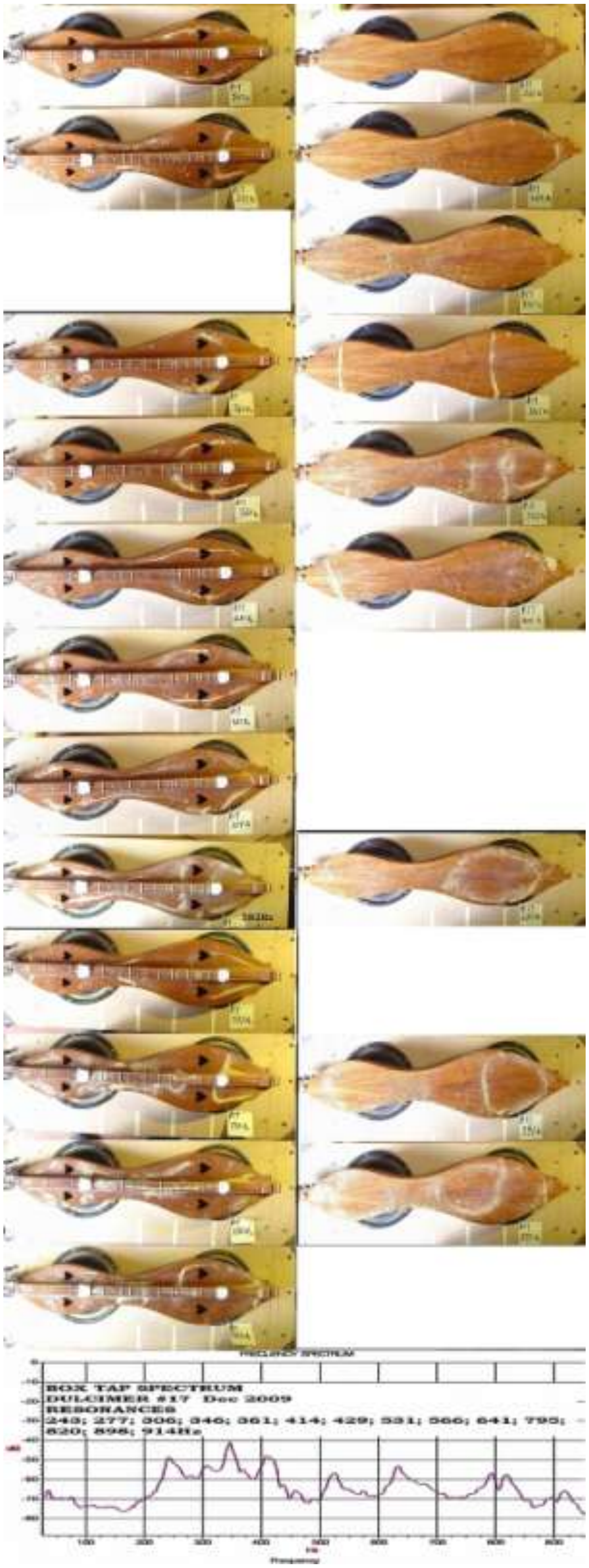


Figure 3.11. Vibratory pattern of dulcimer # 17 Western Red Cedar/ New Guinea Rosewood

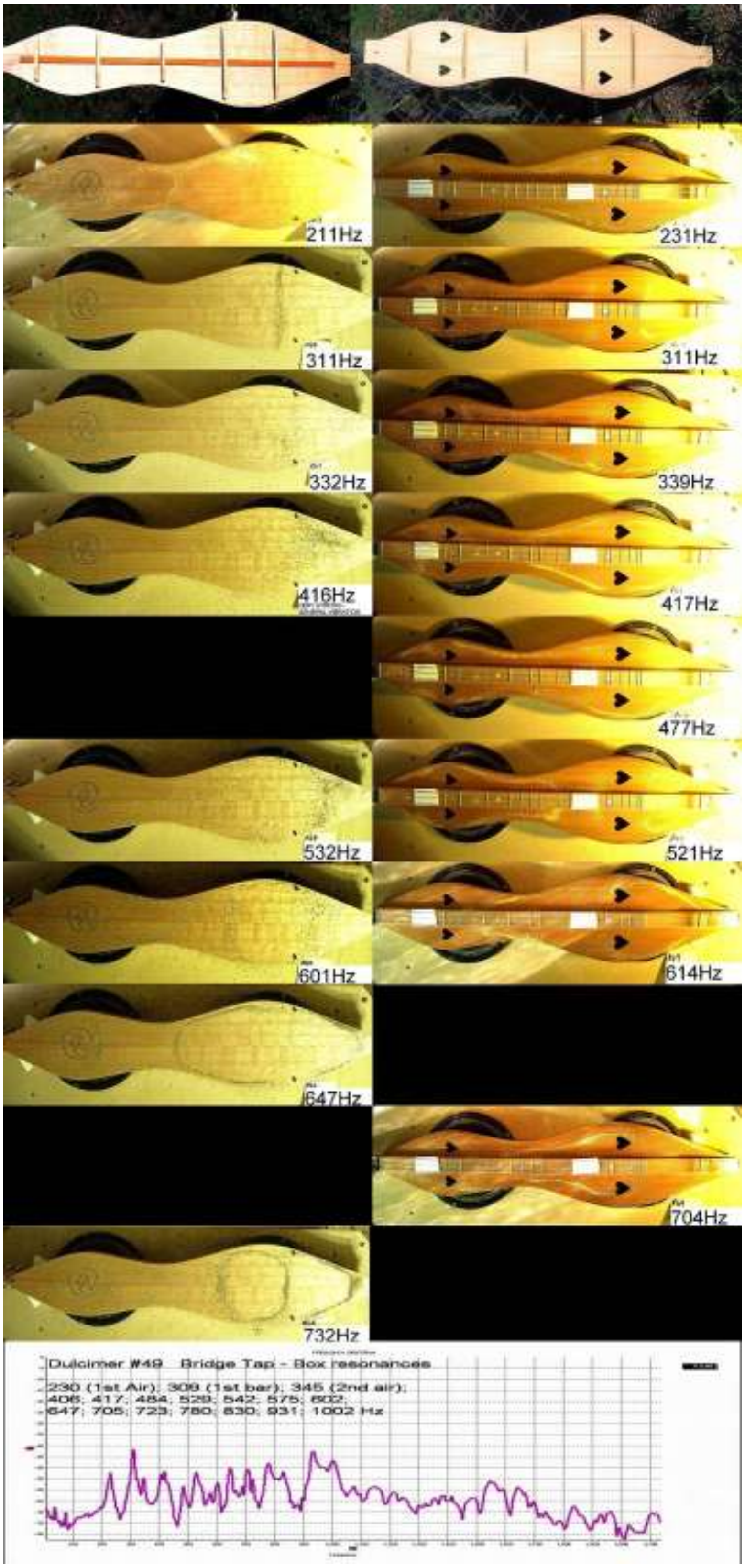


Figure 3.12. Vibratory pattern of Western Red Cedar/ Alpine Ash (Eucalypt) dulcimer

In the process of measurement, it seemed like some of the nodal lines were just following the back braces in the instruments. To test this proposition was why I took the braces out of the plywood test dulcimer. The result is shown in Figure 3.13

Figure 3.13. Effect of braces on position of vibration nodal lines

I've overlaid a picture of the internal back bracing in four dulcimers on top of a vibration pattern that seemed like it might be following the braces i.e. the brace might be preventing that part of the back from vibrating. The bottom picture in Figure 3.13 is the ply/WRCedar dulcimer without bracing, for the same modal vibration pattern. Whilst the right hand brace in the four cases is close to a nodal line, it might be coincidental, as there are clearly other braces which are included in vibrating areas, and the same general pattern occurs in the dulcimer without braces.

I suspect it is possible that vibration nodes might follow braces if they are too stiff and heavy, and this is more likely as frequency increases towards 1000Hz and more, but it seems from these few instruments that reasonable bracing doesn't overly constrain vibration, although it clearly moves resonances to slightly higher frequencies. I should say that these patterns are the ones that most seemed to follow the braces— other patterns were not as questionable.

Octave and Tear Drop Vibration Modes-Feb 13, 2018

This section, regarding mountain dulcimer resonances, was prompted by three octave dulcimers I had just made. They were of teardrop shape, all with two top braces, one with no back braces, one with two back braces, and one with three back braces. All turned out to be little powerhouses of instruments as octaves seem to do.

The standard caveats apply—full length fretboard, bridge saddle on the fretboard, not on the top plate. Whether the following applies to truncated fretboards and/or bridges on the top plate, I can’t say. It ***does*** apply to hollow and/or arched fretboards.

All had similar mass/stiffness fretboards — medium density overlayed with ebony or a hard eucalypt, and the same sides of Spotted Gum, a very tough eucalypt. But there were large differences in the mass and stiffness of the tops and backs, ranging from thin and hard but flexible (Douglas Fir) to thick and soft but stiff (Kauri Pine). It occurred to me that I didn’t know anything about the way these little dulcimers vibrated, or teardrop dulcimers in general for that matter. So I spent some time measuring the vibratory modal patterns of the three, plus a standard sized hourglass dulcimer and a standard sized teardrop dulcimer for comparison, as in Fig. 3.14.

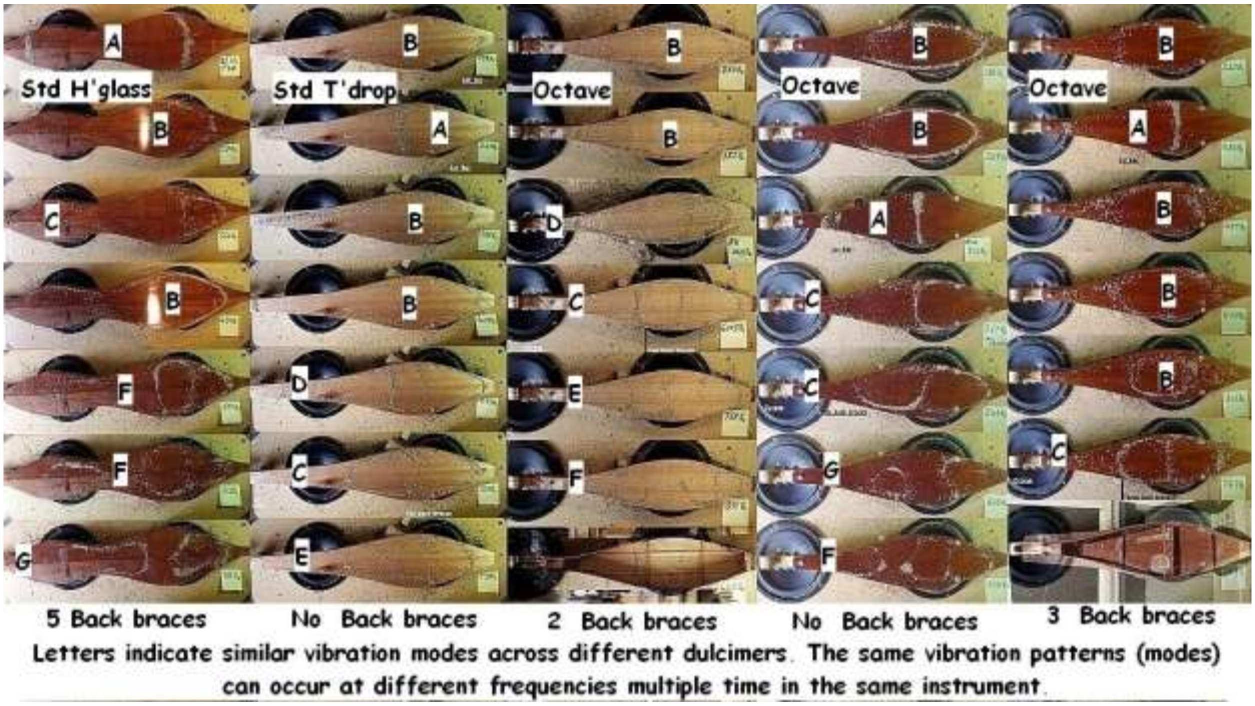

Figure 3.14. Dulcimer comparisons

Only one of the octave dulcimers is shown, the other two are similar.
The general specifications are:

- standard hourglass, VSL = 26.25”, 6-string, total string tension = 48kg,
- octave teardrop VSL= 16.9”, 6-string, total string tension = 51kg., and
- standard teardrop VSL= 26.25”, 4-string, total string tension = 33kg.

I hadn’t given much thought to where the lowest four resonances might fall in a generic octave dulcimer. The internal air cavity would be about half a normal dulcimer’s, and because there are two instead of four soundholes, the sound hole area would be about half. So the 1st Air resonance should be in the same ballpark as a standard hourglass. In a teardrop shape there should be no 2nd “Helmholz” air resonance as in an hourglass, and whether there would be a bar resonance in octaves that fell below 1000Hz I couldn’t guess.

In the end, the dulcimers vibrated as in Figure 3.15. Overall, it shows that Octave dulcimers, and standard sized teardrop dulcimers seem to vibrate in similar ways to standard hourglass instruments. The shapes of the vibration patterns (the “modes”) of the standard hourglass, the standard teardrop, and the three octave dulcimers were entirely typical of hourglass dulcimers that I have measured previously. The order of the various patterns can vary from dulcimer to dulcimer, and some modes may be missing in some instruments (or just missed in the measuring process). The general sequence of resonances in all three types, and probably in mountain dulcimers in general, is that there are one or two prominent air resonances near the beginning of the sequence, with a single bar resonance also early in the sequence. These are followed by several wood resonances of the same shape as the first air resonance, some with an air component, and then increasingly complex wood resonances, up to about 1000Hz – 1500Hz. Here, mode complexity increases to the point where the patterns can't be individually separated.



Letters indicate similar vibration modes across different dulcimers. The same vibration patterns (modes) can occur at different frequencies multiple time in the same instrument.

Figure 3.15. Vibratory patterns for the backs of one hourglass, one teardrop, and three octave dulcimers

This general similarity between the hourglass vibration patterns and those of the teardrop shape might partially explain why there doesn't seem to be a characteristic tonal difference between the two dulcimer types. Differences in tone between any particular hourglass dulcimer and any particular teardrop dulcimer would then be attributable to construction factors other than shape.

Regarding the two "Helmholtz" resonances, the 1st and 2nd Air resonances in an hourglass dulcimer, all the teardrop dulcimers here had only two sound holes each, as most teardrops seem to also. However, a previous particle board box experiments showed that even in a plain rectangular box with no waist as in a dulcimer, but with four sound holes, there were still two distinct "Helmholtz" resonances. So perhaps the two "Helmholtz" air resonances common in hourglass dulcimers are more a product of two sets of widely spaced sound holes, rather than any cavity separation caused by the dulcimer waist. If so, teardrop dulcimers that have four sound holes might also have the two "Helmholtz" air resonances.

In the case of octave dulcimers, the fact that the modal vibration patterns cover a similar frequency range to standard sized dulcimers may actually make them more efficient at turning string inputs into sound. A standard sized dulcimer has a resonance sequence starting about 180Hz to 250Hz (the 1st air resonance frequency). This is well above the lowest note of the dulcimer, D at 147Hz, so the fundamental harmonic of the low string, and perhaps the middle string also, is not efficiently supported, and the sound suffers a little because of it. But the lowest note of an octave dulcimer is D 294Hz, well above the starting frequency of the resonance series (1st air about same as standard dulcimers). Therefore none of the fundamental harmonics are automatically reduced in strength.

So, perhaps a little surprisingly, octave dulcimers, and teardrop dulcimers in general, vibrate in much the same way as standard hourglass dulcimers, and in similar frequency ranges for the modal patterns,

Dulcimer Resonances-Nov 14, 2009

I thought I'd have a closer look to see if changes in sound quality might be specifically related to individual resonances of the dulcimer, particularly the first three main resonances.

Again, keep in mind that this all relates to hourglass dulcimers, with full-length fretboard and four sound holes. Its relevance to other configurations is not clear.

Main Resonances

The first three resonances, or peaks of energy support, in a mountain dulcimer seem generally to be the box response to the first (Helmholtz) air resonance; the first bar resonance of the box; and the second air resonance. The frequency ranges that these might fall into, based on twenty or so dulcimers I have measured, are:

First air resonance peak, Frequency range 175Hz to 240Hz : Excited by blowing across a lower bout hole; the smaller the dulcimer, the higher in frequency this will be. As total sound hole size reduces, the first air resonance also reduces in frequency. For an average sized dulcimer, with normal sized sound holes, it might be about 220Hz.

First bar resonance peak, Frequency range 250Hz to 330Hz: This is equivalent to the note you get when you hold a piece of wood about 1/5th the distance from one end, and tap it in the middle or on either end. You can actually hear a dulcimer ring like this if you damp the strings with tissues, hold the edge about the level of the first fret and tap one end. The dulcimer is ringing like a xylophone bar (but with substantially less sustain).

Second air resonance peak, Frequency range 270Hz to 370Hz: Excited by blowing across an upper bout hole; I don't know what determines the frequency of this resonance, but it isn't correlated to box capacity or sound hole area in the instruments I've tested.

These are the lowest three resonances of a mountain dulcimer (but there will always be exceptions). They are probably the only ones that a maker has any chance of manipulating separately, in terms of frequency, amplitude (strength of effect), or bandwidth (number of notes on the fretboard it encompasses). I believe that when a maker says he or she is aiming for a "bright", "treble" or "mellow" sounding instrument, or any of the other commonly used sound descriptors, what is being done is, in large part, the manipulation of one or more of these three lowest resonances. This is accomplished by the normal methods of experienced lutherie — changes in wood dimensions and density, changes in box size and shape, changes in placement of bridges and break angles, etc. Above these three, the higher resonances are essentially a no-man's land as far as being able to predict and manipulate them. And it's not for want of trying with guitars and violins (although the resonance sequence is different in those instruments). But fortunately, most of what a dulcimer sounds like seems to be contained within the range of these lower resonance frequencies.

I wanted to see how important these three resonances are to the sound using my own dulcimer, by selectively amplifying or reducing frequency ranges of a recorded sound that matched the frequencies of the first three resonances of the instrument. This could probably be done with a narrow band equalizer, but I don't have one, and I wanted to make accurate sound level measurements of the results, so I again used the PRAAT signal analysis software.[2]

Figure 3.16 is a picture of the box tap frequency spectrum of the dulcimer up to about 900Hz, and the sound spectrum of a short tune played on the instrument.

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[2] I use PRAAT, which is free at http://www.praat.org. As I've noted before, it's a voice oriented research package, and fairly idiosyncratic, but it does a lot of things very nicely and it's free. It can record it's own sound files, or use .wav files.

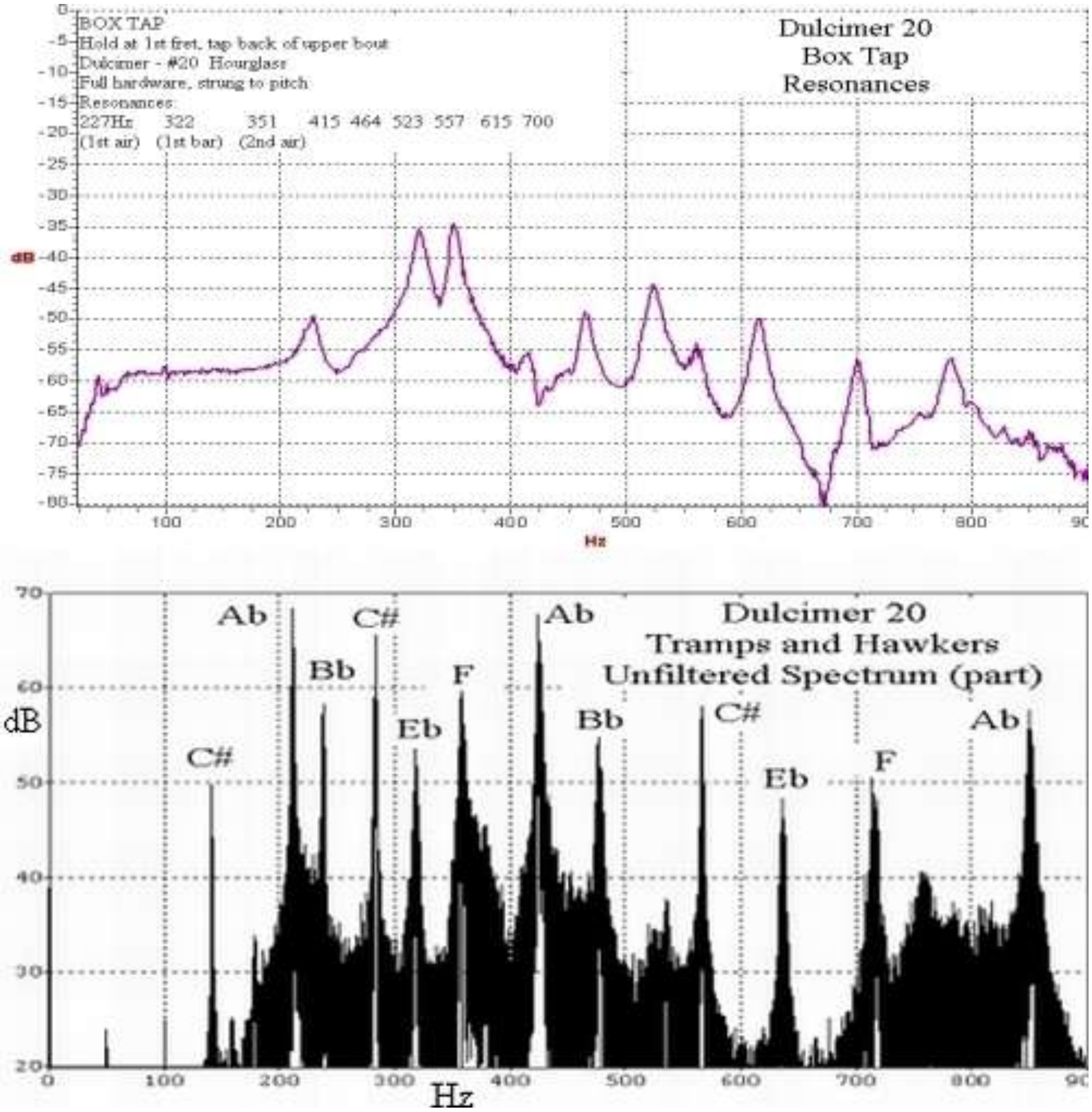


Figure 3.16. Box Resonances and sound spectrum of dulcimer#20

The peaks in the upper part of the figure represent frequencies at which the dulcimer likes to vibrate, and which will enhance those frequencies if they occur in music played on the instrument. The peaks in the lower part represent the fundamentals and the first couple of harmonics of the notes played in the recording. The two parts are to the same frequency scale, and it is clear that the dulcimer resonances are narrow enough to cover at most one or two semi-tones. That might imply that if a strong resonance is centred exactly on a note, then that note might be a potential wolf note. But I haven't noticed that to be the case. Not all notes are present in the tune, so the following is not an exhaustive test, but it is indicative.

Over a range of 50Hz, centered on each of the first three resonances, I reduced or amplified those frequencies in the sound clip by 10 decibels, the equivalent of halving or doubling the perceived loudness at those frequencies. I also did the same for all pairs of resonances, and for all three resonances simultaneously. Outside those frequency bands the sound was unchanged, all the way up to about 9kHz where the sound spectrum energy finally tapered off. The exact ranges were:

- 1st air 200 to 250Hz,
- 1st bar 290 to 340Hz, and
- 2nd air 325 to 375Hz.

The total range of frequencies altered covered only 175Hz out of 9000Hz — about 2% of the total frequency range where sound energy was present. Yet this small range of frequencies is critical to the quality of the sound.

After filtering the sound, I listened critically to see if I could: one, perceive a change compared to the original; two, decide the subjective magnitude of any change; and three, decide whether I thought it was for the better or worse.

Summary of Results

Reducing individual resonances by 10dB: This had almost no perceptual effect. Reducing the 1st air resonance had a just noticeable effect on the two notes nearest — marginally less “full” sounding.

Amplifying individual resonances by 10dB: This had more of an effect than with reduction, but still modest. Increasing the 1st air made the sound verge on boomy. However, increasing the 1st bar (290-340Hz) made the sound subtly fuller, and preferred over the original. There was no effect from the 2nd air resonance.

Reducing pairs of resonances: 1st air/1st bar; 1st air/2nd air; 1st bar/2nd air.
All sounded slightly thinner compared to original, and none were preferred.

Amplifying pairs of resonances: 1st air/1st bar; 1st air/2nd air; 1st bar/2nd air.
All had more “presence”, but the two that included 1st air were a bit boomy, as for the single resonance. The combination of 1st bar/2nd air produced a nice balance of presence and fullness, without boominess. It was preferred over the original.

Reducing all three resonances by 10dB: A thinner sound, but not really tinny — maybe a “traditional” sound.

Amplifying all three resonances by 10dB: Quite a full sound, very slightly boomy—preferred over original.

I also reduced/amplified the triple resonances by 20 and 30dB. A 30dB reduction resulted in a very tinny, unpleasant sound. A 20dB amplification resulted in an exceedingly boomy and unlistenable sound.

Conclusions

1. Enhancing the 1st air resonance seems to add "presence" or "fullness" to the sound, but runs the risk of making it "boomy" if it goes too far.

2. Enhancing the amplitude of the 1st bar resonance in this case also added more "presence" to the sound, without any boominess.

3. Reducing the amplitude of one of the first three resonances hardly makes any difference, but reducing 2 or 3 starts to produce a thinner tone.

The 1st air resonance is under some control by a maker —it is moderately well correlated with a combination of box capacity and sound hole size.

The 1st bar resonance might also be controllable, one day — by changes in length and stiffness of the dulcimer.

I don't know how the 2nd air resonance might be controlled.

Resonance Effects on Ukuleles-Feb 16, 2012

I've just finished 19 ukuleles of the style shown in Figure 3.17. and something showed up that is just as relevant to dulcimers (or any stringed instrument probably), and might be of interest to some.

Figure 3.17. Ukuleles

After the ukes were completed, and for no particular reason, I recorded the bridge-tap resonances of the instruments and filed them on the computer. Later I was listening critically to the sound of each of each uke and was struck that two of them sounded almost identical. When I looked back at the resonance spectra for these two ukes it was clear that not only the gross structure of the resonances was the same, but also the fine detail (Figure 3.18 and 3.19).

Each little bump and wiggle here indicates a frequency that the instrument vibrates at more easily — either the air in the cavity, or the wood. Both #52 and #59 clearly like to vibrate at the same set of frequencies.

I went back and picked the two ukes I thought had the most different sounds and then looked at their spectra (Figure 3.20 and 3.21)

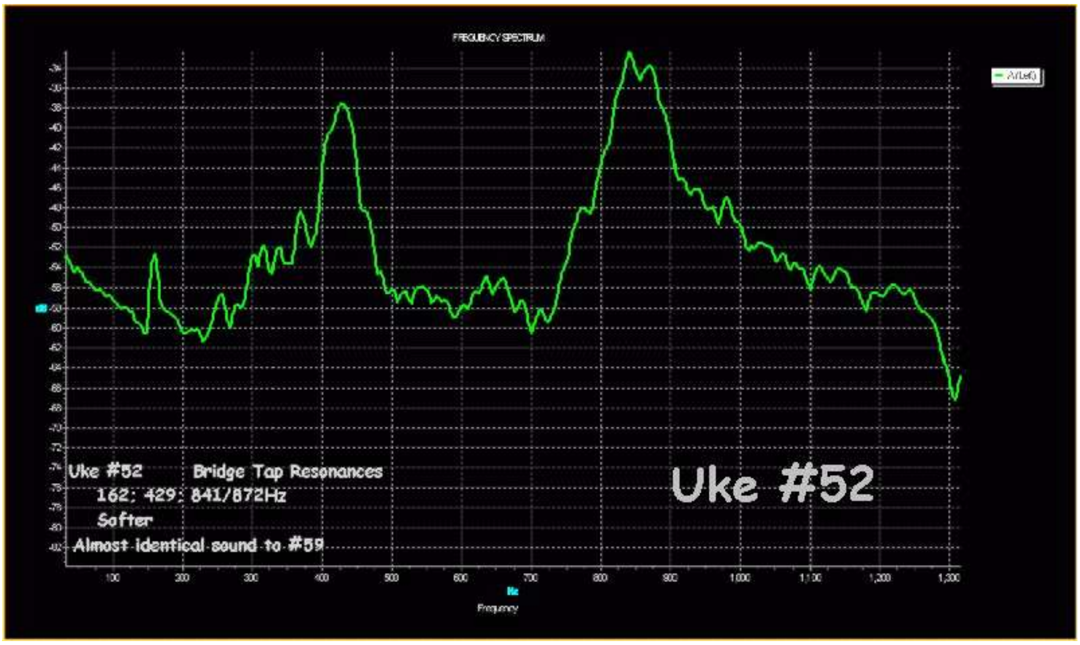


Figure 3.18. Resonance spectrum for Uke #52

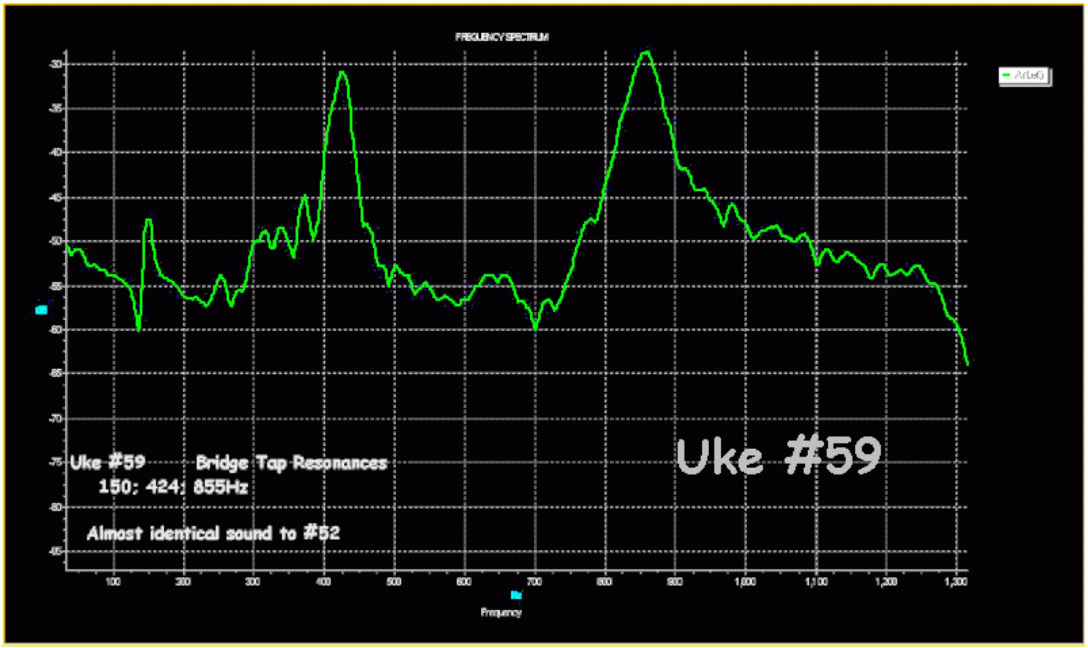


Figure 3.19. Resonance spectrum for Uke #59

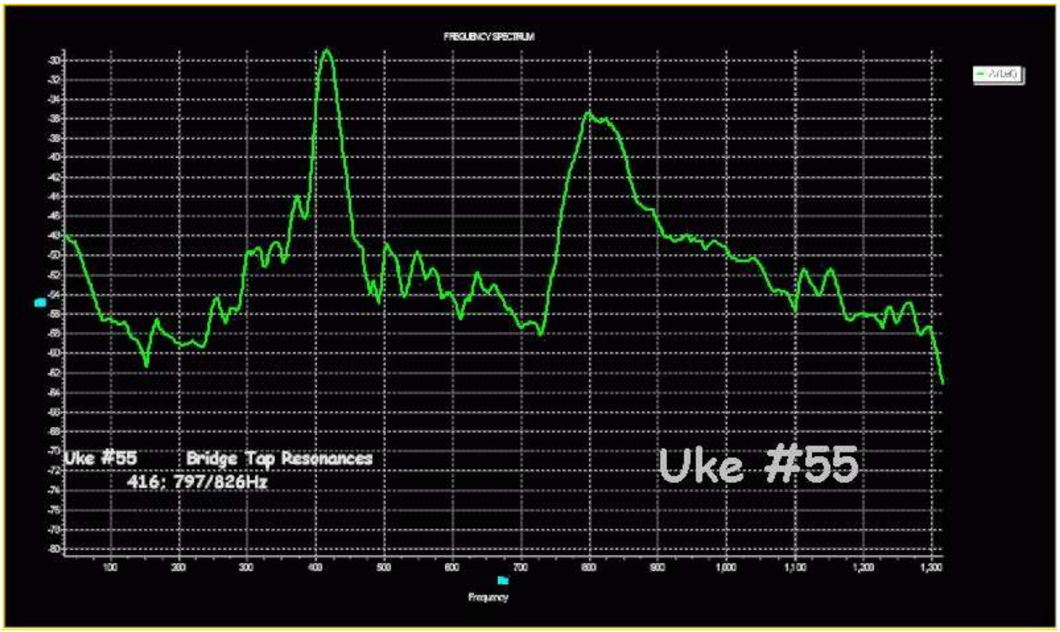


Figure 3.20. Resonance spectrum for Uke #55

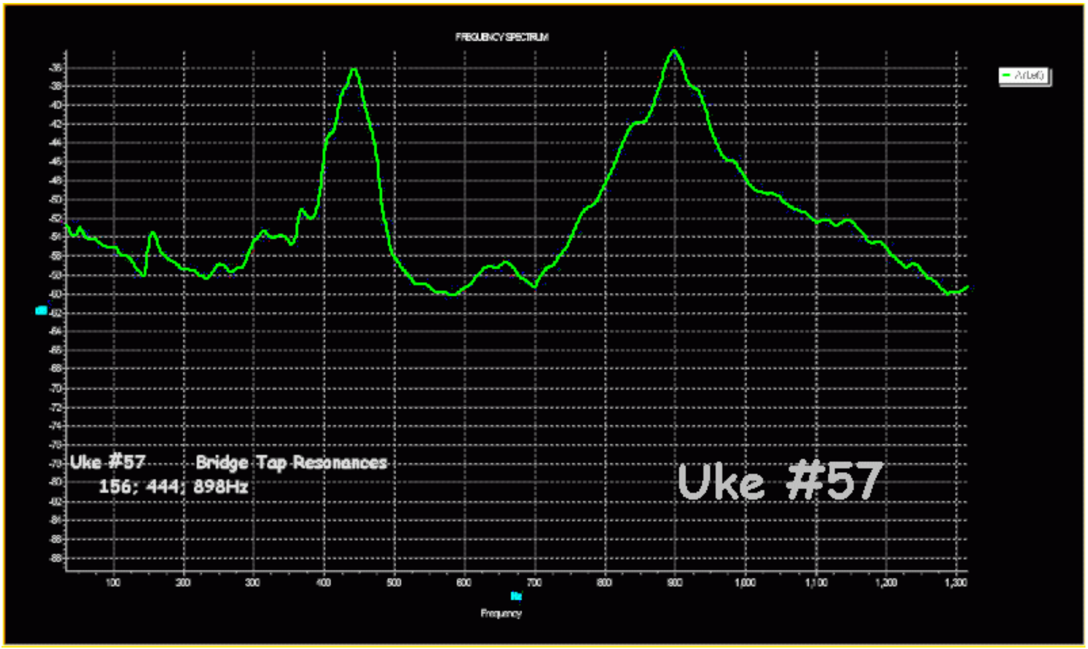


Figure 3.21. Resonance spectrum for Uke#57

These are different in both the detail and the two large resonances.

When I listened to ukes that had the two strong resonances quite close in frequency, but with different smaller resonances, the sound was quite similar, but still not "identical".

So, this seems to indicate that the general tone of the instrument is decided by a few strong resonances, but that the smaller and more numerous minor resonances kind of “finish off” the sound, and make it unique to that instrument. No real surprises there.

When a mountain dulcimer is constructed, the maker has some control over the individual strong resonances (up to maybe 500Hz or so). You might not think in those terms, but that’s what you’re doing when you decide the size of the sound holes and the dimensions of the box and fretboard, and the density of the wood used. (Other factors, such as string break angle and where the bridge is placed have more to do with ease of transferring string energy into the box, which is then filtered by the box resonances.) I doubt that any of the minor resonances are controllable by the maker; at best there might be general strategies that often result in a favorable set of them. What these strategies might be could be why some makers consistently turn out above-average dulcimers by combining design features that produce these favorable sets of small resonances. And it probably only took them 20 years to home in on.

I think there might be something in the “it takes 50 instruments before you start to know what you are really doing” axiom. I’ve made about 60 of these ukes now and have just about figured out what it takes to make them sound good. But what it takes to make them sound “great” is still a mystery, and probably always will be.

Dulcimer Harmonics-Jan 28, 2015

I thought some people might be interested in this — it gives a small hint about the complexity of the sound we are dealing with out of our instruments, and also why it is difficult to pin down just what it is that we think makes a dulcimer (guitar, violin, banjo) sound the way it does.

Here are two spectrograms of the sound of my test dulcimer. They both show six string strikes from left to right. The time between each strike is about 10 seconds while the harmonics die away. The vertical axis is frequency from 0Hz to 2000Hz. Each of the little "flags" is harmonic of the fundamental note. The blackness represents the relative loudness of the harmonic and its length indicates its sustain. The harmonic at the bottom is the fundamental — the note we think we are tuning the string to. The top "flag" is about the 15th harmonic of the note.

The first spectrogram(Figure 3.22) is of the single third string, tuned to C3 (131Hz). The other two strings are damped with tissue paper.

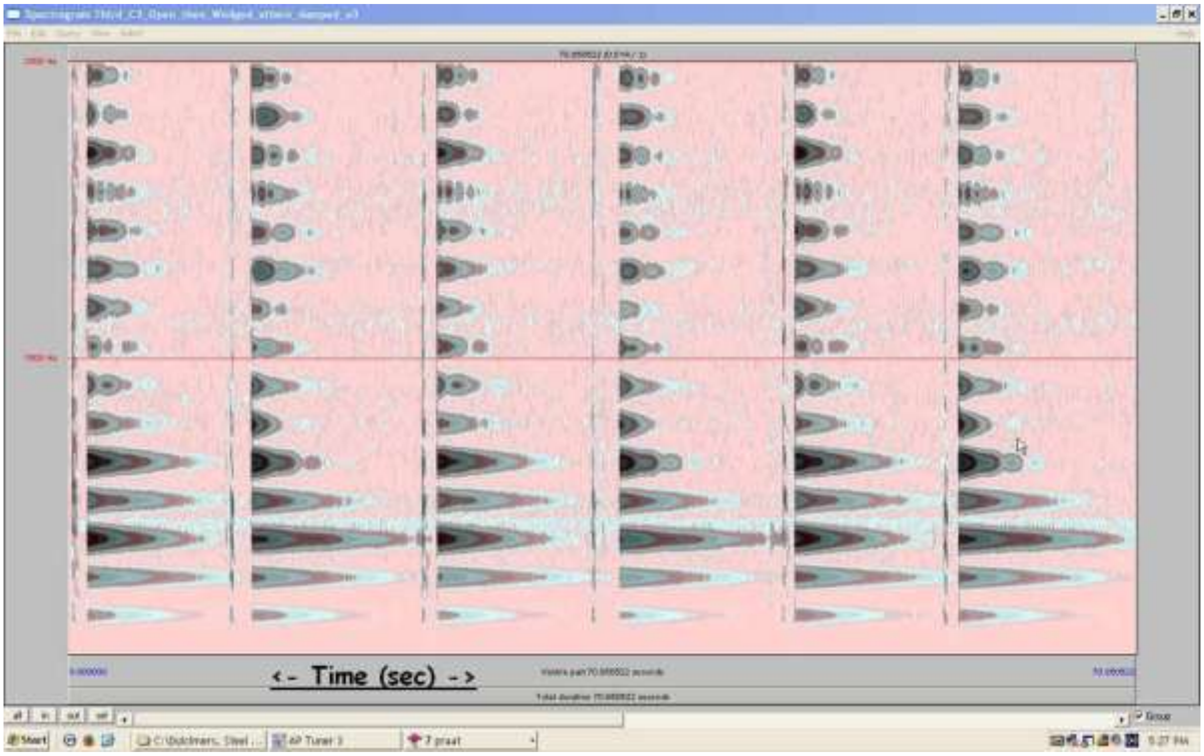


Figure 3.22. Sound spectrogram of six strikes of dulcimer 1st string - note C3

Notice that the fundamental has very little energy - the 3rd, 4th and 5th harmonics are by far the loudest, and last the longest. We probably imagine the fundamental more than actually hear it, as we do over the telephone. After the initial string strike, the harmonics smoothly die away.

The second spectrogram(Figure 3.23) is a series of six strums across all three single strings (no unison 1st), tuned CGc.

This is a lot more complex than just the one single string. The harmonics of the three strings are mixed together, and many of them are amplitude modulated. They are also frequency modulated if you look at the frequency tracks of each harmonic on a program such as AP Tuner. There's a strong interaction between the 3rd harmonic of the third string (C), and the 2nd harmonic of the second string (G). These are notionally the same frequency, but in the real world they differ a little, and hence beat. Whether we can hear the modulation I don't know, but the sum of all these inter-harmonic modulations probably contributes to the overall tonal impression.

You might notice that alternate string strikes have slightly different harmonic series. The reason is that the recordings were made for another experiment and a weight was added to the end block in each alternate strike.

Figure 3.23. Spectrogram of six 3-string dulcimer strums - notes CGc

Air Resonance Effects-Jan 08, 2016

Changes we make in dulcimer construction are not linearly additive and we'll probably never precisely know the effect of multiple combinations of changes.

But the elephant in the room, which has niggled at me since doing the first experiments in cutting the top off, is this:

With no top, a dulcimer has no internal air resonances, no interaction of those resonances with the wood, and no Helmholtz sound radiation from the sound holes. But if you compare the bridge tap spectra of a normal dulcimer (wood vibrations) with the spectrum of air resonances excited by a small loudspeaker near a sound hole (air vibrations), nearly every peak in the tap spectrum has a corresponding peak in the air resonance spectrum. This indicates to me that air resonances play a central role in the sound of a mountain dulcimer, and there are wood and air cavity interactions over a wide frequency range. If this is the case, a topless dulcimer must be producing sound differently than an enclosed instrument. The vibration modes (Chladni patterns) are certainly different from an almost identical dulcimer made about the same time. And yet, when I make a recording of the two dulcimers, I can't tell which is which.

Helmholtz Resonance- Jan 12, 2016

We shouldn't get too carried away with Helmholtz resonance, but it is a natural part of any rigid enclosed structure with a hole in it. The Helmholtz resonance is the lowest resonance of a mountain dulcimer (and a guitar) and interacts with the dulcimer wood to make it vibrate. It's easy to see its effect by strumming and covering/uncovering one or more sound holes with some cardboard. There's likely to be a modest tonal change — maybe for the better, maybe not. It's just one of the 10 to 15 resonances of the instrument below about 1000Hz, and it does affect the tone. It's not even technically the Helmholtz resonance because the body of a dulcimer is not perfectly rigid - the frequency is a bit lower than the true Helmholtz, but that's neither here nor there. I'd rather call it the 1st Air Resonance.

What is not sensible is the notion of "tuning" the dulcimer to the Helmholtz resonance and in the process making the sound better overall. I'm not sure where this notion arose. Positioning one of many resonances at a particular frequency ***might*** be beneficial in some cases, but moving one resonance is not going to "open up" an instrument. It's more likely the density of resonances, their even spread over the spectrum, and maybe the frequency ratios of some of them. All this is largely outside the direct control of the maker.

If I had my way, I'd generally like the 1st air resonance fall at about 170 to 180Hz for a standard sized dulcimer. That should get it well below the first bar resonance to smooth the bass (not boomy with superimposed resonances), and closer to the fundamental of the lowest D note. But because of the size and shape of my dulcimers, it generally falls at about 220 - 230Hz, so I lose the fundamental harmonic of the bass string, and the tone is a little less mellow. Thin plates, large box and small sound holes will lower the Helmholtz resonance, (if that's what you want to do).

The Helmholtz is just one of many resonances — it plays its part but doesn't dominate all the others.

The Sequence of the First Four Resonances- Feb 09, 2018

There are twenty or so resonances below about 2000Hz in a standard sized mountain dulcimer. These are a combination of internal air cavity resonances, vibratory resonances of the wood plates of the instrument, and the interactions between the two. For example, the variations in internal air pressure caused by an air resonance will cause the wood itself to vibrate, which in turn will modify the internal air pressure.

The first few resonances probably influence the general tone and loudness of the dulcimer more than all the others, and may also be under the control of the maker to some extent, so their origin may be of interest to some.

Using a combination of sound spectral analysis, loud-speaker driven dulcimer vibration mode analysis (Chladni patterns) and sound hole size variation, I think I have a handle on the first four dulcimer resonances.

Tapping the bridge of a dulcimer and obtaining a frequency spectrum of the sound thus made will indicate what resonances are present in the instrument, and their frequencies.

Chladni modal analysis shows where the actual vibration is occurring on the instrument, in patterns of sawdust. It can also reveal whether an internal air resonance is involved – just holding a finger above the sound holes shows whether air is flowing in and out or not. Upper and lower sound holes may individually have air flow, or both might. If there is no observable airflow from the holes, then the resonance probably originates in wood vibration only.

Blocking off the sound holes, and observing what happens in the tap spectra can reveal the frequencies of the Helmholz resonance(s) - strictly the first air resonance because of the box flexibility. It seems that mountain dulcimers, of the traditional full fretboard/four hole type, might have two Helmholz resonances – the tone obtained when blowing across the top of a bottle. I don't have enough acoustics theory to explain why this might be.

So what are the lower resonances of a mountain dulcimer?

The lowest resonance is the ***1st air resonance*** ("Helmholtz") and it falls in frequency between about 150Hz and 250Hz for a standard sized dulcimer – a fairly wide range dependent on box size and stiffness, and sound hole size. Smaller holes will lower it, larger holes will raise it. A larger box will lower it, as will a more flexible top, back, and sides. It is unlikely that it will get low enough in frequency to strongly support the fundamental of the low string. Blowing across the lower sound holes will produce it (if they are not of complex shape). If the holes are complex it may not be possible to produce it by blowing, but it will still be there.

The next resonance is usually the ***1st bar resonance*** which depends on the length cross section and mass of the dulcimer. The first (and only?) bar resonance might fall in the range of about 220Hz to 350Hz.. The headstock and the weight of the machine tuners can modify this resonance by a couple of semitones. Heavier end weight and a longer dulcimer will lower the frequency of this resonance.

The third resonance is the ***2nd air resonance*** and is the tone produced by blowing across the upper sound holes. It seems to act like a Helmholtz resonance in that if the sound holes are blocked off, both the first and second air resonances are extinguished – they don't appear in the tap spectra.

The fourth dulcimer resonance is the ***1st wood resonance*** – the lower bout of both the top and the back vibrate strongly with a simple circular mode in the region of 400Hz and are probably in phase with each other because there is no airflow from the sound holes. The sides may be going up and down out of phase with the top/back.

Here's a couple of dulcimers to demonstrate what happens when the sound holes ore systematically blocked (Figure 3.24). This sequence, that has been repeated on seven dulcimers, seems to show that:

With all holes open, the resonance sequence is 1st air; 1st bar; 2nd air; 1st wood.

With upper holes blocked, the 1st air resonances falls by up to 5 or 6 semitones and the 2nd air by 2 or 3 semitones. The 1st bar and 1st wood don't change much.

With lower holes blocked the 1st air resonance ("Helmholz") disappears and the 2nd air resonance remains basically unchanged. 1st bar and wood remain unchanged.

With all holes blocked the two air resonances disappear leaving the bar and wood resonances unchanged.

Changing the size of the sound holes has merged the 2nd air resonance with the 1st bar resonance in the dulcimer shown in Figure 3.24. Sometimes it is difficult to know where the resonances are if they are stacked one on top of the other as in the dulcimer in Figure 3.25 – the 1st air, 1st bar and 2nd air all fall in the same frequency region. This is not generally a desirable situation – it is thought better to have a good spread of resonances for good tone and to prevent boomy areas of the spectrum.

Not all dulcimers will have this sequence of resonances – some may be missing, or occur in a different order, but this generally seems to reflect the low frequency resonant behavior of a standard mountain dulcimer.

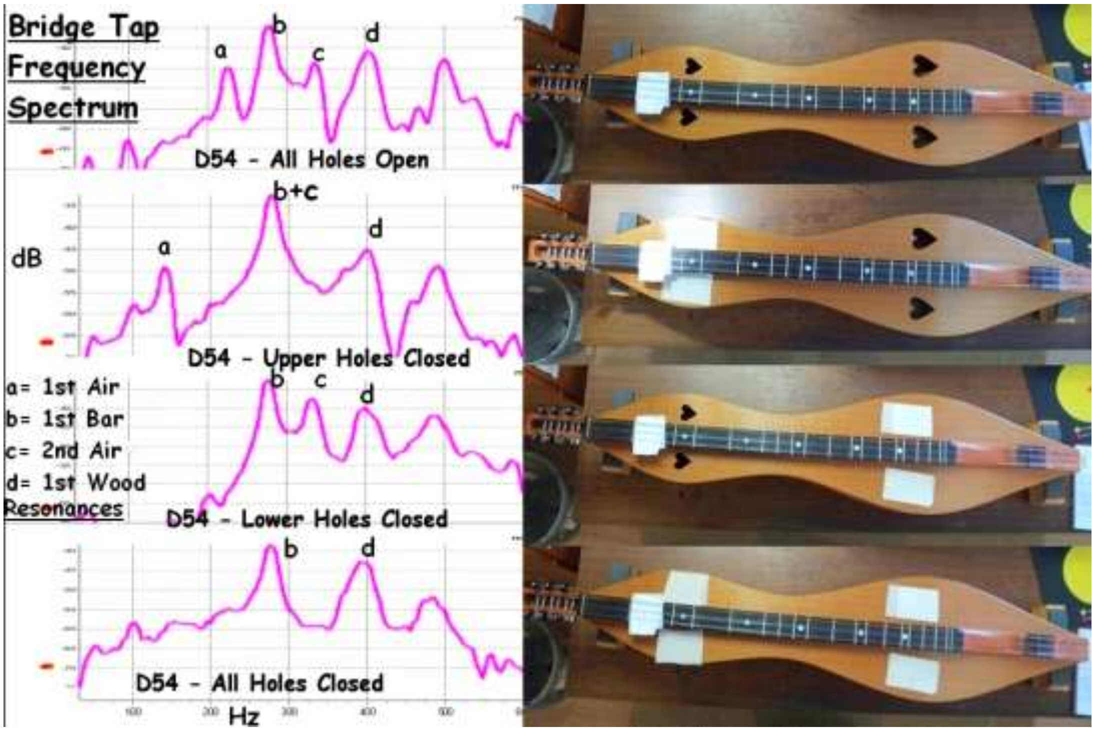


Figure 3.24. Bridge tap frequency spectrum for large sound holes

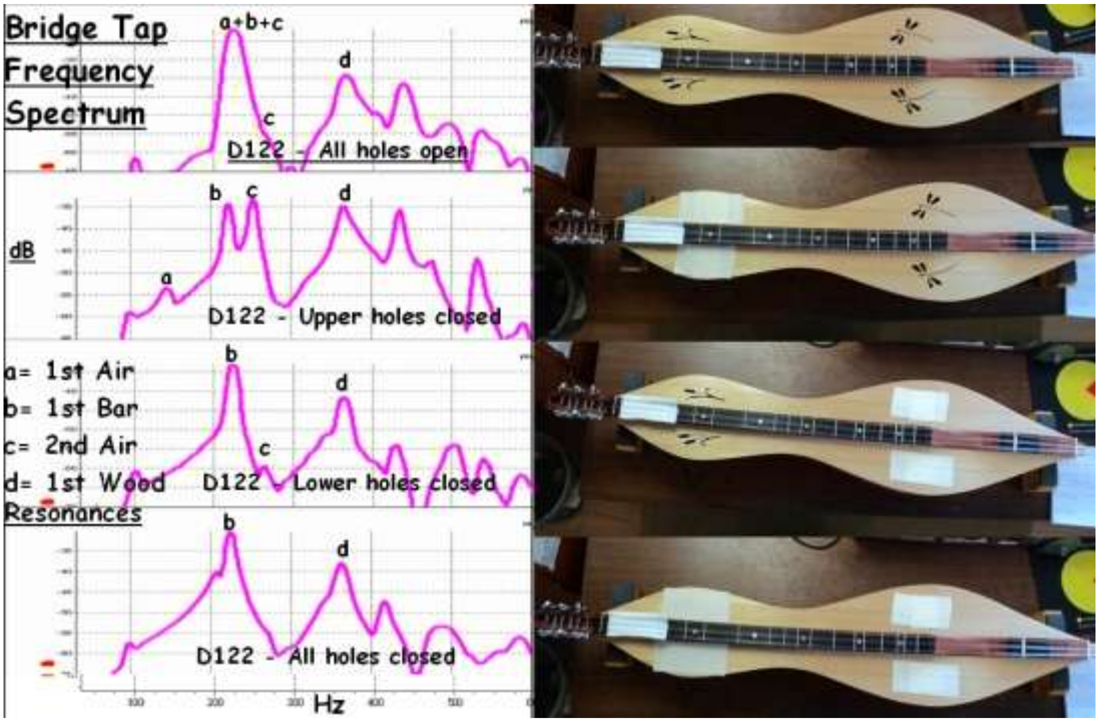


Figure 3.25. Bridge tap frequency spectrum for small sound holes

Chapter 4
Top Plate Thickness

Top Thickness-Sep 17, 2011

There's something of a conflict between some builders' experience over a long period, and my few controlled experiments regarding whether the top wood and thickness matter much to a mountain dulcimer sound. I've said elsewhere that you can double the thickness of the top without changing the sound much. Others say their observations, based on early experiments, indicate that thickness and wood species do alter the sound.

My experiments were on one dulcimer body that I changed the top on, and also my impressions of the 50 or so I have made with different top parameters. But the top change necessarily took a couple of days, plus a bedding in of a day or two, so it wasn't a side by side comparison.

So, I decided to construct a couple of really identical simple dulcimers, except for the top wood, and see if I could hear much difference between the two (which is really the only test). I started to sort through my wood to get the pieces, but something became obvious right away. A whole day was spent just trying to get wood of the same weight and stiffness. And I don't mean solid wood. The body of these two will be high quality Hoop Pine ply (1/8") which I have a small stock of, cut to exactly the same sizes for backs and sides. Even the closest match I could find ends up with a 3% difference in weight. The tops will be Western Red Cedar, each a single piece from a book-matched pair that look very homogeneous. One will be 3.6mm and the other 1.8mm. After thinning, the weight is exactly half, which is good at least.

I had a great deal of trouble getting two fretboards of the same species that had the same density and stiffness and grain alignment. Some had the same density, but greatly different stiffness (more than 20%). The best I could do, for the same physical dimension, was 4% difference in density, and 2% difference in static stiffness. This will probably change again when the fretboards are shaped. I've maximized the chance of the top plate influencing the sound by using quite a light wood for the fretboard, and making it only 16mm high instead of about 20mm. The mass and stiffness of the top plate should then increase in importance.

I spent a lot of time closely matching these parts and the best I can do is about 3 - 4%. In the real world, I suspect we would be lucky to have components of supposedly identical dulcimers closer than about 10% in density and stiffness, on average. (This has different consequences to the dimensional differences where the physical size of the instrument had changed.)

It may be that a mountain dulcimer sound is fairly tolerant of normal variations in the body panels, but I suspect it is much more sensitive to fretboard parameters.
I like solid wood better than ply, I'm just using the ply here because it's likely to be less variable. I want the only real difference between the two to be the tops. Also, I didn't want to use up good wood panels on experimental instruments.

I'm pretty sure there will be a noticeable sound difference between them, but what I'm interested in is whether there is a large sound difference. If you doubled the thickness of a guitar top I think there would be large sound changes — I don't think that occurs to the same extent in mountain dulcimers because of the fretboard. I think that if each was played behind a screen, a listener might have trouble telling them apart. In the past I have made three pairs of notionally "identical" dulcimers; one pair with a fretboard difference (arched vs hollow), and two pairs with top plate differences (internal top plate groove vs no groove). Each one sounded different to its twin, but not very different. But each pair sounded very different from the other pairs; I don't think listeners would have much trouble distinguishing between the different pairs.
Of course, none of this has anything to do with whether one is "better" than another. I don't know what that means.

Effect of Top Plate Thickness on Sound - Oct 17, 2011

It's not entirely clear what effect the thickness of the top plate has on the sound of a mountain dulcimer. Some makers carefully sand or plane the plate to a thickness that seems "right" to them, in some sense. Others set the thickness to bias the instrument to a particular sound. One maker says that a thicker top will give a warmer sound than a thinner top. Another I met in Australia assures me that a dulcimer top should be no thicker than 1mm. I tend more towards thicker than thinner tops, for strength reasons as much as anything. I've generally concluded that top thickness doesn't matter a lot to the final sound.

But experience can be deceptive, and none of the experiments I've previously done have looked specifically at top thickness and controlled for everything else, so a separate experiment was worthwhile.

As usual with these experiments, we are only talking about a generally traditional mountain dulcimer layout — principally a full-length fretboard, arched, solid or hollow, and with the bridge mounted on the fretboard. In this case, the dulcimers were boat-shaped for simple construction, rather than hour-glass, but the conclusions should also be relevant to hour-glass and teardrop shapes. They may ***not*** be relevant to dulcimers with a shorter fretboard and the bridge on the top plate.

The Experiment

Make two dulcimers, of the same design, as identical as possible with the exception that the top plate of one will be twice as thick as the top of the other. Maximize the likelihood that there will be a large sound difference between the two by making the height of the fretboard lower than usual, thereby increasing the relative contribution of the top plate thickness to the top assembly stiffness. The aim was to see if there was a clear and substantial difference in the sound with the changes to top thickness.

Method

Two dulcimers were made from high quality hoop pine plywood for back and sides, and also internal linings and bracing. The fretboards were New Guinea Rosewood, which is a medium density timber, and the tops were Western Red Cedar. All pieces were matched for weight, dimensions, and static stiffness as best I could. Even so, the differences were in the order of 3% - 4% in weight. I suspect that without special selection of parts, the average “identical” dulcimers might vary by about 10% in the weights of the components. The two book-matched tops were not wide enough to cover the dulcimer width, so I had to wing them with density-matched scraps. The finished dulcimers are shown in Figure. 4.1

Figure 4.1. Finished dulcimers for top comparison

The internal structure of the box is shown in Figure 4.2. The linings and the braces are made from the same plywood as the back and sides. No side-linings on the bottom. Boat shape was used for ease of construction, and the sides were not heat-bent, just held to shape whilst being glued to the end blocks.

The tops (Figure 4.3) are braced similarly for two reasons — one of the tops is too thin to survive very long if unbraced, and I intend to sell the instrument. And secondly, the fretboard is arched and I don't like the idea of a fretboard arch foot that is supported by the top plate alone. (Due to bad planning, I put the braces on starting from the wrong end, hence the reason for the non-centered sound holes.)

Figure 4.2. Internal structure


Figure 4.3. Top bracing

One top was planed/sanded to 3.6mm and the other was 1.8mm as shown in Figure 4.4.


Figure 4.4. Top comparison (side view)

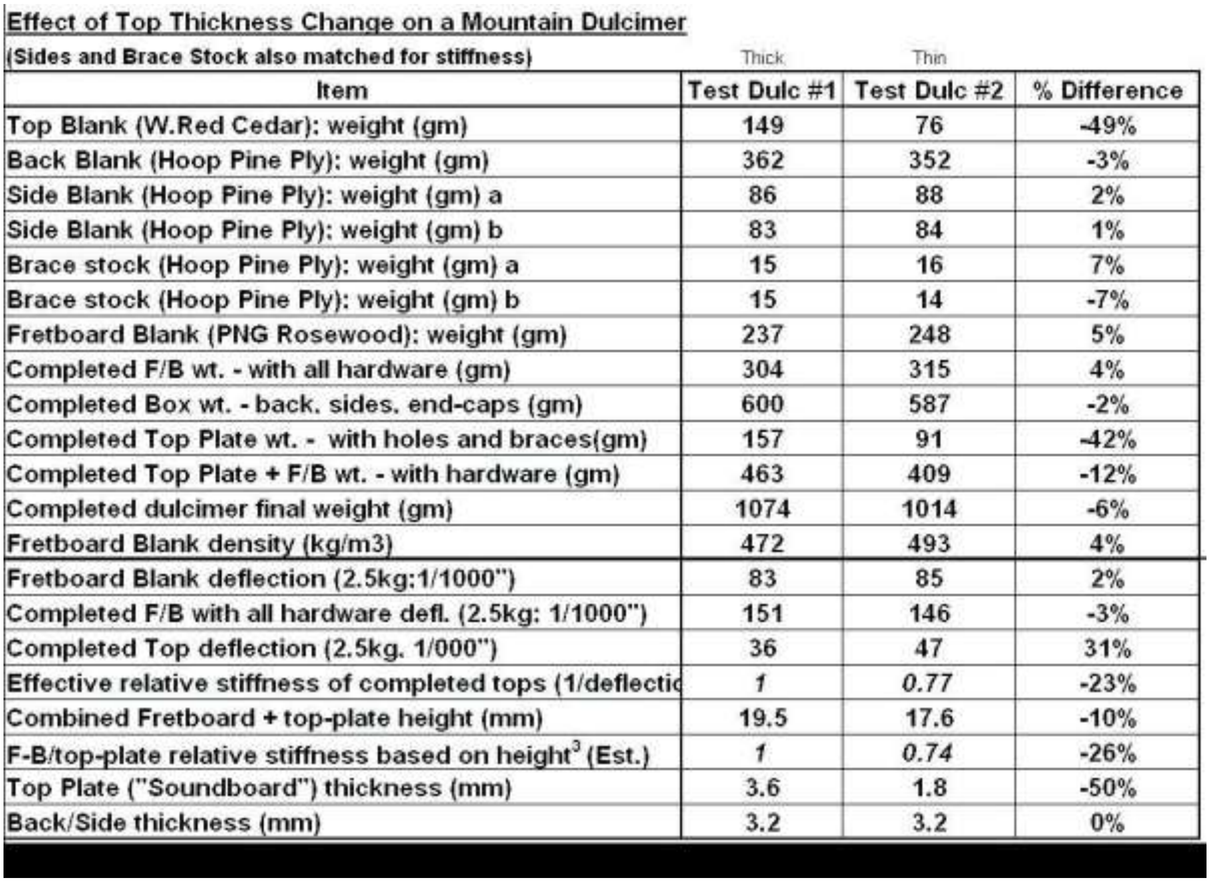
These two thicknesses, 1.8mm and 3.6mm, represent the limits I would actually use for a top — maybe I'd go to 4mm or so sometimes, but I wouldn't do thinner than 1.8mm (using Western Red Cedar). Sides were 50mm high, and the fretboard was 16mm high and 32.5mm wide.

Test Dulcimer #1 had the thick top and Test Dulcimer #2 had the thin top.

Results

The weights and sizes of various parts, and some stiffness measures during construction are shown in Table 4.1. Top #2 was almost exactly half (50%) the weight of Top #1, but by the time the top was trimmed, braced, and the sound holes cut, the weight difference was only 42%. When the top assemblies were finished (with fretboard, headstock and tuners) the weight difference was 12% - the original different weights of the top plates starting to be swallowed up by the larger weights of other parts. In the completed dulcimer, the tops contributed between 12% (132gm) and 7% (66gm) to the total instrument weight. (The top braces weighed 25gm.) Halving the top thickness only reduced the final dulcimer weight by 6%. This sort of difference is likely to be masked by the normal weight variations in solid wood instruments.

Table 4.1
Thick and Thin Top Dulcimers - Weight and Stiffness Comparison



Effect of Top Thickness Change on a Mountain Dulcimer
(Sides and Brace Stock also matched for stiffness)

	Thick	Thin	
Item	**Test Dulc #1**	**Test Dulc #2**	**% Difference**
Top Blank (W.Red Cedar): weight (gm)	149	76	-49%
Back Blank (Hoop Pine Ply): weight (gm)	362	352	-3%
Side Blank (Hoop Pine Ply): weight (gm) a	86	88	2%
Side Blank (Hoop Pine Ply): weight (gm) b	83	84	1%
Brace stock (Hoop Pine Ply): weight (gm) a	15	16	7%
Brace stock (Hoop Pine Ply): weight (gm) b	15	14	-7%
Fretboard Blank (PNG Rosewood): weight (gm)	237	248	5%
Completed F/B wt. - with all hardware (gm)	304	315	4%
Completed Box wt. - back, sides, end-caps (gm)	600	587	-2%
Completed Top Plate wt. - with holes and braces(gm)	157	91	-42%
Completed Top Plate + F/B wt. - with hardware (gm)	463	409	-12%
Completed dulcimer final weight (gm)	1074	1014	-6%
Fretboard Blank density (kg/m3)	472	493	4%
Fretboard Blank deflection (2.5kg:1/1000")	83	85	2%
Completed F/B with all hardware defl. (2.5kg: 1/1000")	151	146	-3%
Completed Top deflection (2.5kg. 1/000")	36	47	31%
Effective relative stiffness of completed tops (1/deflecti	*1*	*0.77*	-23%
Combined Fretboard + top-plate height (mm)	19.5	17.6	-10%
F-B/top-plate relative stiffness based on height^3 (Est.)	*1*	*0.74*	-26%
Top Plate ("Soundboard") thickness (mm)	3.6	1.8	-50%
Back/Side thickness (mm)	3.2	3.2	0%

Remember, these two are probably near the normal extremes of top thickness, so in most dulcimers smaller variations in top thickness will have little effect on the overall weight of the instrument. So, despite what I've speculated earlier in this thread about a thicker top possibly adding tone-altering weight; if a thickness change to the top causes a tonal change in the instrument, it is unlikely to be because of the additional, or reduced, weight it brings.

During construction, I also recorded the tap resonances of the various parts. For those parts that did not have the top plates attached, I expected that the natural resonant frequencies would be very similar, because the shapes, density and sizes were as equal as I could make them. This proved to be the case, even though this is not necessarily tied to identical sound in the finished dulcimer. This is because the fact of gluing parts together changes the resonant behaviors. For those who might be interested I'll show the tap resonances of the various parts.

Resonances for the fretboard blanks – just rectangular section bars of New Guinea Rosewood-are shown in Figure 4.5. Not much difference between the two blanks.

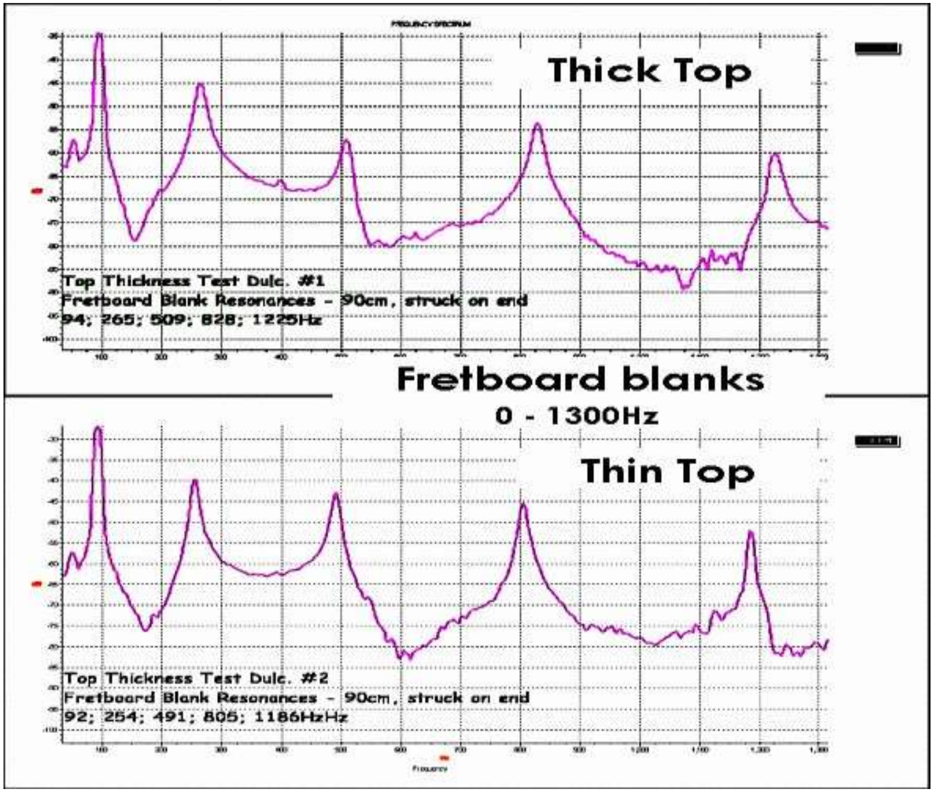


Figure 4.5. Tap resonances of fretboard blanks (The Thick Top/Thin Top labels just indicate which dulcimer they will end up on.)

The completed fretboard, with headstock attached, tuners and frets installed, strum hollow and arches resonances are shown in Figure 4.6. The general thinning, plus the added weight on one end has moved the resonances lower in frequency — increased end weight and reduced stiffness both head in the direction of lower frequencies. But, they are still the same as each other.

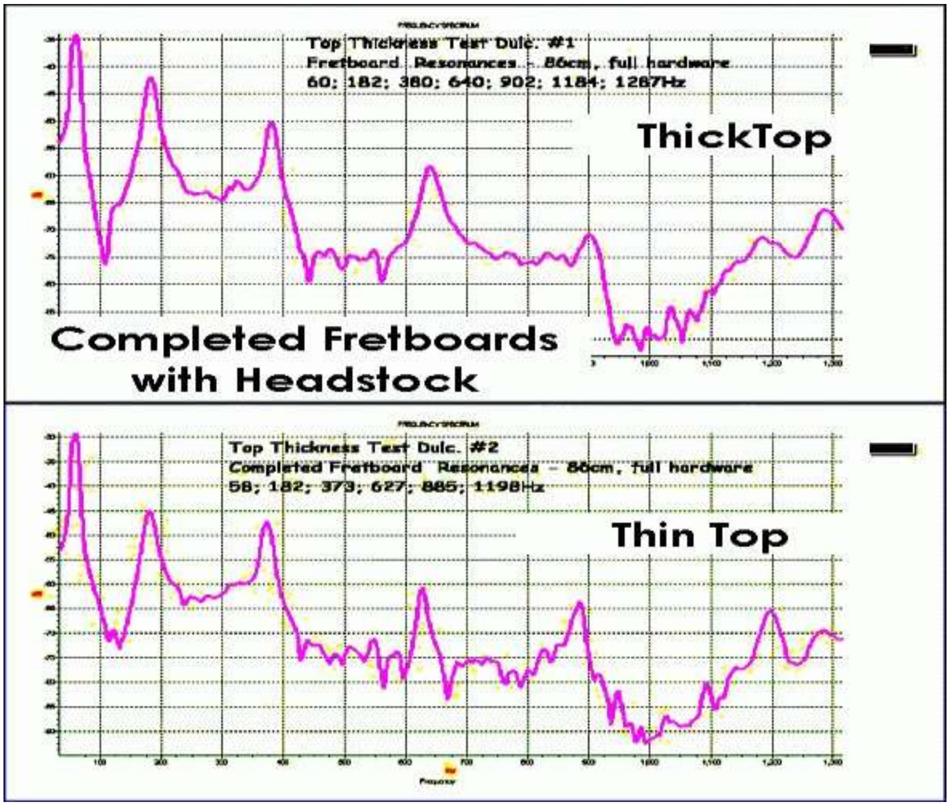


Figure 4.6. Tap resonances of completed fretboards

The boat-shaped open plywood box without the top or fretboard tap resonances are shown in Figure 4.7. These charts are fairly busy because it’s getting to be a complex shape, but the two are very similar, and they sounded the same when tapped; I couldn’t tell the difference. So the pairs of box and fretboard assemblies are very much alike, in isolation, at least.

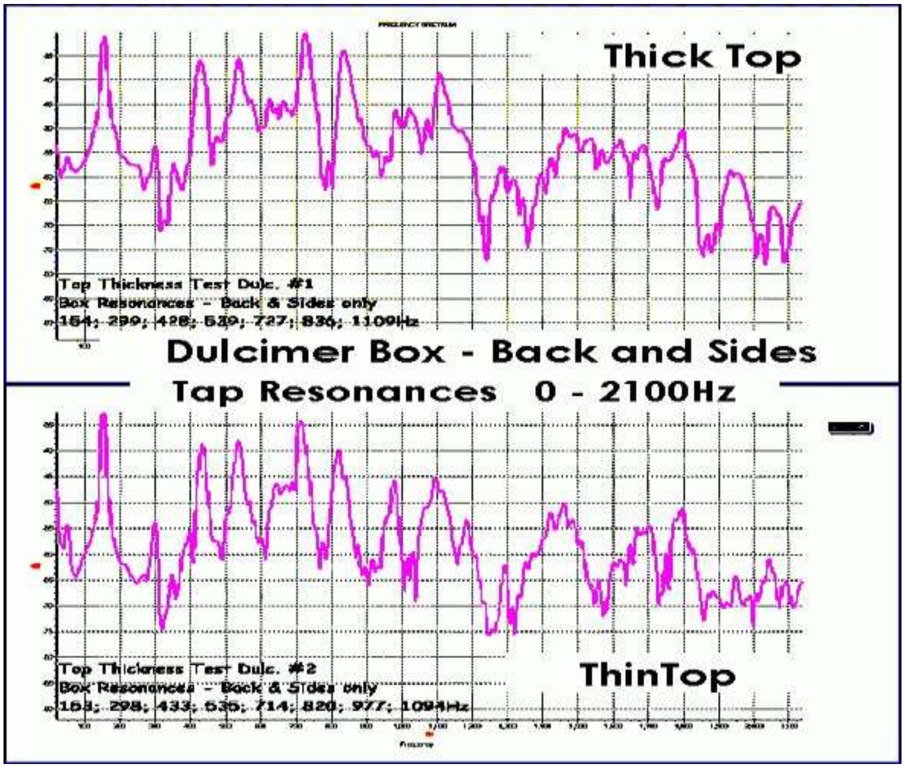


Figure 4.7. Tap resonances of box without top and fretboard

The tops themselves might be expected to have quite different resonances because of their weight and stiffness difference. Figure 4.8 shows the patterns for the shaped tops, with bracing and holes but no fretboard.

It's hard to see much common ground here – the two are clearly different in the way they like to vibrate. Tapping a thin flexible plate that's going to be glued up in complex ways might not be very informative regarding the final instrument outcome (unless you are Dana Bourgeois[3]), but these two sounded completely different. The thin top is half the mass of the thick one, but 1/8th the stiffness, so it should sound more bassy than the thick top, and it did.

When the top was completed by the addition of the fretboard/headstock/tuners, the tap resonances are shown in Figure 4.9.

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[3] https://en.wikipedia.org/wiki/Dana_Bourgeois

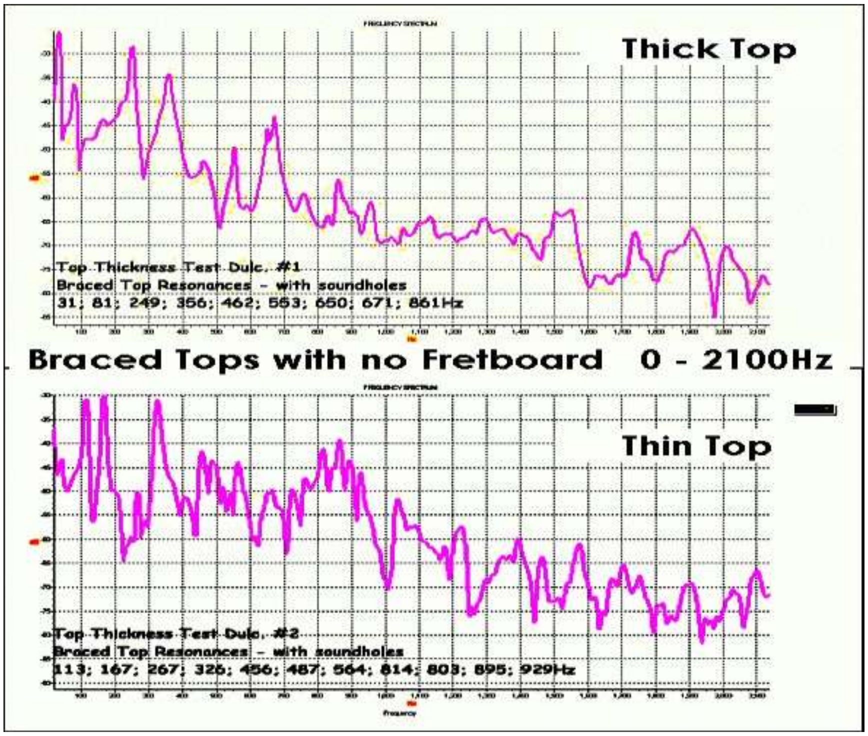

Figure 4.8. Resonance patterns for tops without fretboard.

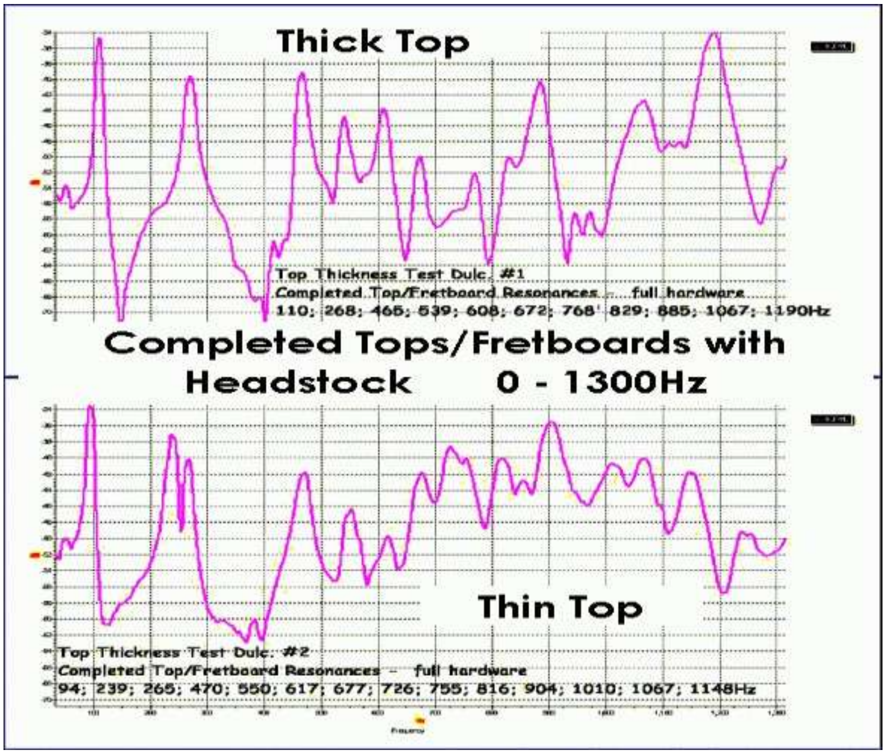

Figure 4.9 Resonance patterns for completed tops

(Figure 4.9 is not directly comparable to Figures 4.7 and 4.8 because the scale is only to 1300Hz instead of 2100Hz.). Whilst the two are still different, there is clearly a family resemblance brought about by the dominating presence of the fretboard. The main consistent difference, and I checked it many times, is the lower first resonance of the thinner top (94Hz, F#2 vs 110Hz, A2), and the double second resonance. Otherwise the spectrum is generally similar in overall outline up to about 4000Hz (not shown), but all shifted down in frequency for the thin top.

There was a clear and substantial difference in tap tone between the two. But why – I'll have to come back to that later.

The final completed dulcimers produced tap spectra as shown in Figure 4.10

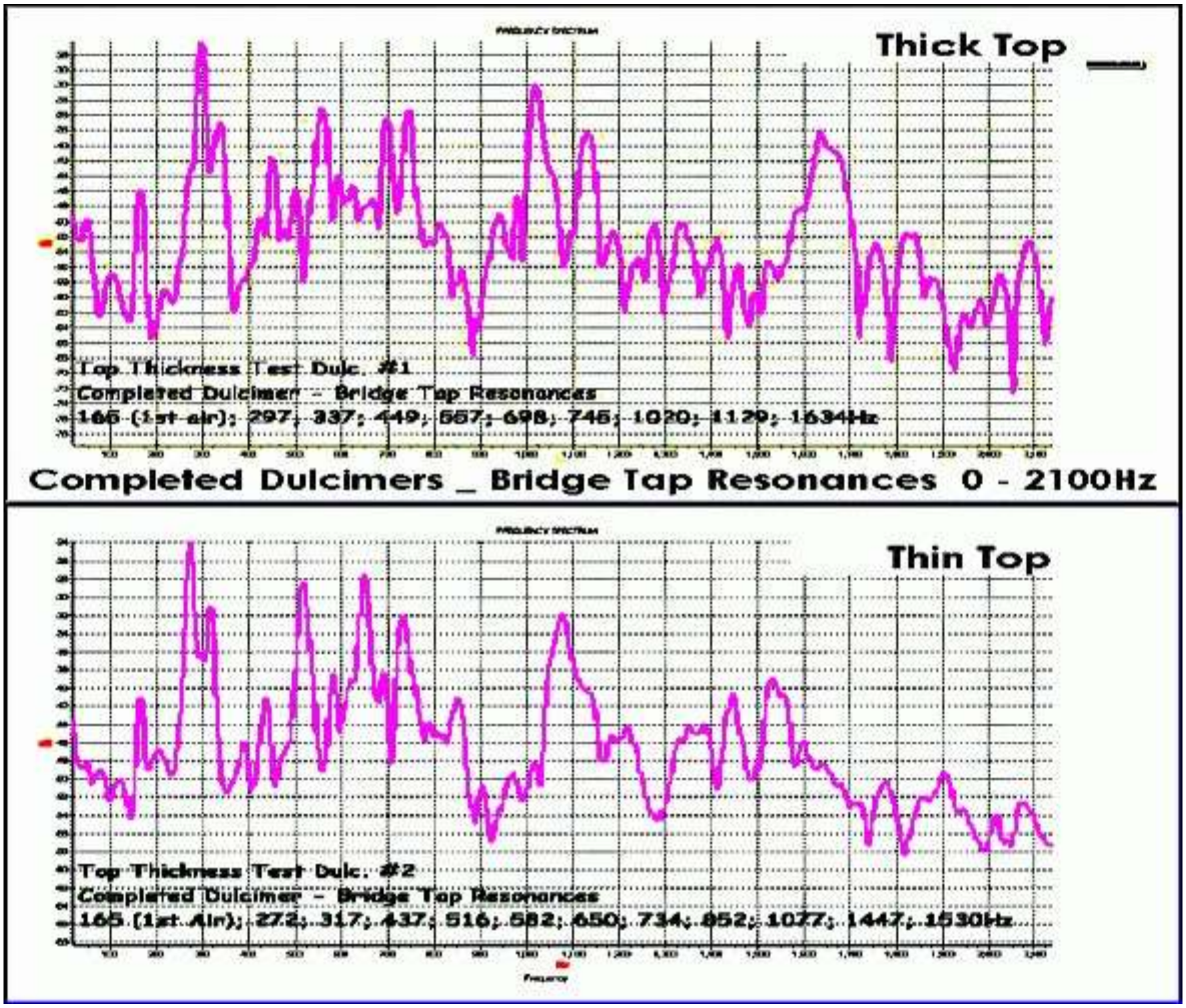

Figure 4.10. Tap spectra of completed dulcimers

These are actually fairly similar to each other, which means that the substantial differences between the tap spectra and sounds of the blank tops has been basically removed when the tops have been integrated into the finished instrument. Never-the-less, to me, the two did sound different from each other, more different than between each pair of dulcimers with identical tops reported elsewhere, but less different than between the pairs themselves. Hidden in the spectra above is enough difference to produce a perceptual distinction in the sound of the two. So, the difference in top thickness might have contributed to a noticeable sound differentiation. Maybe, maybe not.

Maybe the cavity resonances play a part, after all the first two cavity air resonances interact strongly with the top and back plates, and that interaction changes the frequency of the air resonance itself, so a thinner plate might produce lower pitched air resonances. The air resonances of the two dulcimers are shown in Figure 4.11.

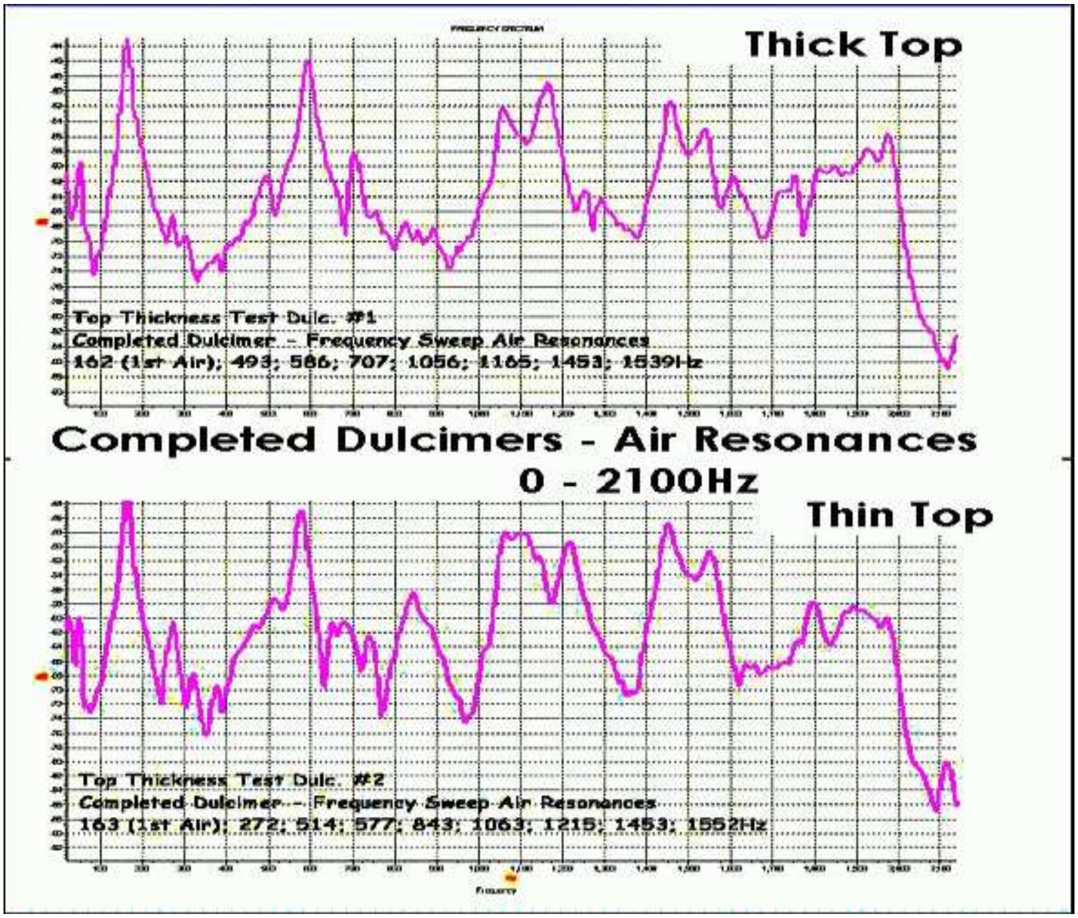

Figure 4.11. Air resonances of completed dulcimers

There are detail differences, but the lowest resonance, the main cavity resonance, is the same in both, and overall they are very similar. It’s hard to see the body air resonances being responsible for a difference in the sound between the two, especially at the mellow end of the spectrum.

Conclusions

I’m fairly confident that these two dulcimers are as close to identical as is reasonable to achieve, except for the top thickness.

To my ear, there is a difference in the sound of these two dulcimers. It’s not a fundamental difference, but it is a noticeable one. The two are more different than with the pairs of dulcimers reported earlier, but less different than between those pairs. The one with the thinner top is more mellow and has slightly shorter sustain. They are both basically equal in loudness. Whether one is better than the other is a value judgment. ***But***: Everything above may have been negated by a small oversight on my part during the building process.

If you’ll look back at Table 4.1, you’ll notice that the completed top/fretboard assemblies are different in stiffness by about 25%. That stiffness change is caused solely by the difference in the height of the fretboard/top combination. A 10% reduction in the overall height, by reducing the top thickness from 3.2mm to 1.8mm, has resulted in a 25% reduction in stiffness.

This means that any difference in the tone between the two dulcimers might be just as likely caused by the 25% reduction in stiffness of the top/fretboard assembly, as by the change in thickness of the top plate itself.

I should have inserted a 1.8mm pad of Western Red Cedar under the parts of the fretboard that contacted the thin top. The two top heights and stiffnesses would then have been the same and any tonal differences could be attributed to the top plate itself, and the way it vibrated differently to the thicker top.

As it stands, I might have to take the fretboard off the thin-topped dulcimer and pad it out, just to see. I’ll probably wreck it, and I can’t redo the tap testing of the top assembly.

Even so the experiment does point to some conclusions.
1. The effective fretboard height is the actual height plus the thickness of the top plate.
2. Tonal changes to a dulcimer, by changing the thickness of the top plate, might be actually caused by unintended changes to the effective stiffness of the fretboard.
3. Changes as small as 1/16” in height to the fretboard/top can change the overall top stiffness by more than 20%.

Figure 4.12 shows how much the stiffness changes in a fretboard as height varies. This graph shows the difference in stiffness and mass of a hollow, 1 3/8” wide fretboard of varying height, compared to that of a 1” high fretboard of the same wood. A ¾” high fretboard is only half as stiff as the 1” high version.

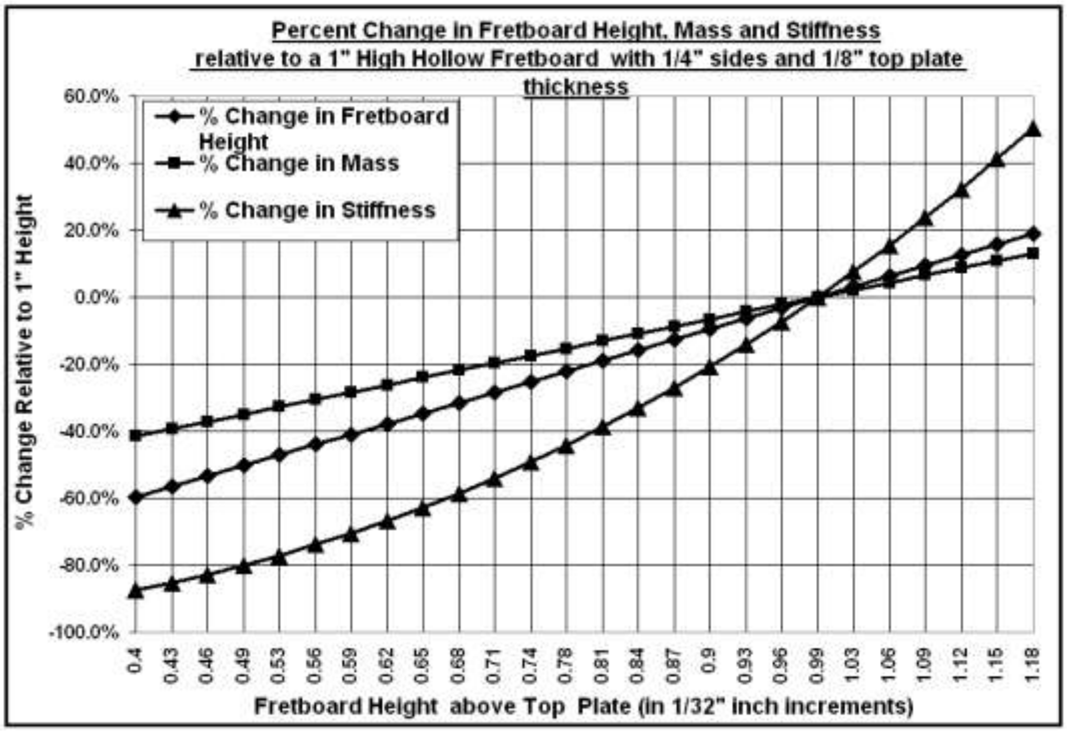

Figure 4.12. Dulcimer top/fretboard stiffness vs. combined height

This physical difference in the tops of the two dulcimers is what most makers and players would consider to be substantial. One is twice as thick as the other. Otherwise I'm fairly satisfied that the two instruments are almost identical. Some listeners have not perceived a substantial difference in the sound of the two dulcimers. This must mean that the top plate of a mountain dulcimer doesn't contribute a lot to the general tone of the instrument. That has been my contention - the parameters of the top plate don't matter a great deal in a mountain dulcimer.

Effect of Top Plate Thickness – Part 2 Dec 03, 2011

The earlier experiment with two mountain dulcimers, identical except for top plate thickness (3.6mm vs 1.8mm), was flawed because the one with the thin top had a different fretboard/top-plate stiffness than the thick top dulcimer (because the combined fretboard/top-plate heights were different). This meant that any difference in the sound between the two might just as well have been caused by that stiffness difference as by the top-plate thickness difference.

This uncertainty bothered me, so I took the fretboard off the thin-top instrument and packed it up to the same height as the thick top. It only took three days, but that's a small price to pay for an assured knowledge gain, is it not? I should know better by now. Before the modification, the fretboard looked as shown in Figure 4.13.

Figure 4.13. Original fretboard on thin-topped dulcimer

Figure 4.14 shows the top after a 1.8mm Western Red Cedar pad was placed between the fretboard and the top plate.

The combined height of the fretboard and the top plate was then the same as for the dulcimer with the thick (3.6mm) top.

Although I couldn't measure it, my assumption is that the stiffness of the two top assemblies are now the same, whereas before the modification the top assembly of the thick-top dulcimer was about 30% stiffer than the thin-top dulcimer.

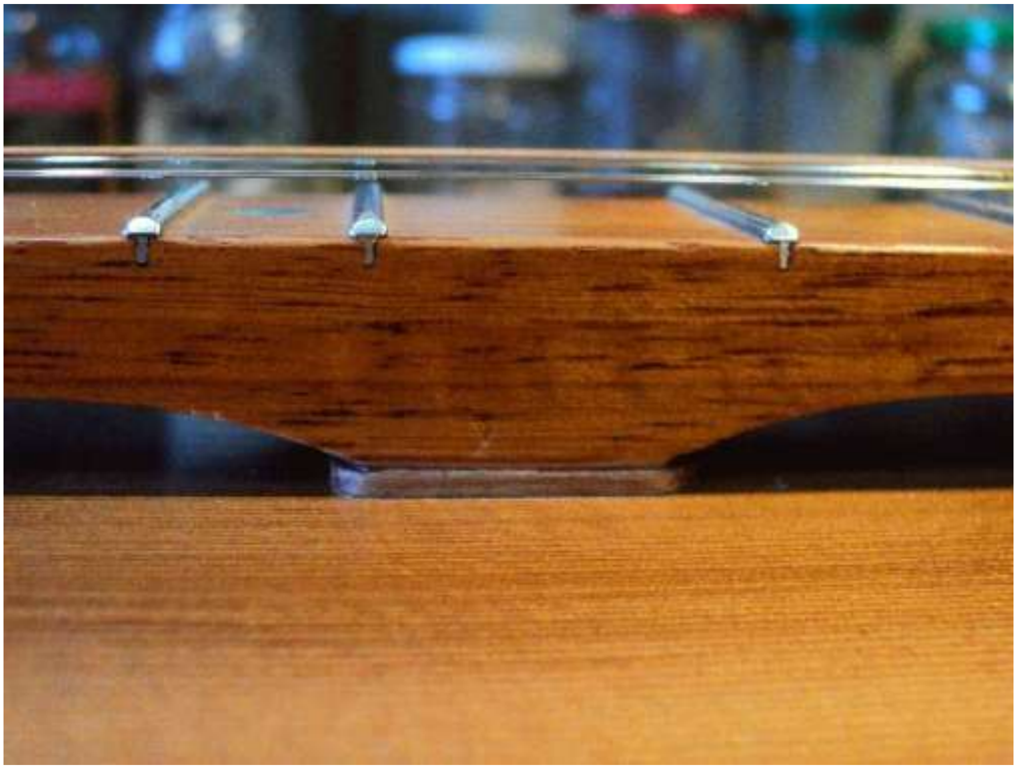
Figure 4.14. Thin-topped dulcimer after fretboard pads added.

Result

No discernable difference before and after! I would have bet a small amount of money that raising the fretboard height of the dulcimer would have modified the sound, but as far as I could tell, three days apart, the dulcimer sounded the same. The sound difference that I formerly noticed between the thick-top instrument and the thin-topped one also remained the same.

I'm fairly confident that the stiffness of the top of the dulcimer was increased by a substantial amount after installing the pads. So, it is clear that for this set of shapes and materials that there is a fair amount of latitude in fretboard/top stiffness before the sound starts to be affected. I didn't expect that.

The tap spectrum of the modified dulcimer is also unchanged, and there is not a lot of difference between it and the thick-top dulcimer – the resonances of the air and wood remain very similar for the two. And yet, although they are similar, I can hear a difference between the two. My preference, most of the time, is for the thin-top dulcimer. It has a warmer, more mellow sound. It doesn't have the same cutting power as the thick top instrument or clarity of note, and has a shorter sustain, but it has an integrated sound that is very pleasing. So, what's the difference?

The resonant amplitudes and frequencies of the two instruments seems quite similar. The damping in the wood should affect the sound, and shows up to some extent in the bandwidths of the resonances in the tap spectra, but there is no clear difference between the two in bandwidths, so I make the assumption that the materials of the two have similar internal damping.

Maybe the combinations of higher overtones are different between the two. To test this proposition I did a little experiment by recording the sounds of the two dulcimers and looking at the sound spectrograms up to about 11kHz.

The two instruments were mounted side by side (on foam pads at each end) and each open string struck for both dulcimers, then the strings at the 8th fret. Each string strike was allowed to settle before the next string was plucked – about 7–10 sec for each strike. The spectrograms are shown in Figure 4.15.

In this Figure, there are six string strikes in pairs of thick-top followed by thin-top – 1st , 2nd and 3rd open strings. The x- axis is time and the y-axis is frequency up to 11kHz. Each stack of “flags” represents the harmonics of that note. The length of each “flag” represents the time that that harmonic is sounding and its loudness is represented by the darkness of the color. The darker the color, the louder the harmonic.

Figure 4.15. Spectrogram comparison for thick and thin topped dulcimers

There aren’t any huge differences between them. The thick top dulcimer seems to have slightly longer-duration harmonics on the first string, and more of them on the bass string, but that shouldn’t account for a mellow-bright distinction. More “mellow” might translate to a cluster of strong harmonics at the lower frequencies, and “bright” might mean stronger harmonics at higher frequencies. There is marginal bias towards the thick-top dulcimer between about 2 and 5kHz, but there’s not a lot in it What about at the lower frequencies? The spectrogram up to 2.5kHz is shown in Figure 4.16

Figure 4.16. Spectrogram below 2.5 kHz.

The first few harmonics of the middle string are a little stronger and longer on the thin-top dulcimer, but on the other two strings it’s the other way round.

The spectrogram of strings played at the 8th fret is shown in Figure 4.17 and 4.18. The only consistent difference between the two instruments, on both the open strings and the 8th fret (and hence probably on all frets) is that the fundamental (the lowest frequency harmonic) is stronger and longer for the thin-top dulcimer. How important that is to the overall sound is a matter for the psycho-acousticians, but it may be the source of the sound difference, and being the lowest harmonic, would be consistent with the perception of the thin-top dulcimer being mellower.[4]

In addition, the relative perceptual contributions of the 1st harmonic (fundamental) vs the higher overtones changes with the loudness of the sound. This test was done with a fairly robust pluck - I might have to do it again with a softer note.

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[4] This is not a simply decided matter - for those who want a technical look at the acoustical and descriptive correlates of violin sounds, have a look at: http://www.oicrm.org/doc/2005/cim05/art ... M05_01.pdf

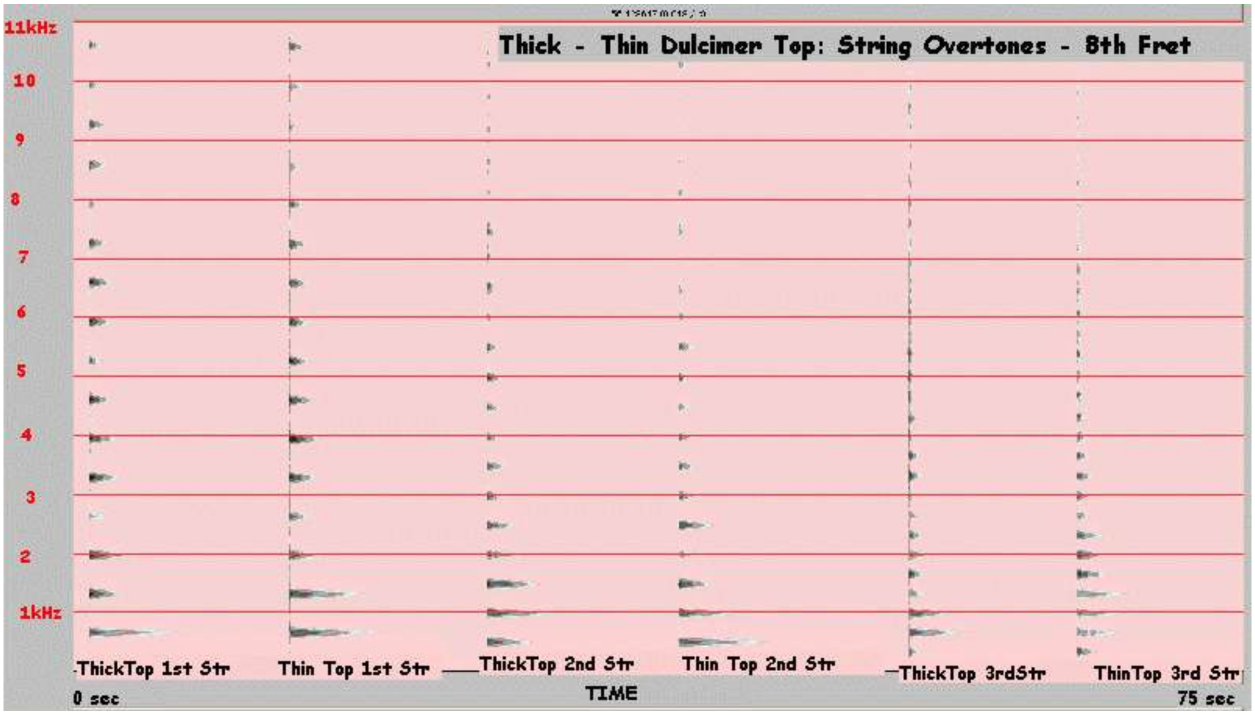

Figure 4.17. Spectrogram of strings at 8th fret.

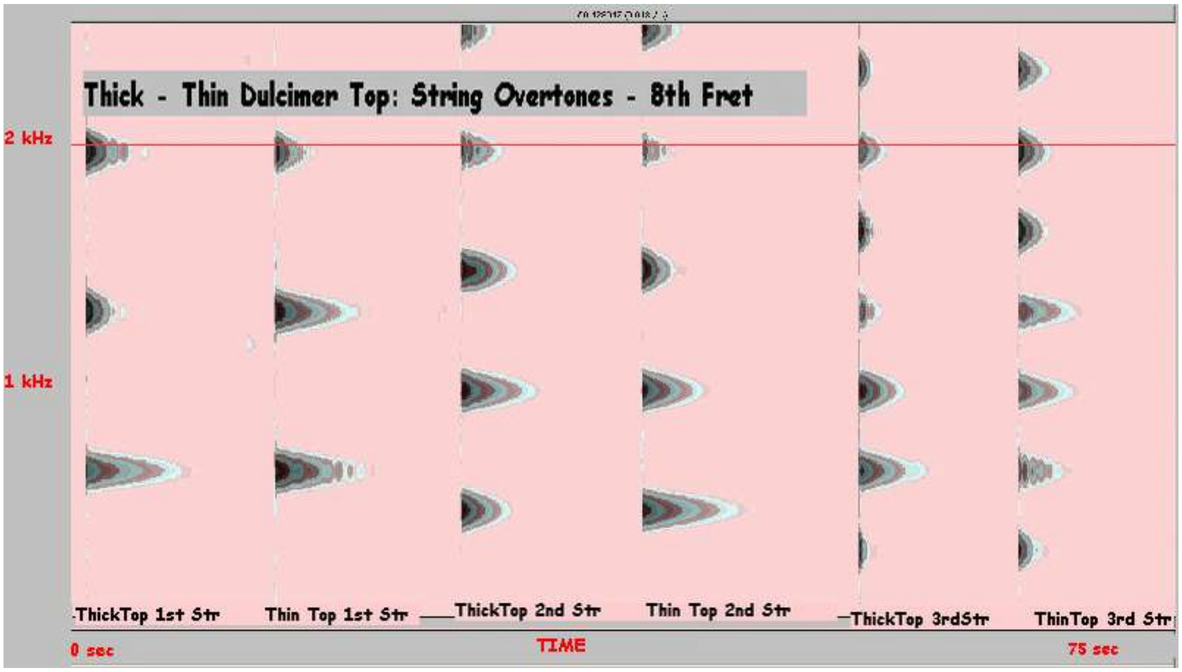

Figure 4.18. Spectrogram of strings at 8th fret below 2.5 kHz.

Conclusion

Varying the top thickness of a mountain dulcimer can clearly modify the resulting sound. In this case, a thinner top produced what I judge to be a more mellow sound than an identical dulcimer with a top twice as thick.

The total stiffness of the top-plate/fretboard combination did not seem critical to the sound in this case, with a 30% variation not affecting the sound noticeably. I can't explain this result and would have expected such a reduction in stiffness to be a cause of the more mellow sound.

But keep in mind, this experiment represents extremes of top thickness. Not many makers would have tops as thin as 1.8mm or as thick as 3.6mm of a soft wood like Western Red Cedar.

In addition, the fretboards were chosen to emphasize the effects of top-plate thickness changes by being lower in height than I would normally use, and of lowish density wood.

So, smaller variations around more normal values will probably modify the sound less than occurred in this case.[5]

Effect of Top Plate Thickness – Part 3 - Dec 20, 2011

I wasn't happy with the results of raising the fretboard of the thin-topped dulcimer reported in Part 2. If the stiffness of the top had increased by the approximately 30% to make it the same as the thick topped instrument; I really would have expected some change in the sound, but there wasn't really any. That lead me to suspect that I hadn't changed the stiffness as much as I thought I had.

A crude test to see if the two dulcimers were at least the same, in terms of static stiffness, showed that they weren't. Two tests showed that the thin topped dulcimer was still more flexible than the thick topped instrument.

First, the dulcimers were sitting on their three small feet, and a 5kg (11lb) weight placed on the fretboard near the center as shown in Figure 4.19.

This tests both the deflection of the top/fretboard, and the whole body of the dulcimer. Second, the dulcimers were tested with their back plates resting on a block (Figure 4.20).

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[5] See Chapter 9, effect on tone of severely thinning the edges of a mountain dulcimer top. It may partially explain the difference in sound noted

Figure 4.19. Dulcimer suspended on small feet — top/body deflection

The box itself can't deflect here, only the top/fretboard.

Figure 4.20. Test of top and fretboard deflection.

The results were:

Configuration	**Thick Top**	**Thin Top**
Resting on feet (top+body deflection)	9/1000"	11/1000"
Resting on block (top only deflection)	7/1000"	11/1000"

These are small numbers, but they were consistent over multiple tests. They seem to suggest that in the thick topped dulcimer most of the deflection is in the top/fretboard, but there is a small component added by the bending of the whole box. In the thin topped dulcimer, all the measurable deflection is in the top/fretboard, and it is still more flexible than the thick top even after being raised to the same height.

This can explain why the thin topped dulcimer sounds a bit more mellow than the thick topped one, but doesn't explain why one top is still more flexible than the other, given the efforts to make them the same. I half think it could be that the section of top under the arches, which is under tension when the fretboard is weighted, can stretch more in the thin top than the thick top because only the feet of the fretboard were raised by pads, not the whole length of the fretboard. This points to a possible difference between arched and continuous fretboards — arched fretboards might be less sensitive to changes in height because the section of the top under the arches is under the same tension for the same down force, largely irrespective of the fretboard height (within reason). So, a thinner top under an arched fretboard might contribute to a change in sound because it can stretch more under an arch, rather than because it is more flexible over its whole area. The experiment would need to be repeated with continuous fretboards to find out if this is true or not.

Chapter 5
Top Plate Alterations

Effect of Grooving the Top Plate Periphery- Feb 01, 2011

Most of the lower frequency vibration modes of a mountain dulcimer top, below say, 600Hz, seem to be simple oval shaped (0,0) vibrating areas covering the lower bout. This is for full-length fretboard dulcimers. (There is an exception in the first bar-mode, in which the whole dulcimer flexes like a bar and the top vibration is not oval shaped.)

With a view to possibly making these oval vibration modes more efficient, I made a dulcimer with a groove running around the periphery of the inside top plate.

Figure 5.1. Grooved top plate

This is not my idea, I have seen a picture of a Taylor guitar top with such a groove – maybe they do it as standard. Carved-top instruments such as violins and mandolins also usually thin the edges of the tops, so there may be something to the practice in a general sense. I didn't groove the back plate because it seems to manage OK, not having a stiff fretboard to overcome, and I don't want it vibrating excessively anyway. As a control, I made an identical dulcimer without the groove, the woods coming from next to each other in the billets. They are fairly standard in shape and construction, but with an arched fretboard. One of the pair is shown in Figure 5.2.

Figure 5.2. Dulcimer #54 grooved Western Red Cedar top

Backs and sides are Australian Red Cedar (*Toona australis*); tops are Western Red Cedar (*Thuja plicata*); and fretboards are ebony over mahogany.

The result was two very nice instruments, approaching the sound I'm looking for in a mountain dulcimer. However, the one with the top groove was the better of the two with a sound quality that has an indefinable "something" extra; to the extent that I'll keep the instrument for myself. Its twin is sold.

It is by no means certain that the grooved top was responsible for the better sound – there were minor differences in weights and stiffness between the two instruments that could just as well be the cause. But putting in the 1mm deep groove in the 3mm top with a Dremel/burr was ridiculously easy and confers no penalty, so I'll do it on subsequent dulcimers to see if there is a consistent sound improvement.

Objective Measurements

I also made some standard measurements of the two dulcimers and these are discussed below for those interested.

Weights and Deflections: The ungrooved instrument was about 5% heavier than the grooved. This was for the overall dulcimer, and for the completed free top as well. Completed weight was 1162gm ungrooved; 1103gm grooved.

The tap resonances of the free top assemblies are very similar in both instruments.

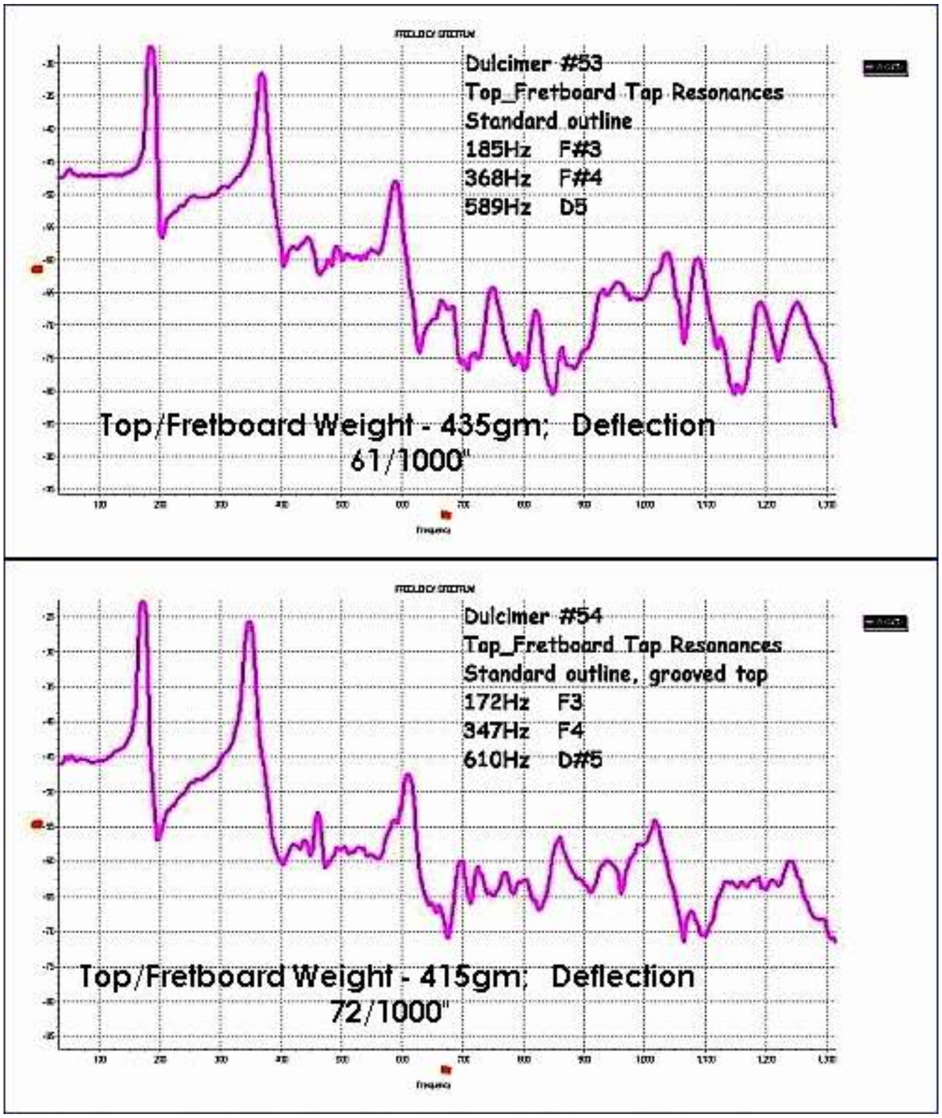

Figure 5.3. Tap resonance diagrams

The top deflection under a standard weight was about 15% higher for the top of the grooved instrument at all stages - fretboard shaped/unshaped and completed top assembly. A lot of this seemed to be the differences in the ebony overlay which was matched for thickness, but not grain or density.

So the grooved instrument was slightly lighter and with a little more flexible top.

Air and Box Resonances The air resonances below 1000Hz were very similar in frequency, amplitude, and bandwidth; although the amplitudes are not accurately calibrated, so are just a guide. Results are shown in Figures 5.4 and 5.5

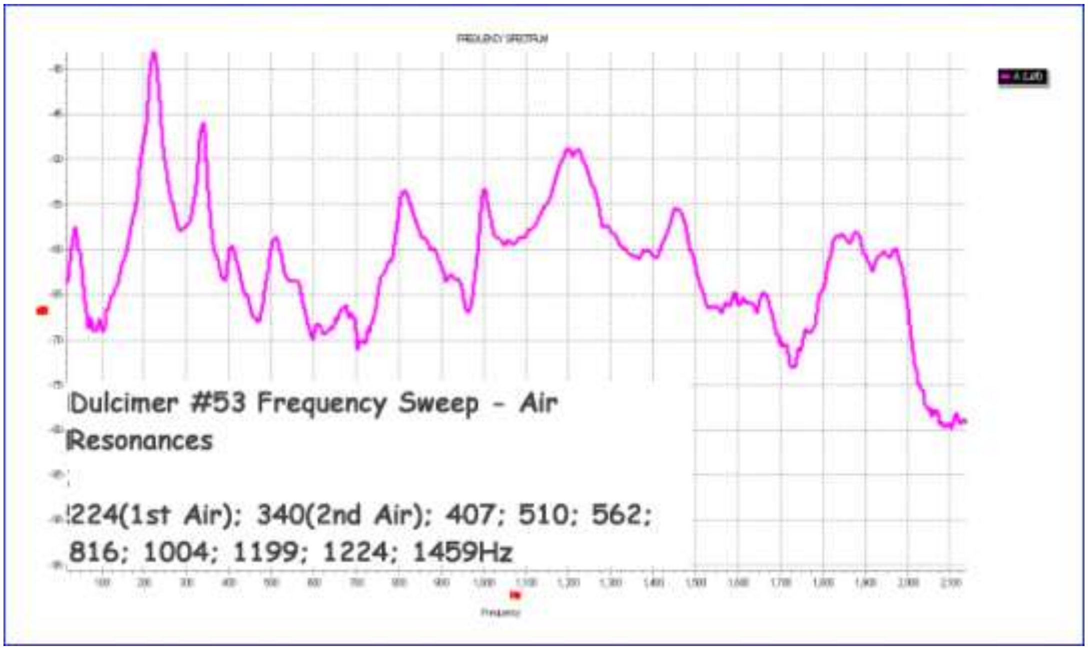

Figure 5.4. Air resonance for dulcimer #53 (ungrooved)

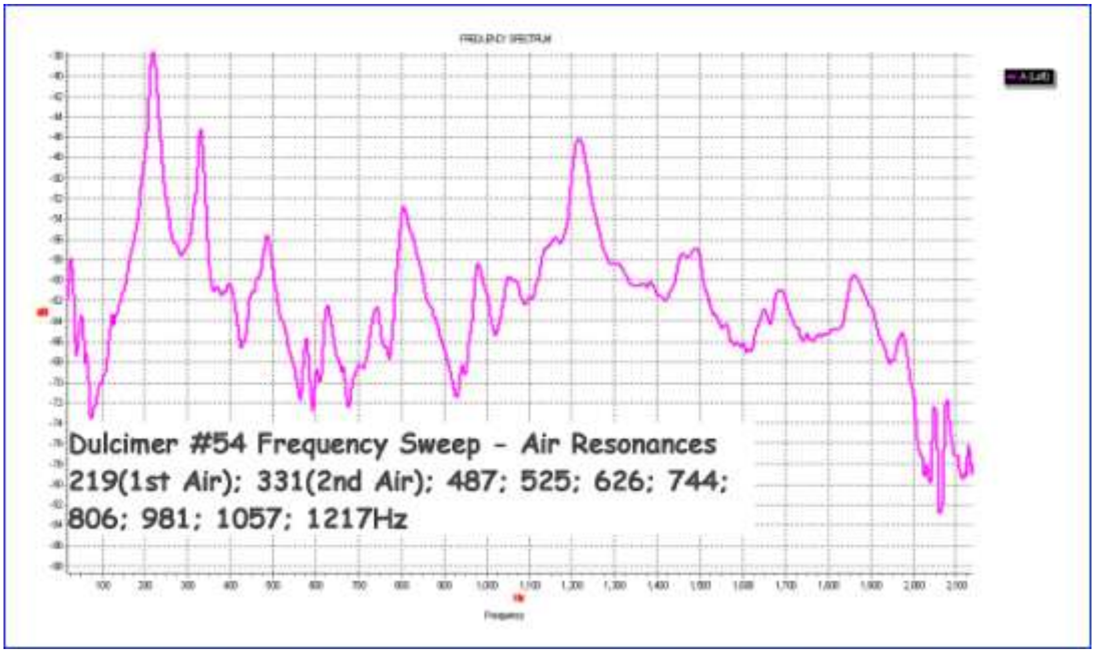

Figure 5.5. Air resonance for dulcimer #54 (grooved)

The peaks represent the cavity resonances of the air inside the box, largely determined by the size and shape.

The resonances of the wood, obtained by tapping on the bridge with a plastic hammer and analyzing the resultant sound are shown in Figures 5.6 and 5.7.

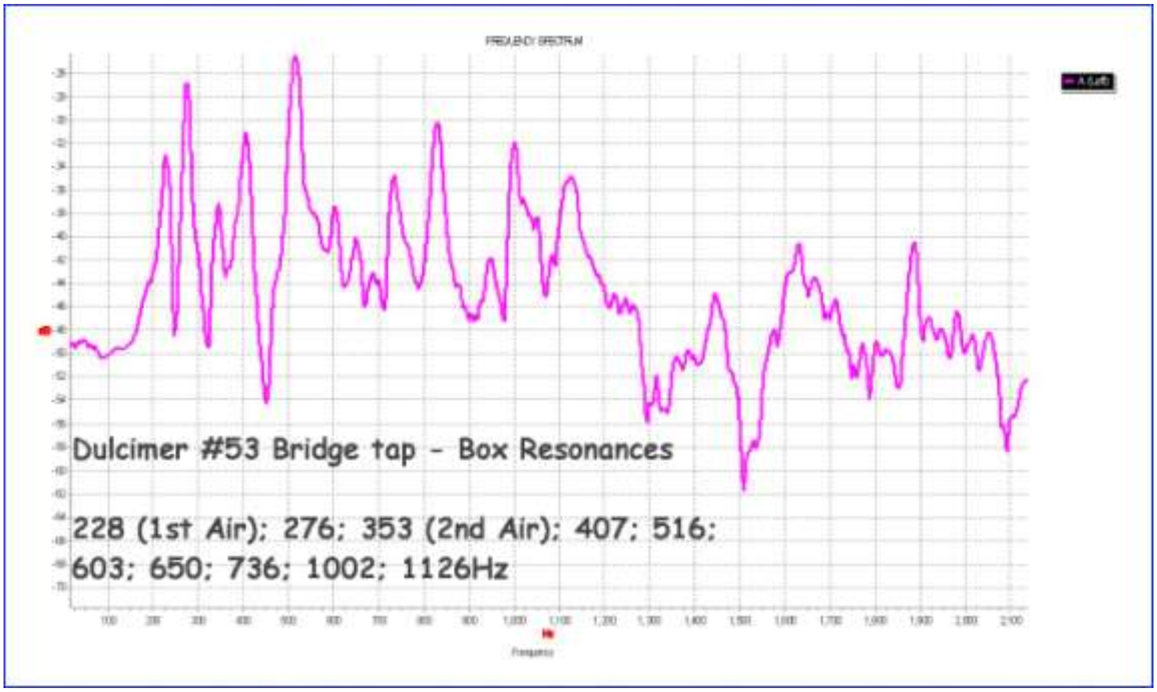

Figure 5.6. Box resonance for dulcimer # 53 (ungrooved)

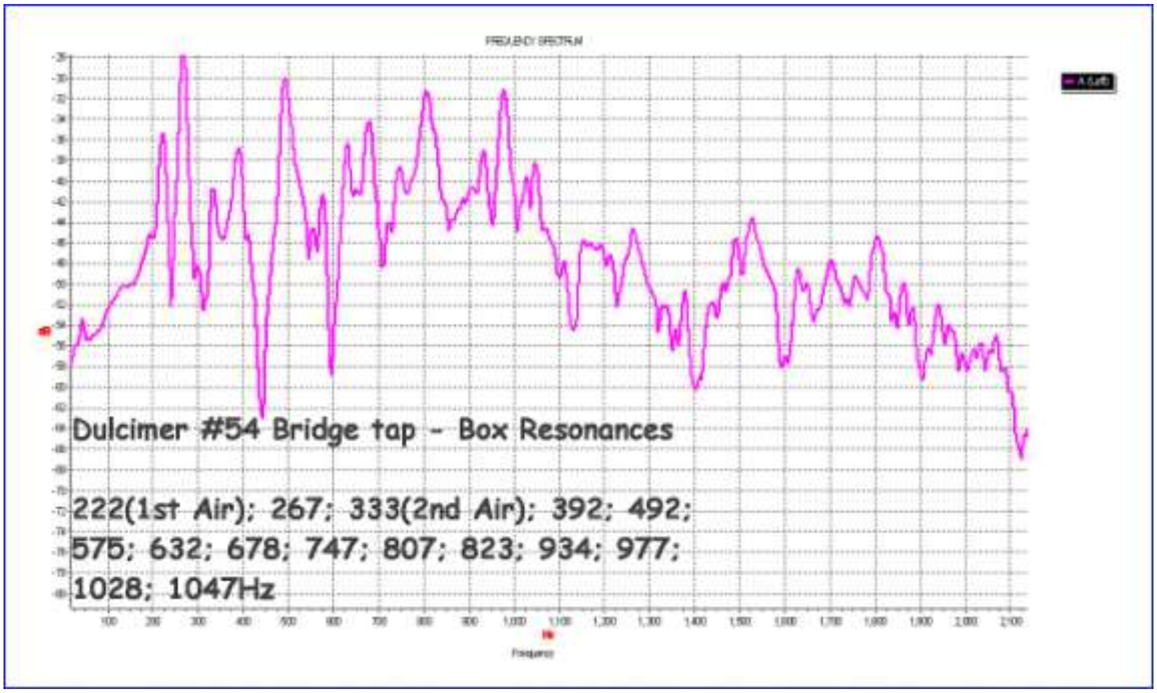

Figure 5.7. Box resonance for dulcimer # 54 (grooved)

The similarities between instruments in both air and tap resonances would be expected because the boxes were identical sizes and were very close in mass and stiffnesses. A number of the box (wood) resonances are a result of interaction with the internal air – air pressure rises and falls at a cavity resonance, and that causes the box to vibrate in and out at that frequency like a balloon – and make sound in the process.

Top and Back Vibration Modes: The actual vibrations the instruments make when excited by the frequencies by the strings, or in this case, by loudspeakers, are shown in Figures 5.8 and 5.9.

Again, there is no stand-out difference between the two, the frequencies and patterns are pretty similar. Above about 600Hz the vibration modes tend to follow the bracing (in these two instruments).

Top-Back Relative Loudness: The grooved top instrument has a slightly louder top relative to its back than the ungrooved dulcimer. This might be as expected, but the difference could be largely experimental error. However, in the grooved instrument the measurements showed the top gained in loudness over the back on the higher fretboard compared to the open strings, whilst the ungrooved instrument lost top loudness relative to the back compared to open strings. This was also the subjective impression I had – the grooved dulcimer had a very ringing upper fretboard.

Conclusion:The grooved top instrument was clearly better, to my ear, than the ungrooved top. Other people also agreed. The measurements are not subtle enough to show the differences, or I may not know what I'm looking at, so until I make a few more this way, I won't know, but it seems a promising thing to do.

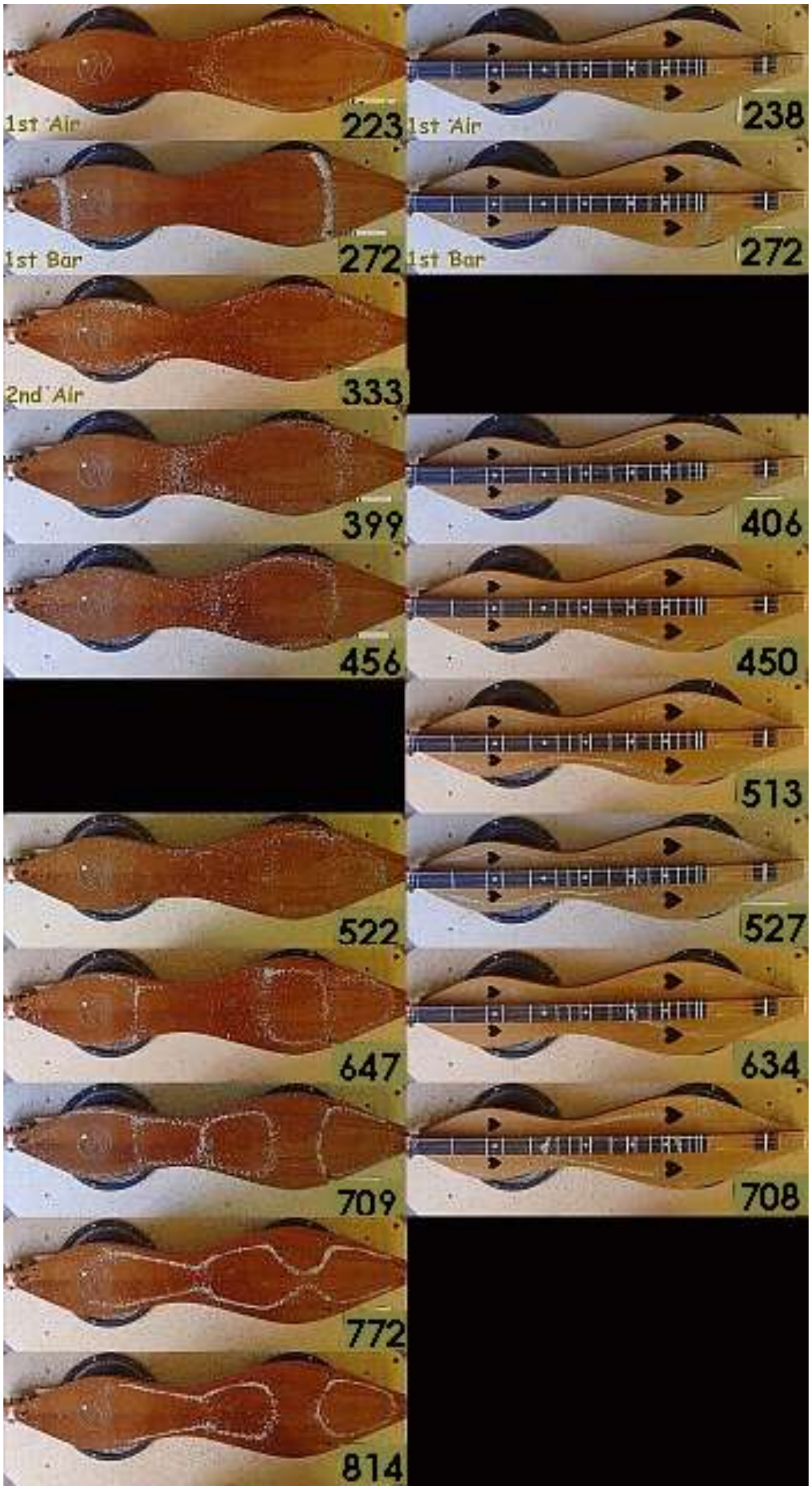

Figure 5.8. Dulcimer #53 ungrooved vibration modes

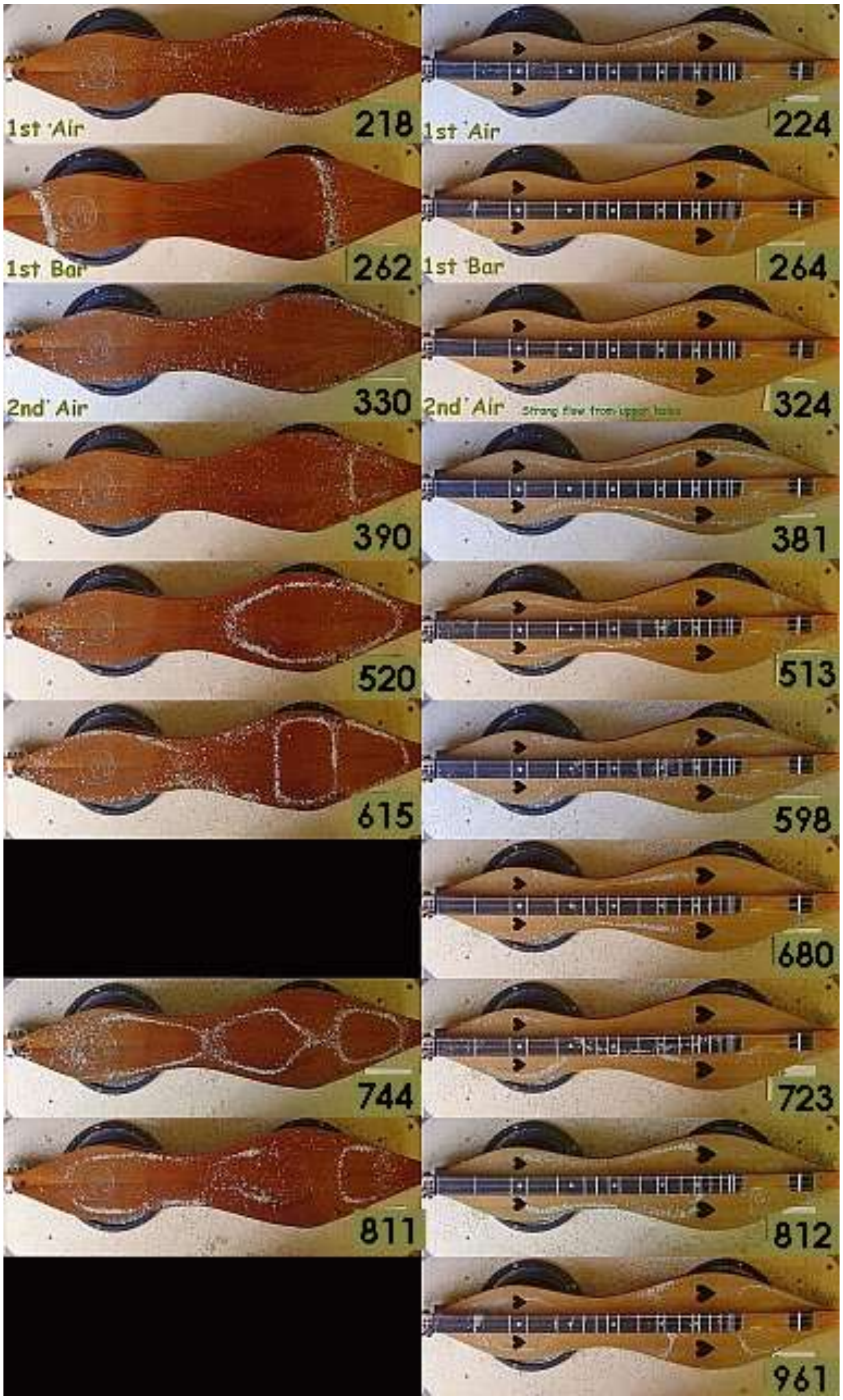

Figure 5.9. Dulcimer #54 grooved vibration modes

A Further Note on Grooved Top Plates- Sep 14, 2011

Subsequent to the report on grooved tops earlier in this thread, I've made two dulcimers with similar grooved tops.

My conclusion is that grooving the top plates of mountain dulcimers probably does not confer significant sound advantages.

The two new dulcimers (Figure 5.10) were similar in general design, construction, and size to the one reported previously (Figure 5.11), which I judge to be a superior sounding instrument. But there are differences. The two new instruments have different arching on the fretboards, and different top wood – Kauri Pine instead of Western Red Cedar.

The backs and sides are the same in all cases – Australian Red Cedar (*Toona australis*), and the fretboards are all mahogany with ebony overlay. Superficially the four dulcimers are very similar (two previous, one grooved, one ungrooved) and these two new ones (both with grooved tops). The two previous dulcimers sound similar to each other, and the two new ones do also, but the two pairs sound quite different.

Figure 5.10. Dulcimer #56 (same as #57) – three arches, grooved Kauri Pine top.

Figure 5.11. Original grooved dulcimer #54 – 4 arches, Western Red Cedar top.

The new dulcimers sound good to me, but not as good as the original grooved top instrument – why?

Maybe the internal bracing has something to do with it (Figure 5.12). The original grooved top has five braces and the new one has three. The backs have five and four respectively. So the bracing is quite different. However, the two new dulcimers have bracing that is shaped different to each other (Figure 5.13), yet they sound quite similar.

I did this deliberately to see if there was an obvious effect. Shaping the braces definitely affects the resonant structure of the tops, but clearly not enough to greatly modify the overall sound. Figures 5.14 and 5.15 show the comparison.

Figure 5.12. Bracing in original and new dulcimer tops

Figure 5.13. Bracing pattern in two new dulcimers

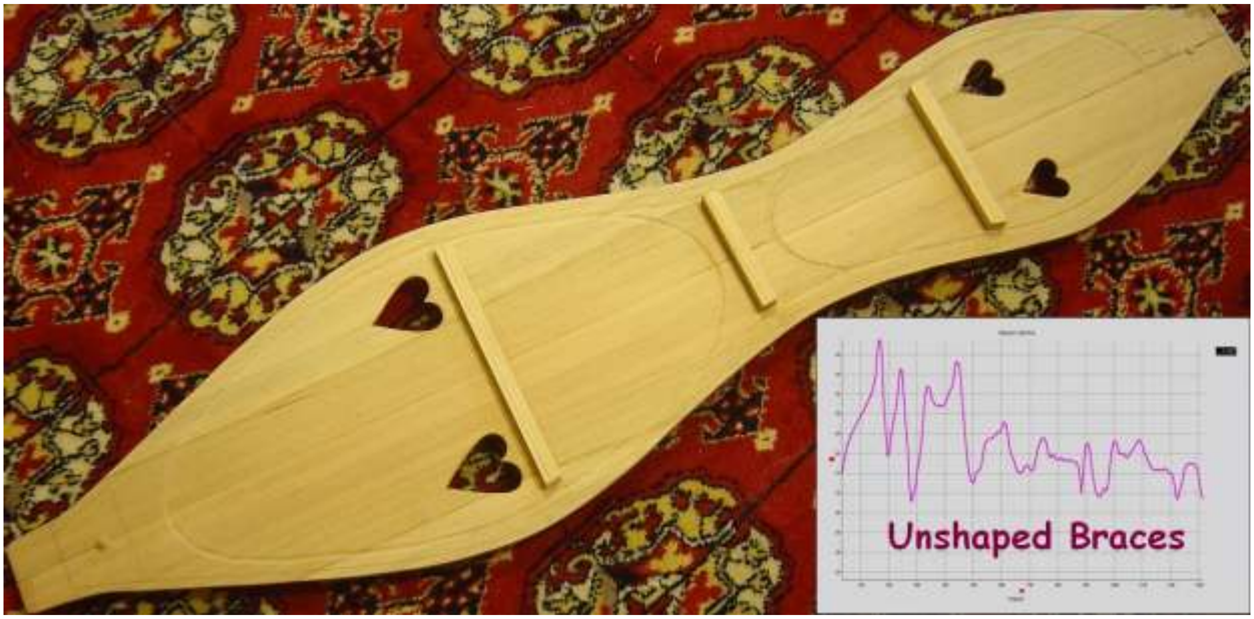

Figure 5.14. Top/fretboard resonances for unshaped braces

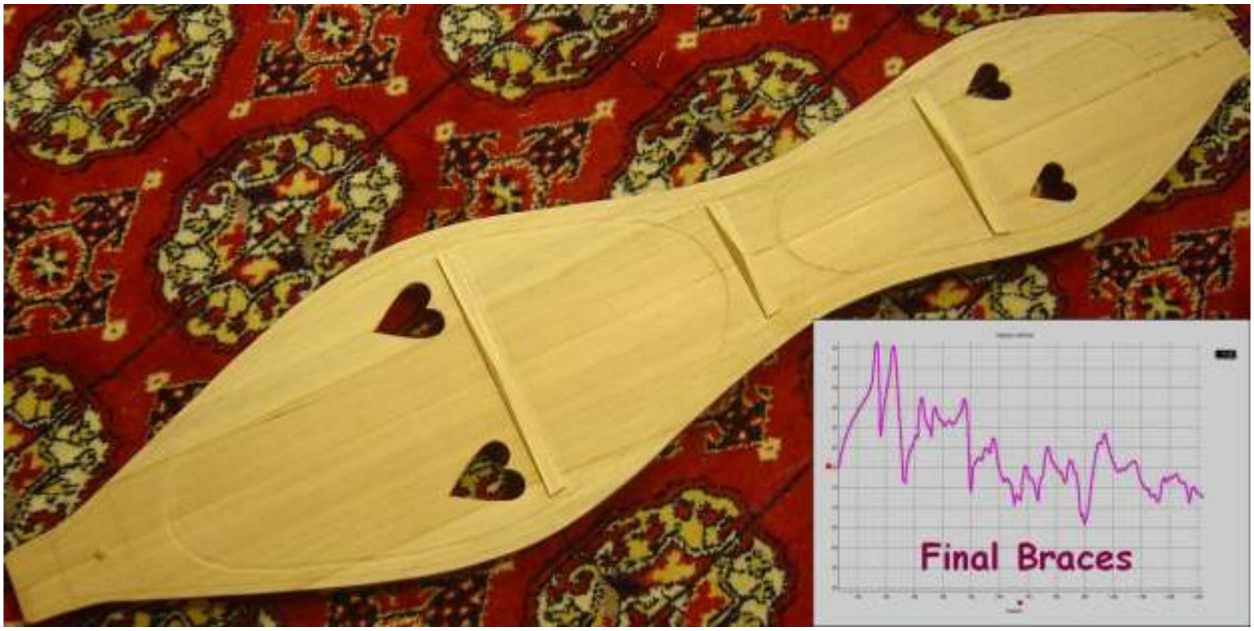

Figure 5.15. Resonance pattern of shaped braces

Maybe the stiffness of the tops was different between the two pairs of dulcimers (Figure 5.16). The static deflection under load of the two sets of tops was fairly similar.

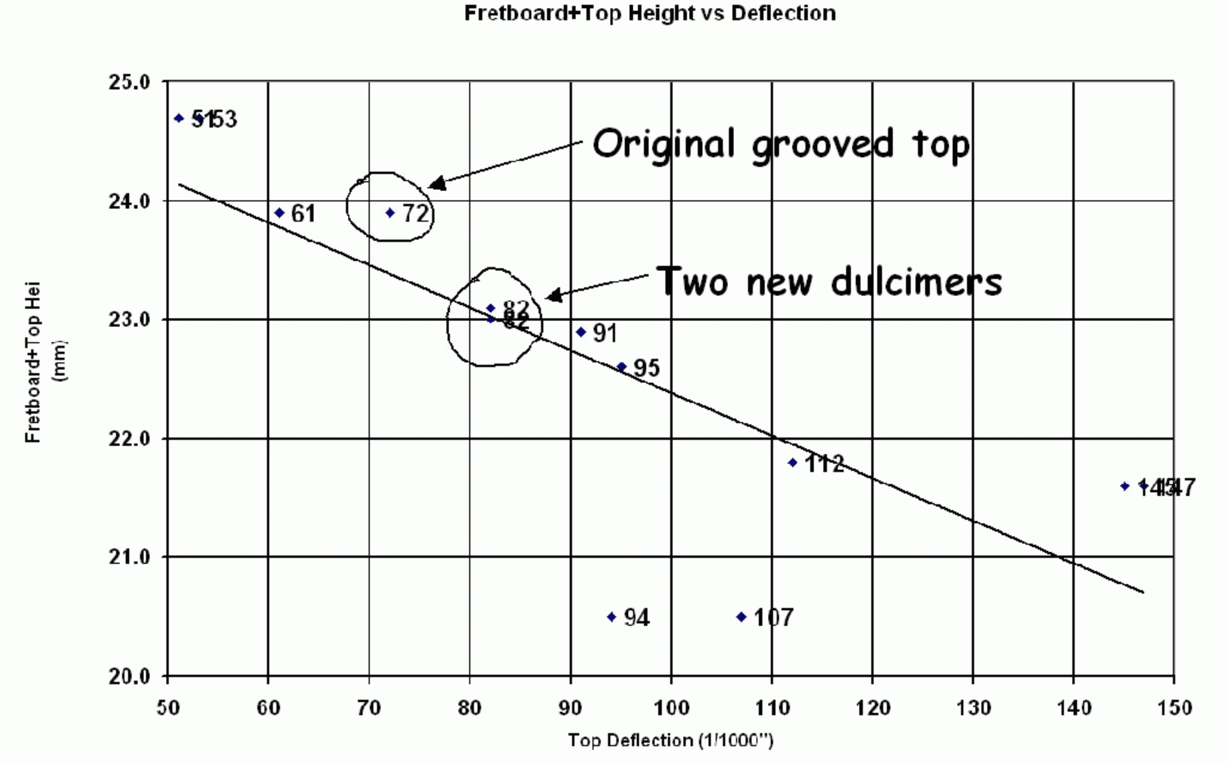

Figure 5.16. Stiffness comparison of dulcimer tops

In general, the higher the fretboard plus top height, the stiffer the top assembly (not surprising). I also seem to prefer the sound of the stiffer tops. The instruments I like the least have the most flexible tops. In this current case, the original grooved instrument deflected 72/1000”, while the two new dulcimers deflected 82/1000” and were about 1mm lower in height. Not a big difference in stiffness, so that doesn’t seem to be a main reason for the sound differences.

However, the wood resonances of the free top assemblies are different between the two pairs. The original ungrooved top dulcimer and its grooved twin resonances are shown in Figure 5.17.

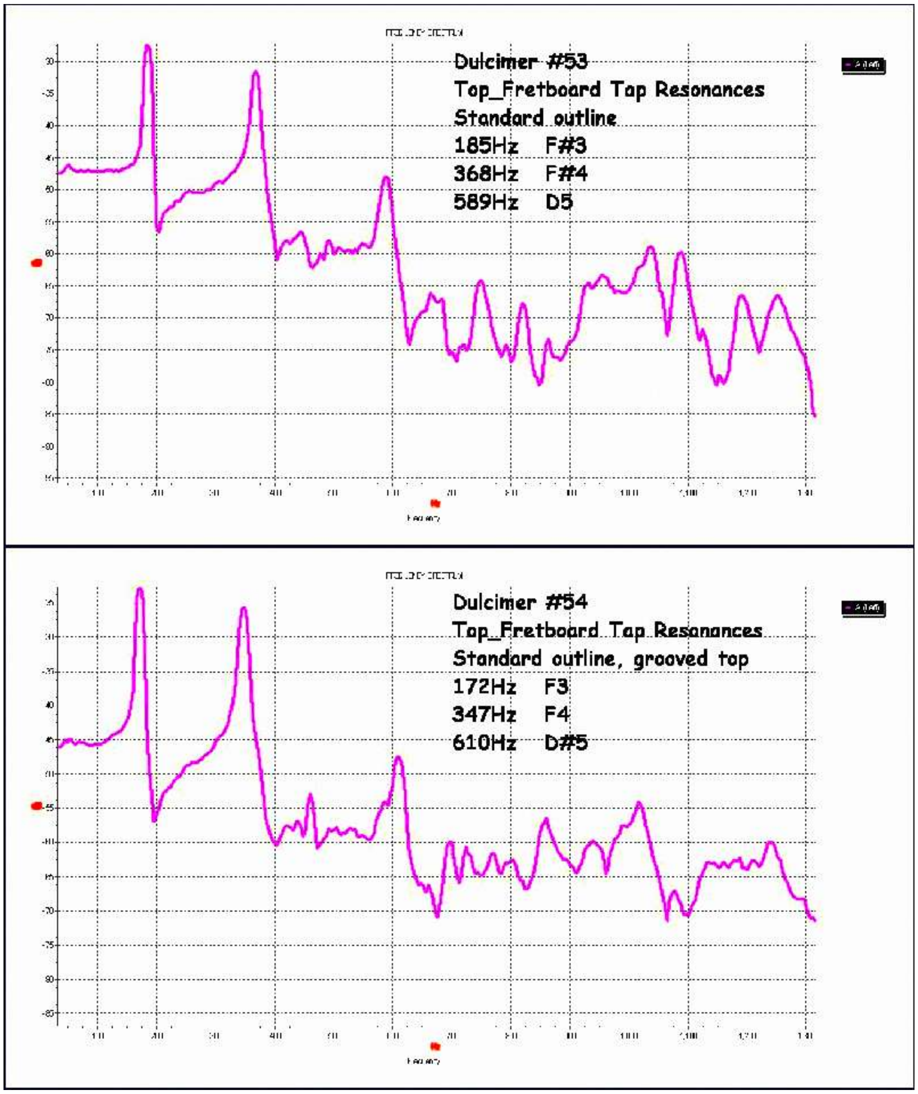

Figure 5.17. Tap resonances of original pair

Figure 5.18 shows the resonances for the two new, grooved tops.

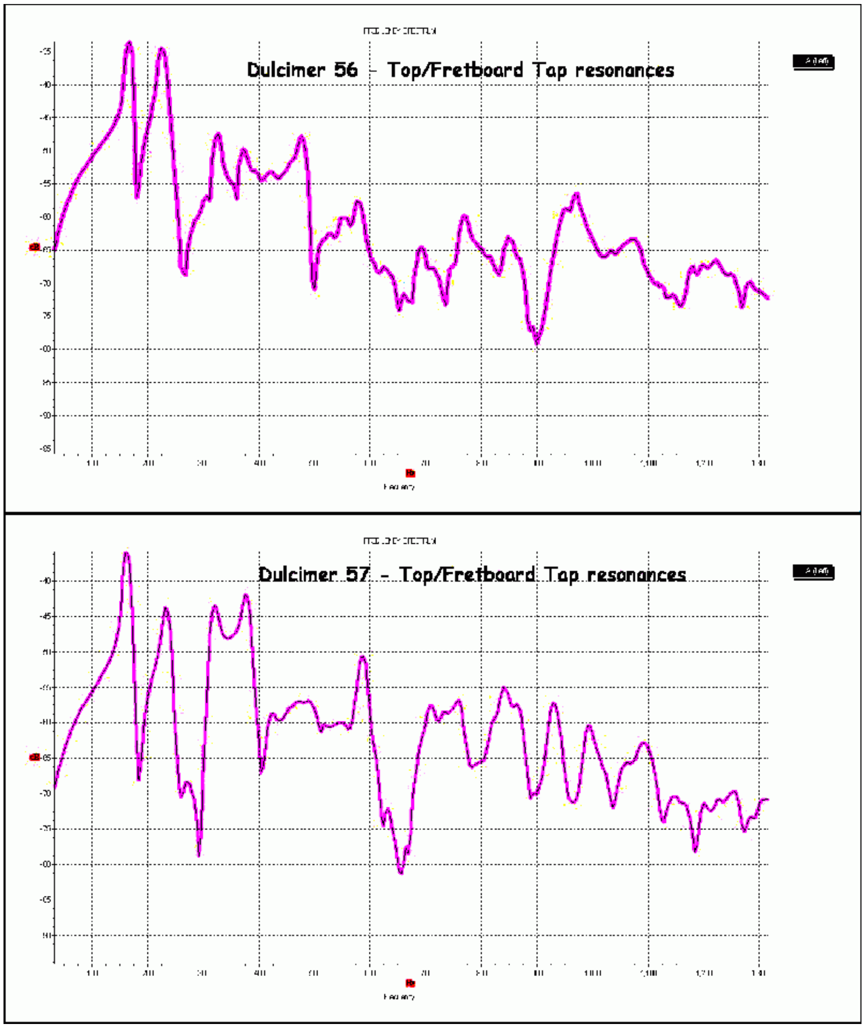

Figure 5.18. Tap resonances of new pair — both grooved tops

The two pairs have quite different resonances in the free top assemblies, and the completed dulcimer pairs sound similar within the pair, but different between the pairs. Since the bodies of the four instruments are very similar, the sound difference between the pairs is probably mainly contributed by the top/fretboard assemblies.

What's different about the tops of the two pairs? The wood type of the top plate and the arching arrangement of the fretboard are the two main differences. My contention in the past has been that the top plate and its wood type, density and thickness don't modify the final sound significantly. Some other makers agree with this, and others don't. That's been my interpretation of the various tests I've done, but it probably needs to be resolved properly.

This gets us back yet again to the importance of the fretboard to the final sound of the instrument. It seems that if you want to modify the sound of a mountain dulcimer, then look to what you do with the fretboard. (other parameters being equal – size, shape, materials etc.) Again, this is only relevant to full length fretboards.

This is a lot of talk for a small result, and three test instruments is not a large sample size, but there may be some relevance to edge thinning of dulcimer tops in general. Cutting a groove on the inside of a top is equivalent to thinning the top towards the edges, which is a common practice in guitar making. The idea is to allow the top to hinge around the edges of the sides more easily. I thought this might allow the lower bout "trampoline" modes of dulcimer vibration to develop more efficiently (i.e., louder), but it doesn't seem to have produced a significant effect. So, thinning the edges of tops to improve the sound may not do much in mountain dulcimers.

The 1mm referred to earlier (height of new dulcimers vs. old) is the difference in the height of the fretboard plus the thickness of the top plate, not the height of the sides or the total height. Differences as small as 1mm in the height (meaning stiffness) of the fretboard might make audible differences to the sound. In static deflection the stiffness decreased by about 15% (but not all because of the change in height). Adding 1mm to the combined height of the fretboard/top plate is different than adding, say, 1mm to the height of the sides, thereby increasing the air volume in the box. Box capacity is clearly another determinant of the final sound, but I don't know how sensitive it is to small changes, such as 1mm, which translates to about a 2% change in volume. It's something worth looking into.

Effect of Thinning the Top Plate Edge - Aug 22, 2013

In an earlier experiment to determine the effect of different fretboards on the one dulcimer,[6] the top plate was thinned at its edges as an unintended consequence of the machine sanding process.

After the original fretboard was replaced there was a characteristic change in the general tone of the dulcimer, towards the mellower end of the spectrum for all three test fretboards, which was quite different from the more nasal tone with the original, thicker top plate, prior to the test. I put this down to the thinning of the top plate edges, or perhaps the use of test fretboards that were about 25% lighter than I would normally

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[6] See Chapter 9

use, or a combination of the two.

Although my contention previously has been that the top plate thickness should not affect the tone of a mountain dulcimer very much, it definitely has a substantial effect on tone in guitars and other stringed instruments. Makers spend considerable time profiling the thickness of the soundboards of guitars, with the edges generally being thinner than the central regions.

In an earlier experiment I looked at the effect of cutting a groove around the inside of the top plate on some of my dulcimers, which should have an effect similar to thinning the edges of the top plate; i.e., a reduction in edge stiffness which might increase top vibrational mobility, and hence make the instrument louder, and "better". Those tests didn't show any advantage in grooving, but four different dulcimers were used, so other factors might have masked any effect of the grooves.

So with edge thinning being common practice in guitar making, and the distinct change in tone during another experiment coinciding with a thinned edge top plate, it seemed like something worth looking into.

Method

One of my main dulcimers is about ten years old, and is quite a loud instrument. It's made of New Guinea Rosewood (a type of Padauk), with a 3mm thick Western Red Cedar top and a fairly light New Guinea Rosewood fretboard with a dense 2mm eucalypt overlay. This dulcimer has previously been used for a side port test, sound post tests, and the installation of a ukulele undersaddle pickup system.

The top edge was thinned by scraping and sanding from a thickness of 3mm to 1.5mm. Three regions were thinned – the waist area, followed by the upper bout and finally the lower bout. The plate was thinned so as to fully cover the glued surface of the internal side linings.

After each region was thinned, the bridge tap spectra were recorded to see if there was any change in the resonant characteristics of the instrument, and a short tune was recorded under constant conditions – four frequency spectra and four tunes. And I played the instrument and listened informally to detect such changes as I could.

Figure 5.19. Edge thinning of top plate

Results

The before, during, and after thinning spectra were the same, within the usual test/retest variation I always see. An overlay of the before and after spectra is shown in Figure 5.20.

The top thinning has not caused the resonant peaks to move in frequency. (The peak at 50Hz is the humming of the fan motor in the nearby computer, and not part of the dulcimer resonances). Inasmuch as the resonant characteristics of the instrument dictates the sound it makes, there was no real difference, thinned or unthinned.

Informal listening also didn’t show any effect from the top thinning.

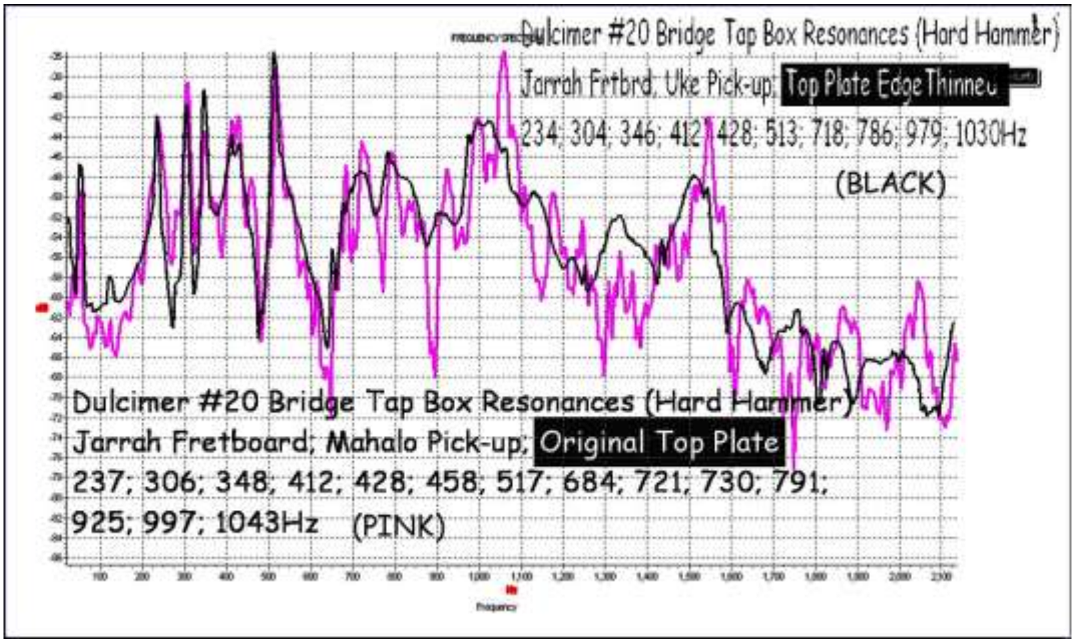


Figure 5.20. Tap resonance spectra

The four sound recordings (no thinning; waist thinning; upper bout thinning; full top edge thinning) were very similar in tone and within variations that would be expected for recordings made over a period of three days. In blind listening, I slightly preferred two recordings over the other two – the one with no thinning, and the one with full thinning both sounded best!

Conclusion

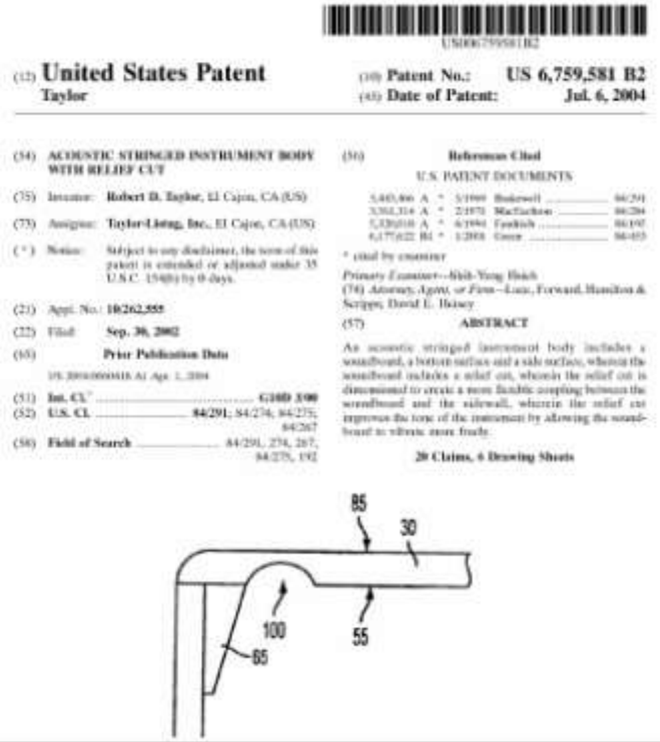
For this one dulcimer thinning the edge of the top plate to half its central thickness had no discernable effect on the tone.

I suspect this is a general finding for all full-length fretboard dulcimers — it is consistent with the grooved top experiment, which looked at the same question in a different way. The mellowing of the tone in the previous fretboard experiment is then more likely to be related to the 25% lighter fretboards than to the thinning of the edge of the top plate. This is consistent with the idea that it is the fretboard rather than the top plate that sets the general tone of a mountain dulcimer (for a given design), and that the flexibility of the top/fretboard assembly (which might govern overall top mobility) is mainly a function of the mass/stiffness along the center rather than along the edges, of the instrument.

For the earlier test dulcimer with the accidentally thinned edges, a simple thumb pressure test showed a clear difference compared to my other brighter dulcimers, including the edge-thinned dulcimer in this test. Placing the dulcimer on a table with the headstock furthest away and the bridge end pointing towards me; strum the strings then hold the back of the dulcimer with the fingers of both hands and push down strongly in the strum hollow with both thumbs. The fretboard test dulcimer shows a large reduction in pitch with thumb pressure, indicating a more flexible (mellow) central top assembly. My other dulcimers exhibit only a very slight pitch change, indicating stiffer tops. There was no difference in this experiments edge-thinned dulcimer's central top stiffness before or after thinning.

Top Accent Line- Jan 11, 2017

Did Uncle Ed Thomas[7] know something that we've lost when he put that groove around the edge of the top plate? I've been told that the groove is so slight that it's just decorative, and I think that might be correct - a token replacement for the inlay around the edge of a violin. But the idea that a groove along the edge of the top plate might increase the flexibility of the top clearly has some believers because Taylor Guitars have a patent on the idea (US Patent 6,759,581, Figure 5.20). Taylor Guitars have that groove, so I'm told.



(12) **United States Patent**
Taylor

(10) **Patent No.:** **US 6,759,581 B2**
(45) **Date of Patent:** **Jul. 6, 2004**

(54) ACOUSTIC STRINGED INSTRUMENT BODY WITH RELIEF CUT

(75) Inventor: **Robert D. Taylor**, El Cajon, CA (US)

(73) Assignee: **Taylor-Listug, Inc.**, El Cajon, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/262,555**

(22) Filed: **Sep. 30, 2002**

(56) **References Cited**

U.S. PATENT DOCUMENTS

(57) **ABSTRACT**

An acoustic stringed instrument body includes a soundboard, a bottom surface and a side surface, wherein the soundboard includes a relief cut, wherein the relief cut is dimensioned to create a more flexible coupling between the soundboard and the sidewall, wherein the relief cut improves the tone of the instrument by allowing the soundboard to vibrate more freely.

20 Claims, 6 Drawing Sheets

Figure 5.20. Taylor patent — guitar top groove

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[7] https://libraryguides.berea.edu/dulcimers

I've also cut a groove on the inside of the top on several of my dulcimers (Figure 5.21). The first one was such a good instrument, to my ear, that I kept it as my own dulcimer.

Figure 5.21. Edge groove

I also did it on a couple of subsequent dulcimers, and also attempted to achieve the same result by thinning the edge of a dulcimer from the outside. None of those subsequent attempts made for superior sounding dulcimers, or a discernable difference in the sound of the thinned edge dulcimer. As others have pointed out - a guitar top is a lot wider than a dulcimer top; there ***might*** be an effect in mountain dulcimers, but it might be proportionately smaller than in a guitar, and not really audible. I don't do it anymore, but it still seems like an OK idea.

The scratch line inscribed along the top edges of many pre-revival dulcimers is not really a groove - it's just a bit of decoration. To increase the flexibility of the top/side joint to give it some chance of influencing the sound, I think a groove would need to be at least about half the thickness of the top plate deep. It shouldn't matter much where the groove is, on the inside, or the outside, but rather than a groove on the outside it would be easier just to sand the edges thinner for the same effective result. I've tried both of these with no real benefit, but that's not to say it might not be worthwhile in some instances, and it's almost trivially easy to do. It took me about two minutes to put the internal groove in the top pictured above, using a round burr in a hand-held Dremel.

Chapter 6
Effect of Top and Back Replacement

Effect on Sound and Vibrational Parameters of Top and Back Replacement - Jul 09, 2010

I would have thought that something useful might have come out of this series of experiments which involved replacing both the back and the top of the same instrument whilst keeping all other aspects unchanged. I shouldn't have — experiments rarely result in clear cut conclusions.

Objective

To see if there were any clear improvements in the sound of a dulcimer when the back and top were replaced and when bracing was present or not.[8]

Method

A six string, three course, 27.5" scale, hourglass dulcimer with four sound holes and full length arched fretboard with four arches, first had the top, then the back replaced. Braces were later added to the backs. The instrument was initially made from good quality plywood with 3mm back and sides, and 1.5mm top. There were four cross braces on the top and back plates, made of 6mm x 6mm Western Red Cedar. Subsequently, the ply top and back were replaced with solid wood plates – Western Red Cedar for the top and a eucalypt, Yellow Stringybark, for the back. No braces were installed on the new WRC top. Yellow Stringybark is not known as a tone wood, and I have not used it before in dulcimers, but it looked nice. It is reasonably dense, but not very stiff along the grain, and like many eucalypts it seems to move a lot with humidity.

Dulcimer Configurations Tested In all configurations, the same fretboard was used.

1. Plywood Top, Plywood Back – both braced (Figure 6.1)
2. No Top (top plate cut off, fretboard remains) – Plywood back – braced then unbraced
3. Western Red Cedar top, unbraced - Plywood back, unbraced
4. Western Red Cedar top, unbraced – Plywood back, braced
5. Western Red Cedar top, unbraced – No back
6. Western Red Cedar top, unbraced – Stringybark bBack, unbraced
7. Western Red Cedar top, unbraced – Stringybark back, braced (Figure 6.2)

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[8] See Chapter 10 on bracing effects

Figure 6.1. Original braced Plywood top and back

Figure 6.2. Unbraced WRC top; externally braced Stringybark back

Tests undertaken Tests made include the following:

1. informal listening to make general judgements on quality of sound,
2. box resonances excited by tapping the bridge with a plastic hammer, frequency spectral analysis of the sound made,
3. two main air resonances measured by blowing softly across upper and lower sound holes,
4. modal vibration patterns determined by speaker-excited sawdust vibrations on tops and backs – compared with tap spectra,
5. average sound pressure levels of a recorded standard tune, and
6. sustain; peak sound level and rise-time of single treble and bass string notes.

The same string set and tuning was used for all tests over all configurations (.012/.012; .013/.013; .022/.024) tuned ddAADD.

The same test set-up and recording methods were used throughout. To obtain consistent “plucks” in the single note tests, the “wire break” method of string excitation was used. This entailed looping an inner filament of copper wire from a power cord, 0.14mm diameter, around the string at a constant position and slowly pulling vertically with pliers until it broke. For the standard tune, the 1st four bars of Wildwood Flower was recorded, the same plectrum and strumming position was used and care was taken to keep the playing style constant.

Recording was done using Audacity, real-time spectral analysis with Visual Analyser, and SPL, sustain and rise time measures using PRAAT.

Results of Tests

Results of the test included sound impressions, sound measurements, and spectral analysis of bridge tap tones. Air resonances and vibration patterns were also measured.

Sound Impressions: Sound impressions are my own.

- **Configuration #1 Plywood top, Plywood back** – **both braced.**
  Reasonably pleasant but quiet – nothing outstanding anywhere; a fairly "bland" sound.

- **Configuration #2 No top** – **Plywood back - braced and unbraced**
  Much as with the top on, but thinner in the bass. No change in upper treble.

- **Configuration #3 Western Red Cedar top, unbraced** - **Plywood back, unbraced**
  Overall better than plywood top, but not much. The bass had a much improved resonant character, but the treble was still weak.

- **Configuration #4 Western Red Cedar top, unbraced** – **Plywood back, braced**
  Much the same as with no back braces – nice bass but thin treble.

- **Configuration #5 Western Red Cedar top, unbraced** – **No back**
  The back was removed while the instrument was strung to tension. Unlike top removal, where there was no appreciable tuning or action change, the removal of the back resulted in a 3mm up bow in the fretboard from end to end, and a minus 50 cents tuning change. The width of the major bout across the back reduced from 182.5mm to 180mm. The waist and minor bout did not measurably change (from 90mm and 135mm).

This would indicate that the back is normally under tension (no surprise). The fretboard bow disappeared when the strings were loosened and the sides went back to original width across the back. There didn't seem to be much string action change in the lower fretboard, so most of the top bending might have been in the strum hollow area.

With the back off, some informal listening was done with the dulcimer raised off the solid wooden bench, and also flush on the bench; i.e., with the bench acting as a very rigid, but not perfectly sealed, back.

Raised on blocks from the bench it was still loud, but “thinner”. The bass had lost such resonant tone as it formerly had and was not “solid”. Flush with the bench, the bass tone was largely restored. Part of this was because the bench was itself vibrating, but no more so than when the dulcimer was mounted on blocks away from the bench (by listening with ear to bench). So the restoration of bass tone must have been principally to do with restoration of air resonances.

On blocks, the upper treble was still OK. Air resonances could not be excited by blowing across sound holes (although it was “trying” to); i.e., with an open back, the air resonances were definitely lost, as well as was their interaction with the wood.

Flush with the bench, the upper treble was actually much quieter than with an open back. The lowest air resonance could be easily excited by blowing across a sound hole. The frequency was 260Hz, much higher than the 200Hz of the original instrument; probably because of leakage around the edges, and the increased stiffness of the bench surface compared to a back plate, both of which would raise the Helmholtz resonance. The 2nd air resonance could not be excited by blowing at the upper sound holes.

The middle string and lower treble also seemed better with an open back.

Off the bench, there was a hint of a wolf note on 1st/2nd frets middle string (B,C notes), but not so prominent when flush with the bench.

Overall, the bass suffered significantly with the loss of the back plate, but the treble seemed to gain significantly. Possibly, the sides now having a free edge, might have been contributing more to the treble end of the spectrum.

- **Configuration #6 Western Red Cedar top, Unbraced – Stringybark back, Unbraced**
  Somewhat “nasal” or “shrill” sound – not very pleasing, and definitely not as good as the plywood back. Reduced bass quality.

- **Configuration #7 Western Red Cedar top, Unbraced – Stringybark back, braced**
  Still “nasal” sound – not very pleasing. Much the same as unbraced back.

It’s hard to rank my preferences for the sounds of the different configurations because of the times and conditions between listening and other subjective factors. But if I had to rank them from best to worst it might be:

- WRC top unbraced; Ply back unbraced,
- WRC top unbraced; Ply back braced,
- all ply; top and back braced
- WRC top unbraced; Yellow Stringybark back braced,
- WRC top unbraced; Yellow Stringybark unbraced,
- no top; Ply back braced,
- no top; Ply back unbraced, and
- WRC top unbraced; no back.

Generally, none of the changes turned it into a much better or worse instrument, and each change seemed to affect different parts of the sound spectrum, making overall comparisons difficult. The most improvement, if any, came with the WRC top in conjunction with the plywood back, which made the bass quality definitely better. Replacement of the plywood back with a solid wood plate was definitely a step backwards in sound, particularly in the treble. But keep in mind what was done:

- a 1.5mm plywood top was replaced with a stiffer 3.3mm WRC plate, and
- a 3mm plywood back was replaced with a more flexible 2.5mm solid plate.

So, the mere fact of a solid wood plate vs a plywood plate is not an absolute factor in sound quality. As well as the material, the stiffness of the plates has an effect, more so in the back than the top. The change in plate stiffness was greater for the top than the back, but the replacement of the back had a larger overall effect on the sound than the replacement of the top.

Unless I am fooling myself (which is quite possible), the fact that I can rank the sounds at all must mean that there were audible changes in the instrument in the different configurations. This is at odds with many of the objective measurements where there were no clear differences between configurations.

Sound Pressure Level and Sustain: For all the dulcimer configurations, and within experimental error, there were no measured differences in:

- average sound pressure level (SPL) of a sample tune,
- peak SPL of single bass and treble notes,
- sustain time of single bass and treble notes, and
- attack time of single bass and treble notes.

In addition, the proximity of a box resonance to the actual frequency of each string did not appear to affect any of the measures, which is counter-intuitive. Some box resonances fell exactly on a string note, but sustain was actually longer; some string notes fell between box resonances and sustain was shorter. The received wisdom says that if a note falls on a strong resonance, it should produce a louder but shorter sound. Unless the box resonances move around significantly in frequency from day to day (with humidity, for example), this did not seem to be the case here. However, only the fundamental of the note would be affected, not all its overtones, which may carry most of the energy. So, depending on the relative strength of the string fundamental vs all of the overtones, there could still be a longer measured sustain even though the fundamental might die off more quickly.

From this data it might be possible to tease out some small, but statistically significant differences, between the configurations but, that would not be of much use in the practical sense of a guide to building dulcimers.

In general for this instrument, a stiffer solid wood top produced a better sound than a plywood top, but a more flexible solid wood back was inferior to a plywood back, despite the loudness and sustain not being significantly affected.

So, the message from these measurements on this instrument is that types of wood for tops and backs, and their stiffness and bracing methods, do not seem good predictors for loudness, sustain, or basic sound quality. These things must reside in other design factors. In addition, the resonance structure of the box did not strongly affect the overall basic acoustic parameters of loudness and sustain.

Spectral Analysis of Bridge Tap Tones: For the four main cases of plywood back/Yellow Stringybark back, with and without braces, the bridge tap frequency spectra are shown in Figure 6.3 and 6.4.

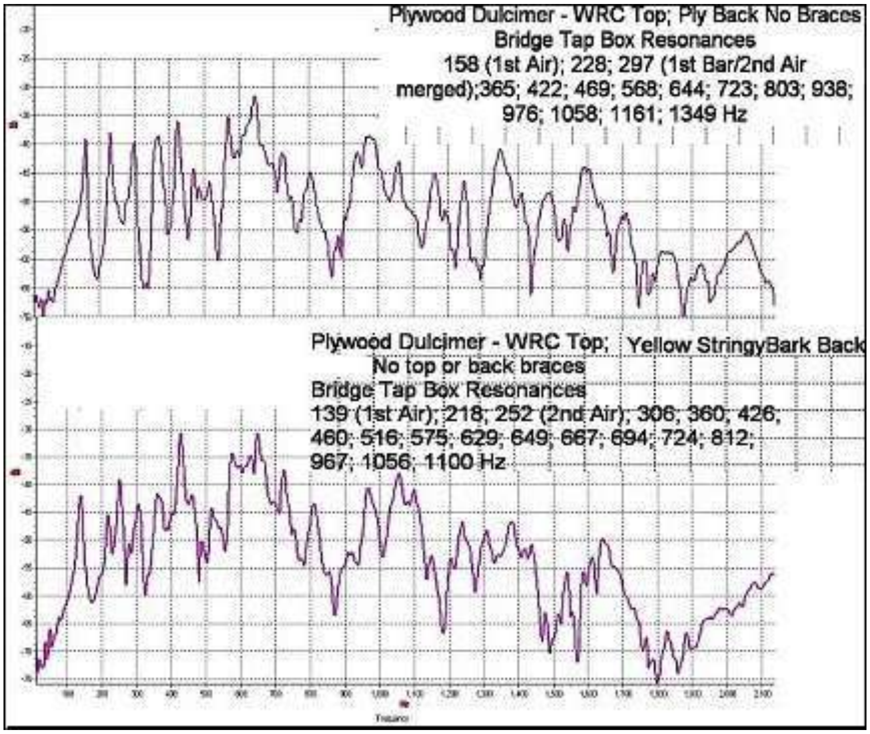

Figure 6.3. Bridge tap frequency spectra for no-brace cases

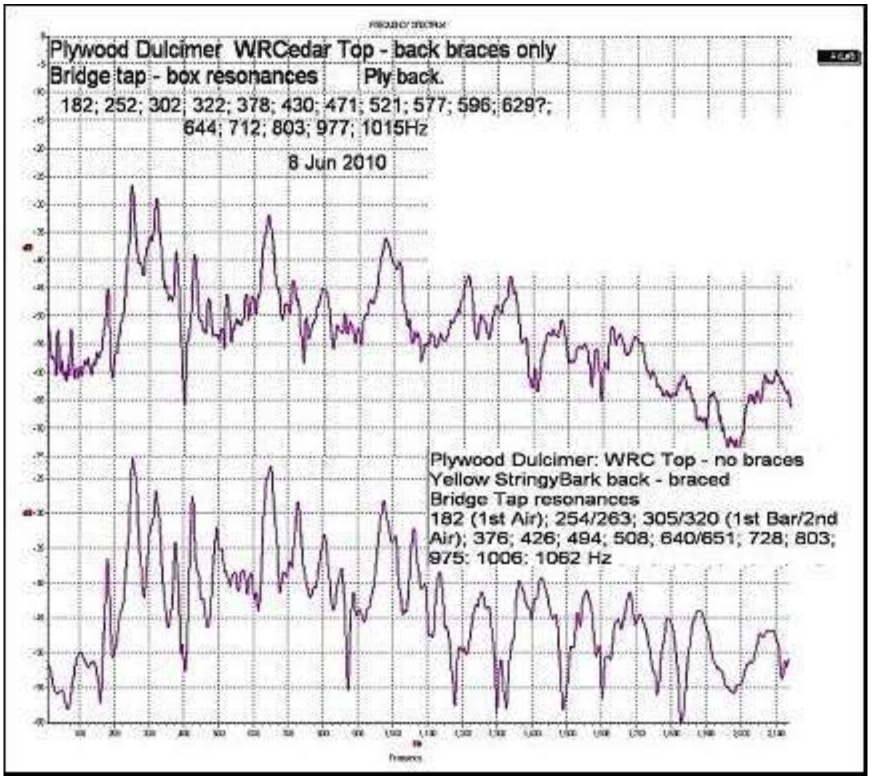

Figure 6.4. Bridge tap frequency spectra for brace cases

Figure 6.3 is for the two no braces case, plywood and Stringybark, 0 to 2100Hz. The first four peaks (1st air, another resonance, 1st bar and 2nd air) below 300Hz have different frequencies in the two cases. Between 300Hz and 1000Hz (which is about as far as comparisons are reasonable) the two spectra are generally similar. So, the change in back material and plate stiffness has affected mainly the lower end of the spectrum, which is an important region for the warmth of the sound. In this case, the plywood back definitely had a better bass tone than the Stringybark back. How that precisely relates to the resonant frequencies, I don't know, but resonant frequency changes in the lower frequency region did occur with changes in bass tone. However, the more favorable bass tone was also largely present in the case of the braced plywood back and absent in the braced Stringybark back, so the improvement may be for reasons as well as the back plate material or stiffness, and their effects on the lower air and wood resonances.

Figure 6.4 shows the spectra from 0 to 2100Hz for the braced cases. Below 1000Hz these are almost identical in frequency and relative amplitude of resonances. And yet there was a clear difference in the quality of the bass – the plywood being better.

So, we have cases of different lower spectra correlating with better and poorer tone, and also similar lower spectra correlating with largely similar better and poorer tone. This must mean:

- the lower resonant structure of the dulcimer box and enclosed air don't have much effect on warmth of tone (which I don't believe is so),
- subtle, and non-obvious, differences in resonant structure can have relatively larger effects on tone (possible, I don't know), and
- there are other factors, not considered here, that in addition to the resonances have large effects on tone (I don't know).

Keep in mind that these tap spectra just show that resonances are occurring at certain frequencies and strengths, but not which parts of the dulcimer are correspondingly vibrating at those frequencies. (See Chapter 3). It is conceivable that similar resonances seen in two tap spectra could correlate with vibration patterns on the instrument that have different spatial projections, and hence different perceived tone. (Since the excitation for the tap spectrum is a tap on the bridge by a plastic hammer, then if a resonance is seen in the spectrum, I take it that the strings can also excite that same resonance. So it can't be a case of the bridge not being able to activate some resonances of the tap spectrum.)

This is unresolved – how apparently similar and also different resonance groups can result in largely similar sound quality.

Effect of Flexibility of the Back on the Two Lowest Air Resonances: The flexibility of the back, determined by the wood type and thickness, and the cross bracing, has a very large effect on the frequency and amplitude of the two lowest air resonances. In the tests on this dulcimer, the measured 1st and 2nd air resonances are shown in Table 6.1

Table 6.1
Effect of Back Flexibility on Air Resonances

Configuration	1st Air Resonance	2nd Air Resonance
Unbraced Stringybark back	139Hz (C#3)	252Hz (B3)
Unbraced 1/8" ply back	158Hz (Eb3)	280Hz (C#4)
Braced Stringybark back	182Hz (F3)	305Hz (Eb4)
Braced 1/8" ply back	182Hz (F3	322Hz (Eb4)
Ply top and back, both braced	200Hz (G3)	354Hz (F4)

Except for the last entry in Table 6.1, which is for the dulcimer in its original all-plywood state with top and back braces, the top was WRC without braces.

The frequency of the lowest air resonance is supposedly dependent only on the internal capacity of the box and the area of the sound holes – the Helmholtz frequency. But as the box becomes more flexible; e.g., because the back is thinner, or has no bracing, it vibrates more vigorously in sympathy with the internal vibrating air. This coupling of the wood with the air has the effect of lowering the frequency of the air resonance to something less than the Helmholtz frequency.

Although I didn't measure the relative flexibility of the plywood and solid Stringy Bark, the Stringy Bark was thinner and felt less stiff than the ply. It also produced the lowest of the air resonance frequencies, which is consistent with it being more flexible (less stiff).

It's clear that in this dulcimer the removal of cross bracing from the top and back plates reduced the first and second air resonance frequencies by 4 to 6 semitones, depending on the stiffness of the unbraced back.

In addition, even though the back bracing was not particularly heavy or stiff, when installed it seemed to even out the underlying stiffness or flexibility of the back plate, resulting in the same 1st air resonance for two different types of back material. The box tap resonant frequencies for the two braced backs (ply and Stringy Bark) were almost identical below 1000Hz, whereas below 300Hz, the spectra with unbraced backs were quite different from each other and from the two braced conditions. In particular, the first air resonance, coupled to the wood, was weaker when the backs were braced. This means that the braced backs were vibrating less strongly at the first air resonance frequency than the unbraced backs were. But it probably also means that more of the air resonance energy was coming out of the sound holes in the braced-back condition because less of it was used up moving the back (which is what nature intended of air resonances – coming out of the sound holes). This might partially explain why, even though there was a stronger and lower frequency 1st air resonance in the unbraced back (e.g., 139Hz vs 182Hz), this dulcimer with an unbraced back, didn't sound substantially more mellow than with a braced back, and no louder, even when played on a stand that didn't touch the back.

This might imply that:

1. If a back is braced with, say, three or more cross braces, the stiffness of the back plate itself might not be so critical – thicker or thinner (within reason), the air and box resonances may remain much the same, as far as the back's contribution to the overall sound is concerned.
2. In an unbraced back, variation in flexibility of the plate itself appears to affect air (and hence wood) vibration more directly, and this might result in a wider variation of tone with unbraced backs, but see (5) below.
3. Bracing a back will increase its stiffness and therefore bias its vibration frequencies generally higher, but from these tests this does not necessarily translate to reduced warmth or loudness which may be compensated by increased output from the sound holes at the lowest air resonance frequency (this is speculation).
4. Bracing the top adds additional stiffness to the box, which further reduces the 1st air resonance coupling to the wood, and therefore may further add to sound hole output (more speculation).
5. Given that the first air resonance falls in a frequency region that seems important to the mellowness, or fullness of the dulcimer sound (150Hz to 400Hz), it might be expected that the 1st air frequency and amplitude would be strong factors affecting mellowness. The fact that there can be substantial variation in 1st air (139Hz to 200Hz in this case) without much perceived change in mellowness of sound, means that a maker might have considerable latitude in side height and sound hole size before adversely affecting the bass tone of the instrument sound.

Modal Vibration Patterns: The actual vibrations of the tops and backs were visualized using the loudspeaker excitation method described earlier in Chapter 2.

Some general observations about the modal vibration measurements are:

- The speaker-excited vibrations closely followed the resonances of the bridge tap spectra, which is to be expected since they are just two different methods of looking at the same box resonance behavior.

- As observed previously, if there was a top plate vibration at a resonance, there was almost always a back plate vibration at the same, or a very close frequency.
- Without top or back braces, the backs seem to vibrate more easily and more vigorously than the tops.
- Top vibration modes don't seem as clear-cut in their boundaries as back modes. ie. The transition from a point of vibration to a point of no vibration is fuzzier. As usual there are exceptions to this.
- Above about 600Hz the vibration modes become more difficult to identify – there can be general, as well as resonant vibration, and mode patterns seem more likely to run together.[9]
- When the first Bar and 2nd Air resonances are close together, the pattern of the bar resonance (two lines across the dulcimer) might be absorbed and the pattern of the air resonance predominates.
- Different resonances have different sensitivities (Q) and the demarcation of the modal pattern is fuzzier for low-Q (less peaky) resonances.

For the four cases of plywood back/Yellow Stringybark back, with and without braces the first five vibration modes of tops and backs are shown in Figure 6.5 through 6.8.

For both braced backs, the first air resonance caused very strong general vibrations.

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[9] By "general" vibration, I mean that the whole of the surface is vibrating over a range of frequencies, but with no identifiable nodal lines of low vibration, and no particular frequency at which vibration is stronger. I don't know whether this is a good thing or not. It might be the result of waves that don't resolve to standing patterns, but continuously ripple back and forth. By "resonant" vibration I mean that as the speaker frequency approaches a box resonance, the back, or top, rapidly starts to vibrate strongly, then stops vibrating as the frequency further increases, and generally settles to a characteristic pattern of nodal lines at the resonance.

Figure 6.5. Ply back, no braces; WRC top, no braces.

without displaying any nodal patterns. There were strong correlations in patterns over all four configurations, but at different frequencies between braced and unbraced, and generally better defined in the unbraced backs. The patterns were dominated by the simple in-out “trampoline” mode of vibration at these lower resonances, except in the region of the 1st bar resonance where it’s interaction with the 2nd air resonance in a couple of the cases distorted the modal pattern. It’s a trap to take each pattern as an absolute entity. Merged or missing resonances can upset the orderly scheme of things. As Benjamin Franklin said: “Don’t believe anything you hear, and only half of what you see.”

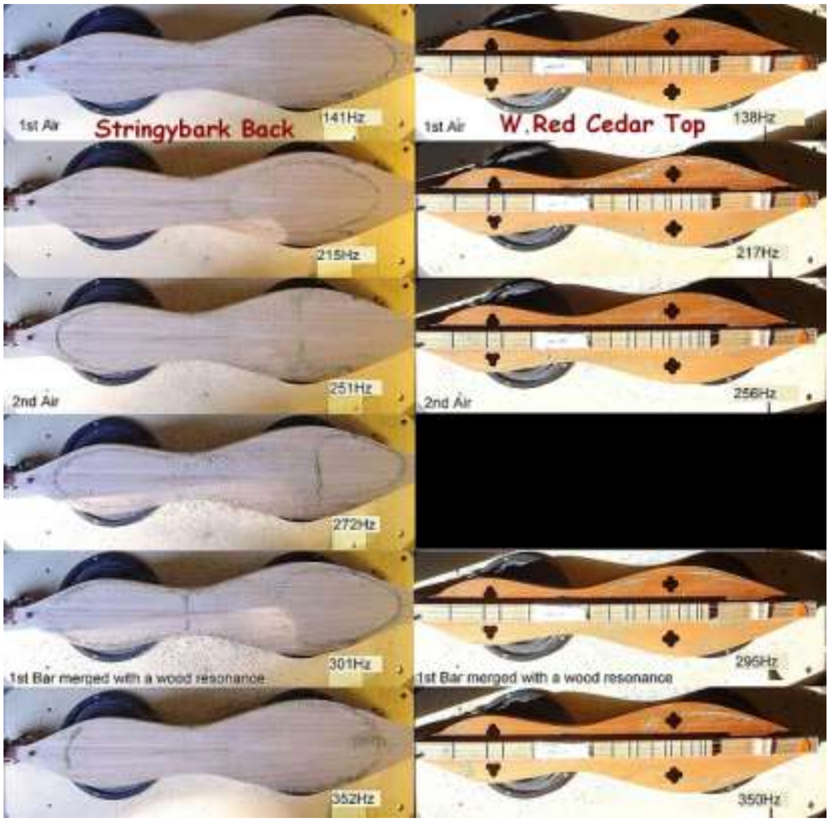


Figure 6.6. Stringybark Back, no braces; WRC top, no braces

Figure 6.7. Ply back, braced; WRC top, no braces

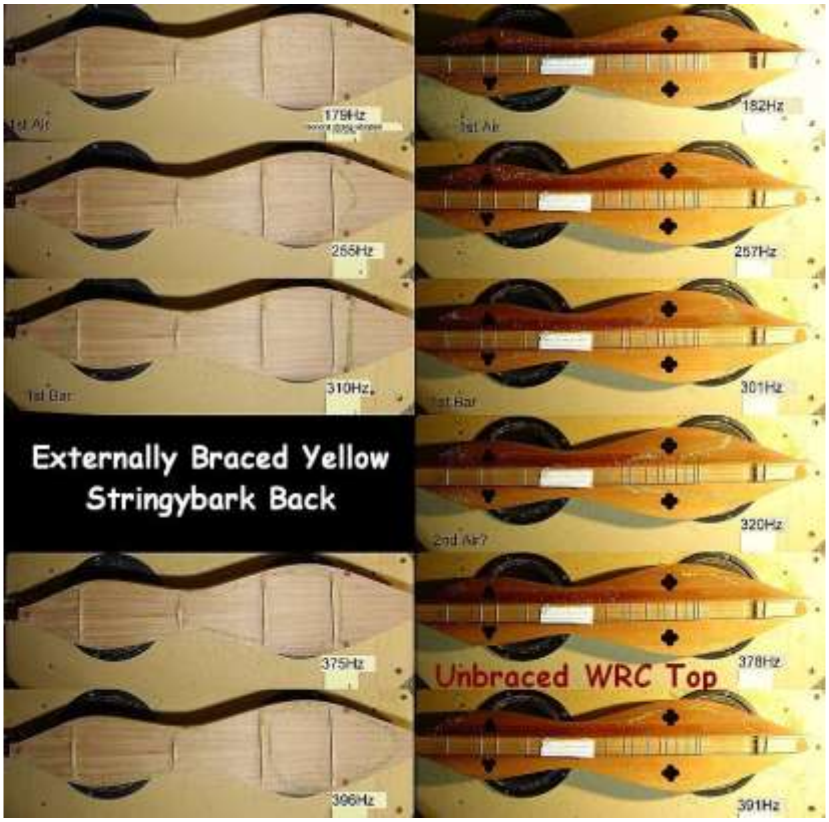


Figure 6.8. Stringybark back, braced; WRC top, no braces

The higher frequencies produced more complex patterns, particularly in the backs.

Figure 6.9 shows higher frequency back modes between about 350Hz and 800Hz. It is possible to match up some of them, but not all.

The pictures marked with the same letters (probably) represent the same vibration modes in the different configurations. Note that there is no overlap between the patterns of the braced and unbraced backs at these higher resonances, meaning that not only do unbraced backs vibrate at different frequencies and amplitudes to braced backs, but the patterns of vibration are also different. Whether the shapes of the vibration patterns significantly colour the sound, I don't know. It may have to do with the wavelengths of sound at the different frequencies, and hence whether the sound remains local to the dulcimer or can radiate away to a wider field.

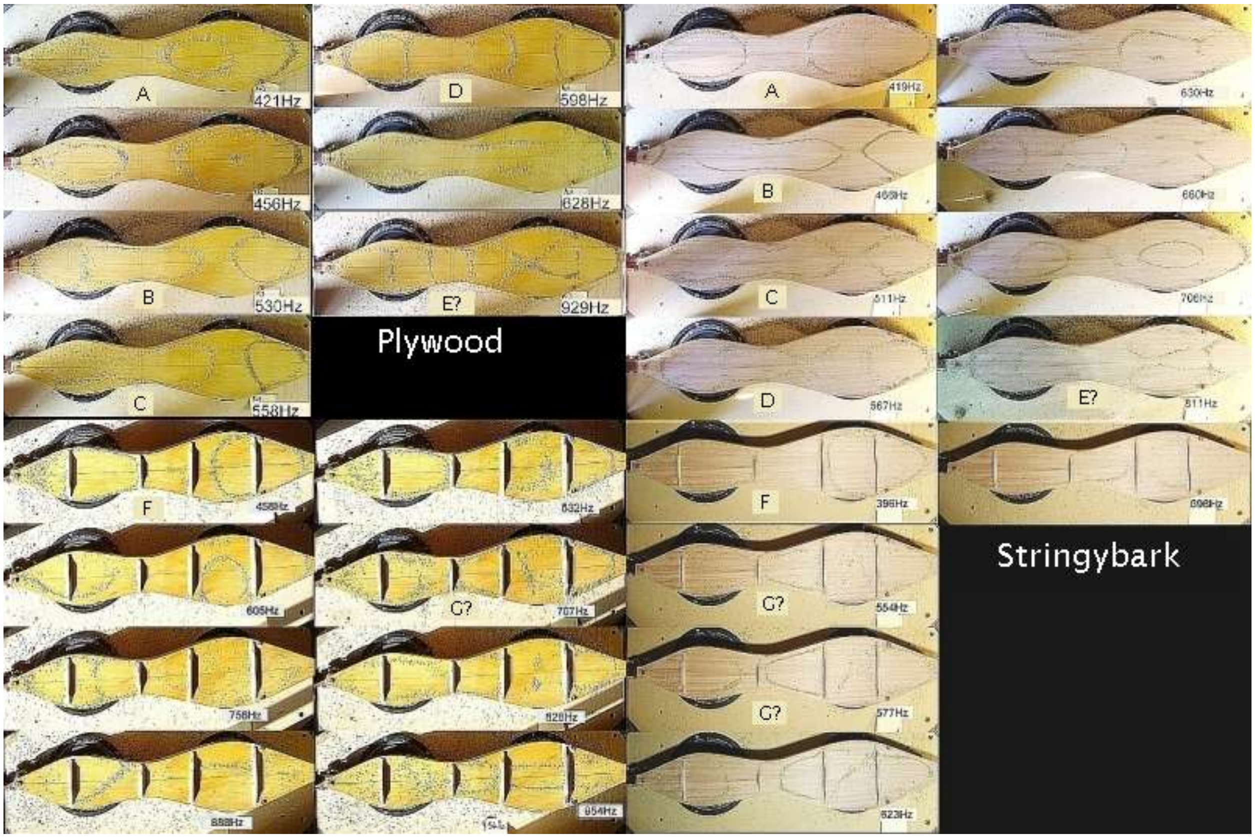


Figure 6.9. Higher frequency back vibration modes

Somewhere hidden in all this, or in patterns I didn't record, might be the reason why the bass tone is different between a Plywood back and a Stringybark back, but if it is, I'm not sharp enough to spot it.

Conclusions

The end result of changing the top and the back, and putting braces on the back, is that the dulcimer did not markedly improve, to my ear, under any of the configurations. None of the acoustic measurements made, or the vibrational analysis, shed much light on such differences as I could hear. Some standardized modal patterns did emerge, but these can't be connected to sound quality at this stage, much less designed into an instrument. The reasons for any sound differences between configurations is therefore unresolved. This doesn't surprise me greatly – I would have been more surprised if some clear connection between measurement and sound quality had shown up. There never seem to be single major contributors to sound quality, so questions such as "What's the best (wood, string, shape, thickness, length, weight, tap tone, etc.)" can probably never have definitive answers.

But that doesn’t stop me, and everyone else, from hoping there might be. So, the next logical step is to remove the Stringybark back and replace it with a Western Red Cedar plate, and maybe subsequently with a (stiffly braced) false back. Then start cutting and drilling pieces from the fretboard and end blocks. Or maybe the sides have more of an influence than have been assumed; or the presence or absence of side linings.

Chapter 7
Dulcimer Shape and Stiffness Effects

Effect of Dulcimer Shape on the Lowest Air Resonances-

Dec 09, 2009

I had some spare high density particle board, and made up three dummy dulcimer boxes of different shapes to get a feel for whether the dulcimer shape, as well as the capacity, affects the frequency of the lowest air resonances. This is not a rigorous examination of air resonances, just a quick and basic look at the lowest two air resonances that radiate sound from the sound holes.

The backs and sides of the boxes are 6mm thick, and the tops are 3mm - all particle board. All boxes are 750mm long (internal) with 50mm side height.

The three shapes I tested (Figure 7.1) were:

- a plain box - the simplest case,
- a stepped-sided box to simulate a smaller bout at one end, but with no appreciable waisting, and
- a narrow waisted box to simulate an hourglass shape.

The cubic volumes have all been adjusted to 4250cm^3, which is typical for a standard dulcimer(the numbers in the picture are not the final volumes). The sound hole area is also typical – 25cm^2. Because I was only looking at air resonances, which depend principally on the properties of the internal air cavity, no fretboards or endblocks were attached.

In isolation, the strips of particle board were acoustically dead when tapped, but once enclosed I was surprised at the reasonable tap tones, and the spectral analysis bears this out – they might actually sound OK as dulcimer boxes!

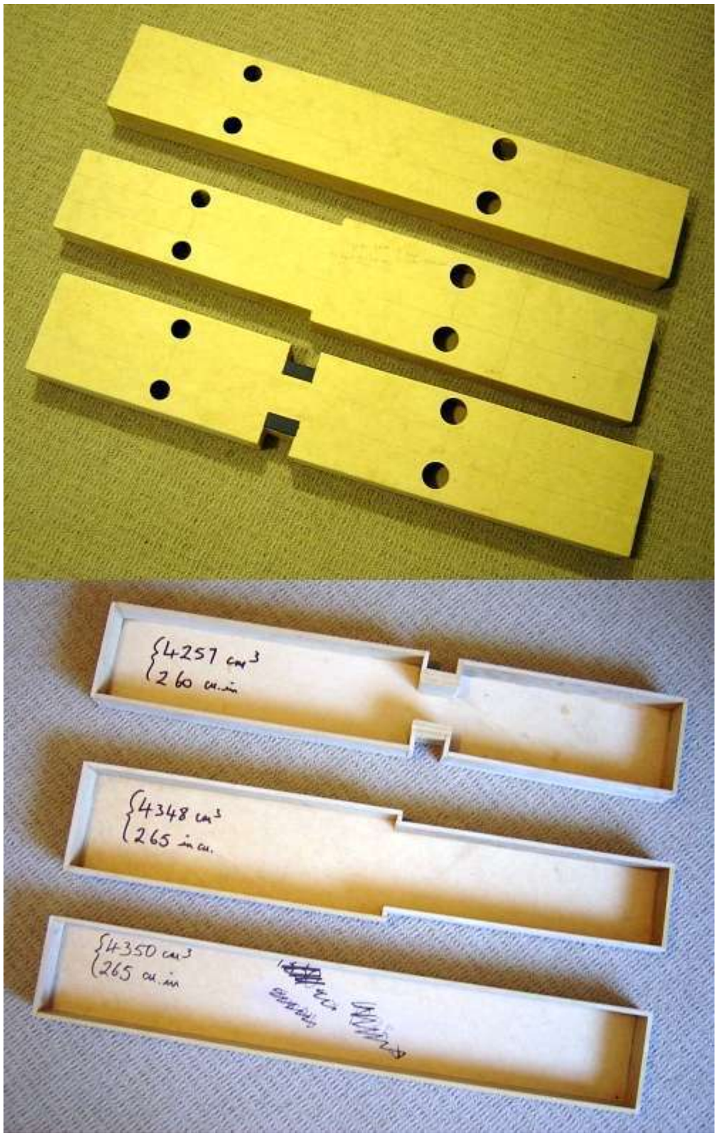


Figure 7.1. Three tested shapes

I measured the tap resonances of the boxes before and after cutting the sound holes, and that was instructive. It confirmed that the 1st and 3rd tap resonances of a mountain dulcimer box represent the 1st (Helmholtz) and 2nd air resonances that emanate from the lower and upper bout holes respectively (Note: this applies only to 4-hole dulcimers). In between these two is usually the first bar vibration of the box. The box tap spectra, with and without holes, are shown in Figure 7.2.

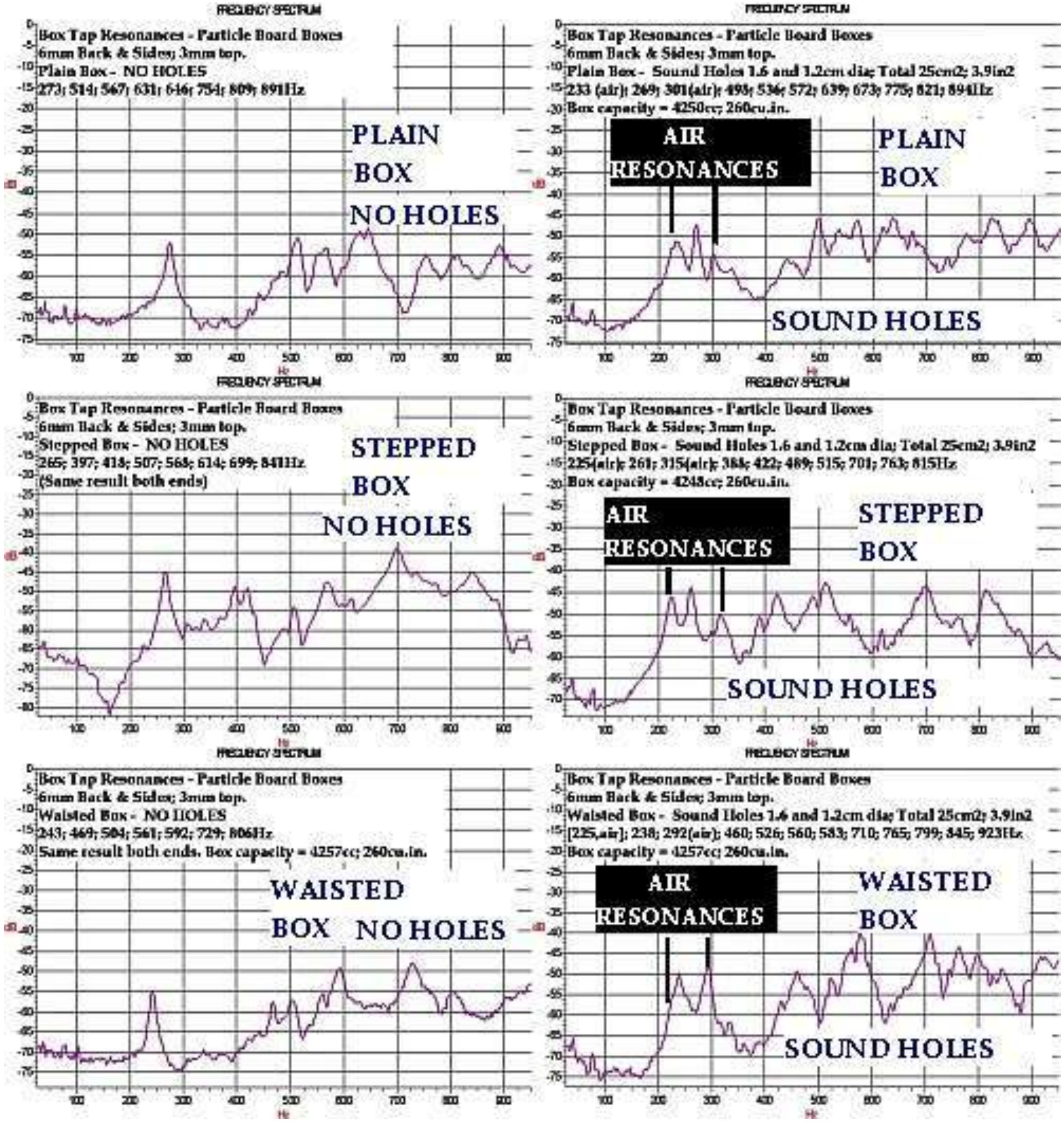


Figure 7.2. Tap spectra of three box shapes

The addition of the holes produced the characteristic air/wood vibrations, and show up as the 1st and 3rd peaks as shown in the figure, which were not present before the holes were cut. In the case of the waisted box, the 1st air resonance was so close to the first box (bar) resonance that the two were superimposed. This is a reason why they may not always show up separately.

So what does it mean?

Well, the 1st and 2nd air resonances from the above tap spectra are shown in Table 7.1

Table 7.1
First and Second Air Resonances

Configuration	**1st Air Resonance**	**2nd Air Resonance**
Plain Box	230Hz	306Hz
Stepped Box	222Hz	319Hz
Waisted Box	227Hz	298Hz
Typical Dulcimer	225Hz	370Hz

I confirmed these by blowing across the sound holes and measuring the frequencies.

The shape didn't seem to have a lot of effect on the 1st air resonance, which is good to see because it confirms that this resonance is basically dependent on the box capacity and the sound hole area, as expected.

But the 2nd air resonance frequency is more variable in these tests and might be related to the shape of the instrument in some way, or perhaps the position of the sound holes. This idea is supported by the fact that of 23 various shaped dulcimers I have measured, there is about twice the variability in the first air resonance compared to the second, in terms of musical intervals – in those dulcimers the box capacity has varied more than the basic shape, mainly due to side height changes, but the same basic hourglass outline has been used, which may have minimized 2nd air resonance variation.

So, overall, this confirms the proposition that the first three box resonances, which I consider to be the foundation of what a particular dulcimer sounds like, are the 1st air, the 1st bar and the 2nd air resonances.

The 1st air resonances don't seem greatly affected by the shape, but the 2nd air resonance might be.

The thin waisted box has a lower frequency 1st bar resonance than the other two, and it makes sense if it is a little less stiff than the two wider boxes. So maybe the shape also affects that bar resonance.

The idea of the mountain dulcimer as principally a vibrating bar needs revisiting. There is clear evidence for the 1st bar vibration mode in the 250Hz to 350Hz region, and it being number two in the box resonance sequence, but I can't reliably see higher bar vibration modes – these would be in the regions of 700Hz to 1000Hz which is less fundamental to the sound, and not really controllable anyway. So other mechanisms seem to be producing the vibrations between say 400Hz and 1000Hz.

All parts of a mountain dulcimer vibrate and contribute to the overall sound, and back and top bracing will modify the sound in some way. But as far as I know, and certainly from my own experience, the direction and magnitude of that sound modification isn't reliably known for mountain dulcimers. Therefore what type, position, number and grain orientation of the braces produces the "best" sound is anybody's' guess.

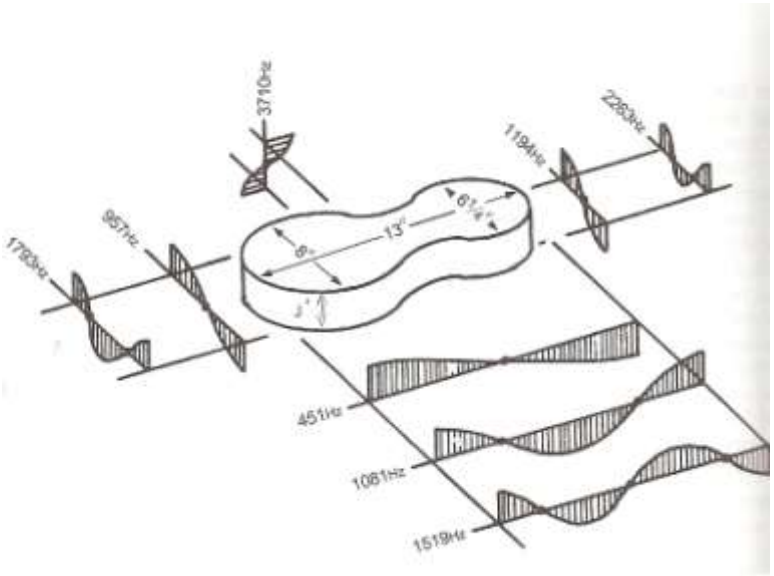
I tend to have lots of heavyish bracing, and the result has been that my instruments seem to be relatively unaffected by knee damping, yet still quite loud. Perhaps that is another way of saying I have de-emphasized the extent to which the back can vibrate (by making it stiffer), with some of that unused energy then available to make other parts vibrate. Or, another way to say it, a heavy, stiff back might be more isolated from energy transfer within the wood than a light flexible one would be. But in general, changes in the bracing will affect the frequency bias of the parts braced. So a stiffer back will emphasize the higher frequencies, which are less likely to be affected by knee damping than the lower frequencies. But overall, the sound produced by a vibrating back is directed away from both the player and the listener; i.e. downward, and is basically wasted (although some of it will also pass through the top in a filtered fashion, and some of it will interact with other air and wood resonances). So if a braced, heavy back vibrates less, and a reasonable proportion of the unused energy produces vibration elsewhere in the instrument (tops, sides, fretboards, ends) it might appear louder to both the listener and the player simply because more sound is radiated in their direction. As others have said elsewhere, loudness is not everything — but players still seem to want more of it.

Speculations on Possible Effects of Dulcimer Waisting-

Jun 12, 2010

From time to time, people say that a narrow waist on a dulcimer favorably contributes to the tone produced by separating the air masses at each end of the instrument. They could be right, or they might not. But I've noticed a couple of things that might be related to the question – the effect of waisting on the two main air resonances, and the possibility of some back vibration modes being inhibited by narrow waists.

Air vibration modes in a dulcimer-like box might be predictable in theory, but in practice the curving shape and flexible walls make analysis difficult. Air resonance series in a pseudo violin-shaped box might look like this:



Originally published in *American Lutherie* #13, 1988

Tuning Air Resonance

by W.D. Allen

based on a talk given at the Illinois State Museum Luthiers' Conference

Figure 7.3. Tuning air resonance

There are standing waves of air pressure from end to end, side to side, and up and down. A mountain dulcimer will have similar sets of series. These interact with the wood through its flexibility, and therefore contribute to the sound. Also those resonances that have a maximum near a sound hole will also radiate sound directly. How much all this modulates the sound – who knows, but it is part of the total sound.

In a dulcimer, the lowest two air resonances are the ones you hear when blowing across the sound holes – there's a different one for lower and upper sound holes (I'm only talking about 4-hole dulcimers here). A systematic study by blocking upper, lower, and then all sound holes on five dulcimers seems to indicate the upper and lower tones are somewhat interactive; i.e., blocking one pair of holes will make the tone at the other holes fall in pitch. (This, and the fact that they disappear from the spectrum when their holes are blocked seems to indicate they are ***both*** Helmholtz resonances. I don't know how that might arise in a single enclosed chamber.)

I wanted to see if the two lowest resonances were affected by narrow waisting, so I modified one of the particle board boxes referred to earlier in this section, to have adjustable baffles I could slide in and out to vary the cross-sectional area at the waist.

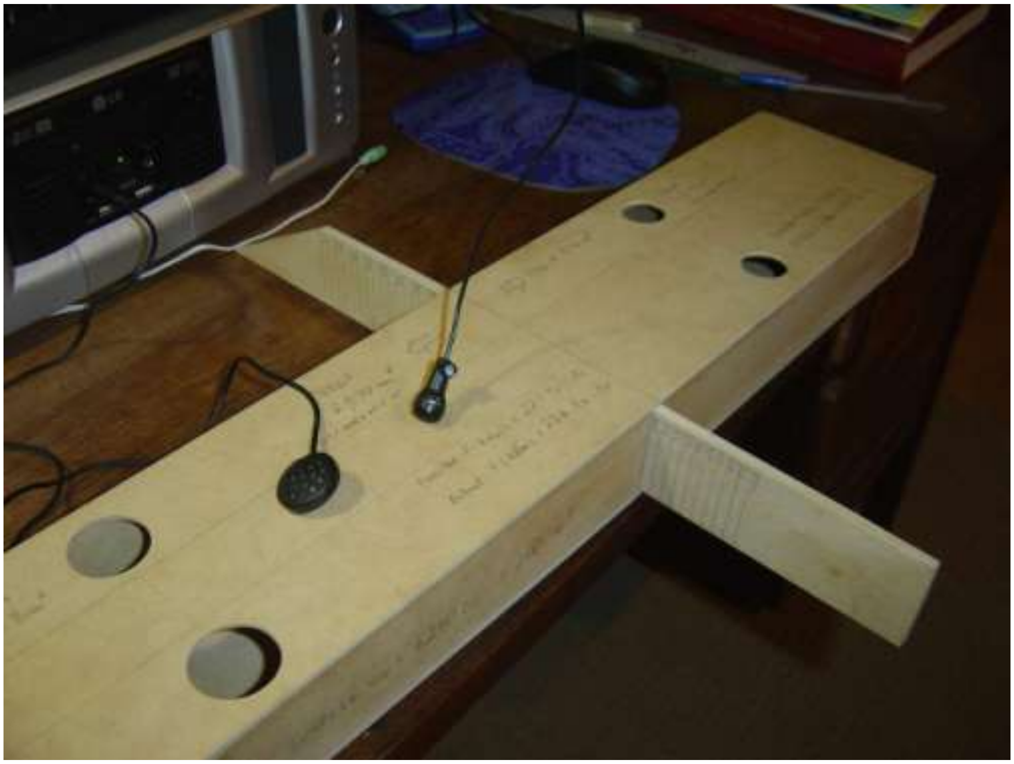


Figure 7.4. Box set up to measure waist effects

The results of blowing across the upper and lower sound holes and measuring the frequencies are shown in Figure 7.5. This showed that the upper and lower hole tones remained unchanged until the opening was less than 10% of full width; i.e., even with a waist much smaller than the narrowest dulcimer waist I've seen, the two low air resonances remained at the same frequency. When the slides completely blocked the two ends, each end reverted to its separate Helmholtz resonance.

The first peak at about 225Hz is the tone at the lower sound holes, and the second peak at about 300Hz is the tone at the upper sound holes (until the opening falls less than 5%). This result is what would be expected from the violin model in Figure 7.3 — the air resonances are mainly dependent on the long dimensions rather than restrictions placed in their path.

So if a narrow dulcimer waist confers some tonal benefit, it might not be related to air resonances by separating the two ends, because even a very narrow waist doesn't seem to affect the low air resonances.

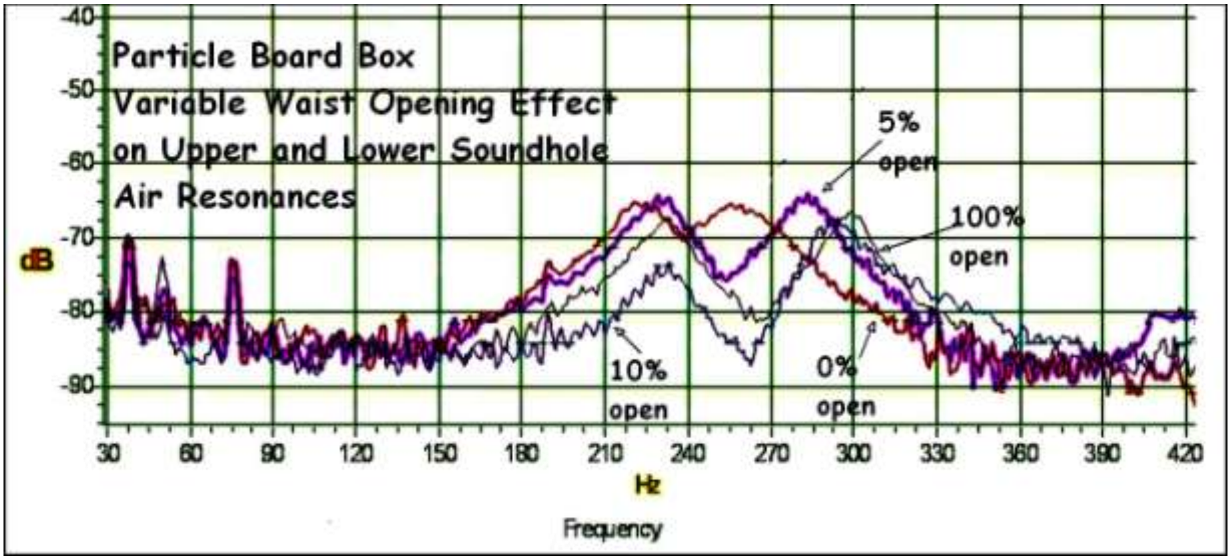


Figure 7.5. Effect of waist width on air resonances

Another other thing that a narrow waist might affect is the ability of the instrument top and back to develop some of the vibrational modes I've observed.

Figure 7.6. Vibration pattern for 3.5 inch waist

Vibration modes with a long vibrating area straddling the waist occur on all the dulcimers I've looked at with a 3½"width waist (Figure 7.6), but not on the one instrument I've tested with a 3" waist. This is not definitive proof of anything, but there might be a waist width below which it is difficult for these vibration modes to develop, and hence add to the sound. If that's the case, I don't know whether it's a good thing or a bad thing for the sound.

It may be that the best shape to allow all the resonant modes to develop is the Virginia boat shaped dulcimer. In addition, such a shape would concentrate the larger vibrations in the center — between the knees, and hence might not suffer so much from knee damping (yet many of them have double backs). I haven't seen such an instrument so this is just guessing – I have no information on the vibration mode shapes of boat dulcimers. And it might not be a desirable thing to have all the modes anyway.

Overall, in any claims for the tonal benefits of narrow waisting, I'd lean towards the wood being the cause of any change, rather than the enclosed air or its separation into compartments.

Dulcimer Stiffness-Effect of Fretboard- May 15, 2010

I made a test dulcimer out of good quality plywood to do some tests on, which I didn't get around to doing. But now I want to use the dulcimer for some other tests that involve replacing the ply top with solid wood, and removing the top and bottom bracing.

So I took the opportunity to remove the top, leaving the fretboard in place, whilst still strung to tension, to see if there were any changes in tuning, action, or overall static stiffness. The fretboard is an arched one, and initially I left in place the parts of the top that joined the fretboard feet, then later cut them out, then also removed the bottom braces.

The summary of results follows, and while not particularly illuminating, may give an idea of the contribution of different parts of a full-length fretboard dulcimer to overall stiffness.

The dulcimer is of the shape I have been using for the last fifteen or so I have made. It has a fretboard made of *Eucalyptus delegatensis* (Alpine Ash), with three arches. Initially it had four top and back braces, but no side linings.

The stiffness was measured as the deflection of the center of the back of the instrument under a 7.67kg weight placed on the center of the fretboard between support points 787mm apart at the ends of the instrument. I had also measured the deflections of the fretboard prior to construction. Back and sides are 3mm ply, and the top was 1.5mm ply; 50mm side height.

I did no sound analysis after the top was removed, but it sounded much the same as with the top on, but somewhat thinner (as might be expected on losing the air resonances). I thought it sounded a little thinner again after I removed the bottom bracing, and it was also then more affected by knee placement. The instrument is shown in Figure 7.7.

Figure 7.7. Test dulcimer before and after top removal

Static deflection results are shown in Table 7.2. In retrospect, maybe I should have measured the deflection of the fretboard under a weight, rather than the back under a fretboard weight, especially for the case with the top removed, but it’s too late now. The measurement set-up was essentially as shown in Figure 7.8.

Table 7.2
Static Deflection

Configuration	**Deflection**
Plain fretboard blank	110/1000”
Shaped fretboard without frets	192/1000”
Shaped fretboard with frets	194/1000”
Dulcimer box only (no fretboard)	19/1000”
Dulcimer box with shaped and fretted board resting on top	14/1000”
Completed dulcimer strung to tension	7/1000”
Dulcimer with top removed , but arch fillets and back braces in place	5/1000" [1]
Dulcimer with arch fillets removed	5/1000"[2]
Dulcimer with bottom bracing removed	5/1000"[3]

[1] No observable change in string action
[2] Dulcimer stayed in tune, and action was unchanged
[3] No change in tuning or action

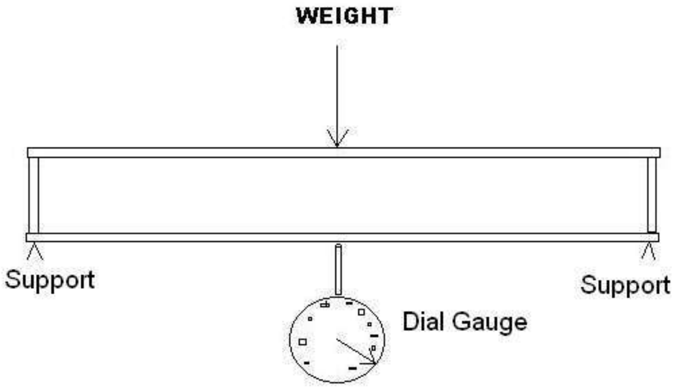


Figure 7.8. Deflection measurement set-up

This might be OK with a boxed-in top, but with the top gone, the sides can move in and out, so maybe the movement of the back is not so representative of the deflection of the fretboard.

Some things are clear though.

- A shaped fretboard might be about half as stiff as the plain solid blank.
- Separately, a dulcimer box seems about ten times as stiff as a nearly solid (but shaped) fretboard. Joined together, they are substantially stiffer again.
- The fretboard/back/sides combination seems to be the major stiffening factor in a mountain dulcimer, whether the top is there or not, and whether the back is further stiffened with bracing or not.
- A typical full length fretboard, glued to the ends of a topless box, is more than strong enough to withstand the compression of the string tensions without producing dimensional changes in the overall structure (as indicated by unchanged tuning or string action). With the top in place it would be even stronger.

The top plate does not appear necessary for the structural integrity of the mountain dulcimer, as far as its ability to function as a musical instrument. Long term dimensional stability might be a problem though.

And whilst this is not to say that different top woods don’t contribute to the color of an instrument's sound, the fact that the topless sound is not radically different, supports my contention that the thickness, mass and stiffness of the dulcimer top plate don’t have much influence on the way the whole structure vibrates, and so frees a maker to choose top plates on grounds other than their supposed overriding acoustic merits.

Dulcimer Stiffness-Effect of Top-May 18, 2010

I put a new top on the plywood test dulcimer used to test stiffness (Figure 7.9). It was quite a nice piece of western red cedar, 3.6mm thick, compared to the 1.5mm original plywood top. I didn't do any rigorous acoustic measurements before and after, but my subjective impression is that it sounds much the same, maybe a little fuller, maybe a little louder, but not a lot in it. The only changes were the new top, and removal of internal bracing. I was a bit disappointed, really, that such a nice top didn't make more of a difference. But I would have been more disappointed if it had because it would negate my argument about top not contributing significantly to sound quality.

Figure 7.9. Test dulcimer with western red cedar top and 2mm high arches

I measured stiffness in the same way and it returned to 7/1000". I also measured the deflection of the fretboard, as well as the back, and that was 14/1000", so backs and tops deflect differentially - not surprising.

But something unexpected did arise. The frequency spectrum of the sound made by tapping on the bridge seems to have been shifted down by about 40Hz. The first air resonance is now quite low at 158Hz (was 200Hz), and yet the instrument doesn't sound much more mellow or bassy. The lowering of the first air and first bar resonances I can understand because of the increased flexibility caused by brace removal. But I can't explain why other resonances should fall. The relative spacing between resonances seems to be largely preserved, and it's this that is usually thought to give the characteristic sound to an instrument, rather than the absolute frequencies, which would explain why the dulcimer still sounds basically the same. Another mini-mystery.

Effect of Small Changes on Stiffness- Sun Oct 09, 2011

In the process of making two identical dulcimers, except for tops which were 1.6mm and 3.2mm thick, it became clearer to me how sensitive mountain dulcimer structures are to very small dimensional changes.

If we accept, as guitar and violin makers do, that stiffness of the wood structures has a significant impact on the instrument sound, then cavalier attitudes to the odd 1/16" or 1mm here or there might explain some of the variation in sound we get in the finished dulcimer. Those larger scale makers who are jigged up to produce dimensionally identical instruments are spared this type of variability to a large degree.

So let's think about some aspects of mountain dulcimer stiffness, but ***warning***: ***slight science content***.

For simplicity let's separate a typical mountain dulcimer into three major structures, from a stiffness point of view:

1. The dulcimer box itself — this would be described by a mechanical engineer as a thin-walled box-section beam.

2. The fret board, for simplicity a continuous, hollow type — again, a box-section beam.

3. The top plate ("sound board") —a solid, rectangular section beam.

Each of these structures has its own intrinsic stiffness. I don't know how the overall stiffness might be characterized when all glued up, but it will be at least as great as the sum of the component structure stiffnesses. Also, it seems clear to me from a bit of study, and my own experiments, that a mountain dulcimer is not heavily loaded and that structural deformation by the string tension is small. We are not talking here about non-linear deformations that buckle the plates of the top and sides.

There are two aspects to the stiffness we might be interested in.

First is the ***Modulus of Elasticity*** (MOE, symbol E; "Young's Modulus"). This is a property of the material itself, the wood, and in the same way as density and color, does not change as the material is shaped and stressed (within destructive limits). The formula, for a piece of the material under tension is:

MOE=(Tension x Length)/(change in length x cross sectional area)=$(T*L)/(\Delta L* A)$

It is a measure of the material's intrinsic resistance to deformation.

The other aspect of stiffness is called the Second Moment of Area, or ***Moment of Inertia*** (MOI, symbol I). This is a measure of the stiffness conferred by particular SHAPES. It is used to predict the resistance to bending or deflection of beams with different cross-sectional shapes.

For a solid rectangular section beam (eg. solid fretboard or top plate) of width w and height h, the MOI is:

MOI (solid) = (width x height^3)/12 (don't worry about the units)

For a box section (e.g., dulcimer body, hollow fretboard) of outer width W and height H, and inner width w and height h, the MOI is given by:

MOI (hollow) = (W * H^3 - w*h^3)/12

So: MOE is stiffness of the stuff itself -------------- MOI is stiffness of the shape of the stuff.

A practical measure of the actual stiffness of a beam-like structure is the MOE times the MOI (MOE*MOI; E*I), but let’s assume the whole dulcimer is made of the same wood, so the MOE is constant throughout. Then how much might a real mountain dulcimer change in stiffness as the dimensions change, and what is the relative stiffness of the box, the hollow fretboard and the top plate? Some quick and crude arithmetic can give an idea, for a typical dulcimer, with cross sections measured at the waist. Waist width, say, 4"; plate thickness, say, 1/8"; side height, say, 2". Fretboard 1 1/4" wide and 3/4" high, with 5/16" walls.

For this dulcimer:

The ***Box*** itself will have a MOI of about 500,000 units. If we change the side height by 1/16" (3%), we will change the box stiffness by about 7%. Higher sides means higher box stiffness.

The ***Fretboard¸***, on a 1/8" top plate, will have a MOI of about 30,000 units. Reducing the fretboard height by 0.05" (4%) will reduce the fretboard MOI (stiffness) by about 12%.

The ***Top Plate*** will have a MOI of about 200 units. Reducing the thickness by 0.02"(15%), will reduce the stiffness of the top plate by about 40%.

These substantial stiffness changes are caused solely by a small change in the SHAPE of the cross-sections of the dulcimer parts, independent of its mass or density.

So:

The ***Box*** of a typical Mountain Dulcimer is approximately 15 times stiffer than the ***Fretboard*** and about 2500 times stiffer than the ***Top Plate***.

The ***fretboard*** of a Mountain Dulcimer is about 150 times stiffer than the ***top plate***.

The irregular shape of a dulcimer box, the shape and placement of the strum hollow etc., will vary all of these, of course, but the general relative stiffness magnitudes will be similar between the parts of the instrument - the box is a lot stiffer than the fretboard, and the fretboard is a heck of a lot stiffer than the top plate.

In addition, small changes in the height of those parts will produce relatively large changes in the stiffness of those parts.

Does any of this matter? It does if you intend to make some predictions about the sound of a mountain dulcimer before it's finished. This consideration of MOI stiffness is in addition to the effects of component mass, cavity capacity and sound hole size, all of which will also modify the sound.

In general terms, the effects on sound are:

More ***Mass*** => emphasis on lower frequencies; more mellow
Larger ***Air Cavity*** => emphasis on lower frequencies; more mellow
More ***Stiffness*** => emphasis on higher frequencies; brighter

But because stiffness is related to the cube of the height of things, it can change much more quickly than the other two, and while, for example, you might think you are reducing the mass of a fretboard by lowering its height, you might well be overriding the tonal effects of mass reduction by reducing the stiffness even more.

These sorts of interactions can explain unexpected sound outcomes – e.g., the expected increase in mellowness by raising the side height to increase box volume might not occur because the whole instrument became stiffer with a subsequent bias toward higher frequencies sufficient to counter the mellowing effect of larger air volume. (Both will occur, but one might dominate perceptually.)

I doubt that any of these variables in stiffness are linearly related to sound quality — but they are related. Particularly, I'll be a bit more circumspect before I just slap on that good looking fretboard overlay of indeterminate thickness. Along with box capacity and bridge placement, I think that the height of sides and fretboard have a major influence on the final sound of a mountain dulcimer because of their sensitive effect on stiffness.

Some Observations on Fretboard Stiffness- Mar 16, 2012

From time to time I see or hear of a dulcimer maker putting carbon fiber bars in the fretboard of an instrument and I always wonder why they do it. The result is fairly clear – the carbon fiber rods make the fretboard stiffer, and might even make it a little lighter. But is that a good thing? Does it improve the sound (whatever that means)?

For fretboards that don't run the full length of the body it might seem reasonable to stiffen them with carbon fiber rods, but for full-length fretboards I couldn't really think of any advantage. But I bought a couple anyway to try on my long-suffering test dulcimer, and see the results for myself.

The test dulcimer(Figure 7.10) has been reported earlier and has a Western Red Cedar top, 1/8" ply sides, a Balsa inner back and a 1/8" ply outer back. The fretboard is Yellow Stringybark, and Australian eucalypt. I've never liked the sound of this dulcimer – there's a hollowness about it that I attribute to the fretboard somehow (the top and back have been replaced more than once).

I measured the deflection of the box, and the top/fretboard before gluing on the carbon fiber bars.

Figure 7.10. Test dulcimer — high fretboard arches and double back

This is a crude test that gives an idea of the relative stiffness between instruments – measured resting on their feet to include deflections of both the top and the box as a whole, and on a block to measure the top deflection only.

The results for this dulcimer showed that it was already somewhat stiffer than others I have tested this way.

A carbon fiber bar was then glued to each side of the fretboard as shown in Figure 7.11.

Figure 7.11. Test dulcimer with carbon fiber bars

Deflection measurements showed that the carbon fiber bars didn't change the stiffness; i.e., the fretboard/box combination was already so stiff that additional fretboard stiffening was not measurable.

The before-carbon-fiber and after-carbon-fiber bridge tap resonances are shown in Figures 7.12 and 7.13.

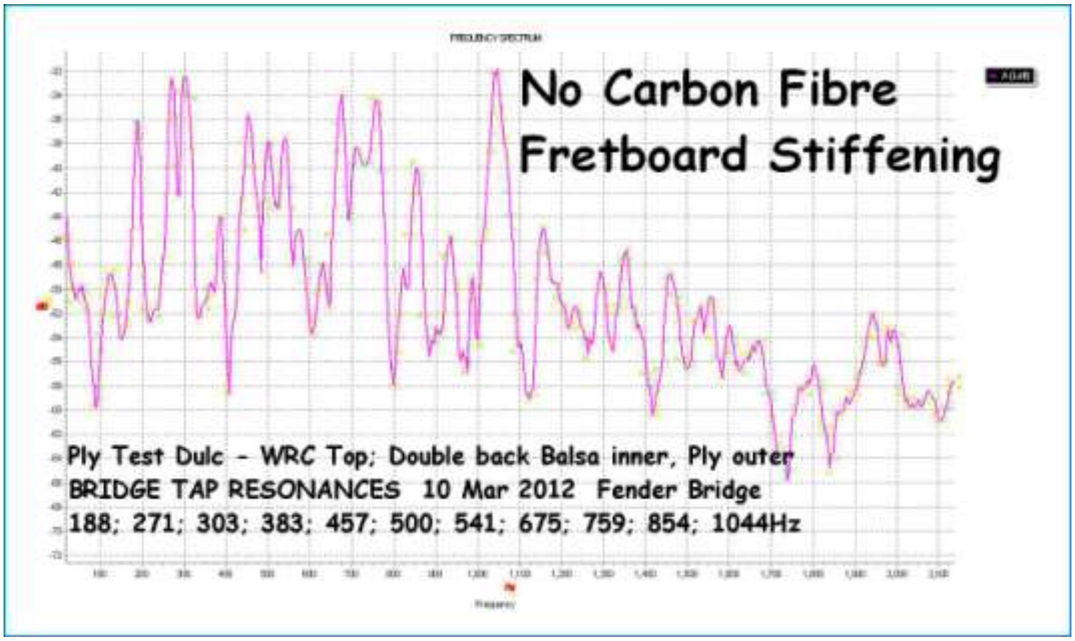


Figure 7.12. Bridge tap resonance without carbon fiber

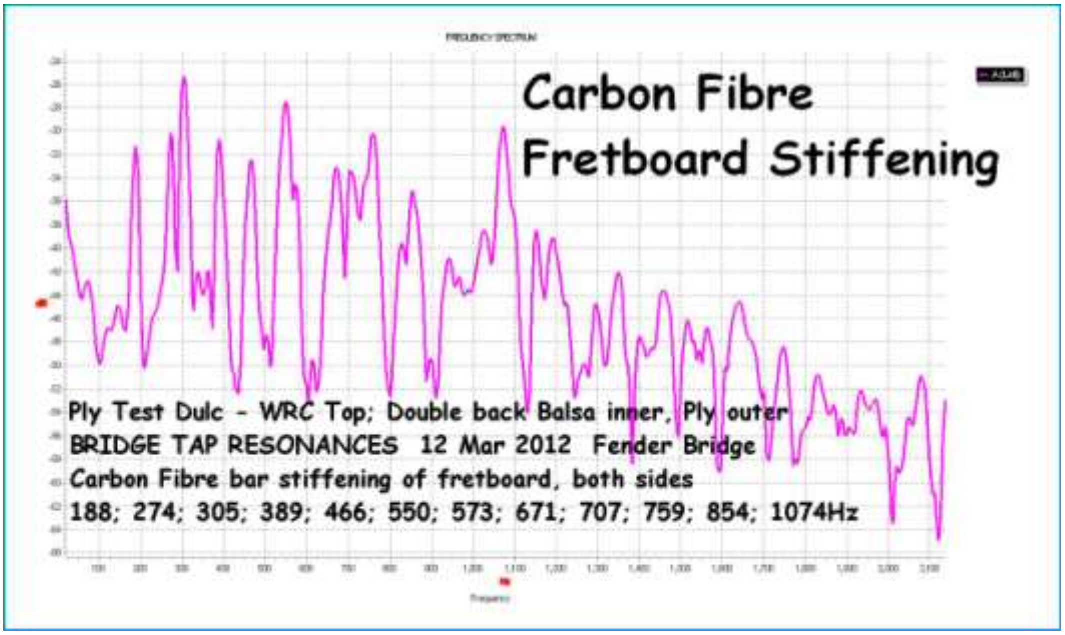


Figure 7.13. Bridge tap resonance s with carbon fiber stiffening

The only place where there is much difference is around 500Hz where a resonance has moved up 3 semitones to merge with one already there. The lower air and box-bar resonances are not changed in frequency, but may have reduced somewhat in strength.

The dulcimer sounded a little “thinner” with the addition of the carbon fibre – it was definitely not an improvement to my mind.

Popping the bars off the fretboard returned the instrument to its pre-bar state of sound and tap resonance.

Overall there seemed no advantage in additionally stiffening an already stiff full-length fretboard. I don't know if there might be an advantage in shorter fretboards.

At the risk of subjecting my test dulcimer to one experiment too many, after the carbon fibre exercise, I sawed the fretboard off to reduce its height above the top-plate by half (Figure 7.14).

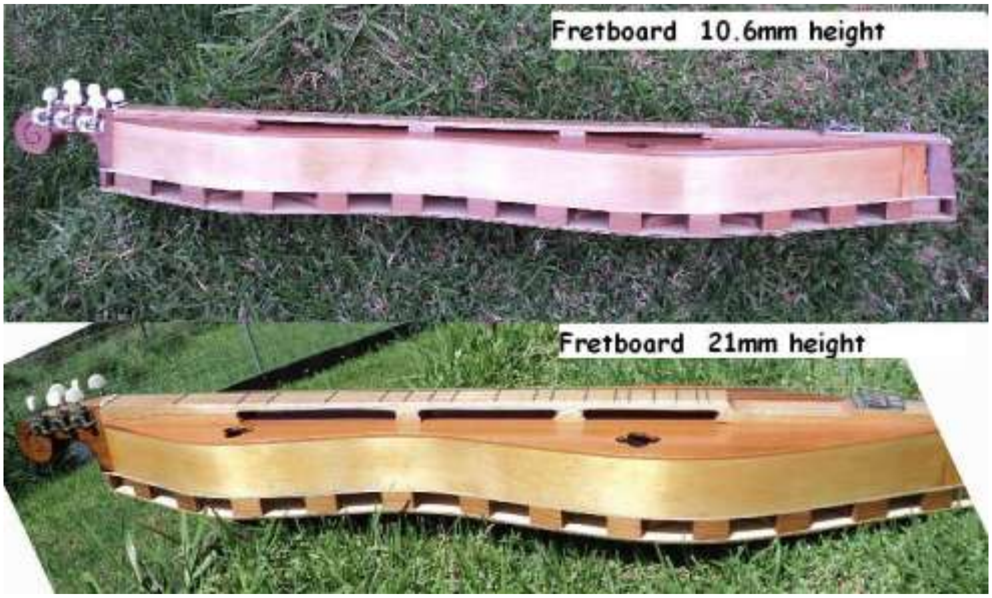


Figure 7.14. Fretboard heights

A bit of smoothing and gluing and the fretboard went from 21mm high to 10.6mm high.

The deflection of the top doubled with the lower fretboard (stiffness reduced by about 50%) and the bridge tap resonances changed substantially as shown in Figures 7.15 and 7.16.

There are resonance frequency changes all over the spectrum compared with the original height fretboard.

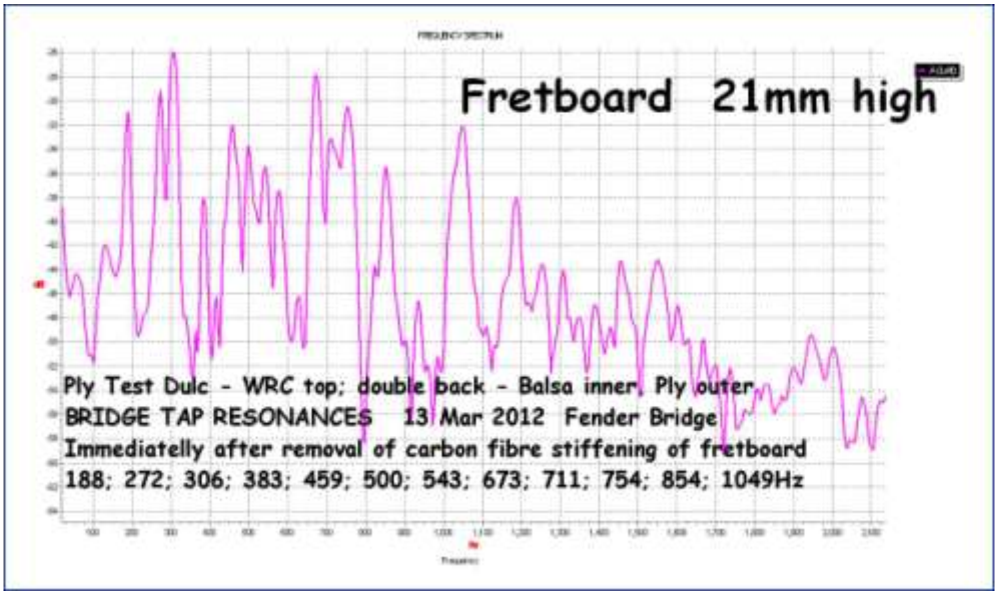


Figure 7.15. Tap resonances for 21mm high fretboard

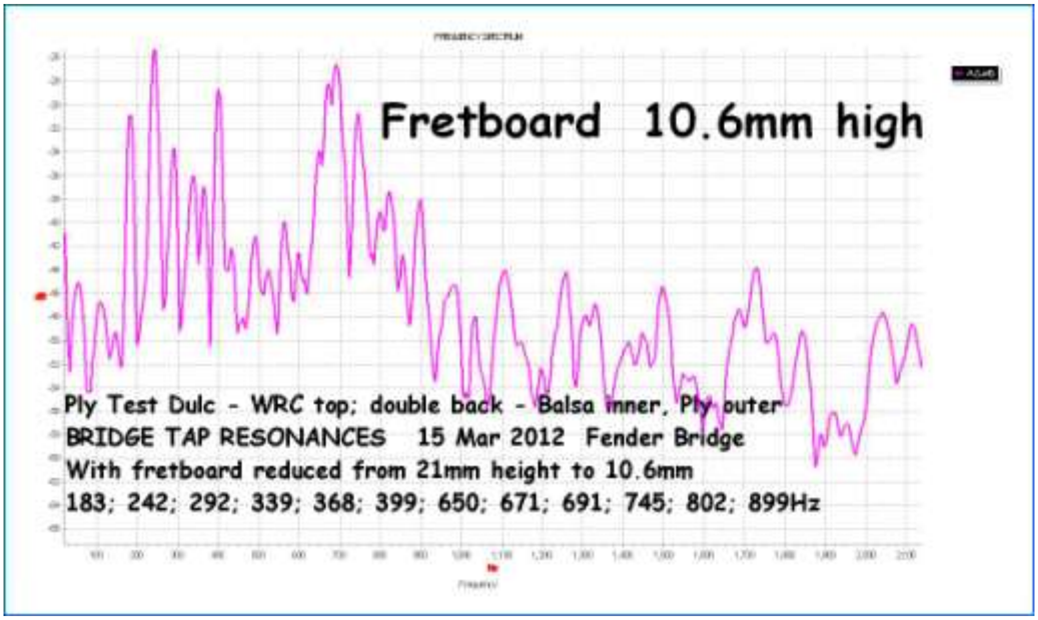


Figure 7.16. Tap resonances for 10.6 mm high fretboard

The sound was also changed considerably, but still not for the better. It was loud and brash, but still sounded “hollow”, and sustain was greatly reduced above the 3rd fret.

So, the message might be that neither an excessively stiff fretboard, nor a too flexible one is a desirable goal. But one that is “just right”. The next step will be to replace the whole fretboard with a new one in a different timber.

Effect of Frets and Fret Slots on the Basic Stiffness of a Fretboard- May 08, 2012

I've wondered, from time to time, if cutting fret slots in a fretboard materially changed the stiffness, and whether the stiffness is restored after installing the frets. I did a simple experiment to see.

Method

The deflection of a simple dulcimer fretboard-shaped medium density beam was measured at several deflecting loads; 21 chromatic fret slots were then cut in the beam on a 25.5" scale and deflection measured again. Frets were installed and deflection re-measured (Figures 7.17 and 7.18).

The frets were then removed, the beam planed down and a high density, but thin, overlay glued on and trimmed to same height as plain beam. The deflection of the overlaid beam was measured, then fret slots cut again, measured, and frets reinstalled, and measured for deflection.

Figure 7.17. Fretboard deflection measurement with fret cuts

Figure 7.18. Fretboard with frets added

Results

Fretboard deflection measurements were plotted and are shown in Figure 7.19. the measurements are shown in Table 7.3

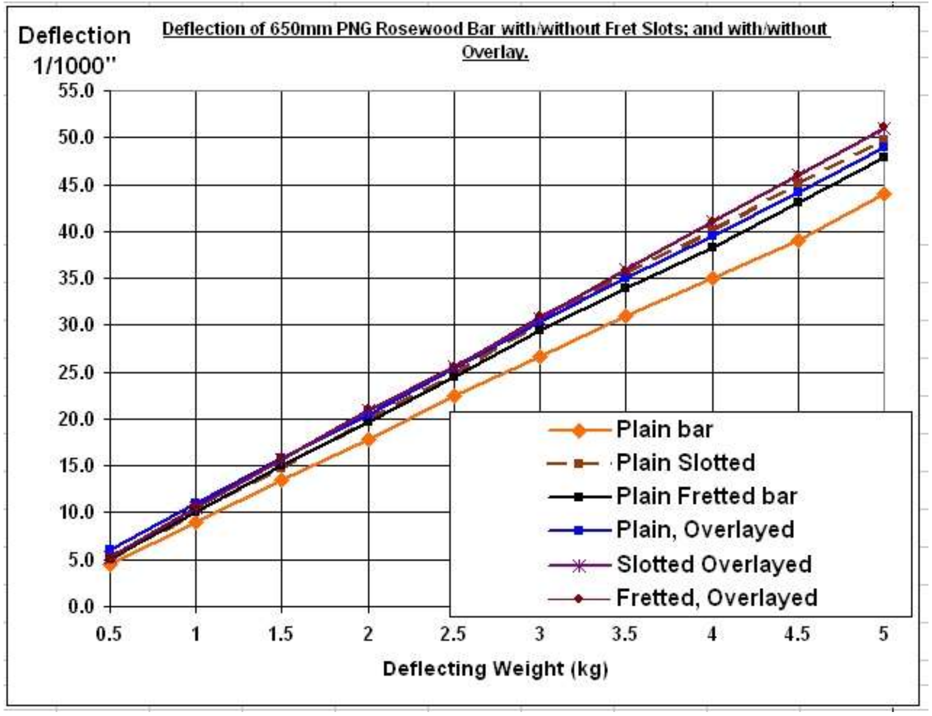
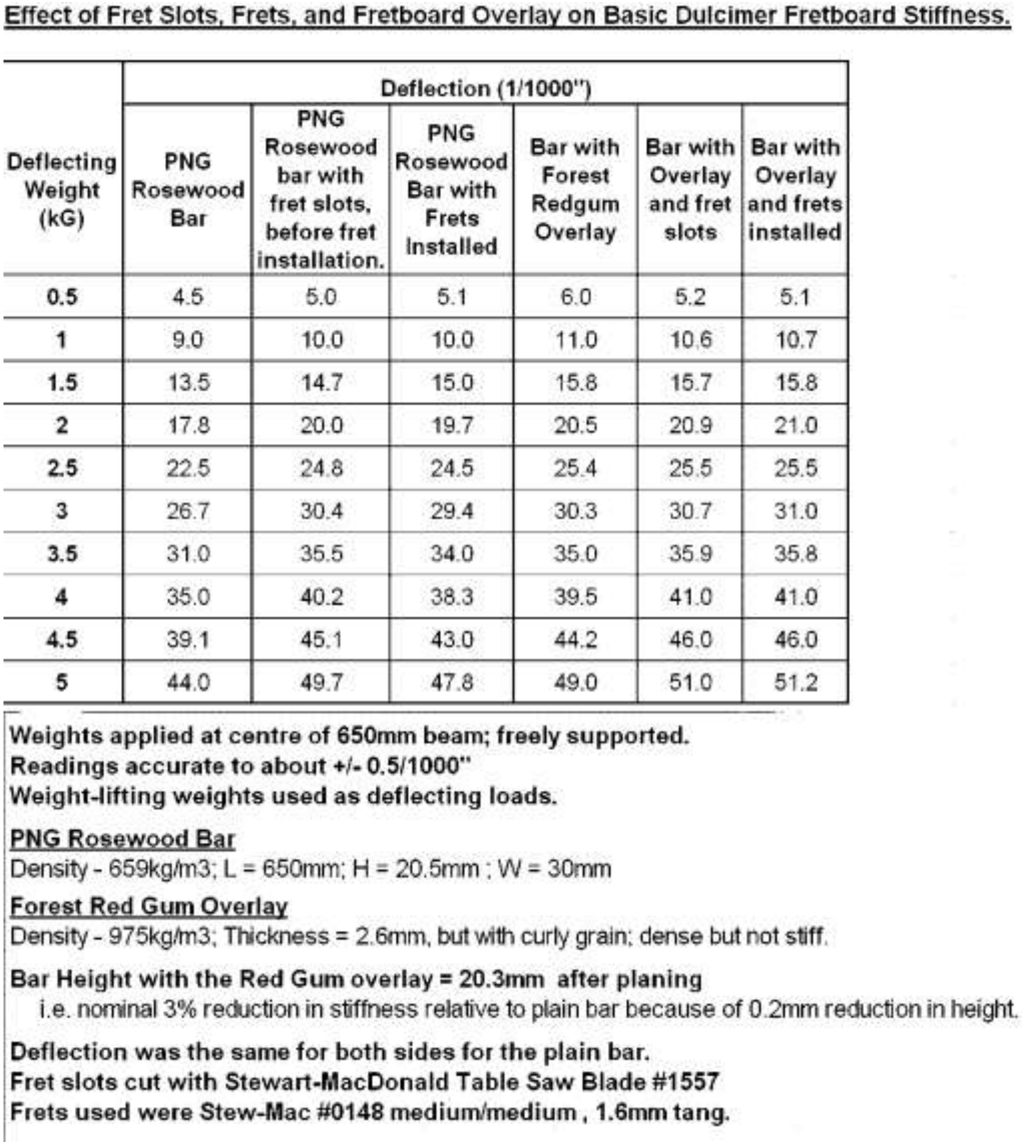


Figure 7.19. Fretboard deflection vs. load

Table 7.3
Fretboard Deflection Measurements



Effect of Fret Slots, Frets, and Fretboard Overlay on Basic Dulcimer Fretboard Stiffness.

Deflecting Weight (kG)	Deflection (1/1000")					
	PNG Rosewood Bar	PNG Rosewood bar with fret slots, before fret installation.	PNG Rosewood Bar with Frets Installed	Bar with Forest Redgum Overlay	Bar with Overlay and fret slots	Bar with Overlay and frets installed
0.5	4.5	5.0	5.1	6.0	5.2	5.1
1	9.0	10.0	10.0	11.0	10.6	10.7
1.5	13.5	14.7	15.0	15.8	15.7	15.8
2	17.8	20.0	19.7	20.5	20.9	21.0
2.5	22.5	24.8	24.5	25.4	25.5	25.5
3	26.7	30.4	29.4	30.3	30.7	31.0
3.5	31.0	35.5	34.0	35.0	35.9	35.8
4	35.0	40.2	38.3	39.5	41.0	41.0
4.5	39.1	45.1	43.0	44.2	46.0	46.0
5	44.0	49.7	47.8	49.0	51.0	51.2

Weights applied at centre of 650mm beam; freely supported.
Readings accurate to about +/- 0.5/1000"
Weight-lifting weights used as deflecting loads.

PNG Rosewood Bar
Density - 659kg/m3; L = 650mm; H = 20.5mm ; W = 30mm

Forest Red Gum Overlay
Density - 975kg/m3; Thickness = 2.6mm, but with curly grain; dense but not stiff.

Bar Height with the Red Gum overlay = 20.3mm after planing
i.e. nominal 3% reduction in stiffness relative to plain bar because of 0.2mm reduction in height.

Deflection was the same for both sides for the plain bar.
Fret slots cut with Stewart-MacDonald Table Saw Blade #1557
Frets used were Stew-Mac #0148 medium/medium , 1.6mm tang.

Conclusions

Fretboard stiffness conclusions are as follows:

- if the fret slots are cut into low/medium density wood, it looks like there could be about 5% - 10% decrease in stiffness over the plain bar,
- installing frets in the medium density wood only restored stiffness marginally, and

- cutting fret slots in high density wood reduced stiffness by less than 5%, and installing frets did not change the stiffness.

In a diatonic fretboard the changes in stiffness would probably be even smaller because the fret slots are farther apart on average.

So, overall, for a typical mountain dulcimer fretboard, cutting fret slots does alter the stiffness a little, but installing frets does not seem to restore the stiffness. If you are actually measuring or calculating fretboard stiffness as part of your building process, then the slotted or fretted unit should be used rather than the plain bar. The shape of the strum hollow will also affect local stiffness.

Chapter 8
Fretboard Effects

Fretboard vs Top Stiffness-Apr 07, 2009

It is suggested that the stiffness of the fretboard will always dominate the stiffness of the top plate to the extent that the top plate parameters of material and thickness are not very important, and further, that the fretboard stiffness is a significant contributor to the whole dulcimer behaving as a bar resonator.

However, three recently finished dulcimers have caused me to modify the thinking about bar vibrations somewhat, but not the basic conclusions. I've made more measurements on these three instruments than I usually do, and whilst they are not controlled experiments as such, I've learned a few things.

But firstly, I should say to any beginning makers who might be reading, or experienced ones for that matter – don't view this as "The Way Forward" in mountain dulcimer making. I can't say yet that it has helped me make better instruments at all – not the least because we don't know, and probably can't agree, what "better" means. And good players can make silk purses out of sows' ears.

It's also important to note that the following material relates to four hole hourglass dulcimers with a full-length fretboard. It may or may not apply to other configurations.

The Dulcimers – Construction

All three dulcimers share the same outline shape, but one has sides just under 2.5" high and medium density end blocks and a hollow fretboard; the other two have sides just under 2" high, with highly arched fretboards and end blocks of quite high density (sinks in water in one case).

The woods used are different for the three, but the internal bracing pattern is the same for all as shown in Figure 8.1.

Figure 8.1. Dulcimer bracing pattern

The top bracing is fairly light and doesn’t reach to the sides. However, in the two arched-fretboard instruments, the second and fourth top braces are very stiff laminated spruce and are glued firmly to the side linings. This is to reduce possible twisting instability in the fretboards because they are so flexible. The back bracing is quite stiff and made of triple laminated material - offcuts from the back plate.

The placement of the braces is at 0.22L;, 0.35L, and 0.5L from the ends — where L is the total dulcimer length including the headstock. These are nodal points for the first, second and third plain bar resonances; the idea being to maximize the cross stiffness of the back and top whilst minimizing the effects on longitudinal bar vibration.

Two instruments have wooden inserts in the sound holes and this reduces the total sound hole area to about 50% of the hearts sound holes of 4.5 sq. in. This had the effect of lowering the first air resonance of the box by about three semitones in those two instruments.

Due to bad planning, the two arched fretboards had arches higher than I would normally do. The thickness at the arch centers is only about ¼”, consequently they were very flexible in the vertical direction (Figure 8.2). Figure 8.3 shows pictures of the fretboards of the three:

Figure 8.2. Arched fretboard

Figure 8.3. Three fretboards

Internal box volume was 255 cu.in and 269 cu.in (arched) and 334 cu.in. (hollow fretboard). Total weights were 3 lb, 2.7 lb, and 2.5lb. Of this, the machine tuners contributed .45 lb. They all are quite heavy instruments.

Dulcimer Sound

All three instruments were loud, technically more than 1.5 times as loud as the instrument I play myself, and which people tell me is a loud one.

The two arched fretboard instruments have a particularly woody/bassy sound, and surprisingly the largest (by about 30%) has the most balanced sound between treble and bass – so that says something.

The two arched fretboard instruments also had wolf notes – the first within a semitone of both first and second air resonances, and the second within a semitone of the first box resonance. I don’t know for certain the origin of wolf notes in mountain dulcimers, but an experiment in progressively filling up a dulcimer with marbles, and watching the first air resonance predictably change but not affect the wolf note, leads me to suspect that they are not related to air resonances (i.e., box volume and sound hole size). Also, I have been able to reduce wolf notes by inserting brass slugs at points along the fretboard. This leads me to think that dulcimer wolf notes are mainly related to the fretboard and its mass distribution. The wolf notes are definitely frequency related and not fretboard position related; i.e., if you retune, the wolf note moves to a different position on the fretboard.

Stiffness of Component Parts and Overall Stiffness

My contention has been that stiffness plays a big part in modulating the sound in mountain dulcimers. For these three instruments, I measured the stiffness of:

- the unshaped fretboard
- the completed fretboard mounted on the top plate (with braces and sound holes), and
- the completed instrument.

I didn’t measure the stiffness of the top or back plates or the shaped arched fretboards because they would have snapped under the 17lb weight over the 31inch distance.

As a practical indicator of actual stiffness, I just measured the deflection under the weight and length rather than the Modulus of Elasticity (MOE) or MOE/density. Deflections are shown in Table 8.1.

So even with fretboards arched to the point of being almost floppy, when glued to the top plate the stiffness is of the same order of magnitude as the unshaped fretboard of the same dimensions. The top plate dimensions have clearly not increased the overall stiffness to any obvious degree. Therefore, rather than the stiffness of the shaped fretboard being the critical parameter, the combined stiffness of the fretboard and top glued together is probably the more relevant.

The shaped arched fretboards seemed to be about as stiff as the cut out top plates, maybe a little stiffer, but I didn’t measure them accurately.

The stiffness of the completed boxes is clearly about ten times greater than the top/fretboard, the hollow fretboard dulcimer, with the tallest sides, being the stiffest even though the fretboard itself was the least stiff.

Table 8.1
Fretboard Deflections

Dulcimer	Unshaped Fretboard	Completed Top/Fretboard	Completed Dulcimer
Dulcimer 43*	127/1000"	106/1000" (more stiff)	12/1000"
Dulcimer 44**	65/1000"	79/1000" (less stiff)	11/1000"
Dulcimer 45***	142/1000"	60/1000" (more stiff)	10/1000"

* See Figure 8.3, middle; Figure 8.2
** Figure 8.3, closest
*** Figure 8.3, farthest

Therefore, it seems that side height not only increases box capacity (cu. in.) tending to lower frequencies and a warmer sound, but also raises box stiffness, which might favour the higher frequencies and make for a brighter sound, which seems to have happened with this instrument, being the brightest of the three.

Box and Air Resonances

Like all resonant systems, musical instruments have frequencies that they like to vibrate at (the natural resonances), and frequencies they are forced to vibrate at (the notes of the strings the player plucks). The natural resonances of the instrument selectively enhance or diminish the notes played, including the overtones, and give the instrument its character.

For these three dulcimers I’ve measured the natural resonances of the box, and the air enclosed, by tapping with a rubber hammer, and sweeping frequencies with a small loudspeaker and analyzing the sound produced; also, the instruments’ response to playing a two octave scale (tuned to D147, A220, Bb233) — two occurrences of each note, about 50 sec recording.

I’ve noticed some things about measuring wood resonances:

1. They don’t vary in frequency with where you hold the instrument (no surprise), but the relative amplitudes change.
2. The same resonances are recorded with the microphone at the front, back or side of the dulcimer – individual resonance amplitudes vary though.
3. There are no differences in frequency or amplitude whether the instrument is strung

to tension or not.

4. The bandwidths of the resonances are less than a semitone — relevant if attempts are ever made to tune them to specific frequencies; e.g., to moderate wolf notes.

Figure 8.4 shows the frequency spectra of the three dulcimers (plus one other). These are the averaged Fourier spectra of the sound made by tapping on the bridge of the instrument (strings damped), and indicates the natural resonant frequencies at which the dulcimer box vibrates most efficiently.

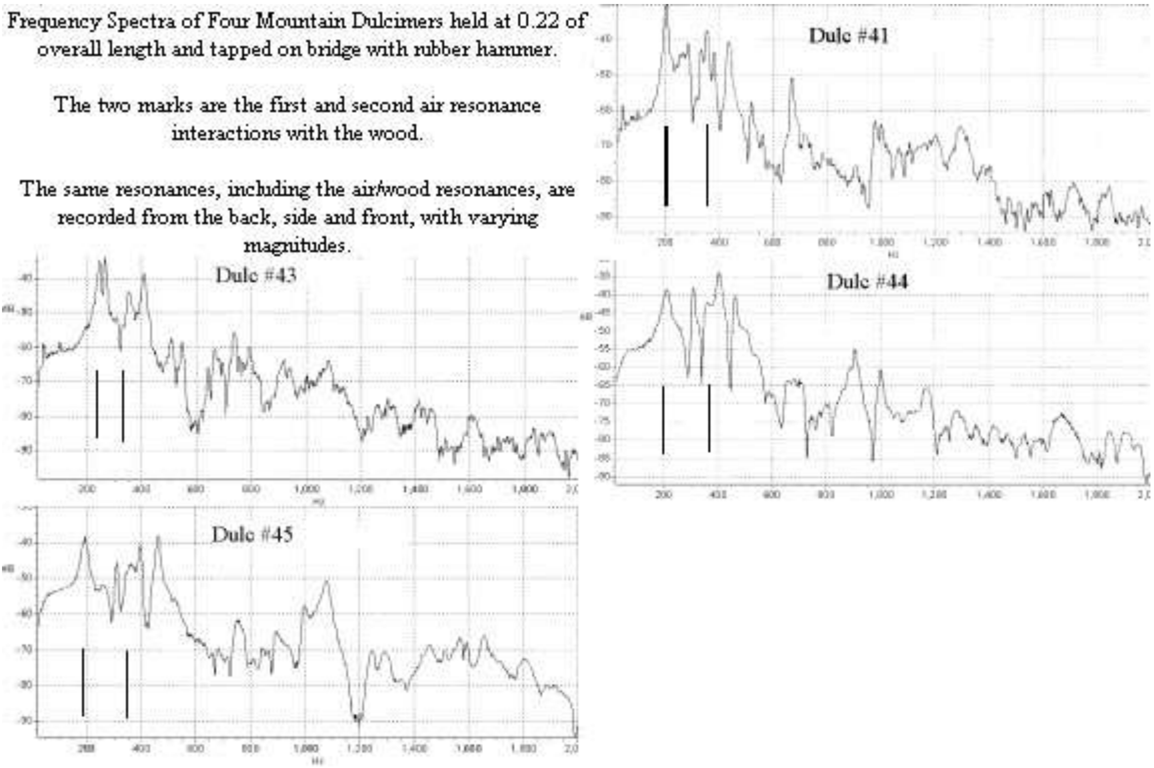


Figure 8.4. Bridge tap frequency spectra for four dulcimers - showing the intrinsic resonant characteristics of the boxes

The first resonant peak is always at the frequency of the lowest air resonance – somewhere between 180 and 250Hz in my dulcimers. Terry Hennessy's[10] are sometimes lower. Then there is one, sometimes two, wood resonances, followed by a peak at the frequency of the second air resonance. After that I haven't identified the source of higher resonances. It's interesting to note that the peaks at the air resonance frequencies are ***wood*** resonances; i.e., the wood is vibrating at that frequency. This

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[10] http://richardandmimi.com/hennessy.html

means that the air is set into vibration by string energy, by a mechanism I don't know, and the air vibration (in the form of pressure changes inside the box) in turn sets the wood vibrating at the same frequency. Hence air resonance sound energy comes both from vibration of the wood, and as energy radiated from the sound holes, analogous to blowing across the top of a bottle. In other words, the air resonances are "coupled" with the wood – at least the first two, which I can identify reliably.

In a full-fretboard, four hole, hourglass dulcimer the first air resonance (Helmholtz in a really stiff instrument) can be found by blowing across the lower bout sound hole with a drinking straw. For reasons I don't know, the second air resonance can be found by blowing across one of the upper bout holes. The frequency of the first air resonance is dependent upon the box cubic capacity and the size, and to some extent the placement, of the sound holes. It's the only parameter that I can accurately predict before a dulcimer is made. The second air resonance doesn't seem to be dependent on the size of the box or sound holes.

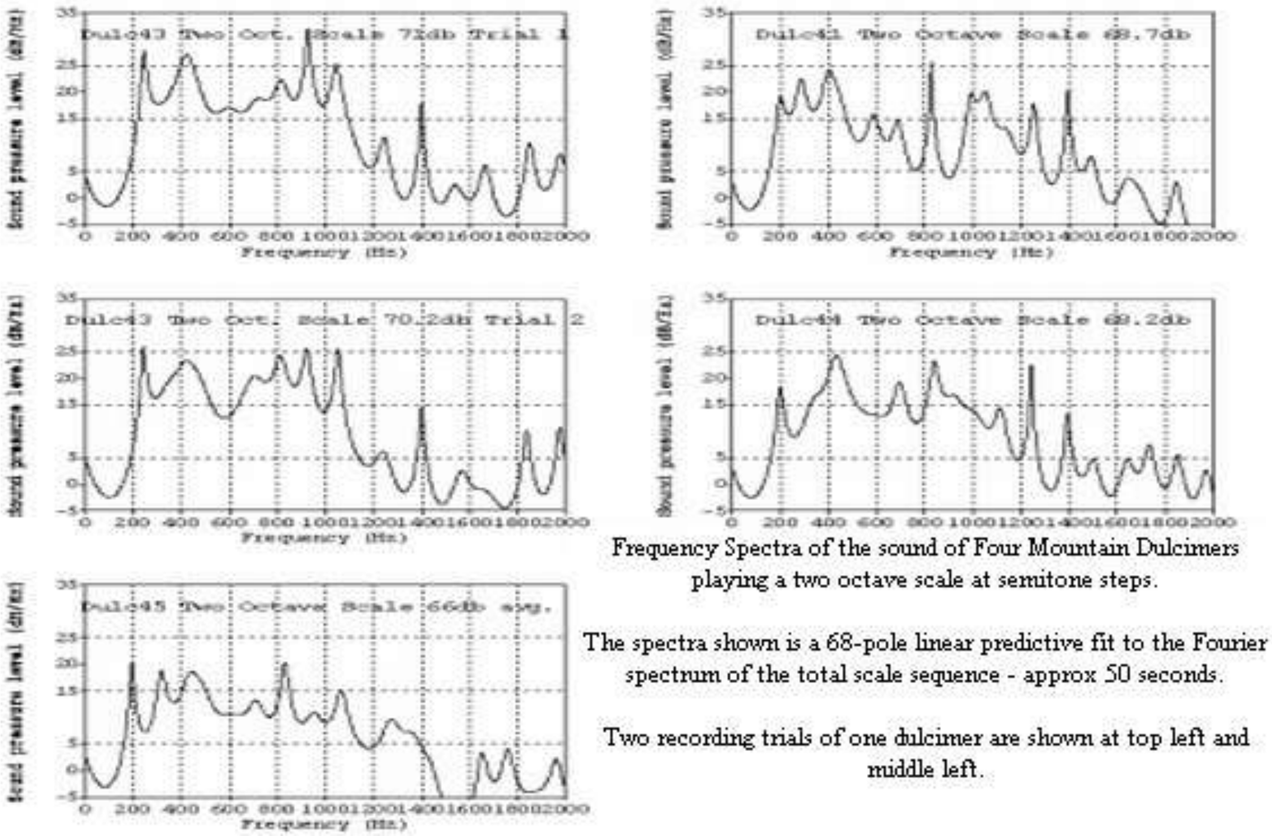
The resonance between the first and second air peaks is the first bar resonance of the instrument as a whole. This is where my proposition of the dulcimer as a vibrating bar starts to break down – and it's no surprise that things turn out more complex than we'd like.

It does appear that the second resonant peak is a bar resonance. But none of the subsequent peaks occur at frequencies predicted by a standard bar model. This could mean a couple of things.

1. Mountain dulcimers act as a bar for the first mode of vibration — two bar nodes for the whole box, and the remaining resonances are local to certain areas of the dulcimer plates.
2. Dulcimers act as bars in higher vibration modes, but not a standard bar model.

There is also the possibility that bar vibrations in dulcimers occur from side to side as well as up and down. After some measurement confusion I've noticed that this routinely happens in the fretboard blanks if they are not struck exactly vertically to the face of the bar. Bar resonances are very predictable in the fretboard blanks, and follow the standard F1; 2.76 F1; 5.44 F1 sequence of frequencies. Since we don't require players to strike the strings exactly vertically, there may be lateral box bar vibrations. I haven't confirmed this.

Figure 8.5 shows the smoothed spectra of the sound of the dulcimers playing a two-octave scale, including all semi-tones. This maximizes the chance of some note or harmonic falling on all of the natural resonances of the dulcimer box. In this case, the strings are forcing the box to vibrate at ***their*** frequencies, rather than the frequencies the box "likes" to vibrate at, and in an ideal world the two-octave scale spectra should look much like the tap spectra shown in Figure 8.4 above. There does seem to be a family resemblance between the two sets of spectra, but detailed conclusion should not be drawn."



Frequency Spectra of the sound of Four Mountain Dulcimers playing a two octave scale at semitone steps.

The spectra shown is a 68-pole linear predictive fit to the Fourier spectrum of the total scale sequence - approx 50 seconds.

Two recording trials of one dulcimer are shown at top left and middle left.

Figure 8.5. Smoothed frequency spectra of two octave scales played on four dulcimers (one dulcimer shows two trials)

Contribution of Machine Tuner Weight

I was interested to see if the weight of the machine tuners made a difference to anything. The short answer is that they do. The effect is on the first wood resonance, the second peak in the tap spectra above.

The tuners used were Gotoh Mini sealed units. Six of them weigh 200gms, which represented about 15% of the total instrument weight. Adding them one at a time and measuring the tap resonances showed that the first wood resonance was lowered by about 1 ½ semitones from no tuners to six tuners. This makes sense in terms of the whole instrument vibrating as a bar.

The differences were:

- 3 tuners - 0.95 semitones lower than no tuners, for 1st wood resonance’
- 4 tuners - 1.1 semitones lower,
- 5 tuners - 1.2 semitones lowe, and
- 6 tuners - 1.25 semitones lower.

No other resonances, wood or air, were affected by the weight of the machine tuners.

Effect on Sound by Various Parts of the Frequency Spectrum

The first two air resonances, and the first box bar resonance fall below about 400Hz. I was interested to see if they affected the sound very much, and it may be that they do.

The effect on the sound of specific parts of the frequency spectrum can be assessed by making a recording of the instrument and filtering out, or amplifying selected frequency ranges of the total spectrum. The tune is then reconstructed from the modified spectrum and listening assessments made. I have used the PRAAT software package to do this.

It seems that whilst the tune can’t be clearly recognized by the 0 to 400Hz section of the spectrum, that part contributes greatly to the warmth and presence of the sound. Between 400 and 2000Hz, most of the melody and power is occurring, and above 2000 Hz there is a thin tinkling, which we could probably do without if we really had to.

Summary

The first two air resonances and the first bar resonance fall in a frequency region that is important to the quality of the sound. So, can we:

1. Control them so that we know where they will fall prior to construction? In the case of the first air resonance, yes. Second air resonance and first bar resonance? I don’t know.
2. Can we alter their frequencies after construction? First air – yes, by enlarging or reducing sound holes. Second air and first bar? I don’t know.
3. Can we tune them to be between notes to moderate non-fretboard wolf notes — maybe one day (but then you would have to stay in tune of course).
4. Do we know what it “should” sound like – No.

One thing is clear to me. None of the resonances of individual components of the instruments (fretboards, tops, back and sides, all of which I measured separately) were carried over into the completed instrument. Therefore, trying to tune individual parts prior to assembly may be of little value in a mountain dulcimer.

Effect of Re-shaping the Fretboard of an Existing Dulcimer- Aug 27, 2010

It's not often that I've made a change in an instrument that clearly resulted in a dramatic change in the sound. Often it is even difficult to tell whether there has been a sound change at all. But here is a case where there was certainly a very significant change.

The test dulcimer I've been experimenting with has had its top and back changed, bracing removed and added. Replacing the ply back and top with solid wood improved things a little, but nothing dramatic. The only things unchanged in the instrument are the sides, the end blocks, and the fretboard.

In this experiment, I cut back the fret board from what is shown in Figure 8.6 to that in Figure 8.7, whilst the strings were still strung to tension.

The original fretboard had three arches, but the clearance from the top plate was only about 1mm. This modification raised the bottom of each arch to about 12mm above the top plate (the height of the fretboard remained unchanged). The result was a reduction in mass, compared to the original shape, of 35% (and with no change in action or tuning).

Figure 8.6. Test dulcimer with original fretboard with low arches

Figure 8.7. Test dulcimer with fretboard modified to make arches higher.

Since I couldn't directly measure the change in stiffness of the new fretboard shape on the dulcimer, I did some tests on the bar in the picture above. This was a twin of the fretboard used on the dulcimer. The result of that testing indicated that whilst mass was reduced, stiffness, as measured by deflection, reduced even more (even though the slots were boxed in). Reduction in mass would tend to emphasize higher frequencies, whilst reduction in stiffness tends to emphasize lower frequencies. Stiffness wins out in this case and the result of cutting back the fretboard might indicate a tonal shift towards the lower frequencies – a general response increase below, say, 400Hz, for the dulcimer.

What actually happened is shown in Figures 8.8 and 8.9.

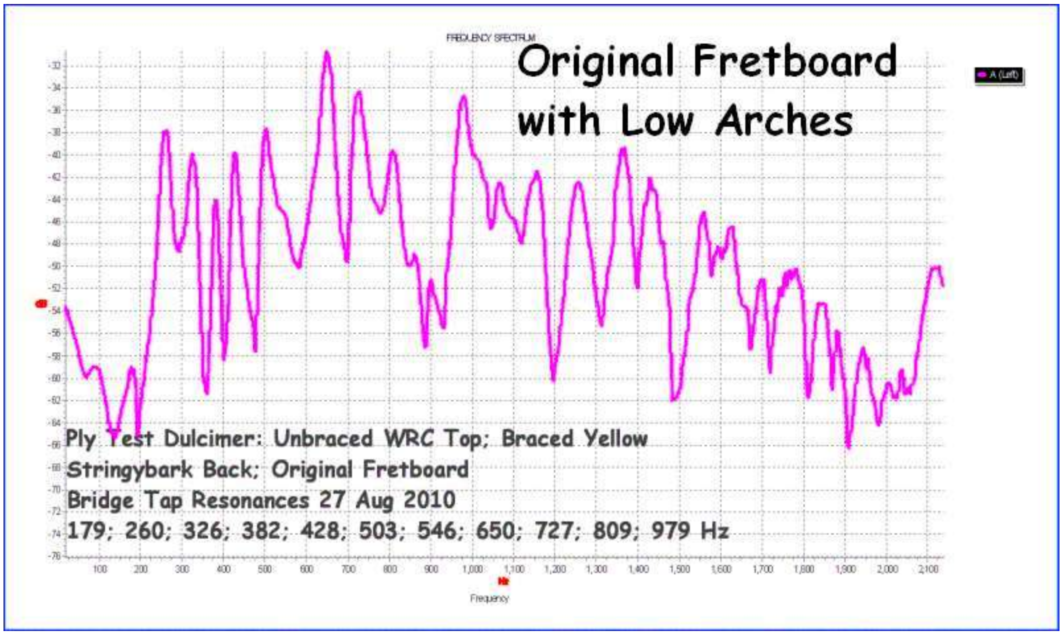


Figure 8.8. Bridge tap resonances for original fretboard with low arches

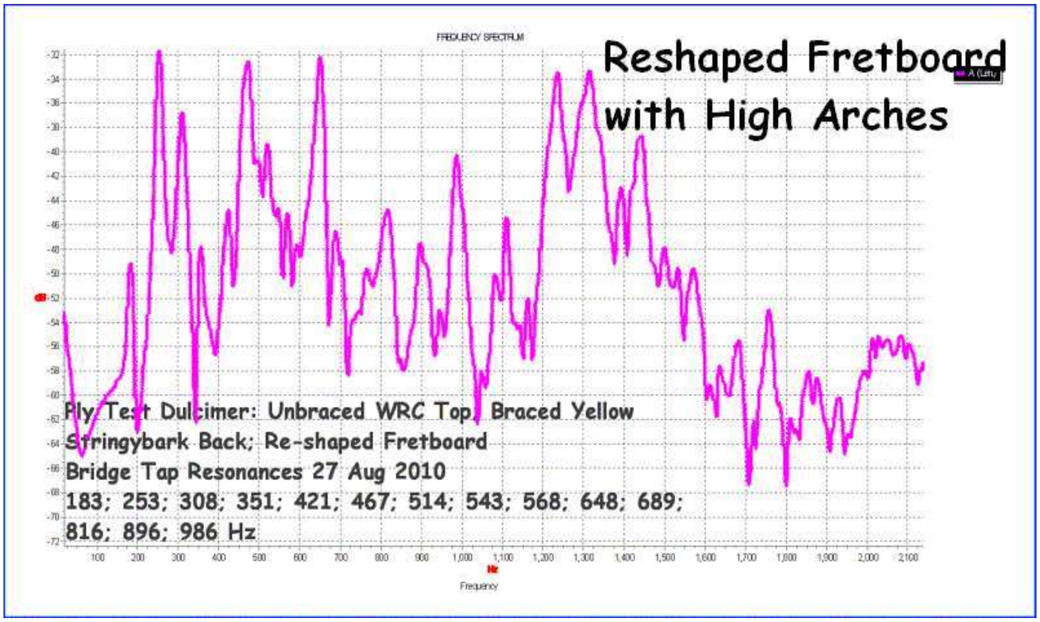


Figure 8.9. Bridge tap resonances for modified fretboard with high arches

The scale on the x-axis is 0 to 2100Hz; the y-axis is deciBels. The lowest resonance (1st Air, 179Hz) and another two at about 250Hz and 650Hz have increased substantially in amplitude. But in addition, there was a large increase between 1200Hz and 1400Hz. This region wasn’t so prominent in any of the other configurations of this dulcimer and must be a result of thinning the fretboard, as is the increased amplitude of several lower resonances. So both lower and higher frequencies were enhanced.

The change in sound was dramatic. It went from a softish thin sound, but with a pleasant resonant bass, to a very loud sound with ringing trebles, that I like, and a strong middle string. But, of course, there's no free lunch – the bass lost a bit of resonance (but was still solid), and overall sustain was marginally reduced, but not unacceptably. Another consequence was the introduction of a mild wolf note. However the new sound, with the thinner, higher, less massive and less stiff arches, is a huge improvement over the original.

It is important to note that the change in sound can't be related to increased area of top plate vibration, because the original fretboard had 1mm high arches in the same places as the new higher ones.

So, major changes to the top (new top plate, different wood, different bracing) only resulted in minor changes to the sound.

Major changes to the back (new wood, different bracing) only resulted in minor changes to the sound.

Major changes to the fretboard resulted in dramatic change to the sound.

It's clear that fretboards are worthy of examination when talking about what makes a mountain dulcimer sound the way it does. I have the feeling that making a fretboard too light and flexible heads in the direction of very loud, but brash; too heavy and stiff towards soft and thin. The right balance between weight and stiffness, for a desired sound, is probably what comes with dulcimers-under-the-belt experience.

Some people might say that these conclusions about fretboards are self evident – but they aren't to me. Even a heavy fretboard coupled to a light box only makes up about 30% of the total weight. And the box itself is an order of magnitude stiffer than the fretboard. So on the face of it, changes to box mass and stiffness might seem more likely candidates to greatly modify the sound – but they don't.

A quick addition to the previous posting regards changes in fretboard mass and stiffness with shaping. I hadn't actually previously measured these changes in a channeled (hollow) fretboard and so I did it on two bars of the same species and billet – as identical as they can be. One is channeled as shown in Figure 8.10 and the other is solid.

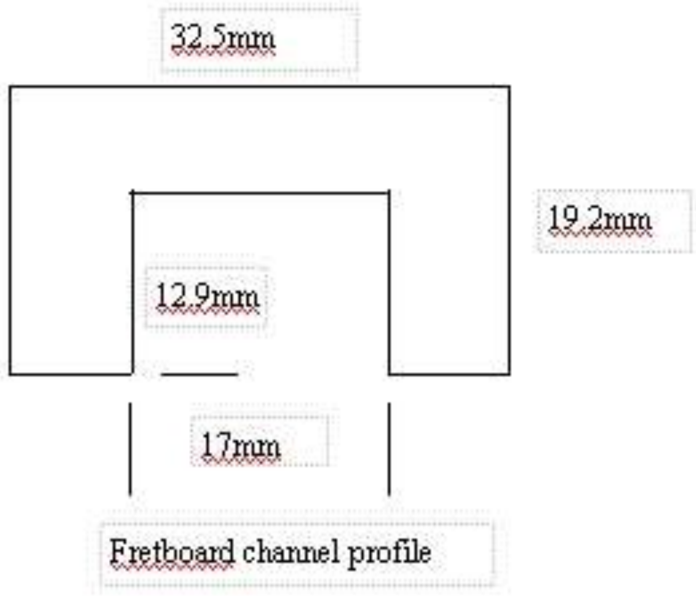


Figure 8.10. Channel dimensions

The change in weight and stiffness of the channeled bar relative to the solid bar is shown in Table 8.2.

Table 8.2
Effect of Fretboard Channel

Measure	Solid	Channeled	% Change
Deflection (stiffness) (under a standard weight)	26/1000"	36/1000"	-38%
Relative weight	1	0.65	-35%

It seems that in a practical sense, channeling reduces stiffness at least as much as it reduces weight, and maybe a little more. The changes in these two parameters have opposing effects on frequency emphasis – reduction in mass would tend to emphasise the higher frequencies; reduction in stiffness (increase in flexibility) would tend to emphasise the lower frequencies.

Fretboard Thoughts-August 29th 2010

When I started up making dulcimers, I tracked down and corresponded with Al Carruth[11] and Jerry Rockwell[12]. Knowing nothing, I asked about many things, including fretboard design - woods, arches, hollowed, etc. The "what's best" question. They both said something about fretboards which I didn't assimilate at the time, but has now come full circle, at least in my mind. Al Carruth said that he would have moveable blocks as the feet for an arched fretboard, and move them up and down until he found the spots he liked the best, then glue them in place. I didn't pursue that idea because I didn't like the possibility of a fretboard foot not having a supporting brace beneath it - the reason for that reservation being Jerry Rockwell's opposition to arched fretboards on long-term stability grounds. But Jerry also said that whilst he hollowed his fretboards, he didn't make them "way hollow", only sufficiently hollowed. Although not couched in terms of mass and stiffness, both of these comments are consistent with the idea that a correct balance between mass and stiffness of the top/fretboard assembly is a principal shaper of the overall sound of a mountain dulcimer. It has only taken me ten years to believe it.

Regarding the idea that the feet of an arched fretboard constrains the top to vibrate in the same way as the fretboard at those contact points, but not necessarily elsewhere - I think the jury is still out. On the one hand, in my own vibrational studies, I have seen independent vibration of the top plate below fretboard arches, indicating that the fretboard feet are affecting the top vibration locally. But on the other hand, the vast majority of the identifiable vibration modes seem to act as if the feet weren't there at all; i.e., there are the same general modal shapes as a continuous fretboard. Like nearly everything, it is not a matter of either/or — sometimes, and at some frequencies, the feet have a local effect, and at other frequencies they seem transparent. But mostly they seem transparent. This is not to say the feet don't have an effect on tone, but if they do, it's more likely to be subtle than dramatic.

In fact, all of my discussions can only focus on the gross effects on tone. Measurement is not refined enough to tease out subtle tonal content, and we, as listeners, have just as hard a time defining it.

Fretboard Design -Aug 29, 2010

The fretboard in the low/high arched experiment reported earlier in this chapter (**Effect of Re-shaping the Fretboard of an Existing Dulcimer)** was of Yellow Stringybark – a

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[11] alcarruthluthier.com

[12] jcrmusic.com

moderately dense eucalypt. But in the light of this fretboard experiment, and looking back at dulcimers I've made with high and low arches, and reading the notes I've made about their sound, I will be less inclined to make very high or very low arches in the future, for average density woods —half height will be a good compromise. I don't base this on any particular results. Another approach might be — you want loud and brash? Make high arches (and suffer the possible longer term stability problems); silvery and plaintive, make lower arches.

As for feet placement — I don't have any firm idea. I have been placing them at the notional bar mode nodal points, 0.22L, 0.35L; 0.5L, etc. where L is the total length of the dulcimer including the headstock. But, only the 0.22L position has any real validity that I have found. That point is the first bar node of the dulcimer, which clearly occurs in real instruments. Placing a foot and brace there should allow that bar mode to vibrate basically unimpeded by extra mass. Whether that vibration mode contributes to a great sound —only the listener can tell. I like to put a cross brace under each foot for strength, and have three or four arches. I don't know what the acoustic or structural consequences of a multi-foot design might be.

Top vs Fretboard Effect-Nov 01, 2011

I tend to believe that the back and sides do color the dulcimer sound, but I feel (without a lot of proof) that it's mainly the subtleties of tone that are affected, as conferred by different wood species and thickness/mass/stiffness parameters, etc. In my test dulcimer I have changed the back from 1/8" ply to a 3/32" dense eucalypt to 4mm balsa wood to a double balsa/eucalypt back, to a double ply/balsa back, with and without bracing. There were tonal changes, but not substantial. It was only when I greatly modified the fretboard (in situ) that there was a clear and substantial difference in the overall sound. My money is on the fretboard as the part of a (standard) mountain dulcimer that most affects the final sound. But it would be interesting to see the effect of backs of the same species with different thicknesses in two identical dulcimers.

I should also reiterate. When I say that the top plate doesn't contribute a lot to the general tone, I don't mean that it doesn't vibrate vigorously; it does. I mean that the top plate vibrations are governed mainly by the attached fretboard, and it's the combined effect of the two that determines the part of the total sound coming from the top assembly. And the fretboard parameters, (mass, stiffness) not the top plate parameters, that dominate that assembly. Generally, more sound does come from a mountain dulcimer top than from the back, but it’s mostly the fretboard calling the shots, not the top plate itself.

Fretboard Effect on Sound in a Topless Dulcimer-Jan 17, 2016

Technically, a dulcimer with no top does have a top - the fretboard. But in a practical sense, I wonder how much air the fretboard on its own can push around. A guitar neck is also flailng around in a bending motion, but I can't recall hearing that it contributes much to the total sound. The physical size of the neck compared to the soundboard is small.

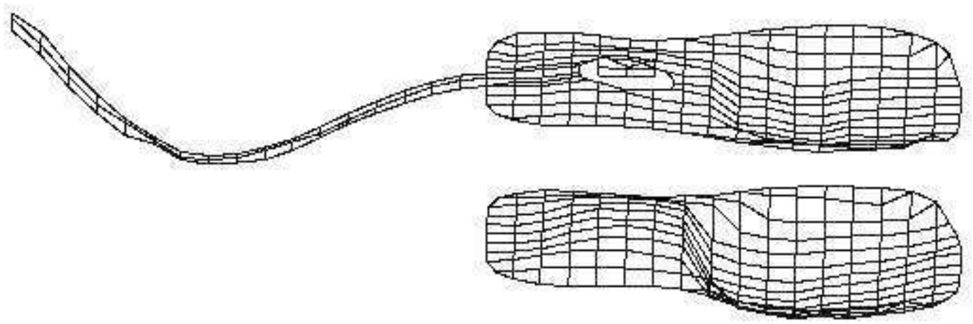

Figure 8.11. Guitar vibration pattern
(Ref. http://paws.kettering.edu/~drussell/guitars/hummingbird_modes.html)

The topless dulcimer in my experiment ***is*** just as loud as when it had a top, in terms of sound pressure level. I had assumed this was because the back was then the new top — it does vibrate strongly. I had also assumed that all the air resonances were lost, because there was no enclosed cavity remaining, but maybe the air resonances have just moved up the spectrum.

I did some quick tests with a small loudspeaker inside the dulcimer body near the nut, and recorded the microphone response inside the body along the length of the instrument. It's not a full mapping of any standing waves, but the frequency spectra give an idea if there's any resonant air activity still going on. The speaker swept in frequency from 100Hz to 2000Hz. Figure 8.12 shows the results.

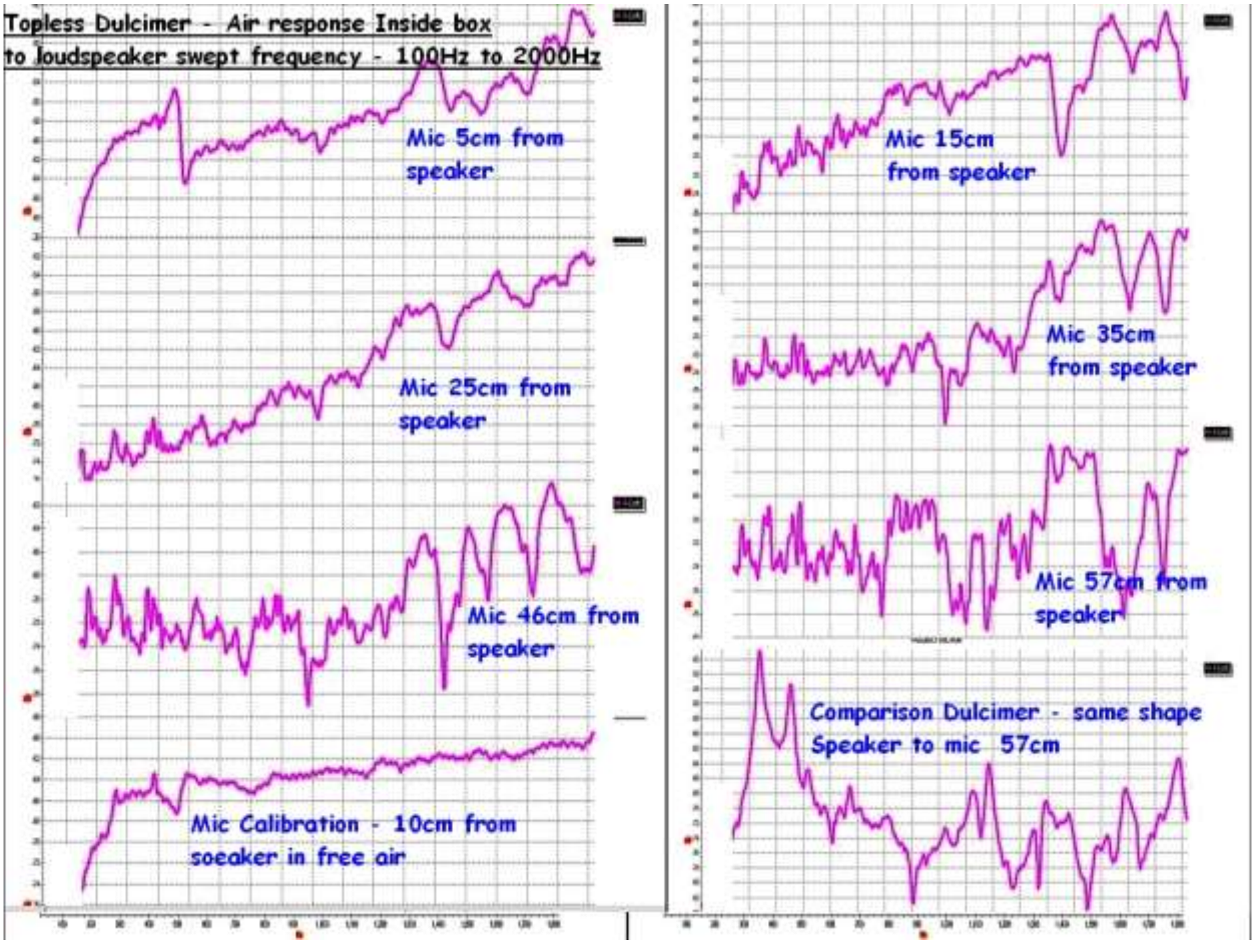

Figure 8.12. Frequency spectra inside dulcimer

The bottom left is the response outside the dulcimer - it's surprisingly flat given the cheap mic and the 1" speaker. The bottom right is another dulcimer of the same pattern, with top intact - speaker at the upper sound hole, mic at a lower sound hole. It's typical of the air responses I normally see. The two main peaks are the first and second air resonances - about 230Hz and 360Hz.

The other panels represent what's going on in the body of the dulcimer with no top, at different distances from the nut. And there's something going on — the spectra were quite repeatable. Between 1000 and 2000Hz there's clearly some variation in SPL at different frequencies. How much of that gets radiated out, I can't say, but it indicates that all air resonance activity is not lost and may contribute to the sound in a topless dulcimer after all.

Effect of Opening a Hollow Fretboard Channel by Removing the Top Plate Wood Beneath the Channel.- Aug 17, 2016

Two baritone dulcimers were constructed, tuned AEA. A problem arises in that the low A-note is 110Hz, the middle E-note is 164Hz, and the high A-note is 220Hz.

A typically normal sized dulcimer can't produce sound much below 200Hz, or at least it does so very poorly. This means that the fundamental harmonic of the low and middle strings won't contribute to the sound, and the fundamental of the melody string (A220) will only just start to contribute. We then rely on the higher harmonic series to carry all the tonal information, without the fundamentals, which might well be perfectly OK and sound good, but we've lost part of the sound.

It would be good to include the contribution of the string fundamentals to the sound if we can, so how might we do it? The problem is to get the dulcimer box to vibrate at a frequency down to 110Hz, or near it. Keeping in mind that the Helmholtz resonance, the lowest air resonance of the box, the "rum jug" tone, is also the lowest resonance of the whole instrument, then three ways to do it spring to mind.

1. Make the dulcimer box very large - as the box size increases, the Helmholtz frequency decreases. I'm not sure how large a box would be necessary, but I can't do it anyway because the wood I am using is already cut to standard dulcimer size.

2. Reduce the size of the sound holes – the smaller the sound holes, the lower the Helmholtz frequency. But even if the holes were really small, I know from experience that it would not get the Helmholtz frequency anywhere near 100Hz. In any case, I'm using wooden rosettes, so the sound hole size is fixed.

3. Make the dulcimer box, and specifically the top plate/fretboard assembly very flexible. The Helmholtz frequency in wooden musical instruments is not strictly the correct term to use because it refers to a totally rigid body. As the box gets more flexible, the "Helmholtz" frequency falls, and is better called the first air resonance. But, a flexible enough dulcimer box to reduce the first air resonance to 110Hz would probably need very thin plates and no internal bracing – easily damaged.

So basically we are frustrated – a standard sized dulcimer, with normal sized sound holes, and normally robust construction won't reproduce the fundamentals of the strings if baritone-tuned.

However, I was interested to see what a token gesture in the flexibility direction might achieve – ***specifically whether opening the hollow channel of the fretboard to the inside of the dulcimer would have any effect on the flexibility and vibrational behavior of the top/fretboard assembly*** – before it is mounted on the sides. It isn't known for mountain dulcimers how the resonances of the free top/fretboard might map onto the assembled instrument, but I suppose it's reasonable to expect that generally lower resonances in the free top will translate to lower resonances in the assembled instrument.

Tests

For the two dulcimer top/fretboards in question I measured :

- static deflection under 7.6kg weight – a measure of flexibility
- spectral analysis of the tap sound using a rubber hammer (tapping the bridge area), and
- weight before and after cutting out the top plate wood below the fretboard channels – as in Figure 8.13.

Figure 8.13. Two Dulcimer Tops with fretboard channels closed then opened.

Results

Resonance effects are shown in Figure 8.14. As is usual with nearly all my experiments, results were not quite what I expected. I expected a modest reduction in resonant frequencies of the top/fretboard after the channels were opened, and reduced stiffness (increased flexibility).

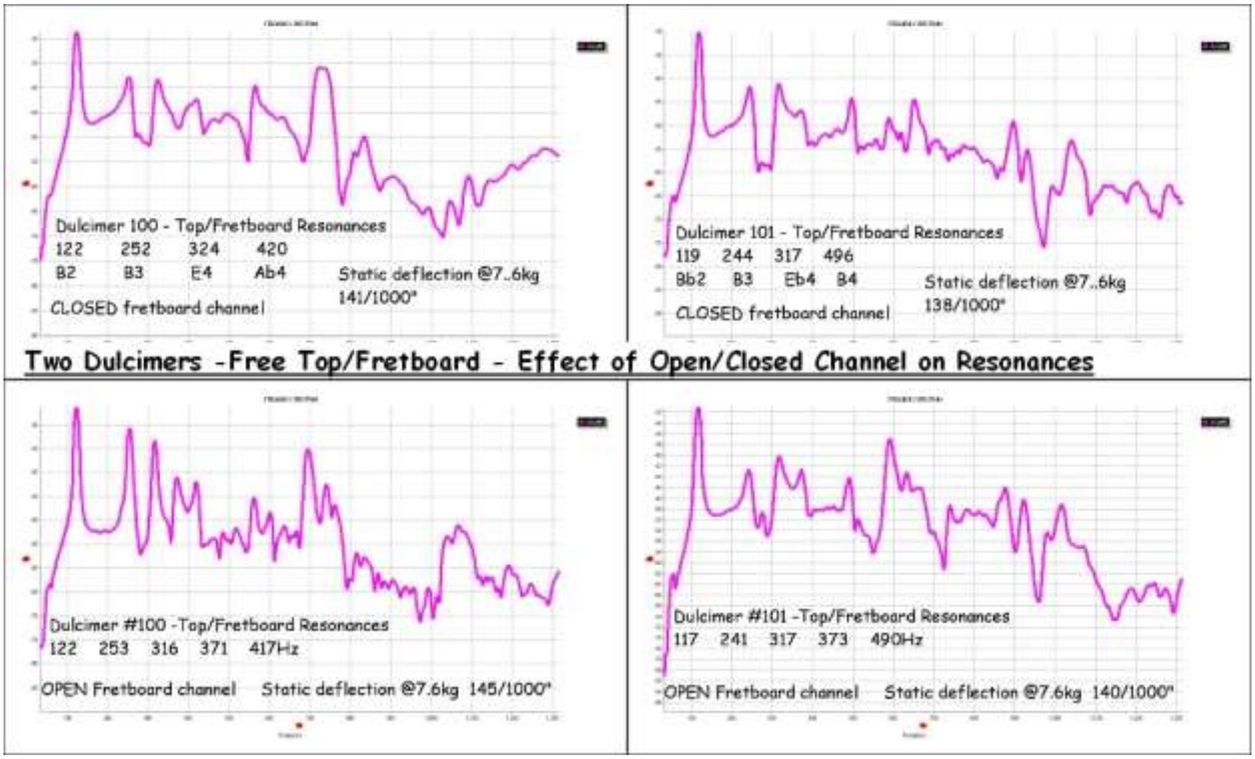

Figure 8.14. Effect of fretboard channel on resonances

But, for these two dulcimers, opening the fretboard channel had almost no effect on the stiffness of the dulcimer top, nor on the way it likes to vibrate. Changes in stiffness, resonant frequencies and weight were less than 1% or 2%.

Conclusion

The removal of the top-plate material below the channel of a hollow fretboard probably has very little effect on the tone of a mountain dulcimer. It doesn't seem to affect top-assembly stiffness very much, or change the resonant behavior of the free top. Weight is only reduced marginally. Open or closed – it seems OK either way.

There is a slight increase in box capacity with the open channel which does lower the first air resonance – but only by about 5Hz; not enough to notice an effect.

This all might not be very surprising, at least in my designs, because the fretboard channel only extends up to the strum-hollow area, leaving most of the lower bout unchanged with or without the fretboard opening. And most of the sound from the top of a mountain dulcimer comes from the lower bout.

The bracing on these two tops are only 3mm high and are quite flexible - so they are low and wide rather than higher and narrow as I more usually do. It was another attempt to make the top assembly a little more flexible and lower the resonant frequencies, but still keeping it structurally strong across the grain, which I like to do. As it happens, the resonances didn't really turn out any lower than for other tops with stiffer bracing. I haven't tested opening the fretboard channel on a top without braces, but I have measured my complete test dulcimer (which is a better test) with and without top and back cross braces. There was about a semi-tone reduction in frequency of the first two or three resonances when going from top and back braces to back-only bracing, and another semitone reduction when removing the back braces (no top or back braces). But for those three conditions; full, half, and no bracing on the same dulcimer, I couldn't really tell much change in the sound when listening to it. It might well be because even though the first air resonance fell from about 200Hz (full braces) to 165Hz (no braces), that's still above the D147 or C130 for the bass string of a dulcimer, and so the fundamental part of the sound would still be missing. The presence or absence of top/back bracing alone doesn't contribute enough to get the first air resonance low enough to cover the bass string fundamental. A combination of no bracing, small sound holes, and a large body might do the trick, but I haven't seen ***any*** reasonably sized dulcimer that ***does*** have a low enough first air resonance. I might make myself a Tennessee Music Box and see what that looks like - they look ***unreasonably*** large to me and might represent the upper extreme in size, and hence a lower limit of box resonances.

I do recall Lois Hornbostel[13] once saying that when playing acoustically with other instruments the principal requirement of a mountain dulcimer is ***loudness***. Other tonal subtleties have to be subordinated to that. So, that is a point as a player that non-performing makers such as myself sometimes don't appreciate.

Some players also don’t want too much bass. Many players these days say they want a "warm", "mellow", "resonant" sound in a dulcimer, and the bass string probably contributes most of that component of the sound. I've drawn attention to the mismatch between the lowest note the strings are tuned to, and the lowest note the box is capable of producing — the bass string asking the box to produce a note it's not capable of doing. But like everything to do with musical instruments, it's not that simple. The

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[13] www.loishornbostel.com

box ***does*** reproduce the bass note, it just gets less and less efficient as the string note gets lower, and the lowest box resonance (the Helmholtz!) gets higher. So that situation might well suit some styles of playing, and noter-drone in general, especially with small bodied dulcimers. But many clearly want improved bass contribution to the sound (or say they do), so there's a move towards larger bodies with a view to improving the bass sound.

Chapter 9
Arched vs Hollow Fretboards

Effects of Arched vs. Hollow Fretboards on Top-plate Vibration- Apr 12, 2013

There is always a steady stream of comment and questions about the merits or otherwise of arched vs continuous fretboards in a mountain dulcimer.

In the past, I have made two “identical” dulcimers with the only difference being that one had an arched fretboard, with four arches, and the other a hollowed fretboard of the same material. Informal listening tests seemed to indicate that the two were very similar in sound quality, but no serious analysis was undertaken.

Many of the dulcimers I’ve subsequently made have had arched fretboards, and many have been continuous hollowed. I’ve measured vibration modes of the top plates of many of them. No characteristic differences in the way the tops vibrate have been seen, and no basic sound differences that I could specifically attribute to the fretboard being arched or hollow has been heard.

Overall, questions regarding arched or continuous fretboards and “freeing up” or “smothering” of top plates have seemed like red herrings to me – an unproductive waste of time. Both approaches can, and do, lead to good outcomes in terms of fine sounding dulcimers, depending on many other factors as well as the fretboards. So, all my tests and observations have been on pairs of instruments that have had many other differences as well as the fretboard arching, making it difficult to attribute anything specifically to the fretboards. In addition, there was a hint in an experiment earlier, that an arched fretboard might have subtle effects on the stretching/compression of the web of top plate under the arch, and this might affect top/fretboard stiffness and hence the sound (this is pure speculation on my part).

So I got out my long-suffering test dulcimer to see what happens with different types of fretboards on the one instrument.

Method

The existing fretboard was sawn off and the top smoothed by putting the instrument through the drum sander (Figure 9.1)


Figure 9.1. Test dulcimer with fretboard removed

The process of sanding also thinned the top plate smoothly from about 3mm thick at the center to about 1mm thick at the edges, so as an aside it will be interesting to qualitatively note the effect of that. I also had to replace the scroll head with a flat head. The instrument had an outer (double) plywood back which was removed for the fretboard tests leaving the balsa inner back as a single outer back.

Tests were conducted on three types of fretboard:

- a single continuous arch from the nut to the strum hollow,
- four arches each approximately 4 in. long (as I would normally do), and
- a hollowed fretboard up to the strum hollow (as I would normally do).

The four arched case was made by packing wood blocks under the single long arch at the positions of the braces inside the top plate.

The fretboards were made of mahogany and had the same treatment from the start of the strum hollow to the end block of the dulcimer.

They were ***NOT*** of the same stiffness, and the top/fretboard assemblies are also ***NOT*** the same stiffness, but the region of the major bout from the sound holes to the end block should be similar in stiffness and mass in all cases.

With such radical differences in the fretboard and top stiffnesses, I would expect sound differences, but not necessarily large differences in the vibrations of the lower bout where most of the vibration occurs.

Figure 9.2. Continuous arch and hollowed fretboards

For interest, I measured the vibration modes of the test dulcimer without a fretboard before and after the plywood outer back was removed. This gave some sort of a starting point for comparison with the three fretboards that were glued on in due course. It also gives some hints as to how a double back might influence the way a top vibrates – but only hints.

Figure 9.3 shows vibration modes below about 500Hz, without a fretboard and before and after removal of the outer (double) back.

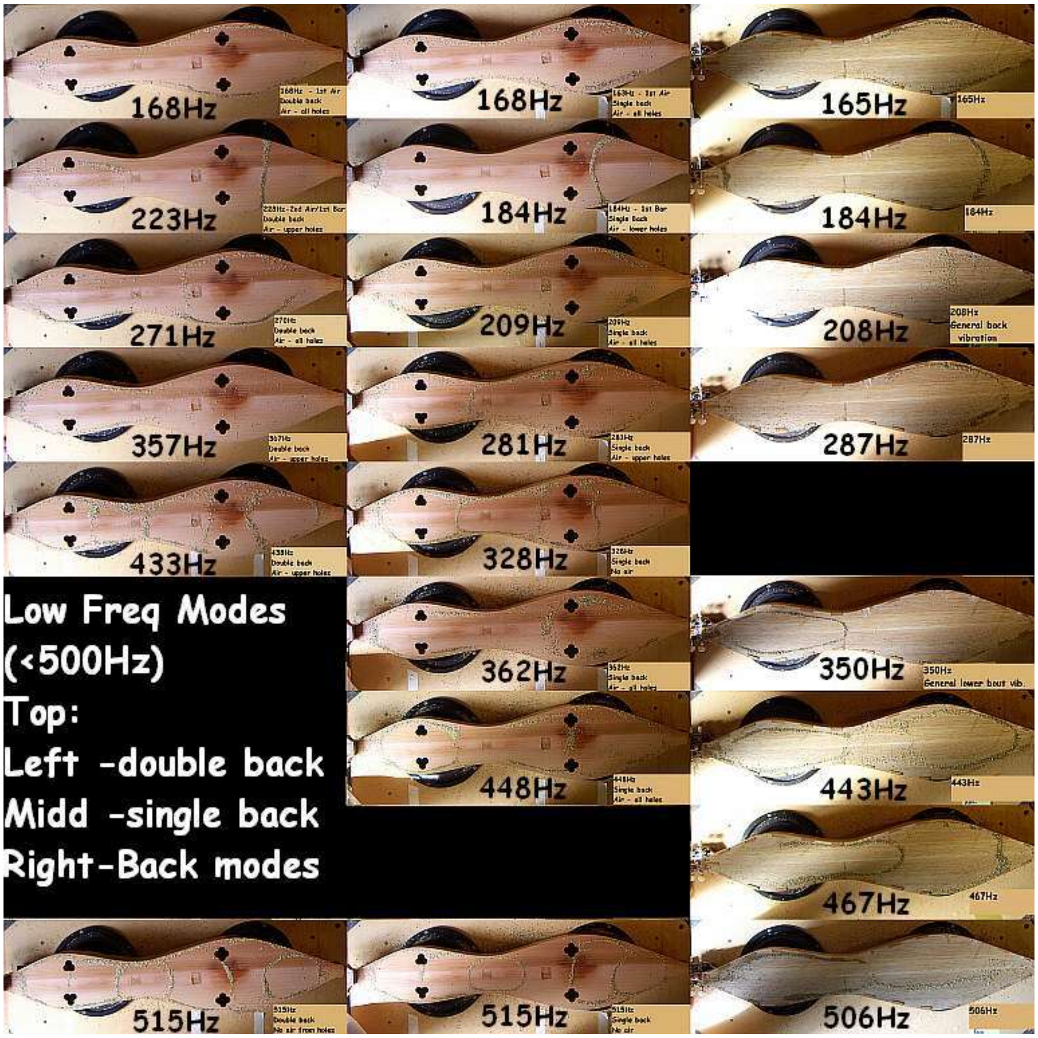


Figure 9.3. Vibration modes below about 500Hz, without fretboard

The added stiffness of the double back has changed the lowest air resonance by less than a semitone, but the first bar resonance reduces by nearly four semitones when the outer back is removed because of the large reduction in dulcimer box stiffness (no surprise). The next few resonances are also lowered when the back is removed. These might be expected to change the general tone of the instrument. When the fretboards were later added, for all three fretboards the 1st air mode was basically the same with or without the fretboard — set by the box cavity. The 1st bar mode, also remained the same with and without a fretboard. From there upwards in frequency, the single arch, and to a lesser extent the four-arch fretboards, had several vibration modes in common with the no-fretboard box. The frequencies varied around a general region, as would be expected. The hollow fretboard only preserved the 1st air and bar modes, as far as could be seen by the patterns of vibration.

Above about 500Hz the higher vibration modes (with no fretboard) get more complex, but match up in frequency fairly closely with and without a double back (Figure 9.4).

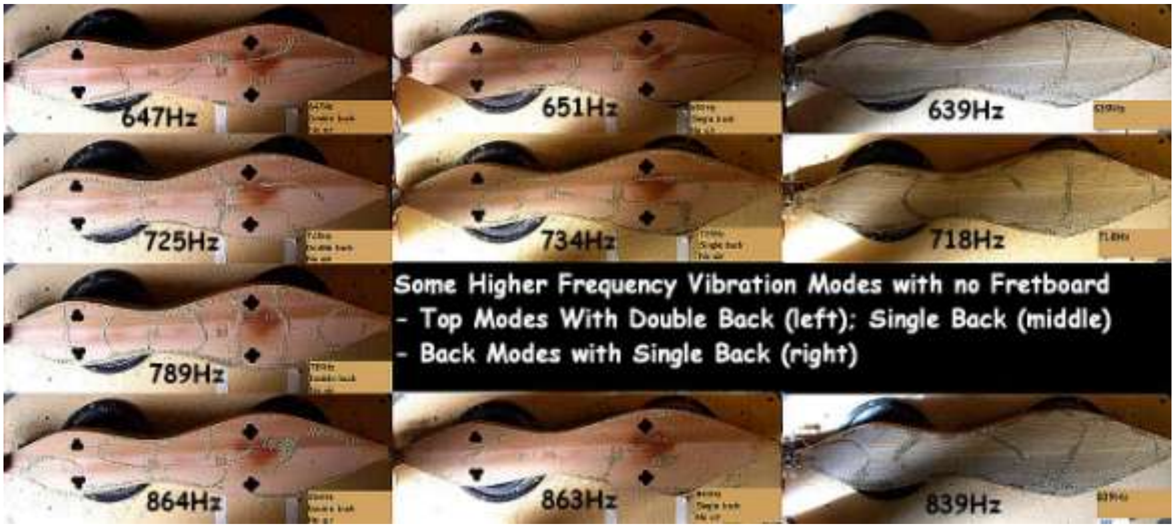


Figure 9.4. Vibration modes above 500Hz, without fretboard

This seems to imply that any effect on the top vibration by an outer back (other than the first bar mode) might be restricted to the lower frequencies. This doesn't comment on any increase in perceived loudness by the outer back slots directing sound out sideways, although that wasn't the case in this dulcimer when I measured it – loudness was basically unchanged with double back, and even reduced if the sound hole size was reduced.

After measuring the response of the box with no fretboard, with and without a double back, the fretboards were added in turn, and measurements made. During testing for all three configurations the same strings were used and the same bone bridge. No modifications to the body were made except that for the hollow fretboard; the underside of the fretboard was opened into the body by removing the top material, as shown in Figure 9.5.

Figure 9.5. Body of dulcimer with hollow fretboard

Hide-glue was used to facilitate removal of the fretboard between configurations, however, it was still difficult to remove the fretboards between tests.

Summary of Results

Did anything sensible come out of this study? As usual – yes and no. A general summary of outcomes is:

1. In the process of smoothing the top plate in preparation for the new fretboards the edges were reduced to 1mm thickness whilst the center-line of the top remained at 3mm. This severe tapering of thickness seems to have significantly modified the tone of the instrument to become mellower. The three fretboards all sounded different, but the general impression of a mellow, treble-reduced, and somewhat brash tone remained in all three. Thinning the edges of a mountain dulcimer top was specifically investigated elsewhere in Chapter 5.

2. The hollow fretboard was the clear winner of the three in terms of my own preference for the sound. It was louder, had better sustain and more punch on the higher fretboard, and a more pleasing tone overall.

3. The hollow fretboard was lighter than the arched fretboards.

4. The hollow fretboard was by far the loudest of the three. The single long arch was the quietest. This goes against the argument of freeing up the top plate by making arches in the fretboard. The reason became clear when looking at the way the tops vibrated. Releasing the fretboard below a long arch made it so flexible (less stiff) that much more vibrational energy was expended in the upper bout, ***but at the expense of the lower bout***, which all but ceased vibrating at a number of frequencies.

5. The long single arch suffered from significant tonal and loudness variation in central regions of the arch (frets 5 to 7).

6. Recordings of the same short tune for each fretboard returned the unexpected result that the four-arch fretboard was clearly the preferred recorded sound. This indicates that perceptions of a live instrument may not be the same as a recording of the same instrument.

Physical Changes to the Test Dulcimer and Some Comments about Top Edge Thinning

In the course of these experiments, the original fretboard and scroll headstock were sawn off and the top plate was smoothed by running the dulcimer through a drum sander. In this process the centre of the top plate, being less constrained than the edges, deflected downwards under the pressure of the sanding drum and remained thicker than the edges. The result was a top plate very nicely (but unintentionally) tapered in thickness from about 3mm at the centre-line to 1mm along the edges. Although some makers advocate doing this in dulcimers, it hasn't been my practice.

The outer ply back was removed and the inner balsa back became the single outer back. Both the top and back plates therefore ended up lighter and more flexible, at least around the edges, than I would normally make them.

The four-arch fretboard was formed by gluing snug fitting blocks under the single arch fretboard at the positions of the internal top braces. The whole arched fretboard was removed prior to replacing it with the hollow unit.

For the hollow fretboard, the top plate of the dulcimer was cut away under the hollow channel.

A fairly heavy, flat headstock replaced the original scroll headstock. Figure 9.6 shows the three dulcimers.

The same bone bridge was used on all three cases, and the same strings. I didn't measure the stiffness of the three fretboards, but I did measure their weights:

The Weights of Three Completed Fretboards

1. Single long arch fretboard______209 gm

2. Four arch fretboard___________218 gm

3. Hollow fretboard_____________200gm

Figure 9.6. Three test fretboards - full arch, four arches and hollow

The hollow fretboard was actually the lightest. The height of the arches was typical of what I normally do, and so were the channel dimensions of the hollow fretboard so I think this is likely to be a general finding; i.e., ***hollow fretboards are likely to be lighter than equivalent arched fretboards***. This can always be calculated from dimensional measurements anyway, but I had intuitively thought that the arched fretboards would be lighter.

The average weight of the fretboards on my previous twelve dulcimers was 274gm, so these three test fretboards were about 25% lighter than usual.

The height above the top plate was the same for all three fretboards, at 22mm. This was high compared with an average of 19mm for 25 previous dulcimers – about 15% higher. This might make them stiffer than average, but that would depend on the size of the channel or height of the arches, and also the fretboard width and wood type. In this case the wood was mahogany, of average density.

I wasn't worried about the stability of the long single arched fretboard because it was only a short-term test. The fretboard visibly deflected under finger pressure, but played surprisingly well, though long-term stability might be an issue.

To get an idea of the top/fretboard stiffness, I measured the top deflection of the hollow fretboard test case against my own dulcimer #54, which has a fretboard height of 21mm. Some crude calculations of the stiffness based on the Moment of Inertia formula indicated that the two fretboard/tops should be similar in stiffness in the region of the fretboard; i.e., down the center-line of the top. However, the measured deflection of the top/fretboard of the test dulcimer was 2 ½ times greater than #54 i.e. it was ***much*** more flexible (less stiff). This could be for a few reasons.

1. The test fretboard could actually be a lot less stiff than #54, despite the calculation.

2. The test dulcimer has no side linings whereas #54 does, so the edge of the #54 top plate might be generally stiffer.

3. The test dulcimer top plate is severely thinned to 1/3 its central thickness. Dulcimer #54 does have a groove around the internal perimeter of the top plate, but is still at least twice as thick as the test dulcimer near the top edge.

Both tops are Western Red Cedar and internal top bracing is similar in both (with one exception, below).

Perceived Tonal Changes With Fretboard Type

First, some comments on the possible contribution to tone of the top thinning and lack of side linings.

The test fretboards were lighter and possibly stiffer than I usually use, both of which might point to stronger trebles, but this seems to have been outweighed by the tapering of the top down to 1mm at the edges, contributing to increased overall top flexibility which favors the lower frequencies. ***The result was that for all three fretboards the general tone was more mellow than bright***, but with reduced dynamic loudness range overall and less cutting power or punch on the treble string. In a previous experiment about internal edge grooving of top plates (Chapter 5), I concluded that grooves didn't much modify the tone, but perhaps those grooves, which I equated to edge-thinning, were not deep enough to demonstrate an effect. Or maybe they were in the wrong place. In this dulcimer, the very thin top edges seem the likely cause of the mellow sound, with some additional contribution by the lack of side linings which would make the edges easier to hinge up and down. So:

a very thin top edge, say 1mm, rising to 2.5mm to 3mm centrally beneath the fretboard might result in a more mellow tone even with a stiff and light fretboard.

I noticed that on the test dulcimer, for all three fretboards, I could change the pitch of a plucked note by pressing heavily on the fretboard along the middle two thirds of its length, but could not do this on dulcimer #54 which has a very bright and cutting treble. Mountain dulcimer top mobility by edge thinning might therefore be a profitable area for study. In addition, if severe edge thinning is confirmed as having a tonal effect, and that tone is desirable, then it is an intervention that can be done ***after*** the instrument is completed.

The following subjective impressions of the test dulcimer were in comparison with my dulcimer #54, which to my mind is a superior instrument. One thing I can say for certain is that the sound of the test dulcimer, for all three new fretboards, was preferable to the fretboard I took off, which I never liked. This re-confirms to me that ***the fretboard is one of the main determiners of the tone of a mountain dulcimer.***

Tonal impressions of a fretboard with a single long arch:

- There was a reduced sustain and dynamic loudness range; a “choked” sort of sound.
- It was possibly slightly louder, but had less cutting power and punch.
- The sound was mellow but brash and seemed mellow because of a lack of trebles rather than an improved bass. It was “muffled” rather than balanced.
- There was a noticeable tonal change as notes were played up the fretboard, most pronounced on the bass string. Towards the middle of the arch, over frets 5 to 7, there was a definite reduction in loudness.
- The note obtained by blowing across a sound hole (the “Helmholtz” tone) was the same for both major and minor bouts. Most dulcimers have two different tones, lower for the major bout and higher for the minor. This might imply that this effect is modified by the fretboard rather than the size and shape of the box cavity. But that’s another study.

Overall, it wasn’t a particularly pleasant tone, and given the variability of the sound up and down the fretboard, and the general instability of the structure, the single arch approach doesn’t seem to have a lot to recommend it. If the fretboard was made super stiff, with carbon fibre rods for example, the sound might be more consistent over the whole length, but that assumes the general tone from the top plate is acceptable and stiffening the fretboard might not affect that. Another test to study. The single arch configuration did not hold its tuning well.

Tonal Impressions of a Fretboard with Four Arches: There was an improvement over the single arch, but a generally similar mellow/muffled tone. The balance up the fretboard was acceptable, but there was an “echoey” brassy edge to the sound and the hint of a wolf note.

This configuration seemed marginally louder than the single arch, and maintained tuning better.

Tonal Impressions of a Continuous Hollow Fretboard: Without question this configuration produced the best sound of the three, to my ear. In common with the other two fretboards there was the mellow bias, and still with reduced clarity of note compared to #54. But, it has a much improved “punch” and tonal attack, and is balanced over the whole of the fretboard. There were no wolf notes and there was improved sustain on the higher fretboard, including the bass string. The brashness of the other two configurations was much reduced. They were clearly louder than #54. The general impression was of muted mellowness with improved dynamic range compared to the two arched fretboards, but not as good as #54.

Since the only change between the configurations was the fretboards, I’m assuming that the hollow fretboard is the source of the preferred sound over the two arched fretboards. This leads me to lean away from arched fretboards in the future, even though I like the look of them (and #54 has an arched fretboard). But all other things being equal, as they were here, the hollow fretboard was a clear winner.

Others may argue that different arch arrangements will produce better results than mine, and that might be so. But unless the same instrument is constructed and compared with a continuous fretboard on the same dulcimer, we’ll never know for sure.

Modes of Vibration of the Top and Back Plates

The modes of vibration of the tops and backs of the three fretboard configurations were visualised by loudspeaker excitation over a range of frequencies up to about 1000Hz.

In the test dulcimer, as is the case with most dulcimers, once the excitation frequency was above about 600Hz the vibration mode patterns get quite complicated and run into each other. The wood and/or air resonances are so close to each other that the top and back is in a continuous state of vibration and it becomes difficult to make much sense of the patterns. This doesn’t matter a lot, because in the building process a maker has essentially zero control over resonances above about 500Hz.

Figure 9.7 shows an example from another dulcimer where two resonances are within a quarter tone of each other, but the top is vibrating quite differently in each. These two vibration modes would both fall between frets 10 and 11 in a DAd-tuned dulcimer (or overtones of lower notes).

Figure 9.7. Two top resonances close in frequency with quite different vibration modes

This can happen at lower frequencies too, but often there are large frequency gaps between resonances and if the string vibrates at frequencies in those gaps the top and back will not respond much, or vibrate more weakly. That's one reason for having a sufficient number of low frequency resonances.

Generally the backs vibrated with the same patterns across all three, but with the normal sort of frequency variation for a particular vibration mode that I'd expect in dulcimers with different constructions; and sometimes in a different order. Keep in mind this is exactly the same back and top in all cases, so the different fretboards are influencing the way the back vibrates. Figure 9.8 shows the first bar vibration mode for the three.

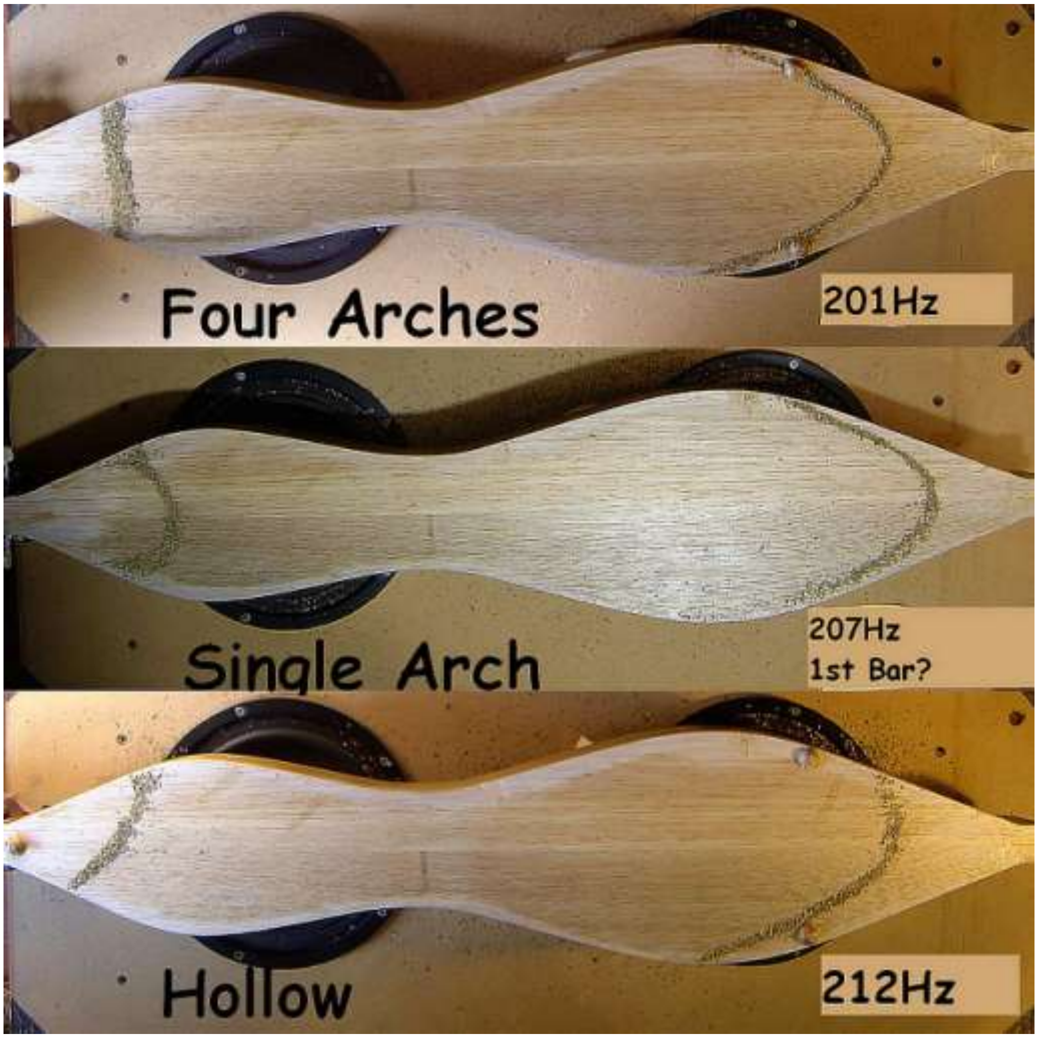


Figure 9.8. First back bar vibration mode for three fretboard types

In an ideal bar, the lines would be straight across rather than curved.

At a higher part of the frequency scale, a wood vibration mode is shown in Figure 9.9. There were some unusual back vibration modes, but by and large they were comparable.

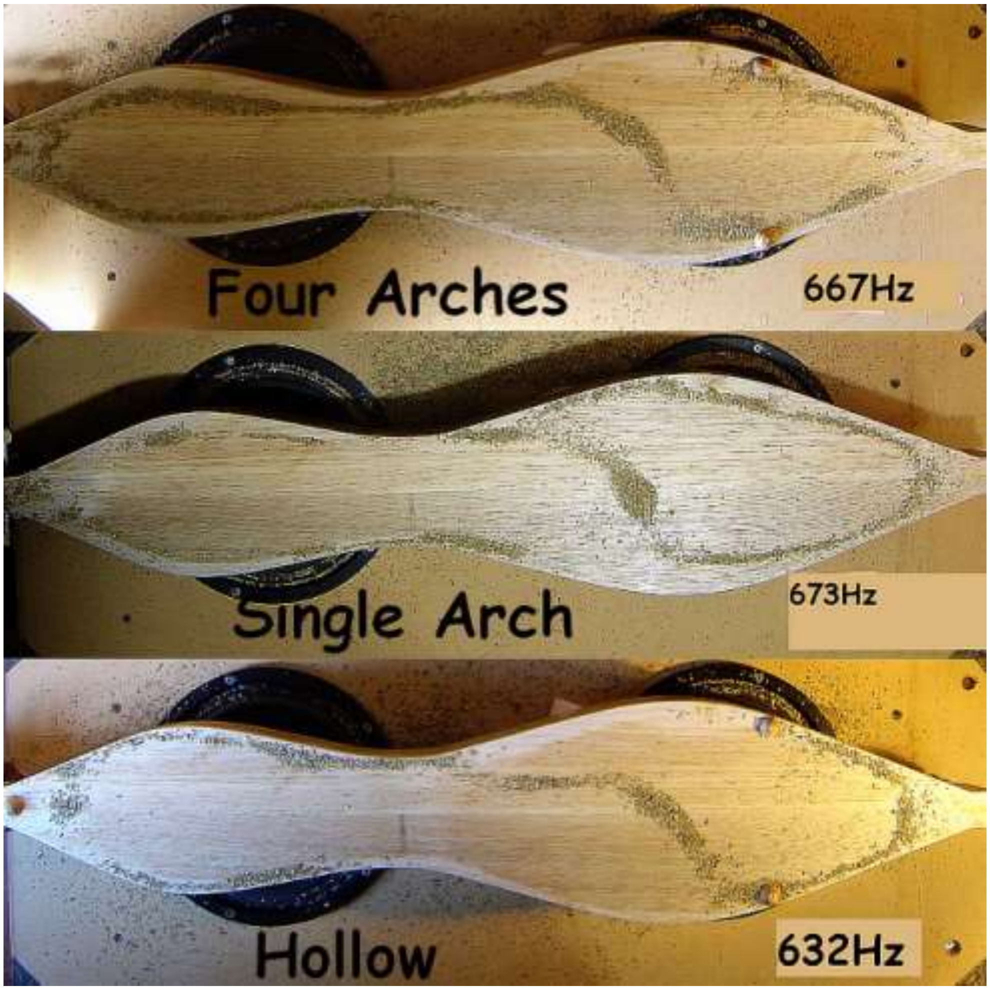


Figure 9.9. A back vibration mode at higher frequency

As might be expected, the tops were less alike than the back, in the way they vibrated. Figure 9.10 shows the first bar vibration mode on the tops.

This is an interesting picture when taken in conjunction with the back vibration for the same bar mode (Figure 9.8). The bar vibration patterns are quite different for the three tops, but the end points of the arcs, at the instrument edges, match up with the end points of the corresponding arc in the back modes; i.e., the bending of the whole dulcimer like a bar is occurring at the same point on the sides, but within the top and the back, the bend line seems to take the path of least mechanical resistance.

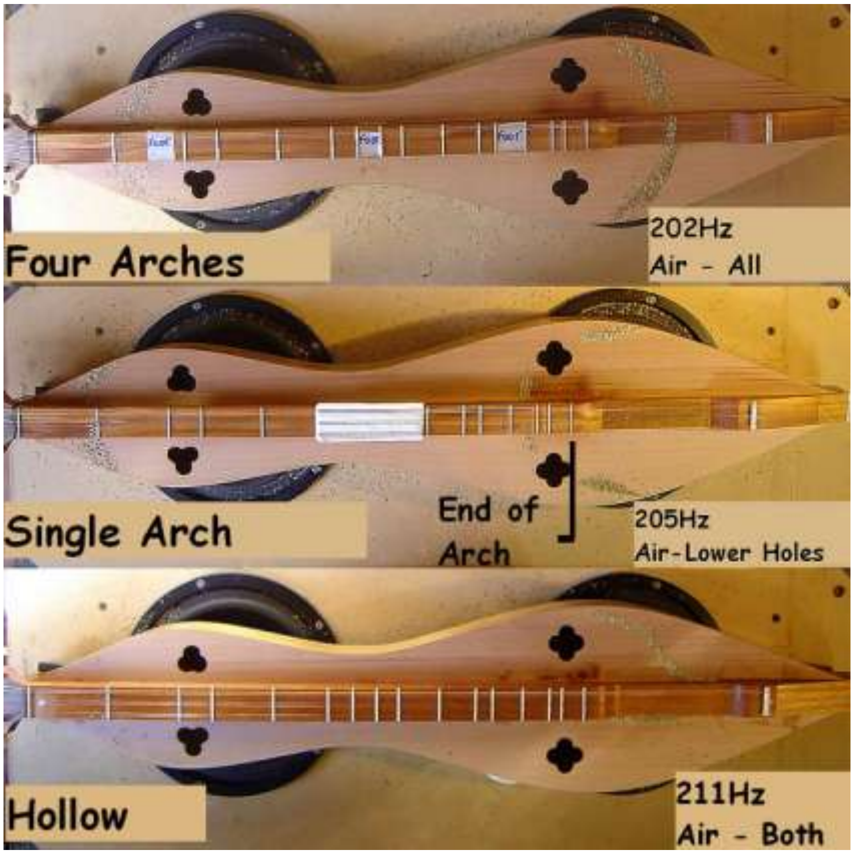


Figure 9.10. First bar vibration modes for same tops, different fretboards

In the case of the back, the curved bending line could be because of the criss-cross (#) internal bracing and the very light and flexible back plate. The back is bending around the outside of the criss-cross bracing.

For the tops, the four arch fretboard bend line is nearly straight across, which seems to imply that the top/fretboard is effectively equally stiff the whole way along the fretboard, including the strum hollow. In contrast, the single arch top goes out of it's way to bend under the arch where the whole top is clearly less stiff, certainly less stiff than the strum hollow area. A vibration preference like this for the lower stiffness areas might partly account for reduced sustain in this configuration compared to the other two.

The bending line on the hollow fretboard doesn't seem to know where to go, and ends up with the dulcimer twisting instead of bending straight across. I haven't seen this in any other dulcimer I've tested, so I'm not sure how it might arise. But a bit of asymmetry is not necessarily a bad thing, and it doesn't occur in all vibration modes.

Figure 9.11 shows the top mode vibration corresponding to the ~670Hz back mode shown in Figure 9.9.

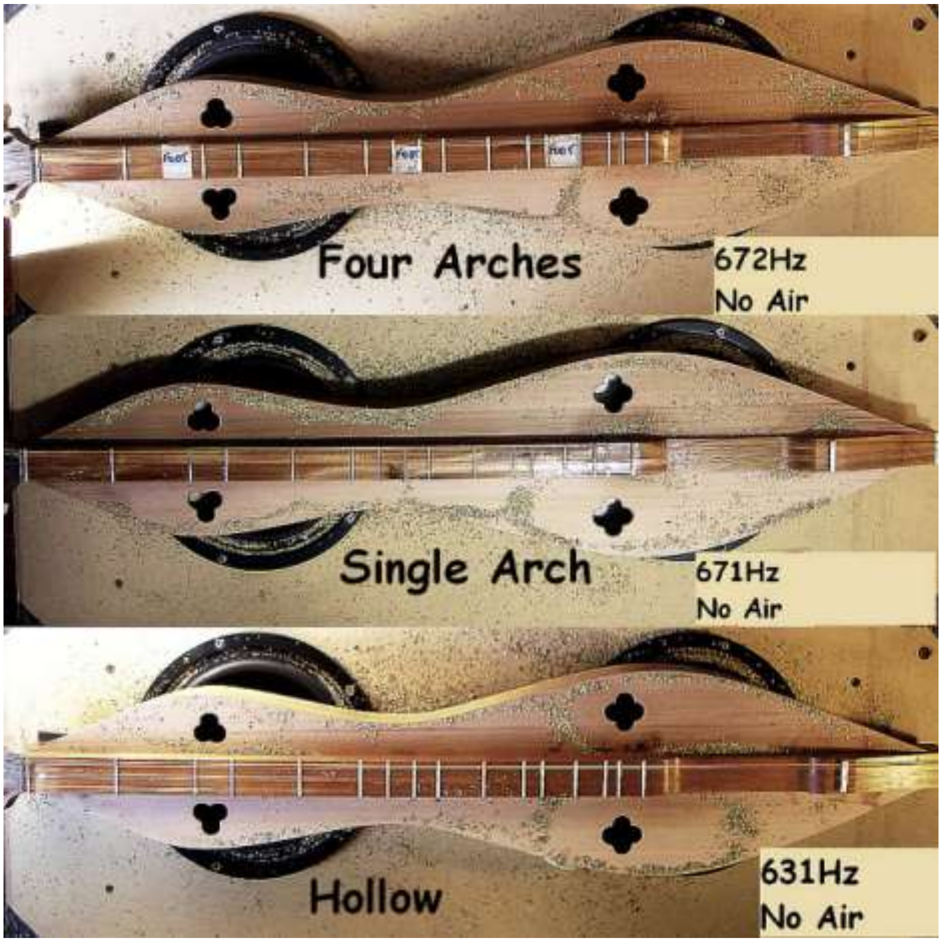


Figure 9.11. Top mode vibration at higher frequency

This is clearly the same vibration mode for all three, meaning that at these frequencies the vibrations are occurring in the same areas of the top in each case. This in turn means that the very different fretboards have not prevented the tops from vibrating in a way possibly dictated by the top plate itself, rather than the fretboard. Which is something I've said elsewhere doesn't happen much, although it could also just reflect the general common increased stiffness of the whole box with a fretboard attached.

Even though the vibration patterns are all generally the same, the fretboards ***do*** influence the top here in a way that may well affect tone. The pattern of vibration is different on the lower and upper bouts for the different fretboards. With the single arch fretboard, there is well-defined vibration of the upper bout and the waist area (because the sawdust has been vibrated off in those areas), but the lower bout has a large area from the start of the strum hollow to the end of the instrument that is not vibrating at all (Figure 9.12). This is shown by the fact that the sawdust has remained in place on a large part of the lower bout of the top instead of being jostled away as it would have been if that part was vibrating. The reverse is true of the hollow fretboard — the lower bout is vibrating more cleanly than the upper bout. The four arched fretboard is a little fuzzier in its vibration over the whole of the top. I don't know what this might mean for tone overall, but it's a demonstration that the distribution of stiffness along the fretboard ***can*** influence a resonant mode of the top plate to make it vibrate stronger or weaker at different parts of the top. For the single arch fretboard this lack of vibration over half of the lower bout was present in several resonances.

Figure 9.12. A vibration mode for the full arched fretboard where the lower bout stopped vibrating.

A speculative summary of this effect of fretboard type modifying the upper/lower bout vibration bias might be:

- single arch — less stiff at nut end of dulcimer — bias towards upper bout vibration,
- multiple arches — more even stiffness — vibration of whole top, but fuzzier, and
- hollow — less stiff in strum hollow area — bias towards lower bout vibration.

This has ramifications for the "free up the top plate with fretboard arches" argument: ***an arched fretboard may result in changing the bias of vibration from the lower bout to the upper bout of a mountain dulcimer, rather than just increasing the vibration below the fretboard arches*.**

This is not necessarily a good thing or a bad thing as far as resultant sound goes, but it again reinforces the importance of the fretboard in shaping tone.

Looking at the top vibrations without a fretboard; i.e., just the dulcimer box, there are a number of commonalities in the mode shapes with those of tops with a fretboard, and at similar frequencies. This points to these vibration modes being resonances of the air in the box rather than wood resonances. Others have speculated that cavity resonances in a mountain dulcimer may be as important as the wood resonances themselves. If this is the case, then the fretboard is modifying the way that the internal air pressures at resonance interacts with the wood of the instrument. The end result is the same – wood or air resonance, the way the top actually vibrates is modified by the nature of the attached fretboard.

Top/Back Relative and Absolute Sound Levels

Generally speaking, the tops of mountain dulcimers I've measured produce sound levels 2 or 3 decibels higher than the backs — i.e., the tops are noticably louder than the backs.

In this case, the test dulcimer has a back plate made from balsa wood, which is much lighter than other dulcimers and less stiff. I would therefore expect the back to make more of a contribution to the overall sound output.

For the three fretboard configurations tested I measured the top-vs-back sound level difference using the method described in Chapter 15. I also measured several other dulcimers under the same conditions.

The process also produces a measure of absolute sound level of the tops. Although this is more prone to error than the difference between top and back, I was careful to keep the measurement protocol as standard as possible, and so, with the averaging of a number of trials, the absolute sound level of an instrument could be reasonably indicated.

In terms of top vs. back loudness, for all three test fretboards — a single long arch; four arches and continuous hollow fretboard, the top was essentially the same sound output as the back - all three configurations averaged less than 0.5dB SPL difference between top and back. The collection of other dulcimers tested varied between 1dB and 3dB top to back SPL difference. I take this to indicate two things.

1. The three different fretboard configurations did not appreciably alter the acoustic relationship between the top and the back, as far as loudness goes anyway.

2. The light balsa back produces relatively more sound that a normal denser back.

The estimates of absolute top sound output were more interesting – there was a consistent difference in top SP levels between the three fretboard configurations. The averaged top SPL measurements were:

1. single long arch fretboard____________60.9dB,
2. four arch fretboard_________________62.4dB,
3. hollow fretboard__________________ 64.3dB, and
4. three other dulcimers (average)______ 60.5dB.

This implies that the continuous hollow fretboard configuration was noticably louder than the four arched fretboard, and louder againcompared to the single arched fretboard case. All three were louder than the other dulcimers I tested. Whilst these numbers might be a bit fuzzy round the edges, they are averages of multiple trials with small variation between trials. So, I am reasonably confident that the order of things is correct. In addition, the measurements were consistent with my subjective impressions.

The increased loudness of the test dulcimer over the comparison dulcimers might be because of increased mobility of the top plate because of the very thin top-plate edge, or because the three test fretboards were all about 25% lighter than the average for my dulcimers. More likely both contributed.

This result, for this one dulcimer, is the opposite of what would be expected if it is argued that using an arched fretboard will “free-up” the top and produce more sound. The most free top of the three, the single long arch, was the quietest, possibly because although the upper bout was vibrating more under the arch, it was at the expense of the lower bout, which simultaneously vibrated less.

Measured Chord Attack Time

The three test fretboard configurations produced a mellow sound, but they lacked “punch” — there was less impact from staccato chord playing compared to my own dulcimer, #54. I thought this might be because of increased attack time for the sound; the top, even though light, might be so flexible that it takes longer to initiate box vibrations via the string energy.

But measuring the sound rise time for all three fretboards, and for comparison dulcimers, showed this not to be the case — the test dulcimer attack time was just as quick as other dulcimers. The follow through immediately after the attack transient also looked the same for the test and comparison dulcimers. This might imply that the mellowness is associated with reduction in the higher partials, rather than a slower note attack time, and that attack time is unrelated to thinness of the top-plate edges.

Recorded Sound Clips of Three Fretboards

Under the same conditions, I recorded the same short tune for each test configuration, and for dulcimer #54. The tune only utilised the lower fretboard, up to fret 4.

And then — listening critically to the replays, it surprisingly became clear that I preferred the sound of the recording of the four-arched fretboard, even to my own dulcimer. The single arch was still last, but the hollow fretboard was second-last.

Surely I must be imagining this! So I analyzed the sounds to see if numbers could reassure me I was just fooling myself. I measured the center of gravity frequency of the spectrum for each fretboard case, the standard deviation of the frequency, the spectral slope. I changed the spectral filtering, played recordings through filters, cut out different parts of the spectrum… but it was no good. The numbers confirmed what my ears were telling me: the recording of the four arched fretboard had the highest center of gravity frequency (the average frequency of the spectrum, weighted by its energy; higher meaning a brighter sound) and the greatest frequency variation around that center (meaning a wider range of overtones), and the best balance of energy below and above the center of gravity (meaning that bass and treble frequencies were both amply present). Dulcimer #54 was a close second in these measures, followed at some distance by the hollow fretboard, and a considerable numerical distance back to the single arch fretboard. This ranking was also my subjective judgement of the recordings. What does this mean?

It could be that the microphone was positioned differently for the four arch recording — it was 3cm from the edge of a sound hole, but I wasn't overly rigorous in the measurement of the distance. Or maybe some instruments just record better than others. The recordings did not cover the full range of the fretboard, or include different playing styles, and they could be factors also.

In the flesh, my clear order of preference is #54; hollow; 4-arch and single arch, with hollow being audibly better, to my ear, than the two arched fretboards. In fact my first impression of the hollow fretboard was "This is so much better than the arched fretboards".

But the recordings show me that context of hearing may alter preference, so those makers and players who like arched fretboards needn't worry too much about this particular experiment. All instruments have something to say, and a place to say it that makes them shine.

Chapter 10
Bridge Design Effects

Movable Bridge-Sep 29, 2010

I don't use fixed bridges on the mountain dulcimers I make because for best intonation you are then locked into one string weight, one tuning, and one action setting.

On the other hand, a moveable bridge can accommodate variations in tuning and strings, but over the years it's going to get moved. And not all players are comfortable with resetting the position correctly.

So ever since seeing an adjustable dulcimer bridge, I thought I'd try to make one. The one I saw only adjusts length, and I wanted height adjustment also so I bought a set of Strat guitar saddles from Stewart Macdonald (Part #0047) which would make two bridges. To mount them I bought an L-bracket from the hardware store. Some cutting, filing and drilling later, I had this mounted on my test dulcimer: (Figure 10.1)

Figure 10.1. Adjustable bridge on test dulcimer

Not very scenic, but proof of concept. Initially I mounted it on a flat pedestal of the fretboard, but the break angle over the saddle was almost zero, so I cut the pedestal to make a slope and re-mounted it (Figure 10.2).

It seemed just as loud with no break angle, but the strings did bounce around a bit, so I think a sloped mounting is the way to go.

Figure 10.2. Bridge mounted flat and on a slope

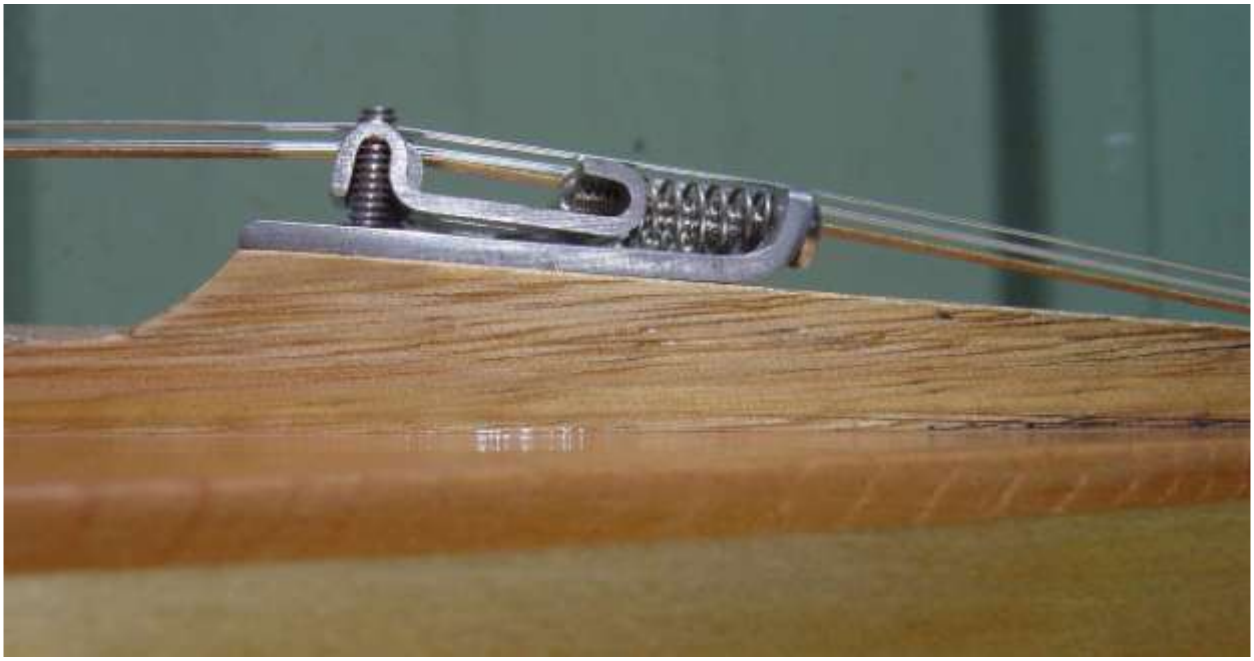


Figure 10.3. Side view of slope-mounted bridge

It was very easy to adjust the action and intonation with this bridge, and I was surprised how loud the dulcimer was compared to the bone saddle it replaced. However, there was nothing sweet about the sound — it was definitely metallic — kind of like a tin-can telephone. Loud and brash, and a bit of sustain is lost — I don't think I'll put one on my main dulcimer, even given its intonation convenience.

The Effect of Break Angle at the Saddle on Loudness and Tone- Mar 08, 2014

It seems that the angle at which the strings bend over the saddle, and at the nut, of stringed instruments, is recommended to be about 15 degrees. I've generally accepted this, and it seems like a reasonable idea – but no-one has satisfactorily explained the reason for the 15 degrees. A quick check of the guitar community indicates they are in the same situation. There is a lot of confusion, myth, and plain disinformation out there about what the string break-angle does or doesn't do. (The worst myth is that the break angle modifies the string tension, and hence the "feel" — ***it doesn't***).

I didn't know what to think, but it's a fairly easy thing to test, so I got out my test dulcimer once again. This is a standard configuration full-length fretboard dulcimer with the bridge approximately from the end block.

So what does changing the break angle definitely do?

> 1. It changes the down force on the bridge saddle. A larger break angle means a larger down force. But this is the STATIC down force, not the dynamic forces produced by the vibrating strings.
>
> 2. It might modify the friction of the string over the saddle and nut. Larger break angle means higher string friction.

That's about as much as I know for sure, and neither of these have an obvious direct effect on instrument tone.

The Test

My test dulcimer was modified to allow the saddle break angle to be adjusted by a screw. The weight of the dulcimer remained the same throughout the tests and the same strings and measurement set-ups were used throughout as shown in Figure 10.4.

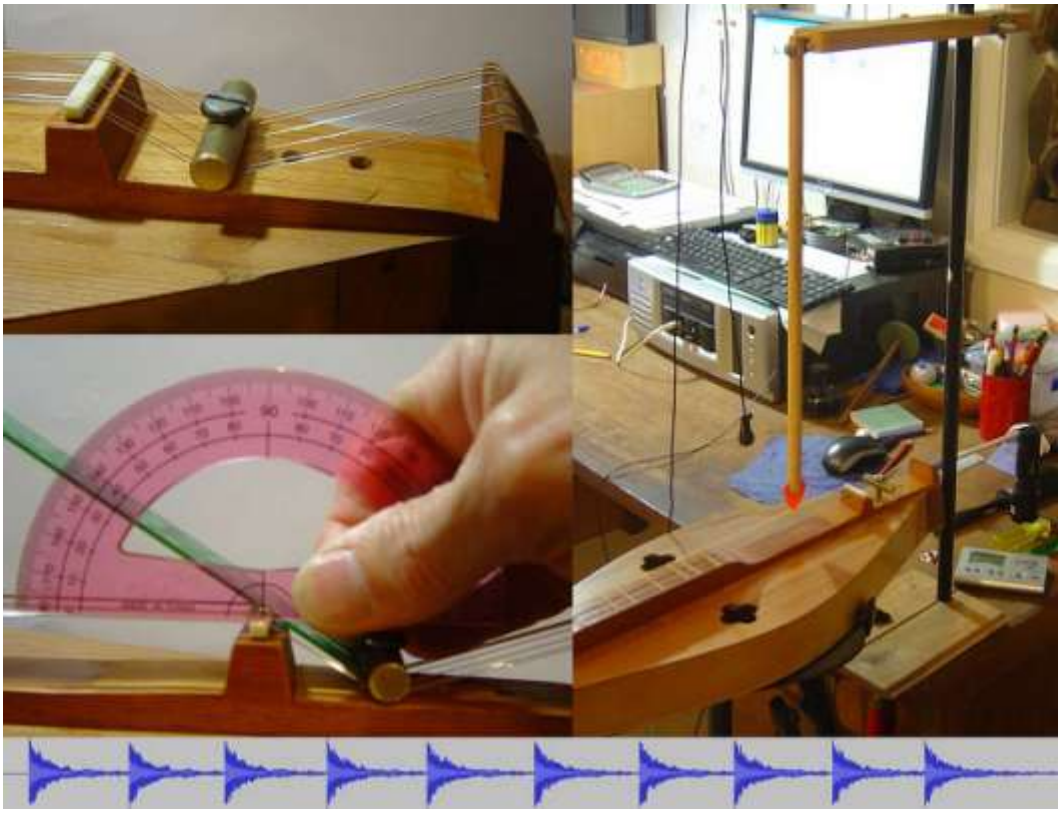


Figure 10.4. Break angle test set-up and string-strike waveform

The string break angle was set with the screw, measured with the protractor, dulcimer retuned to DAd, and the strings struck by the pendulum-stick-plectrum. This ensured a fairly consistent string strike.

For each break angle, five recordings of ten strikes each were recorded using Audacity software (fifty total strikes per break angle). Between each recording of ten strikes, the dulcimer was moved slightly to average out variations in plectrum contact with the strings that might occur whilst adjusting the break angle to a new setting. The first test was at 30 degrees, and the break angle reduced in 5-degree increments until it was zero. At the end, the break angle was reset to 30 degrees and retested to ensure there had been no gradual setup changes during the tests.

The recordings were analyzed using the PRAAT sound analysis software.

Parameters measured were:

Sound Pressure Level: An average of the SPL of five recordings was made for each break angle. This gives an indication of any changes in overall loudness with break angle.

The Spectral Centre of Gravity of the Fourier frequency spectrum of a recording for each break angle: This determines the frequency at which there is as much energy below as above that frequency in the sound. In the absence of a clear definition of the mellow/bright divide in describing a sound, I've used this measurement as a general indication of the bias towards one side or the other. A low spectral C of G frequency would indicate that more energy is concentrated in the lower frequencies, and hence might be more mellow sounding. A high C of G frequency might imply a bias towards the higher frequencies.

Sustain: An estimate of the duration from the initial sound transient SPL to 50% of the background noise level was made for a recording at each break angle. This gives a (rough) estimate of how the sustain of the instrument might vary with break angle.

General Change in Tone: I played and listened critically at each break angle. The usual caveat applies – your perception might be different to mine.

Results

Quick Result: For this one dulcimer, varying the string break angle at the saddle, between 30 degrees and zero degrees, had no practical effect on the sound or playability.

Measured results are shown in Table 10.1.

Table 10.1.
Effects of Break Angle on Sound Level, Sustain and Tonal Bias for One Dulcimer

Break Angle (deg)	Av SPL (dB)	Sustain to 50% SPL (sec)	Spectrum C of G (Hz)
30 at start	64.3	2.6	2294
25	64.4	3.7	2318
20	63.3	2.7	2251
15	63.5	2.8	2714
10	64.0	2.2	2215
5	62.9	2.7	2395
0	62.7	2.6	2030
30 at end	63.3	3.1	2411

There is no clear trend here tying break angle to loudness, sustain or tonal balance. The variations in the numerical results are basically about the same as the measurement repeatability of the recording setup. Even if there is a statistically detectable trend, it would be barely above the "noise".

In playing and listening at the different break angles, I was hard pressed to tell any difference. At zero degree break angle there might have seemed a bit more sustain and a little loss of “body” to the sound, but more mellow. Overall, any change in tone could have been as much caused by my playing differently than by the change in break angle. I wouldn't claim that changing break angle has ***no*** effect, but if there were any effects in the above tests, it was small enough to be lost within other variables such as playing style. Also the numerical measurements supported the subjective perceptions and observations on other dulcimers of the same general design, so I'm fairly confident that for this test on this one dulcimer the break angle does not play much of a role in the final sound.

A question about the validity of the method is worth asking, and I did ask it myself. I realized that there would be different stresses on the end of the fretboard caused by the screwing down of the brass bar to change the break angle, so I accurately checked the string height at the last fret to see if the fretboard end had rotated at all. There was no change over all the break angles tested, accurate to 0.01mm, so I took this to mean that the fretboard was amply strong enough that the change in angles did not distort it.

With regard to the effect of static break-angle-down-pressure on the dynamic actions of the strings - it's a complex question, and not resolved in guitars, and therefore not in dulcimers either. My feeling is that the dynamic (as opposed to static) effects of break angle, in full-fretboard dulcimers, should be less than in guitars or mandolins because of the relatively massive amount of material that has to be traversed before the string-created pressure wave can get to something that can bend (the top plate).

In setting up the experiment I had considered gluing on a series of wedges behind the saddle to alter the break angle, but that would alter the weight of the end of the instrument, which in itself could alter the tone and sustain. So, I opted for the constant-weight method reported. It's worth considering whether tonal changes reported by some makers as being a result of different break angles were possibly related to weight changes as much as angle changes.

Nothing is simple, but for myself I am now less worried about the precise value of the string break angle, provided it is enough to keep the strings in place. In other dulcimer designs the break angle may have more of an effect than I have observed in these tests, but I suspect it is still not a large one.

Conclusion

A shallower break angle does reduce static down force on the saddle. That might allow a structurally weaker but lighter instrument to be made, which in turn might affect tone. But it hardly seems applicable for mountain dulcimers with continuous fretboards.
A zero degree angle might not be sensible for the practical reason of keeping the strings in place on the saddle.

Other than that, any angle seems about as good as any other – for this one dulcimer and at least up to 30 degrees. My general experience with other dulcimers also supports this view.

Break angle might be one more thing that could be crossed off the list of design factors to be overly concerned about.

Effect of String Break Angle at the Saddle – A Second Trial- Jun 01, 2014

After the first break angle test, it was suggested by another dulcimer maker that finger pressure on the fretboard should damp the sound of a mountain dulcimer. It was furthermore suggested that break angle changes in string downforce at the saddle should also affect tone. Practically speaking, neither of these suggestions seems to be true. At least on the dulcimers I have around me, pressing harder on the fretboard does not seem to affect tone or sustain, and the previous section regarding string break angle didn't show any practical changes in tone.

But why doesn't increased fretboard or saddle down force affect tone? There must be some point at which it starts to. Perhaps that point is outside limits that are reasonably encountered in our making and playing.

In addition, I've been thinking about the weight of the fretboard at the saddle, and whether it might be worth reducing it in order to modify tone or loudness. The couple of cubic inches of fretboard in the area of the saddle can only add (or subtract) one or two ounces This is in comparison to the string down force on the saddle of about 30lb at 15 degrees break, six strings, tuned DAd. That's about four house bricks pushing down on the bridge.

On the face of it, if varying the effective static weight on the top-plate, via the fretboard and saddle, from 0 lb (0 degrees break) to about 30 lb (15 degrees break) doesn't affect tone much, then hollowing or arching under the saddle should have no practical effect (unless there are non-weight-related factors involved, or dynamic factors dominate, as opposed to static).

Inconclusive experiments with some cylindrical metal doorstops, weighing 1.5kg gives some clues as to why finger pressure on the fretboard doesn't change tone, and what is happening regarding static weight on the saddle, but no clear answers. The weights have a bare metal top and a hard rubber base.

When pressing on the strings with fingers I can easily apply a force of more than 1.5kg, but 3kg is about my limit. Even 1.5kg is hardly a comfortable playing pressure — during normal playing it is typically a lot less than that. If I use two doorstops (3kg) to press the strings down on the frets I hear no change in tone compared to fingers, whether the rubber side or the metal side is contracting the strings, and on a table or on my lap. However, if I balance a doorstop directly on the bone saddle there is a dramatic change in loudness and tone, ***but only if the metal side is in contact with the*** *saddle* — the rubber side has no effect. So it's clearly not just the weight pressing on the saddle, but also how it's coupled, that modifies the tone. I know from a previous occupation in voice analysis that muscle tissue doesn't pass sound energy much above 500Hz. So the fretboard may be vibrating away without much of it leaking into our fingertips pressing down with pads about the same consistency of rubber, but with the string in firm contact with the underlying metal fret. But then, why does the metal contact of the door stops have such a large effect at the bridge, but not the fretboard?

I haven't investigated any of this properly, but it's something to look into.

In the meantime, I redid the break angle test to measure the actual down force on the saddle, and satisfy a reservation about the previous test methodology, expressed by another dulcimer maker. The results of the new test, using a different methodology, is that I still can’t hear or measure any practical difference in the dulcimer sound with a saddle break angle between about 1 degree and 15 degrees.

The Second Break Angle Test

The test dulcimer was changed to anchor the strings at the end block, but still allow variation in the break angle, whilst keeping a constant weight. The maximum break angle was 15 degrees and the minimum, about 1 degree. (Figure 10.5)

Figure 10.5. Second break angle test setup

The parameters measured were:

Sound Pressure Level: An average of the SPL of five recordings of ten standard string strike was made for each break angle (50 strikes per angle). This gives an indication of any changes in overall loudness with break angle.

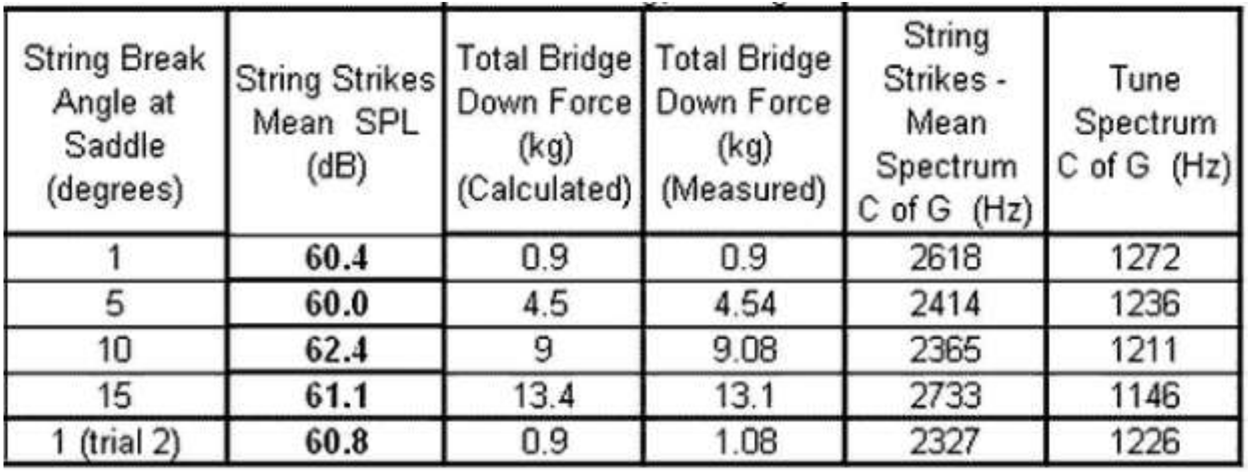
The Spectral Centre of Gravity of the Fourier frequency spectrum of a recording for each break angle: This determines the frequency at which there is as much energy below as above that frequency in the sound. For the same recordings at different break angles, a low spectral C of G frequency would indicate that more energy is concentrated in the lower frequencies, and hence might be more mellow sounding. A high C of G frequency might imply a bias towards the higher frequencies. This should indicate a change in general tone. The range of frequencies in the recordings that show sound energy extend from about 150Hz up to about 10,000Hz.

String Down Force on Saddle: Calculated using simple trigonometry and d’Addario string tension tables[14], and measured in situ with a digital fish scale.

Results

The results are shown in Table 10.2. No trend stands out, and playing at the different break angles reinforced it. As long as the strings didn’t move around on the saddle, the tone was the same over the whole range of break angles.

Table 10.2.
Effects of Break Angle – Second Test



String Break Angle at Saddle (degrees)	String Strikes Mean SPL (dB)	Total Bridge Down Force (kg) (Calculated)	Total Bridge Down Force (kg) (Measured)	String Strikes - Mean Spectrum C of G (Hz)	Tune Spectrum C of G (Hz)
1	**60.4**	0.9	0.9	2618	1272
5	**60.0**	4.5	4.54	2414	1236
10	**62.4**	9	9.08	2365	1211
15	**61.1**	13.4	13.1	2733	1146
1 (trial 2)	**60.8**	0.9	1.08	2327	1226

It’s also interesting to note that the addition of the angle-iron string support bracket in this test increased the weight of the end of the instrument. That should result in the lowering of the first bar resonance frequency. Bridge tap spectra without and with the angle-iron bracket showed that the bar resonance fell from 212Hz and 201Hz (Figure 10.6).

The frequency change is one semitone. However, even though other tests have shown that the first bar resonance is important to the overall dulcimer sound, it was not enough in this case to make a noticeable difference in tone (before and during the test).

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[14] http://www.daddario.com/upload/tension_chart_13934.pdf

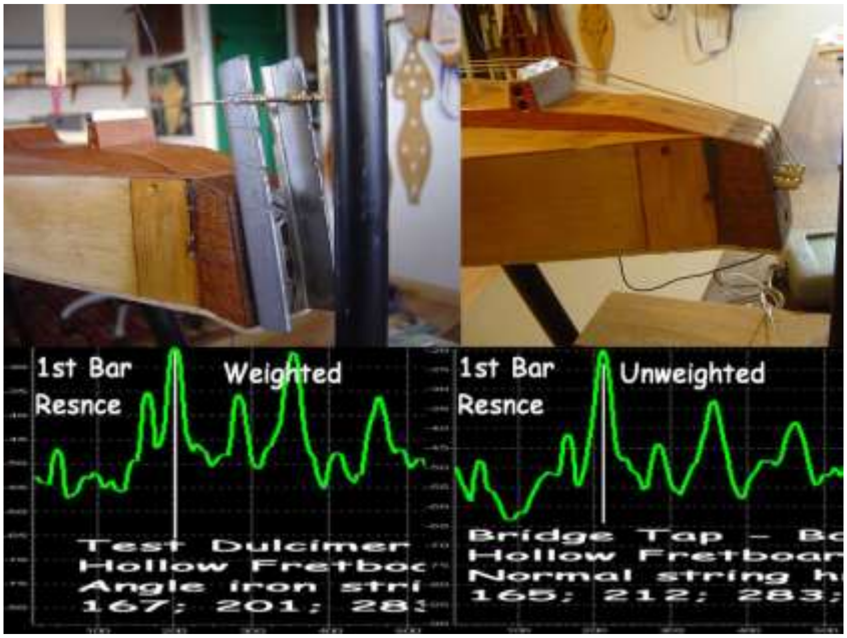

Figure 10.6. Affect on frequency of first bar resonance of adding weight to a dulcimer end.

Conclusion

Overall, I'm fairly satisfied that string break angle at the saddle contributes hardly anything to the tone of the instrument.

Effect on Tone of Bridge Location -Jun 03, 2014

The test dulcimer used in testing break angle does have a nasal quality to the sound. I don't know why that is, but my feeling is that it is not principally the result of the in-board location of the bridge (about 90mm from the end block), because other dulcimers of mine of the same general design, and with the bridge in a similar position, have quite different sounds. I think it's more likely to be the balsa-wood back and the very light fretboard of this test dulcimer – this is unproven speculation.

Moving the bridge inward (toward the nut) is one of the few things that seems to have a large effect on the final sound, rather than a subtle change. I don't know why this is, but it may be because it moves the bridge fulcrum closer to the bending point of the first bar resonance (an important one), or it may just facilitate the mobility of the top plate/fretboard at the lower bout more efficiently. Neither of these suggestions is established, and both may be wrong. But the further the bridge moves inward, it seems to me, the "edgier" the sound gets, to the point of brash unpleasantness if it moves too far – to the middle of the major bout, for instance. So there's a compromise, as there always is. Keep in mind, that "moving" the bridge inward on a fixed Vibrating String Length (VSL) instrument, really means making a longer, and hence larger, box. That adds another variable. Additionally, different people perceive sound changes differently, so the effect, on tone, of changing the position of the bridge may depend on who is listening .

It should be noted that a dulcimer with the bridge near the instrument end will have a string down force greater than if the bridge was inward, because the break angle will in general be higher for an end block bridge position. But there are a couple of reasons why the effects might not be the same: one will be that the string pressure is just compressing the end block for an end block bridge, rather than the top plate (if the bridge was inward more); and the other might be that bridge down force could directly affect the mobility of the top plate/fretboard for an inward bridge. Overall, I don't worry too much about down force on the bridge (by the strings). If bridge down force has an effect, I think it's a small one (in the ranges of force we encounter).

There are problems in the recording and assessing sounds in studies such as this. Microphones and speakers vary in quality and sound fidelity, and listeners’ hearing degrades with age. So, there are a number of pitfalls in making comparisons from recordings. But if the conditions are kept the same, some indications of differences between instruments and configurations are possible.

To that end, I recorded the same tune as in the break angle test on four dulcimers, including the test dulcimer, to see if I could perceive a characteristic sound difference between an end block-bridge dulcimer, and inward-bridge dulcimers. The first three dulcimers are of the same general design with the bridge well off the internal end block (test dulcimer; #54; #20) and the fourth has the bridge above the middle of the internal end block (#17). In listening to the recordings, I characterised the three in-board-bridge dulcimers as having more “presence” than the end block-bridge dulcimer, which had a more “far-away” sound — to me. Not a very satisfactory description, nor even a representative test. It may hint at the spectrum of tonal changes that result as the bridge is moved from a position near the end of the instrument to a position closer to the centre of the lower bout; i.e., a change from the more plaintive, “traditional” sound to a more robust “modern” sound as the bridge position moves inward. Even if this proposition is true in a general way, there are likely to be many instances of individual dulcimers which do not follow this pattern. There are very few absolute rules in musical instrument making.

Figure 10.7. Bridge location comparison for four dulcimers

Bridge-end Fretboard Undercut – Test Results on One Instrument- Jan 01, 2016

A number of dulcimer makers, past and present, cut a slot under the fretboard of their dulcimers up to nearly the bridge position, to "relieve" the fretboard end. The strings are then terminated on this cantilevered portion of the fretboard end. The reason for doing this is usually about removing the influence of the relatively heavy end block on the way the bridge can transfer sound energy into the dulcimer box, and therefore making the sound somehow better.

There is no doubt that this modification ***can*** make a clearly audible difference to the tone. However, I have seen dulcimers that did seem improved in tone (to my ear, yours might be different), and others that were not very impressive at all.

The following tests were made to try to understand what was happening when a fretboard end is undercut.

The Experiment

I did this on my test dulcimer and the result was a noticeable tonal change that I did like, but which was not clearly "better" than the original, just "different and equally as good". As usual there are all sorts of qualifications to the results, and no free lunch – there do seem to be downsides to me. And the usual caveat applies – this is the test result of one dulcimer, others may not follow the same pattern.

The Tests

Some initial measurements were made on my test dulcimer and then a horizontal slot was cut in the fretboard from its end and almost up to the bridge position. Six configurations were tested which included whether there was a slot undercut; where the strings were attached and whether there was a downforce on the fretboard end by the strings,or not. The six test cases were:

- **Case #1** Fretboard end glued to end block (no undercut); strings attached to end block
- **Case #2** Fretboard end glued to end block (no undercut); strings attached to fretboard end
- **Case #3** Fretboard end undercut; strings attached to fretboard end. This pulled the end of the fretboard UP about 1mm.
- **Case #4** Fretboard end undercut; strings attached to fretboard end; slot closed with a light wedge
- **Case #5** Fretboard end undercut; strings attached to end block; strings over a saddle to prevent any pressure on fretboard end (unloaded)
- **Case #6** Fretboard end undercut; strings attached to end block; strings pressing down on fretboard end (loaded). This pressed the end of the fretboard DOWN about 1mm to touch the end block.

Figure 10.8 shows the setups. For each test case the same data were collected under constant conditions:

1. String strike recordings using a rod-pendulum-plectrum for adequate repeatability,
2. Standard test tune recordings,
3. Frequency spectra of the sound recordings of bridge taps with a rubber hammer, and
4. Vibration mode measurements (Chladni patterns[15]) – loudspeaker excited.

From these data, additional sound spectrographs were generated, and spectral Centre of Gravity (C of G) and sound pressure levels calculated.

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[15] Chladni patterns are the patterns formed when a flat plate covered with a fine material such as flour or sawdust is vibrated at a specific frequency. See Figure 2.8.

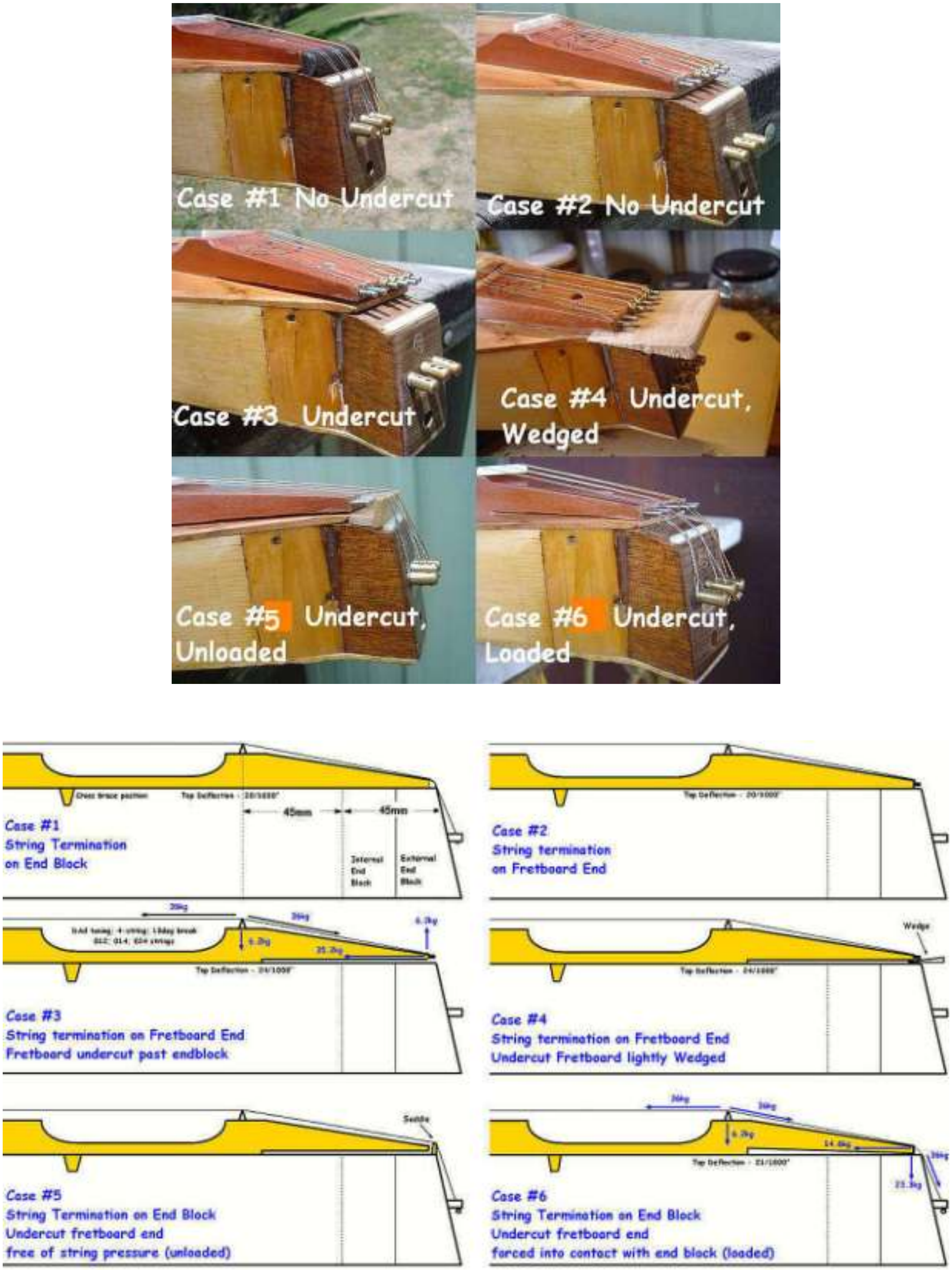
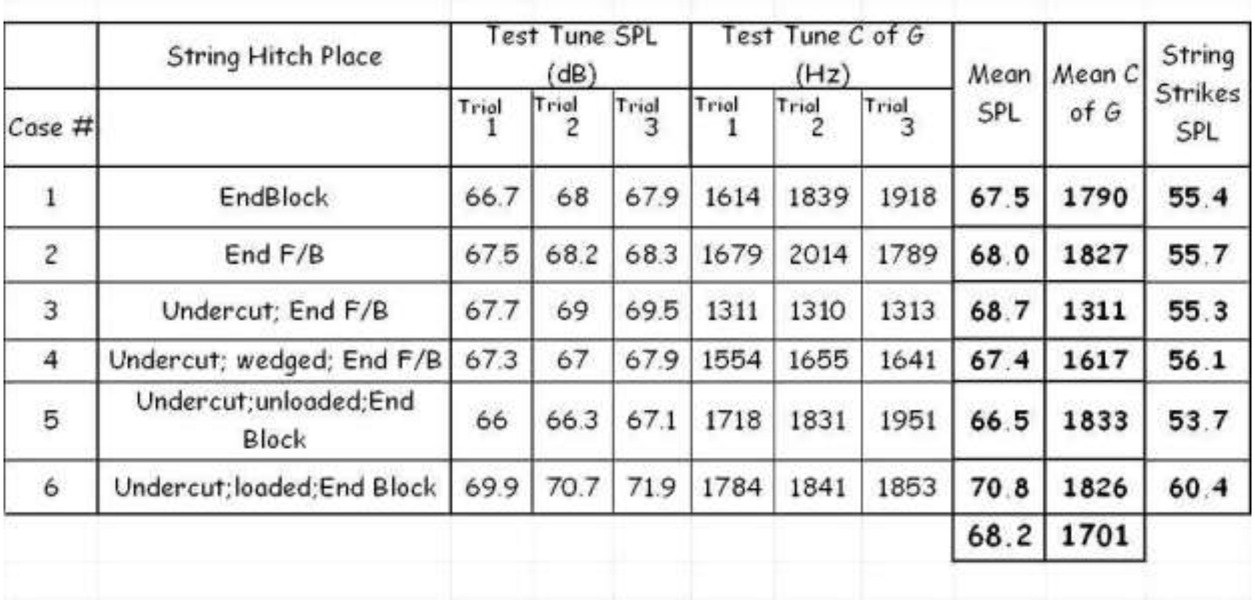


Figure 10.8. String termination and fretboard undercut pictures and diagrams

Results

Sound Pressure Levels: Sound pressure level measurements are shown in Table 10.3. The sound pressure levels were calculated using the PRAAT signal analysis software from the recordings of string strikes and test tunes. There were three test tunes for each test case, and 30 string strikes. The frequency spectrum of each recording was also used to calculate the Spectral Centre of Gravity —the frequency at which there was as much sound energy below as above. High C-of-G might point to a brighter tone; lower C-of-G might indicate a more mellow tone.

Table 10.3
Sound Pressure Level Measurements



	String Hitch Place	Test Tune SPL (dB)			Test Tune C of G (Hz)			Mean SPL	Mean C of G	String Strikes SPL
Case #		Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3			
1	EndBlock	66.7	68	67.9	1614	1839	1918	**67.5**	**1790**	**55.4**
2	End F/B	67.5	68.2	68.3	1679	2014	1789	**68.0**	**1827**	**55.7**
3	Undercut; End F/B	67.7	69	69.5	1311	1310	1313	**68.7**	**1311**	**55.3**
4	Undercut; wedged; End F/B	67.3	67	67.9	1554	1655	1641	**67.4**	**1617**	**56.1**
5	Undercut;unloaded;End Block	66	66.3	67.1	1718	1831	1951	**66.5**	**1833**	**53.7**
6	Undercut;loaded;End Block	69.9	70.7	71.9	1784	1841	1853	**70.8**	**1826**	**60.4**
								68.2	**1701**	

Overall, Case #6, loaded-undercut was a little louder, but there was not a lot of variation between all six test cases. So undercutting a fretboard end did not lead to much change in loudness in this dulcimer.

Case #3; the "standard" undercut configuration did have a consistently lower spectral C-of-G which might point to it being perceived as having a warmer tone.

Listening Preferences:The test tune recordings were randomized and the names anonymized and then ranked according to my listening preference (yours might be different) – three test tunes for each case. I did it twice on widely separated occasions.

The result was a consistent preference for Case #6 - Undercut-Loaded, followed by equal preference for Case#1 – Standard dulcimer (no undercut); and Case #3 – Standard undercut. The preference for Case#6 might have been because it was a little louder than the others – maybe just variation in the recording.

I consistently did ***not*** like Case #5 – Undercut-unloaded.

Bridge Tap Frequency Spectra: The bridge tap spectra for the various test cases showed some consistent similarities, and some differences associated with the undercut slot (Figure 10.9).

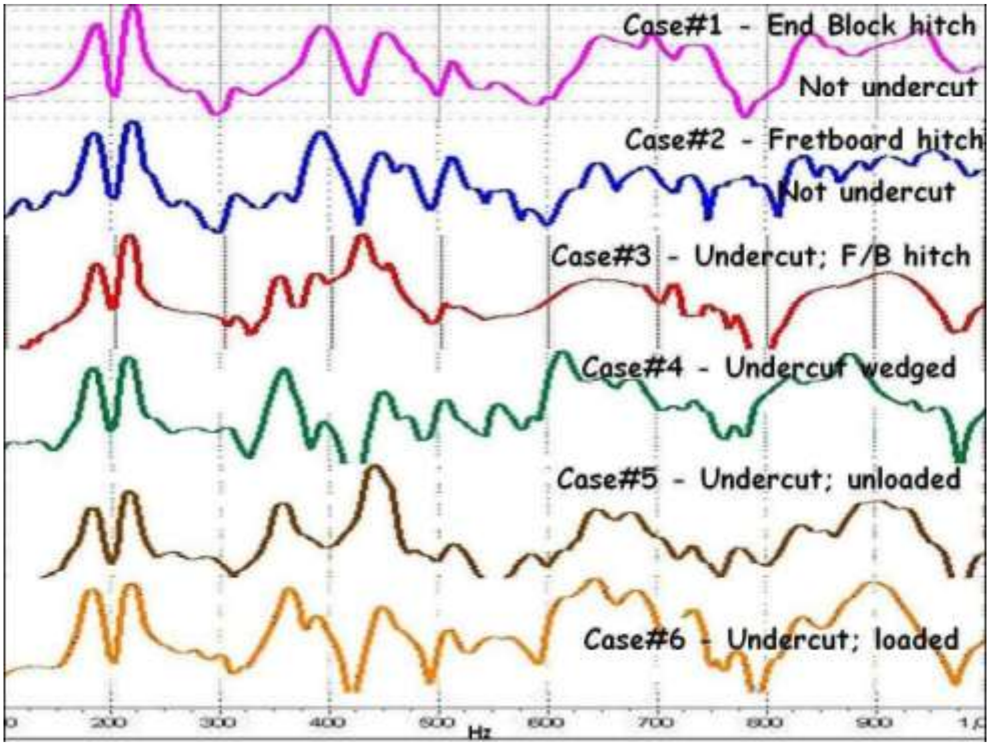


Figure 10.9. Bridge tap spectra for six fretboard undercut configurations (0 to 1000Hz)

When the undercut end of the fretboard was free to vibrate (Case #3 and Case #5) there was an additional strong resonant peak at about 430Hz. Otherwise the frequencies of the resonant peak series were fairly consistent over all test cases, though their amplitudes varied considerably.

Vibration Modes: For each peak in the bridge tap spectra we might expect to find an actual area of the dulcimer that can be made to vibrate easily at or near that frequency if excited by a loudspeaker (or the strings). However, there is not always a direct mapping of the bridge tap (natural) resonant frequencies, and those seen on the bench. The vibration mode series for the all test cases were fairly consistent in pattern and frequency. Figure 10.10 shows the vibration modes of the six cases at about 430Hz - the frequency of the extra resonance in Case #3 and Case #5 shown in Figure 10.9. Here, Case #6 (undercut, end loaded) did not exhibit a vibration mode close 430Hz.

Figure 10.10. Vibration modes near 430Hz

The patterns of the vibration modes in Figure 10.10 are not all the same, although the frequencies at which they occur across the six cases have a spread of less than half a semitone. This means that the different treatments of the fretboard end (undercut/no undercut, string hitch method, loaded/unloaded) have caused different parts of this dulcimer to vibrate at this frequency. That, in turn, means that the dulcimer has an altered sound intensity and/or sound radiation pattern for the different fretboard ends —at that frequency. The patterns for the two non-undercut cases (#1 and #2) are very similar, even though the strings are attached at different points. The other three (all undercut) are different from each other. This shows that undercutting the fretboard end ***can*** result in the whole dulcimer changing the way it vibrates — at least at some frequencies, which might be enough to change the character of the overall sound of the instrument.

But not all vibration modes are affected by the fretboard undercutting. Figure 10.11 shows another vibration mode that is very similar in shape and frequency across all fretboard end configurations.

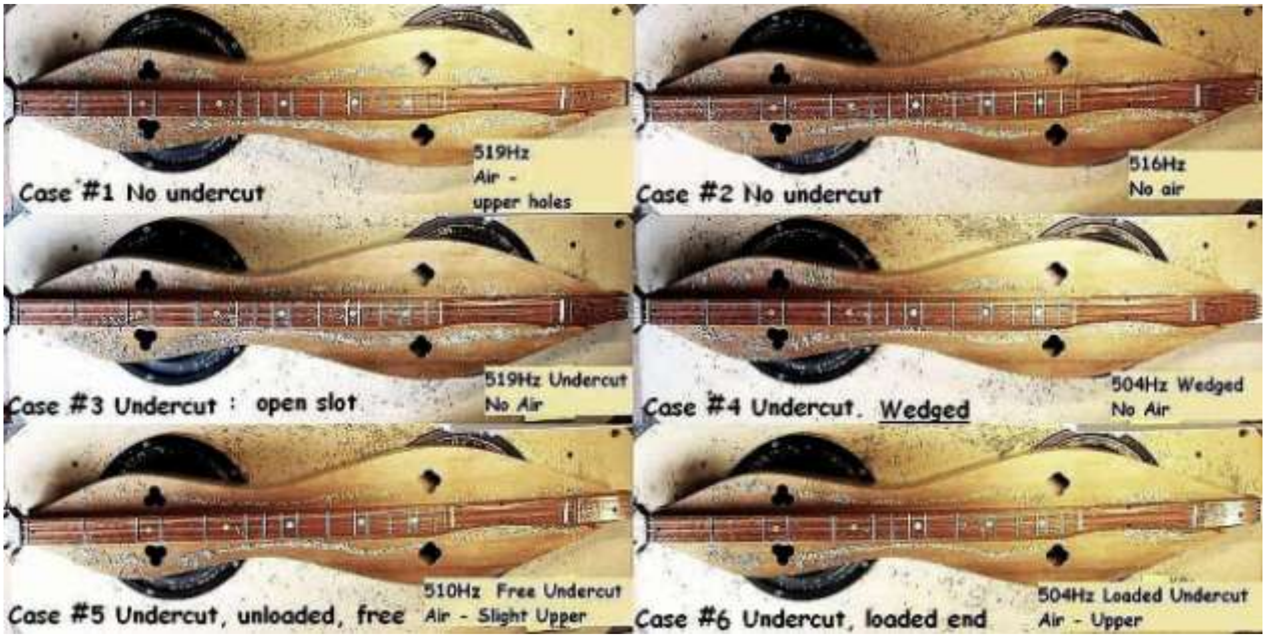


Figure 10.11. A vibration mode similar across all test cases

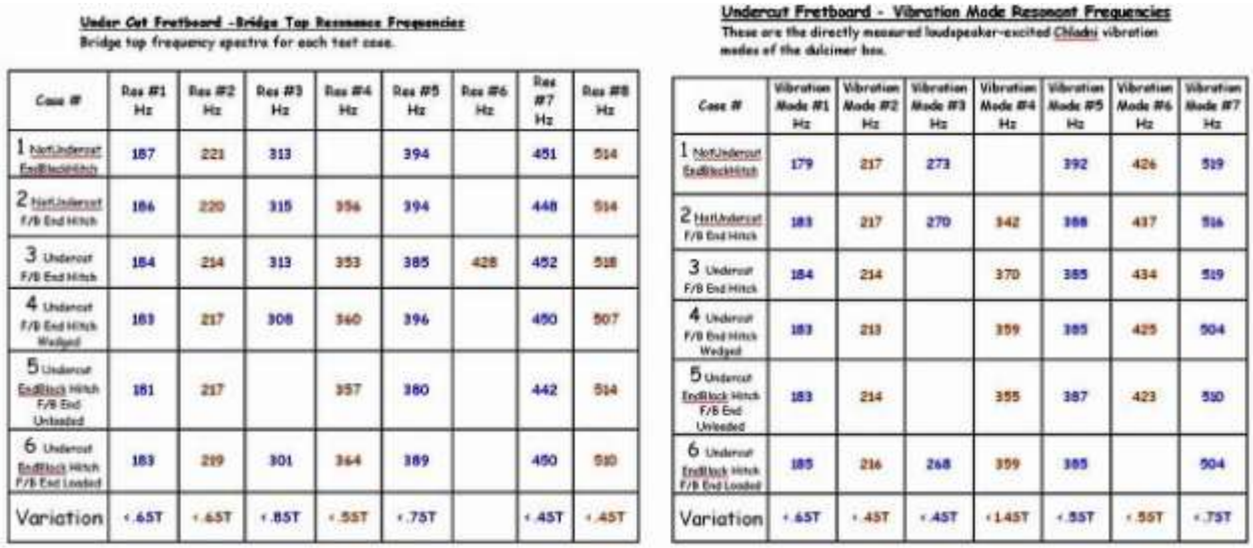
At this frequency (500Hz to 520Hz) the modifications to the fretboard end have not changed the way the dulcimer vibrates, hence has not changed the way it sounds at that frequency. So it seems that modification to the dulcimer tone, by undercutting ("relieving") the fretboard end, is not across the whole frequency spectrum, but occurs at specific frequencies related to new resonances in the undercut fretboard.

The frequencies of the various resonances for both the bridge-tap spectra (natural), and the vibration mode analysis (forced) are shown in Table 10.4.

Comparing the two sides, the undercut doesn't seem to have changed the basic resonance characteristics of the dulcimer box.

Spectrograms: Sound spectrograms of a great number of string strikes were analysed using PRAAT to see if there was any characteristic difference between the open slotted Case #3 and Case #4 where the slot was lightly wedged with a piece of wood. There was a clear tonal change when the open end of the fretboard was either lightly wedged, or had weights added to it. At frequencies around 430Hz there were spectrographic differences between open and wedged. Figure 10.12 shows spectrograms of string strikes.

Table 10.4.
Bridge Tap (natural) and Vibration Mode (forced) Resonant Frequencies



Under Cut Fretboard - Bridge Top Resonance Frequencies
Bridge top frequency spectra for each test case.

Case #	Res #1 Hz	Res #2 Hz	Res #3 Hz	Res #4 Hz	Res #5 Hz	Res #6 Hz	Res #7 Hz	Res #8 Hz
1 NotUndercut EndBlockHitch	187	221	313		394		451	514
2 NotUndercut F/B End Hitch	186	220	315	356	394		448	514
3 Undercut F/B End Hitch	184	214	313	353	385	428	452	518
4 Undercut F/B End Hitch Wedged	183	217	308	360	396		450	507
5 Undercut EndBlock Hitch F/B End Unloaded	181	217		357	380		442	514
6 Undercut EndBlock Hitch F/B End Loaded	183	219	301	364	389		450	510
Variation	±.65T	±.65T	±.85T	±.55T	±.75T		±.45T	±.45T

Undercut Fretboard - Vibration Mode Resonant Frequencies
These are the directly measured loudspeaker-excited Chladni vibration modes of the dulcimer box.

Case #	Vibration Mode #1 Hz	Vibration Mode #2 Hz	Vibration Mode #3 Hz	Vibration Mode #4 Hz	Vibration Mode #5 Hz	Vibration Mode #6 Hz	Vibration Mode #7 Hz
1 NotUndercut EndBlockHitch	179	217	273		392	426	519
2 NotUndercut F/B End Hitch	183	217	270	342	388	437	516
3 Undercut F/B End Hitch	184	214		370	385	434	519
4 Undercut F/B End Hitch Wedged	183	213		359	385	425	504
5 Undercut EndBlock Hitch F/B End Unloaded	183	214		355	387	423	510
6 Undercut EndBlock Hitch F/B End Loaded	185	216	268	359	385		504
Variation	±.65T	±.45T	±.45T	±1.45T	±.55T	±.55T	±.75T

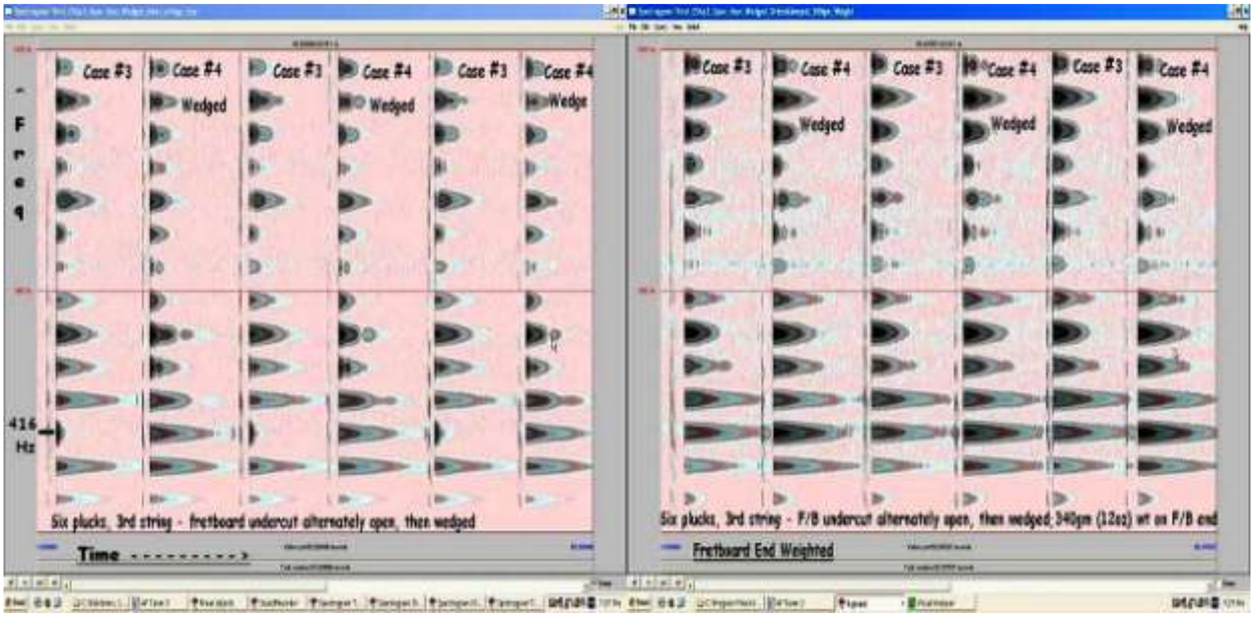


Figure 10.12. Spectrogram of string strikes with fretboard end un-weighted, then with 340gm weight attached; with undercut alternatively open then wedged

Each side shows six string strikes, firstly with the undercut slot open (Case #3), and then with the slot lightly wedged (Case #4). Vertical axis is frequency, horizontal is time. The series of little “flags” are the overtones of the fundamental - darkness of the “flag” indicates loudness of the overtone, and length represents its sustain. The right hand side has a weight attached to the end of the fretboard as well as being alternatively open then wedged (Figure 10.13).

Figure 10.13. Wedged and weighted fretboard end

It was consistently the case that any overtone occurring at about 430Hz was loud but short if the undercut slot was open. If the fretboard end was constrained from vibrating by touching or weighting, the overtone was unaffected by additional wedging, indicating that the extra resonance at that frequency was disrupted.

Fretboard End Vibration: The tap spectra, vibration mode testing, and the sound spectrograms all point to an additional resonant frequency in the fretboard end at about 430Hz. It seems to be flapping in the breeze like a harmonica reed. To see if this was actually the case I recorded open slot and wedged bridge tap spectra with both an air microphone and a small piezo transducer fixed to the cantilevered end of the fretboard. (Figure 10.14)

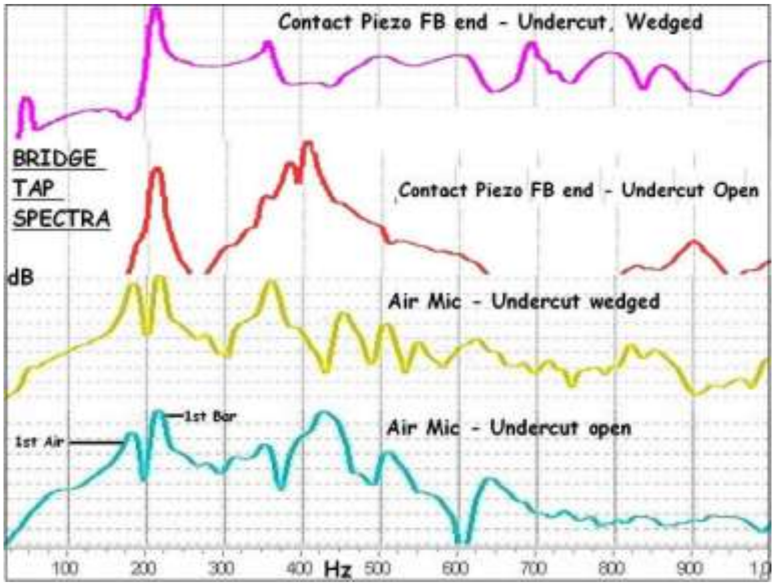


Figure 10.14. Bridge tap spectra for open and wedged fretboard end; recorded with piezo pickup and air microphone

When the undercut is open (and unweighted) there is a dominant resonance at 407 Hz, about 10dB stronger than the 1st bar resonance at about 220Hz. Note that the 1st air resonance does not show up with the contact pickup. It only picks up wood vibrations and the 1st air does not cause the end of the dulcimer to vibrate.

Conclusions

Undercutting the fretboard end of a mountain dulcimer can produce a significant change in overall tone. It may sound “better” to some listeners and others may prefer the original tone. In this one case it made the dulcimer no louder.

The reason for the tonal change does not appear related to the fretboard being glued to the mass of the end block, or released from it, but more likely to the presence of an additional fretboard resonance in the unconstrained end of the undercut fretboard. In this case it fell at about 430Hz — a frequency region that enhances the perception of warmth in a sound. It could be a different frequency in other implementations.

This fretboard-end resonance might be acting as an initial filter to the string-bridge vibrations, altering the strength and duration of overtones that are nearby in frequency, and hence modifying the overall tone of the dulcimer.

Anything that damps this fretboard-end vibration, such as touching, weighting or wedging, seems to revert the arrangement towards the tone of the original glued down fretboard end.
The fact that very small weights or light wedging can modify the overall tone in this case might mean that in different dulcimers with fretboards of different density and dimension it might be possible to “tune” the sound in some respects, particularly for specific string tunings, by adding or removing weight to/from the fretboard end.

The undercut did not generally seem to modify the way the whole dulcimer box vibrated – it appears to be an initial filtering of the string frequencies into the box.

Is there a price to pay for this tonal change? There might be in the long term. The upward string pull component on this fretboard end for an open slot totals about 6kg (13lb). That’s the weight of two housebricks pulling upwards on the unsupported fretboard end. Depending on the materials and design, over time that stress might become significant.

An additional contributor to the tonal change, which is only speculation, is that with the open slot I thought that the end block of the dulcimer vibrated more strongly than with a glued down fretboard. This was a subjective judgement on my part by feeling the dulcimer end with my fingers. If this is the case, then the cutting of the fretboard slot has allowed the 1st bar vibration mode to become stronger. The 1st bar mode is an important component of the overall dulcimer sound. So it would be ironic if the removal of the fretboard from the end block allowed the end block to vibrate more rather than the fretboard, which is usually the reason stated for doing it in the first place. I investigated this possibility.

Using a small button piezo pickup to directly measure the vibrations of the cantilevered fretboard end and the external endblock itself, did not support my subjective impressions. For this dulcimer, at both the resonant frequency of the end fretboard (~430Hz) and off that frequency, the end block remains basically unaffected by the undercut fretboard. Except that the 3rd harmonic at the resonant frequency (430Hz) is loud but short at the end block, whilst much longer at the end of the fretboard (Note: there is no energy in the fundamental here - the 1st harmonic - so it is missing). Not surprisingly — at the resonant frequency of ~430Hz the string energy is being spent moving the fretboard end rather than transferring into the dulcimer body.

Figure 10.15 shows six notes with the piezo pickup at the base of the end block, then fixed to the end of the fretboard — alternately with the slot open, then wedged — three of each. The corresponding spectrograms are to the right of the string sound and sound pressure level waveforms.

The series of harmonics for the wedged condition is basically the same whether recorded from the base of the end block, or from the end of the fretboard – the two are hard-connected by the wooden wedge.

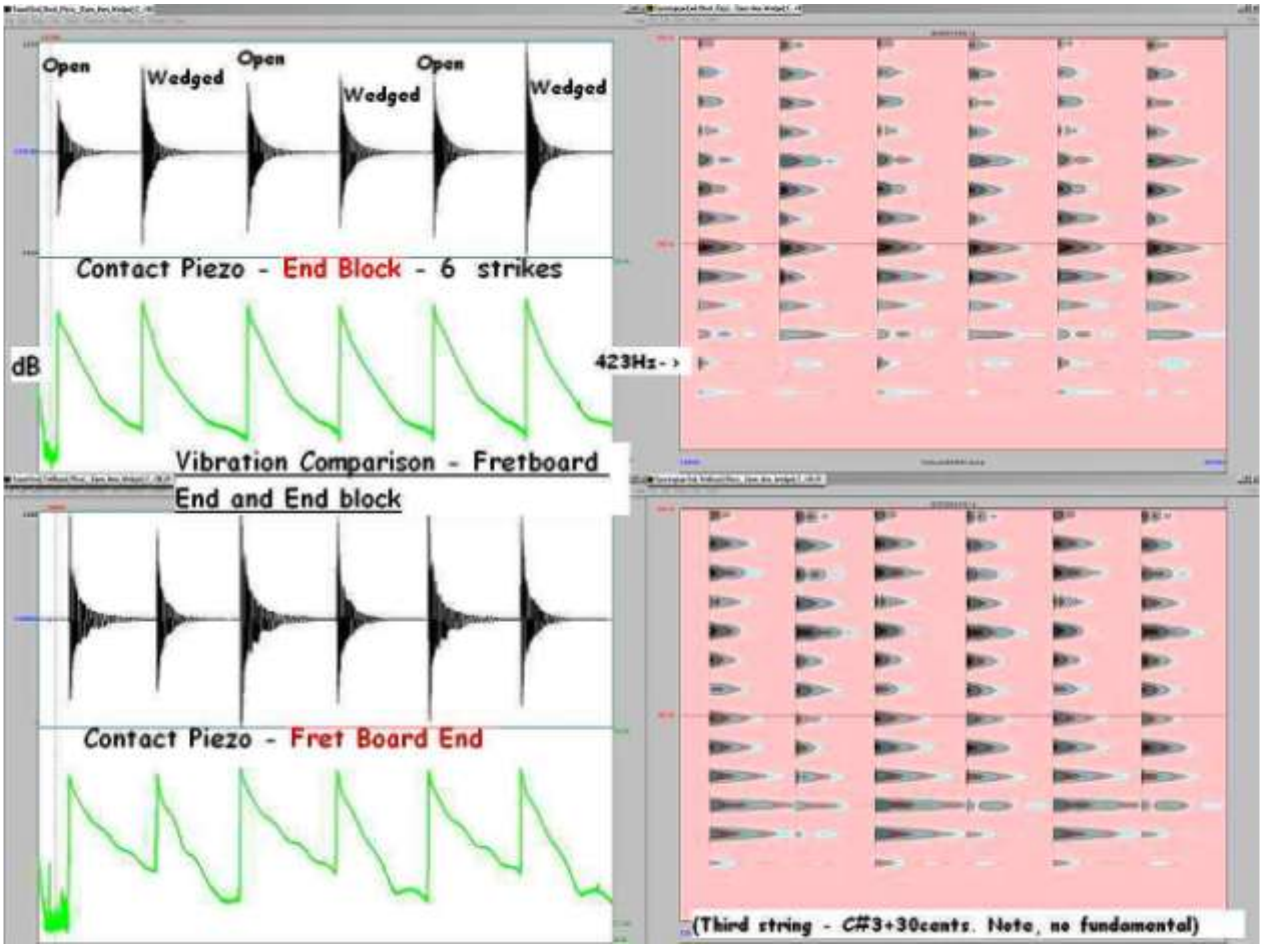


Figure 10.15. Vibration and spectrogram showing effects of position of recording pickup, with end slot open, then wedged

When the slot is open there ***are*** differences in the harmonic series for the fretboard end and the endblock, however the end block harmonics are not clearly louder or of longer duration than the fretboard end harmonics. Neither are the free fretboard end harmonics louder/longer overall than when the fretboard is connected to the endblock. So the premise of allowing the fretboard to vibrate more, by separating it from the endblock, is also not supported.

Other than the damping of endblock harmonics at the fretboard resonant frequency, the picture is the same at other string tunings.

Chapter 11
Bracing

Bracing Effects Dec 23, 2008

Sometimes the bracing I have put on the tops has been stiff, and sometimes light, in an attempt to match the cross-grain and long-grain stiffness. I've tried the method that Dwain Wilder[16] uses of arching the braces, and the method that Terry Hennessy uses, flat braces. But I don't think any variation I've tried has had a clear effect, so my conclusion is that the top bracing is mainly for strength, and doesn't do much one way or the other to the sound (I'm only talking about cross braces here, not other forms such as lattice or X-bracing). In the guitar world, the top bracing contributes to making the cross-grain stiffness of the plate more similar to the long-grain stiffness. That also used to be my aim with dulcimer tops, but I no longer think it's a valid analogy. So, I think tops with no bracing is good also, as far as sound goes, just not as strong. The sound holes, along with the box volume, set the two lowest air resonances (in 4-hole dulcimers anyway), which I do think are quite important to the low-end warmth of the sound, such as it is in mountain dulcimers.

The paper top dulcimer had a bridged fretboard (but with four arches instead of eight). I think the commonly promoted argument of "freeing up soundboard area so it can vibrate more" is a spurious one. It's a natural cross-over from how a guitar top behaves, but I can't find any evidence that mountain dulcimers act that way. And in any case, who is to say that more vibration is necessarily better vibration? Also, what parts of a dulcimer vibrate, certainly not only the top? Also, whilst the mass of dulcimer components is a consideration, it is not the only one; stiffness is also very important. The stiffness of the fretboard is a defining factor in how it will vibrate, and a typical fretboard has a stiffness that dominates the top plate to the extent that the top plate mass and stiffness may be almost irrelevant. The top will vibrate as the stiffness of the fretboard/box combination dictates - not in its own right. I don't think of the fretboard as a brace; i.e., something that modulates the tone or adds strength, or both. It's more of a major structural component. Depending on how a fretboard is shaped, and the material it is made of, a hollow fretboard and an arched one, or even a solid one, may have the same weight and stiffness, and may produce similar sounds.

I'm moderately confident that the main role of the top is to contain the air in the box, and it doesn't matter very much what it is made of – what species of wood. I also do

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[16] http://bearmeadow.com/about/Dwain/index.html

think that the fretboard is an important contributor to the sound (but not because it is arched, hollow, or solid), and is worthy of further investigation to see what it's effects are.

All this relates to full length fretboards. There will come a point, such as top plates 1/2" thick, and fretboards 1/4" high, where things start to get reversed and tops become more important than fretboards in setting stiffness - but those won't be on a typical mountain dulcimer.

Arched Brace-Dec 13, 2009

I made one instrument with arched bracing and though it wasn’t a wonderful instrument, it wasn’t to do with the bracing.

Arching the braces implies the arching of the back and top plates to create a plate that is under a tension to revert to a flatter state. Of the possible effects of this arching on vibration modes of the dulcimer - no one knows. Some guitar makers, some dulcimer makers, and some piano makers advocate the arching of the top plates or soundboards for various (not very rigorously supported) reasons, usually including the fact that the top/soundboard is under a constant tension. A greater number of makers do not subscribe to this idea that a top under tension will produce a superior sound. I have not done any vibration tests on this arched-top dulcimer, and in fact have not done much vibration testing on completed instruments in general because I was trying to come to grips with the vibration modes of the free plates, top and back, before gluing to the sides, and therefore alterable. Having failed to find anything useful in that area, I’ve had a look at the way completed instruments vibrate, and whilst there were no “Eureka” moments, something has been learned. In general, the vibration modes of dulcimers have been fairly simple at all frequencies, top and back. Mainly they are what might be the dulcimer equivalent of the 0,0 or “trampoline” vibration mode —an oval shape that just pumps in and out, with the exception of a very clear 1st bar vibration mode. So, it may be that arched tops and backs add a tonal edge over non-arched plates, but no one knows for sure, and evidence is slight. Only the listener can judge, and then he or she is probably biased by the undoubted aesthetic edge of a gentle curve over a flat plate.

Brace Purpose-Apr 08, 2009

The purpose of my bracing, back and top, is basically for strength. I don't believe bracing does much to, or for, the sound in a mountain dulcimer of standard configuration. I tend to overbrace rather than underbrace. In addition, I've noticed that strongly braced backs don't suffer so much damping on the knee as unbraced ones. The price to pay may be that a heavily back-braced instrument then tends to a treble emphasis rather than a mellow one.

I've made unbraced instruments that were very quiet, and heavily braced instruments that were quite loud. I think other factors control loudness more than bracing does - position of bridge, size of sound box, nature of the fretboard, etc.

But, cross bracing increases stiffness across the grain, which is what I'm aiming to do. The Western Red Cedar tops, and the New Guinea Rosewood backs I frequently use are woods that can split along the grain, so I feel more comfortable having them well supported with braces. In the same shape dulcimers, I've noticed that changing the bracing hasn't affected the sound noticeably, so I'd rather have the braces stronger than less strong. I want my instruments to have a sporting chance of being around and playable 100 years from now.

I've also consistently noticed that the more heavily braced the back is, the less of an effect on the sound when the instrument is played on the knee. There is always some effect of course, but the lighter the bracing, the greater the knee damping. Where that observation fits into ideas about which parts of the instrument contribute to the overall sound - I don't know.

Of course, loudness isn't everything. However, a loud dulcimer can always be played more softly, but not the reverse; so increased loudness is a goal, as well as the quality of tone, and sustain.

Further Observations on Dulcimer Braces and Tops- May 22, 2010

I did some tests without the braces after I replaced the top and removed the bracing from my plywood test dulcimer. It then seemed sensible to see what affect partial bracing might have, so I put back the braces on the back plate – on the outside, but in the same positions (Figure 11.1). This should have no affect on the way the back vibrates – it will have the same stiffness whether the braces are on the inside or the outside.

Figure 11.1. Back braces installed on outside of the test dulcimer

The results were that the lower resonances, below about 1000Hz, seemed to fall in unison as the stiffness was reduced. Figure 11.2 shows the bridge tap resonances for the three conditions.

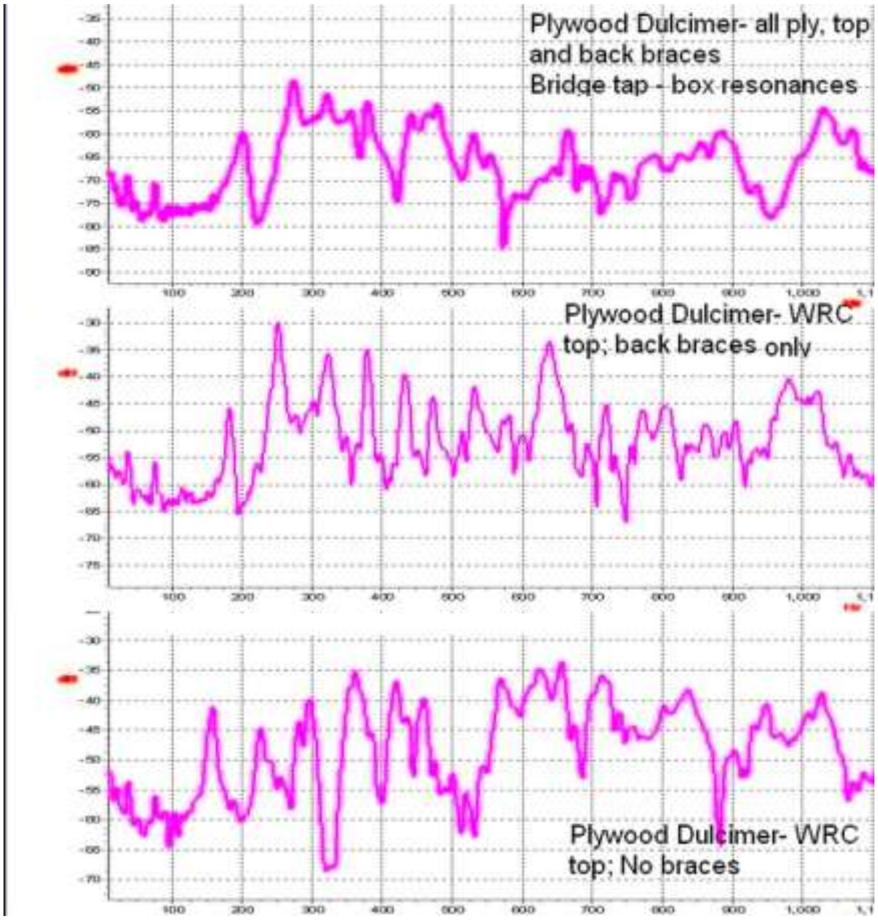


Figure 11.2. Bridge tap resonances for test dulcimer with and without braces

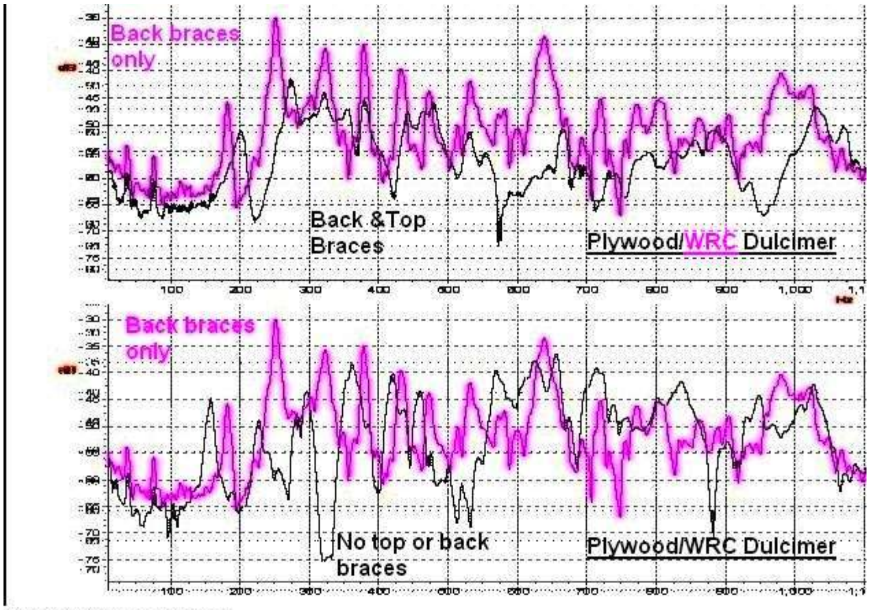
The frequencies of these resonances are very repeatable in an instrument – I've gone back and checked on dulcimers I measured three years ago and I always get the same results, at least below about 1000Hz — above that it gets a bit unpredictable. The amplitudes of the resonances vary quite a bit, which is because of the different ways I tap the bridge at different tests — I don't have a standardized hammer-strike or microphone placement, but the resonant frequencies are always stable.

It's a little difficult to match up the individual resonance peaks, but below about 500Hz it can be carefully done. The air resonances were confirmed by other means as well. As the bracing went from top and back to back only to no bracing, the lower resonances fell in frequency by about 20Hz for each change (Table 11.1and Figure 11.3).

This is in line with the proposition that as stiffness falls, so does the resonant frequency, but I hadn't expected it to affect the whole of the lower spectrum. There are two interesting observations (from a purely technical stand point). The two lowest air resonances seemed to change a bit more than the 1st bar resonance, to the extent that the 1st bar and 2nd air resonances reversed position in the resonance sequence for the no-braces case. The other observation was that there was an additional resonance in the sequence between the first and second air resonances (273, 251 and 227Hz for the three configurations). It's a strong one and I don't know what it is – it doesn't occur in other dulcimers I have measured, but does indicate that these resonant sequences don't always follow the "rules".

Table 11.1
Effect of Braces on Dulcimer Resonances

Resonance	**Top& Back Braces**	**Back Braces Only**	**No Braces**
1st air	200Hz	182Hz	158Hz
2nd resonance	273Hz	251Hz	227Hz
2nd air	354Hz	322Hz	280Hz
1st bar	322Hz	300Hz	295Hz



Back and Top Braces

200 (1st Air); 273; 322(1st Bar); 354(2nd Air) 379; 442; 464;
480; 530; 554; 665; 787; 825; 857; 882;
1029; 1071Hz

Back Braces Only

182 (1st Air); 251; 300 (1st Bar); 322 (2nd Air); 379;
433; 473; 514; 532; 580; 638; 720; 771; 802; 861;
906; 981; 1022 Hz

No Braces

2nd Air and 1st Bar are reversed in order

158 (1st Air); 227 ; 280 (2nd Air); 295;(1st Bar)
361; 420; 458; 570; 624; 656; 717; 801; 835;
949; 1026 Hz

Figure 11.3. Frequency spectra for three brace conditions

As for the sound of the modified dulcimer, I didn't make recordings for comparison. And the time lapse between my listening was from one day to the next, while the glue dried. So it wasn't an ideal listening comparison, but if I had to rank my order of preference for the sound I'd say:

- WRCedar top/no braces on top or back, then
- WRCedar top/braces on back braces but not on top, then
- Plywood top/full braces on top and back.

The test dulcimer has a sweet and gentle sound, tending to thin, but it doesn't have any "oomph" or cutting power on the upper fretboard. It's nice when played quietly and melodically, late at night say, but poor when strummed strongly or when an attempt is made to use a larger dynamic loudness range. This general characterization of the sound remained the case for all top and bracing configurations.

So, what might this mean to a maker?

The common factors are the 3mm plywood back and sides and the fretboard. Whilst replacing the plywood top with a good quality solid wood top, and maybe the brace removal, did improve the sound a little; I still judge it a poor sounding instrument, and the overall sound character was essentially unchanged. I've developed the feeling that the back and sides material (species of wood, and thickness/mass) is important to the general tone. The observation of the lower resonances moving upward in frequency with increasing stiffness (bracing) didn't seem to radically change the sound – perhaps because the relative spacing between the resonances was largely preserved. The fretboard was also unchanged, and I think this is important in determining how the top plate vibrates.

So the take home message, hinted at but not proven, is that better quality and different species of wood for backs and sides might significantly affect the tone of the finished dulcimer; adding top and back bracing doesn't seem to sacrifice too much of the sound; and a good quality top plate might be better than a poor quality one, but not to the same extent as in the back and sides.

As is usual in instrument making in general, these conclusions are likely to have exceptions and modifications in individual cases.

Bracing Issues-Aug 29, 2010

There was a suggestion that the vibration modes of the free back plate be checked before gluing on any bracing with a view to then modifying the plate and checking again until a target vibration state is reached. Unfortunately this assumes we know what vibration modes we want, and at what frequencies we want them, and how they will affect the sound. But we don't. In general the modes of the back (and the top) focus on the major bout and have a form similar to that shown in Figure 11.4. This is the 0,0 pattern of vibration – the trampoline mode.

Figure 11.4. Typical 0,0 vibration mode — Yellow Stringbark back.

Cross braces don't seem to interfere with these patterns too much, but to make it a bit easier for these ring modes to develop, the next step on my test dulcimer is to replace the Yellow Stringybark with a Balsa back, which weighs 1/4 as much as the Stringbark, and with the bracing shown in Figure 11.5.

Figure 11.5. New Balsawood back and bracing

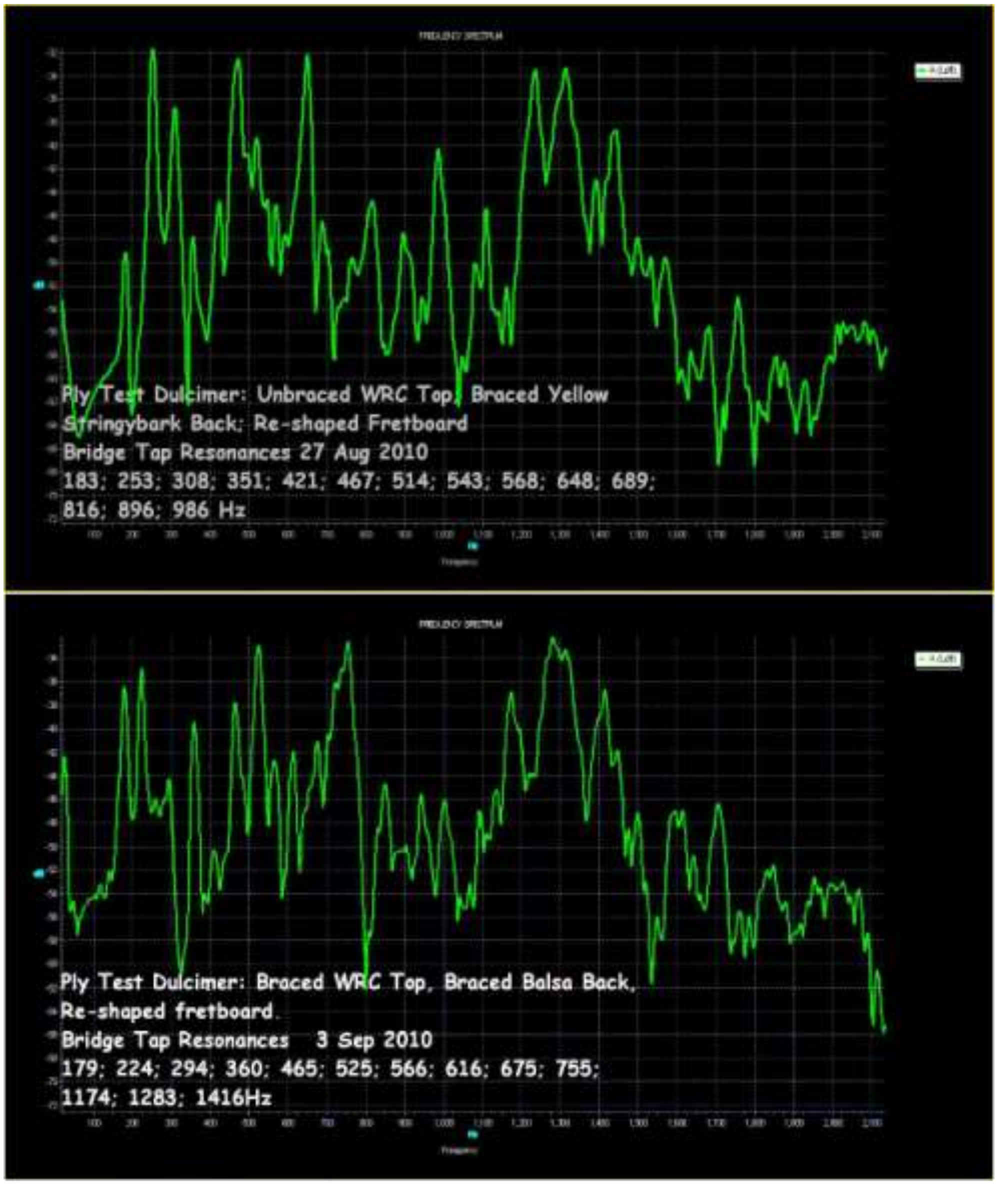
My thinking is that the bracing is symmetrical; still adds strength to the back; and is flexible at the edges where the back must hinge. Time will tell if it makes any difference at all — the weight change may be the over-riding factor in any sound change.

Heavy vs Light Back and Top Bracing-Sep 04, 2010

The Yellow Stringybark back on my test dulcimer, was replaced with a braced Balsa back that weighed 1/4 as much. The Stringybark can be used later as a false back to protect the Balsa — to see if a double backed instrument sounds different or louder. I also lightly braced the Western Red Cedar top while I had the back off. (Figure 11.6.)

Figure 11.6. Western Red Cedar top and Balsa back bracing

The result was, I think, a further improvement in the sound to my taste, but not dramatic. Compared to the Yellow Stringybark back, the Balsa back bridge tap spectrum was changed somewhat in the lower frequencies (Figure 11.7). The first and second air resonances (179Hz/294Hz, Balsa vs 183Hz/308Hz, Yellow Stringybark) fell a little in frequency, but mainly the strength of the first air resonance was increased greatly with the balsa back. (But note — the Yellow Stringybark back also had an unbraced Western Red Cedar top whereas the new Balsa back had a top that was braced.)



Ply Test Dulcimer: Unbraced WRC Top, Braced Yellow Stringybark Back; Re-shaped Fretboard
Bridge Tap Resonances 27 Aug 2010
183; 253; 308; 351; 421; 467; 514; 543; 568; 648; 689; 816; 896; 986 Hz

Ply Test Dulcimer: Braced WRC Top, Braced Balsa Back, Re-shaped fretboard.
Bridge Tap Resonances 3 Sep 2010
179; 224; 294; 360; 465; 525; 566; 616; 675; 755; 1174; 1283; 1416Hz

Figure 11.7. Braced Yellow Stringbark /balsa back spectra

The addition of the very light Balsa back significantly reduced the sound level difference between the top and the back compared with the heavy, but fairly flexible Stringybark back.; i.e., the Balsa back was relatively louder than the Yellow Stringybark back. Unlike some other dulcimers, this test dulcimer had about the same loudness difference front to back on both the lower fretboard and the upper fretboard, and this was the case for both Stringybark and Balsa - heavy and light. However, with the heavy back, the top had about four times the sound output than the back, but with the light back, the top had only about 1 1/2 times greater sound output than the back. The Balsa back is also very sensitive to knee damping.

So, heavy backs might emphasize the sound coming from the top more than a light back does. Which leads to the question: Is it better to have the top dominate the sound output (heavier back), or is a closer loudness balance between top and back better (lighter back)? The question of sound coloration by the two different woods (top and back) is probably related. The Stringybark back can later be used as a double back over the Balsa back.

Vibration testing of the Balsa-back test dulcimer produced some unusual results that may be relevant to the question of whether an arched fretboard allows the top plate to vibrate differently to a continuous fretboard.

The vibration patterns around the feet of arched fretboards have been a topic of discussion amongst dulcimer makers. The vibration modes of this arched fretboard test dulcimer, in Figures 11.8-11.15, show some unusual patterns, some of which clearly depend on the arching of the fretboard for their shape. I'm not sure how to interpret some of them.

First, in Figure 11.8, vibration modes clearly extend under the arch of a fretboard, and out the other side, well away from the fretboard feet.

In these two cases, the center of the distance between the arches is stationary (a nodal line) so the fretboard feet (and hence fretboard itself) must be vibrating equidistant from the node. This might indicate that the fretboard feet are dictating the parts of the top that can vibrate (at these frequencies).

Then there is the pattern shown in Figure 11.9 at a higher frequency. In this pattern there are two nodal lines, both under the same arch, and quite close to two fretboard feet. The light top plate is flexing in a circle under the arch with two heavy feet just outside the circle. Circle middle goes up; the two feet must go down. It is hard to say what is driving what, but I suspect the fretboard is the controller.

Figure 11.8. Vibration pattern relative to arch feet

Figure 11.9 Vibration pattern at 695 Hz

Next is the pattern in Figure 11.10, where the top plate is vibrating in a way that appears to be avoiding the feet altogether – the fretboard is vibrating as a whole. The “Some air” notation means that there is some airflow detectable from a soundhole (by holding a finger or piece of paper over the hole). This means that this particular resonance is an internal air resonance that has coupled to the wood plates because of pressure fluctuations in the air. The wood then radiates sound energy that we can hear. The air vibrations may also radiate some sound from the sound holes if a peak of the internal standing waves coincides with a sound hole position.

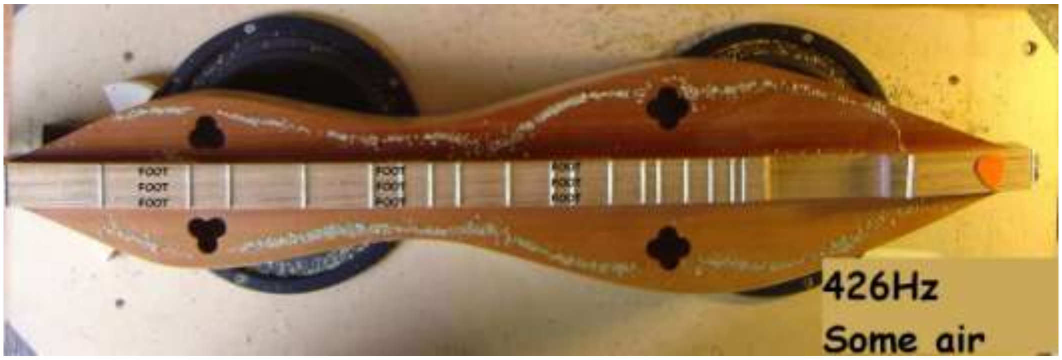


Figure 11.10 Vibration pattern avoiding feet

The pattern in Figure 11.11 shows the vibrations of the plate running up to a fretboard foot and stopping there.

Figure 11.11. Vibration pattern stopping at feet

However, this pattern also occurs in hollow, non-arched fretboards, so it is probably a coincidence that the foot happens to be at that spot. Figure 11.12 shows the same vibration pattern for two continuous fretboard dulcimers.

Figure 11.12. Vibration pattern for continous fretboards

I haven't seen the pattern in Figure 11.13 before, and certainly not with a continuous fretboard

Figure 11.13. Asymetrical vibration pattern

I don't know what to make of this, but that's how this top was vibrating at this frequency. It is evidence that the vibration modes of an individual instrument do not always follow predictable patterns.

In addition, there were also twisting modes of vibration, but they were only on the top, not the back, so the whole dulcimer wasn't twisting (as far as I could tell). This ***might*** be an equivalent of the cross dipole mode of vibration in a guitar top where one side of the sound board goes up while the other side goes down. In this dulcimer (Figure 11.14), the nodal line is clearly running down the center of the fretboard. There were two or three of these twisting modal patterns in this Balsa backed dulcimer.

Figure 11.14. Twisting vibration mode

Figure 11.15 shows another possible cross dipole vibration mode.

Figure 11.15. Possible cross dipole vibration

These patterns are ***atypical***. Most vibration modes in mountain dulcimers are representative of a standard set of vibration patterns, at least below about 1000Hz. Above 1000Hz the vibration patterns become quite idiosyncratic in each instrument – this test dulcimer is an example of the idiosyncrasy extending into the lower modes of vibration. Unfortunately, it did not translate into a superior sounding instrument.

Effect of Top Plate Bracing- Oct 19, 2011

A cross braced top would be stiffer across the grain, but along the grain it will be basically unchanged. At the lower frequencies, the top of a dulcimer mainly flexes around the edges, so if the braces are tapered in height towards the edge, the total edge stiffness should not change much because there are only a few braces and a lot of edge. In the middle where the brace would have to go up and down the most, the stiffness is still dominated by the fretboard, so even though the braced top is stiffer across the grain, it might not interfere with vibration very much at the lower end of the range (but it will to some extent). At the higher frequencies, the areas of vibration become small enough to fit between the braces, even if the braces themselves don't move much (but they do). That's my thinking, and it is supported by crude (and unreliable) listening tests on my test dulcimer with and without top braces. Overall, a braced top probably loses a little bass end because of the bracing, and gains a little upper fretboard "ring". I like a nice ringing high fretboard, and you can't get that by just increasing the size of the box. I think all changes in structure will affect different parts of the dulcimer's sound range to different degrees, so just testing by strumming the first few frets won't give the whole picture. Whether it matters is a question only the player can answer.

I suspect that changes in the stiffness of the box itself have less effect on sound than stiffness changes in the fretboard/top. One maker reports that a change in box capacity of about 2% was sufficient to change the sound. If that sort of volume change affects the sound slightly, then the volume displaced by internal linings and bracing would also have a similar effect. Maybe they do.

I haven't checked the stiffness of the top/fretboard with and without cross braces. I normally put the braces on first, then the fretboard. But it's easy to do it the other way round and I'll check it next time. I don't think there'll be much difference, but we'll see.

Teardrop Bracing- Oct 28, 2011

I've only made five teardrop dulcimers and only two since I started making instruments seriously. The bracing on those two is pictured in Figure 11.16.

Both of these were before I had done any experimenting of my own, and were just shots in the dark. The top one had the most unusual sound of any dulcimer I have made, but not a sound I was looking for. It was extremely loud, not much bass, but not tinny or thin - sweet and strong treble/mid sound. The other one was a lot larger, but had a fairly thin, possibly more traditional sound - not loud, but fairly sweet, but again, not what I was after.

So, I wouldn't draw many conclusions about bracing from these two. If I made teardrops again I still might do something like the one with the leaves sound holes, but the fretboards probably affected the sound in these two a great deal. I didn't understand that at the time.

Figure 11.16. Teardrop dulcimer bracing

Effect on Long Axis Stiffness of Cross Bracing Tops- Dec 03, 2011

A while back I said I'd check to see if the addition of cross bracing on a mountain dulcimer top might affect the long grain stiffness as well as across the grain. I tested this on two dulcimer tops and the general answer is that there is no difference in static long axis stiffness with or without cross bracing.

The top without bracing are shown in Figure 11.17 and with the braces in 11.18.

Figure 11.17. Top without bracing

Figure 11.18. Top with bracing

The completed fretboard was already attached in both cases and the braces were positioned under each fretboard foot (Figure 11.19).

Figure 11.19. Top with fretboard

I tested the static deflection at weights from 0.5kg to 7.5kg, and it was surprisingly linear. There was absolutely no difference with or without braces - the deviations in the graph are basically reading errors on the dial gauge. The deflections under different weights are shown in Figure 11.20.

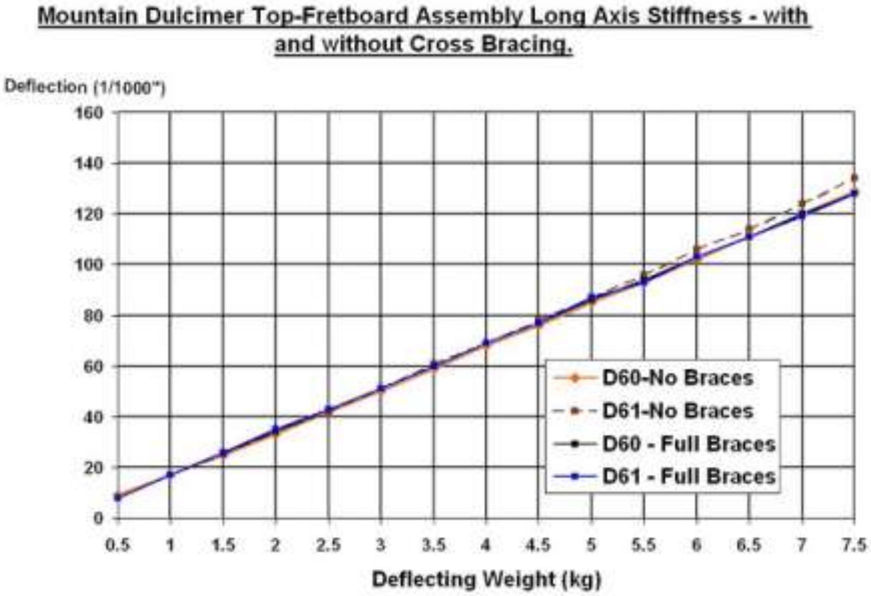


Figure 11.20. Deflection vs. weight for two teardrop dulcimers

The braces were left unshaped for the test to give the worst case scenario – they were tapered before the top was glued on.

This means that cross bracing doesn't change the long grain static stiffness of a top in any noticeable way (although the top cross section will deform a small amount under deflection, and cross bracing would interfere with this minutely). When glued to the sides, the top will change its long and cross grain static stiffness again.

But this test is only for the static deflection - it doesn't say much about the dynamic stiffness under the influence of the strings, and at much lower levels of deflection when playing music. The dynamic stiffness is likely to be different at different frequencies, but even so, the cross braces shouldn't constrain bending in the long grain direction any more than in the static case. My contention is that they don't modify bending in the cross grain direction a lot either.

Correction: cross braces will, of course, modify the overall cross grain stiffness - I meant they don't much modify the way a mountain dulcimer top plate vibrates (in oval modes at the plate edge at the lower frequencies), because of the dominance of the fretboard, and hence don't have a major effect on the sound.

Further Notes on the Effect of Top and Back Bracing- Sep 19, 2015

Players have noted that the mountain dulcimers of George Orthey in Newport Pa. Are quite loud, and one player provided general dimensions and photographs of his Orthey dulcimer, so I made myself a replica, as best I could.

Figure 11.21. Replica of George Orthey dulcimer

It is a very lightly built instrument and it turned out to have a ***very*** nice sound – I would be pleased if my own dulcimers sounded as good. I can’t say whether it sounds like a typical Orthey (never seen or heard one), or how much the design vs the materials was responsible, or if I just got lucky with the combination of everything. But the instrument has a clarity of sound and ease of tuning and playing that is very pleasing. There was nothing I disliked about the sound.

So I thought “Why not try to improve it?” The essence of this dulcimer is a light and stiff fretboard/top assembly with a light and flexible back. The fretboard is hollowed and arched, and the hollow extends to just in front of the bridge, which sits above the end block. Originally there were no top or back braces, but I was interested to see the effect of adding bracing to an already good instrument. In the past, I have added/removed bracing from my plywood test dulcimer with no real change in tone – but I never thought it was a fine sounding instrument to start with.

So, I sawed the back off the Orthey replica and installed five full width braces on the top and back plates, and glued the back on again. There was about 1mm reduction in the side height afterwards, caused by the saw cut and sanding. Figure 11.22 shows the dulcimer before and after adding bracing.

Figure 11.22. Orthey dulcimer replica without and with bracing

The effect? Installing top and back bracing did not result in a better sound. It was generally the same, but there was an additional tone which had a boominess about it, and several frets had what I would call "wolf notes" – a clear difference in tone compared to adjacent frets. Overall, adding the bracing was not an improvement.

After a while, I decided to go back to the original state of no bracing – a sharp flat steel rod, some splintering of wood, some scratches of sound hole edges and the two major bout braces from the top and the bottom were removed. The waist braces and the two minor bout braces were still in place on the top and the back – only the major bout braces were removed. I made some measurements as each brace was removed and listened for any tonal changes. The order of removal was 1st top brace (closest to bridge); 2nd top brace; 1st back brace and finally, 2nd back brace.

Removal of major bout top braces did not audibly change the sound. The wolf notes were still there and the general tone was the same.

Removal of the 1st major bout back brace did reduce the wolf notes, but overall the tone seemed thinner.

Removal of the 2nd major bout back brace sounded very like the original no-brace configuration.

There are a number of things to note here.

- This is a clear case of top/back bracing degrading the sound of a mountain dulcimer – bracing does not necessarily result in a better sound.
- The bracing seemed to be responsible for the introduction of wolf notes to the instrument.
- The top bracing seemed to have much less of an effect on the tonal changes than the back braces.
- The bracing at the waist and minor bout seemed to have little effect on the sound.

The audible changes were reflected in the tap resonances of the dulcimer box, and the air resonances of the cavity. The bridge tap spectra give some clues as to why the sound degraded with bracing. Figure 11.23 shows the box resonances from zero to 800Hz on the horizontal scale for the various stages of brace removal.

In Figure 11.23, the **first panel** is of the original **unbraced dulcimer**. It's unusual in that the first two resonant peaks on the left represent the first air resonance at about 180Hz, and a combined 1st bar resonance and 2nd air resonance at about 274Hz. (Disregard the small peak at 50Hz – it's an artifact of the measurement). So either by a quirk of the selected materials, or possibly because of the design (I don't know) the usually separated second and third resonances both fall at the same frequency.

The **second panel** in Figure 11.23 shows a resonance too far. The **full bracing** of the top and back have stiffened the dulcimer box to the extent that the first air resonance (the "Helmholtz") has been raised in frequency and is nearly the same as the combined 1st bar and 2nd air resonances – three resonances all falling at the same frequency. That's too much to get away with and the result is the boominess and wolf notes.

The **third panel** is after the **removal of the two major bout braces on the top**. I didn't hear much change in tone with their removal, and the spectrum is much the same as the full-brace setup – three superimposed resonances.

The f**ourth panel** is after the **removal of the back brace closest to the bridge**. The back has regained some of its former flexibility and the 1st air resonance has fallen in frequency and moved away from the 1st bar and 2nd air resonances. The wolf notes were improved, but overall the tone seemed thinner to me. Hard to decide if it was an improvement or not.

The **final panel** is the r**emoval of the second back brace**. The spectral pattern has reverted to be much the same as without bracing. There were then no major bout braces on the top or back, however the waist and minor bout braces were still in place — three each on the top and back. To my mind the tone was the same as I remembered with no bracing — no vices or wolf notes, clear and resonant.

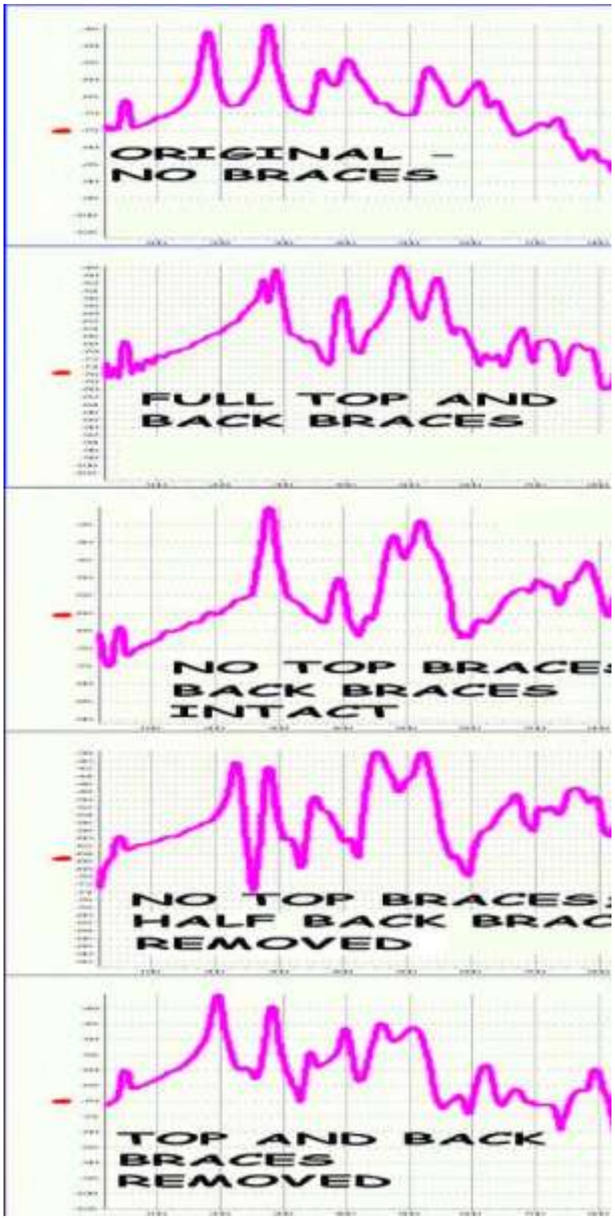


Figure 11.23. Bridge Tap spectra for Orthey replica with and without top and back brac

Vibrational mode testing with a loudspeaker is shown in Figure 11.24.

Figure 11.24. Vibration pattern in Orthey replica

I haven’t seen this in a dulcimer before, although I suspect it’s not really unusual. The pattern on the back results from the second air resonance vibrating the flexible back wood in the usual circular mode, and on the top is a hybrid bar/circle pattern. Two resonances falling at the same frequency is normally a recipe for dead notes or wolf notes, but in this dulcimer, the other resonances happen to be spaced such that the overall sound is very good.

Conclusions

So, is there a take-home lesson here? There might well be.

Bracing the back of a lightweight wood mountain dulcimer can have a significant effect on the tone of the instrument compared to an unbraced back.

This is neatly consistent with the previous post that indicated the significance of back bracing stiffness in the bright/mellow tone divide. It’s an area of construction that I hadn’t considered of much importance, but it seems like it might be after all.

On the other hand, the addition and removal of the major bout top braces seemed to have no audible effect on the tone, and neither did the presence of the waist and minor bout braces. I’m sure there are changes in the spectrum with this other bracing, but I couldn’t hear it. This reinforces the dominant effect of the fretboard on the way the top vibrates — the addition of top bracing doesn’t seem to modify the overall top stiffness enough to alter the tone because of the over-riding stiffness of the fretboard. It also reinforces the principal role of the major bout over the minor bout in producing much of the sound, and may partly explain why teardrop dulcimers don’t sound characteristically different from hourglass dulcimers.

But of course there’s no free lunch here. We pay for a light and flexible back with more effect on the tone with knee damping. Possum boards and table feet become more necessary. After comparing this dulcimer, with removed braces, on my lap and played on a table (with three small feet), it's clear that knee damping negates nearly all the gains made by removing the bracing. Basically, it's fairly ordinary sounding when played on the knee. This might well be a reason to have a double back; not because an outer back somehow makes the instrument louder or better, but just to reduce the effect of knee damping on the inner back and by proxy, maintaining the inner back's coupling to the top plate which then can radiate more sound. It would be important to note that the outer back did not acoustically load up the inner (vibrating) back by completely enclosing it, or by having a very narrow open air gap between the two. The outer back might be perforated over its surface, for example, so that the air between the two did not act as a cushion and modify the inner back’s vibration. A possum board that only touched at the edges of the two bouts would be an alternative as long as the back was prevented from touching the knee at all - even a light touch is often enough to disable the first air resonance coupling between the back and the top.

I always install bracing on the top and back of my dulcimers. In experiments on my test dulcimer, they have not made any real difference to the sound one way or the other, so I put them on mainly for structural strength reasons. For the top, there are a couple of reasons that seem valid to me. Firstly, for an arched fretboard, the long-term stability of the top is more likely if a supporting cross brace is under each foot - up to say four or five arches. Not so necessary for Orthey-type short arches. The other is that if there is no top bracing, then thin softwood tops are more likely to be damaged by squeezing between fingers and thumb. The generally harder backs are not so vulnerable, nor would the more traditional hardwood tops be.

But in the light of this test, I might revise the nature of back bracing in my dulcimers. Like everything, it’s not necessarily a bad thing or a good thing. Heavy back bracing coupled with a lighter top/fretboard might be a very good combination, with reduced knee damping. On the other hand, it might result in a coincidence of multiple resonances as is this case, with poorer outcomes. It's all a bit of a lottery. Having no bracing doesn't guarantee good outcome either. The best dulcimer I've ever made, to my mind, has medium-stiff back bracing and medium top bracing.

Further Comments on Bracing Effects -Jan 09, 2017

The bracing in the Dec 28, 2016 post (Figure 14.4) is typical for my dulcimers. Sometimes I leave off the brace nearest the headstock, it probably doesn't contribute much to overall structural integrity being so close to the solid end block. The braces are in those positions because long ago I calculated that that is where nodes of some of the internal air resonances should be and it seemed like a good idea at the time to have the stiffer bits where the wood was less likely to be asked to bend. The thinking is probably complete rubbish, but I still do it anyway. In sticking to the same pattern I used last week and the week before, I claim solidarity with most of the old time builders who found a successful pattern and stuck to it.

I made three dulcimers in an experiment to determine whether the top-plate size was a major contributor to the mellowness of a mountain dulcimer (whilst keeping the internal air volume the same for the three). The braced tops and backs are shown in Figure 11.25.

Figure 11.25. Bracing of three dulcimers with different top area

The bracing looks a bit bigger than it actually is because of the sun angle. I didn't attempt to make the cross-grain stiffness the same for the three tops because results of other experiments indicated that top bracing doesn't seem to have much affect on the tone of the instrument (for full-length fretboard dulcimers). This experiment further supports that idea; because even though the three dulcimer tops have relatively different cross-grain top stiffness, the completed instruments all had a very similar tone, loudness, sustain, and dynamic range. I think this is primarily because I closely matched the mass and stiffness of the three fretboards, so the long-grain stiffness of the three tops is the same. In another experiment I've shown, at least to my satisfaction, that ladder bracing like this doesn't much change the long grain stiffness of the top.

It all keeps coming back to the idea that the nature of the fretboard is the prime determinant of what a dulcimer sounds like. In a typical dulcimer, a hollow fretboard is about 150 times stiffer than the top plate itself. So when it comes to bending the wood to move some air around, it's the fretboard that has to be overcome more than the top plate itself. Most of the lower vibration modes of the top seem to involve the fretboard, as well as involving the top plate. Figure 11.26 shows a typical vibration mode.

Figure 11.26. Typical dulcimer top vibration mode

The middle part of the lower bout top/fretboard goes up and down while the outer edges go in the opposite direction. The top plate ***does*** vibrate in local areas that don't include the fretboard, and where you might think that bracing could modify the vibration, but those patterns are at frequencies above 1000Hz, and are mostly small enough to fit well within any bracing pattern. Those higher vibration modes are usually too complex to analyze, let alone understand, but possibly add a finishing color to the sound. Looking at my records, I can't actually find ***any*** example of a top mode that ***doesn't*** also include the fretboard, but that may be because I just haven't recorded many of the vibration modes above 1000Hz, being generally too complex to make any sense of.

For the back plate however, I'm coming around to the idea that bracing might noticably affect the sound. The back vibration modes ***do*** sometimes follow the brace lines, but mostly the modal patterns seem to ignore the bracing. Sometimes they appear to follow the back braces, but coincidentally. Figure 11.27 shows two dulcimer backs — the top panel has one of its modal patterns overlayed on the bracing pattern, and the mode matches the bracing closely. But the bottom picture is essentially the same vibration pattern in another dulcimer, and that dulcimer has no back braces. So it's all a bit of a mystery.

Figure 11.27. Similar back vibration pattern for braced (upper panel) and unbraced back (lower panel).

The Effect on Free Top Resonances of a Brace at the Dulcimer Waist May 17, 2013

Whilst working on my test dulcimer, the small 2.5" top brace at the waist cracked. Because I couldn't reach in through a sound hole to re-glue it, I pried it off and assumed that being so small and light it would not change the outcomes.

However, without the waist brace the low frequency vibration modes of the test dulcimer were better defined at the waist than on many previous dulcimers. The areas of vibration also extended closer to the dulcimer top edge, which implies higher top mobility, and higher output of sound. The extra thin edges of the test dulcimer are probably mostly responsible for this (and the absence of internal side linings) but I had the completed top of a new dulcimer at hand so I measured the tap resonance spectrum of it with and without its middle brace — assuming there would be no difference in the spectra. But there was.

The small and light middle brace moved the free-top resonant frequencies by up to ½ semitone in some cases. Figure 11.28 shows the with and without tap spectra, averaged over multiple trials. They were quite repeatable (horizontal scale 0 to 1264Hz)

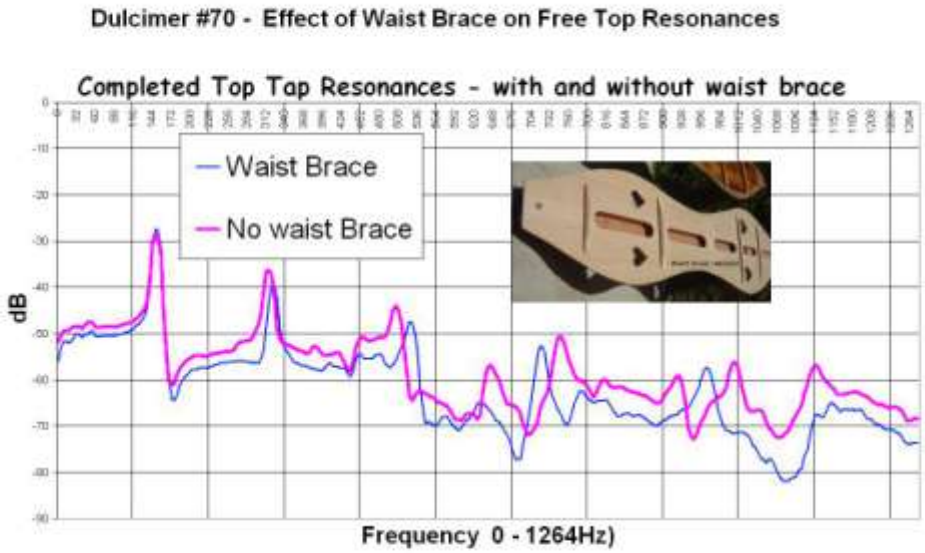


Figure 11.28. Effect of waist brace on tap spectra of completed top

Generally those resonances below about 600Hz were moved lower in frequency without the brace, and those above 600Hz moved higher. If this translates somehow into the completed instrument, it might mellow-up the sound very slightly.

Keep in mind that this is a free top and there is no clear connection between these resonant frequencies and those of the top when it is glued on. Also, the free-top spectra are no indication of any effect the removal of the brace might have on the sound of the completed instrument - but I left it off anyway.

This is all getting dangerously close to saying that top bracing might noticeably modify a dulcimer's tone, which I have claimed elsewhere not to be the case, based on other experiments. But I could be wrong in that, and there could be special cases, or parts of a dulcimer where there is more of an effect. Unstiffening the waist a little across the grain might allow the center of the fretboard to vibrate a little more freely and allow vibration mode areas of the lower bout to extend further along the top towards the middle, and those vibration modes that already run along the waist might spread towards the edges a little to push a bit more air around. This may or may not be a good thing for the sound, but if there is an effect it is probably in the direction of more mellow because of the slightly increased flexibility at the waist.

The waist area is narrow enough that the risk of cracking the top with thumb pressure is a lot less than the bouts, so I'm happy to leave off the brace I normally put there – if it does improve the sound.

Lattice Bracing- Apr 21, 2018

Some readers may have heard of Australian guitar maker Graham Caldersmith[17]. He uses a lattice bracing pattern for his highly regarded classical guitars. There are many makers of lattice braced guitars worldwide, but Graham Caldersmith seems almost unique in having top lattices that run parallel to and at right-angles to the fretboard rather than the more usual diagonal lattices such as those of Greg Smallman[18]. However, they all seem to work on a similar set of principles.

At first glance at the insides of a Caldersmith guitar you think “that couldn’t possibly work”. There is a massive 20mm thick plywood frame under the top with openings only for the sound hole and the lower bout of the guitar surrounding the bridge. In addition, there are two large beams about 3/4” cross section running from the tail block to the sound hole area. The back and sides are at least twice as thick as in a normal guitar. The whole instrument is a heavyweight.

But the top plate is super thin – 1mm or so, and the lattice bracing is often made of balsa wood reinforced with carbon fibre threads. The lower bout of the top is very light, but very stiff. The upper bout is glued flat to the rigid internal plywood frame.

The philosophy behind such instruments is to immobilize, as much as possible, the back and the sides, and also the less important sound producing parts of the top area. This leaves the lattice braced lower bout of the top free to utilize the energy of the string pluck in a much more responsive and efficient way – energy (hence sound) is not wasted moving large parts of the instrument that don’t contribute much to sound production, or in internal damping losses in massive parts of the guitar.

The end result of this approach can be very loud guitars with long sustain – most of the string energy is directed to the light, low damped lattice area. However, there’s always something to pay – I’ve seen a number of comments that thin topped lattice-braced guitars often seem to have a brash, banjo-like quality of sound. The subtle sound contributions of other parts of the instrument are sacrificed in exchange for loudness and sustain. Some people don’t like that “loud” is not the same as “good”, but some lattice braced guitars are clearly very good, although the inclusion of a thin lattice braced top is not a guarantee of it.

In the mountain dulcimer world, players are always asking for louder instruments, and it

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[17] https://www.grahamcaldersmith.com.au
[18] https://en.wikipedia.org/wiki/Greg_Smallman

occurred to me that a similar approach might work to make loud and responsive dulcimers — maybe even good ones. I couldn't find any references to such instruments so my long suffering test dulcimer was called out of retirement — again.

The top was taken off; the internal side linings from a previous experiment were still in place and were four times as heavy as usual linings; a new Western Red Cedar top, 1.2mm thick was made, and a lattice, after the Caldersmith style, of Western Red Cedar was glued to the lower bout area. I know from previous studies that the lower bout produces the lion's share of the top sound — the upper bout is much less important. A 15mm plywood insert was glued into the upper bout from the waist to the headstock. The underside of the fretboard was cut away by a few millimeters over the lower bout to allow the light thin top freedom to vibrate unhindered by the fretboard mass. The top itself weighed in at about 50gm, which is 1/2 to 1/3 the usual weight, and represented only 3.5% of the final dulcimer weight compared with an average of 13% for my standard dulcimers. Two stiff rods were glued from the end block to the waist to prevent the whole body flexing under string tension with the thin top unsupported by the fretboard. The final weight was 1435gm which is on the heavy side for me. (Figure 11.29).

Figure 11.29. Lattice-braced test dulcimer

The bracing wasn't reinforced with carbon fiber and the stiffness was just a wild guess – the top of a dulcimer doesn't have to support the pull of a guitar bridge, so I might have overdone it. The main aim was to see if the approach offered promise – if so I'd make a proper dulcimer along those lines.

The ***result*** was — a disappointment. I thought the dulcimer was better than it's previous incarnation; a bit louder perhaps, a bit longer sustain, but not the paradigm shift I hoped it might be. The tone was banjo-like and a bit nasal - I didn't particularly like it. Informal listening and playing comparisons with other dulcimers were not favorable.

So what was wrong? One thing was that the back of this dulcimer, far from being thick and massive, was made of balsa wood – a leftover from a previous experiment. And the sides were 1/8" ply (the only remaining original parts). Both were much lighter than desirable for this approach. So how to remedy that? Bury the dulcimer in a sand box to positively immobilise the back and sides (Figure 11.30). The only part that can now vibrate is the lattice braced lower bout of the top.

Figure 11.30. Dulcimer buried in sand to immobilize back and sides

The buried dulcimer was compared for individual string loudness and sustain using the copper thread string-pull method and the PRAAT software suite to do the arithmetic. Sustain was defined as the time period that PRAAT could detect a valid pitch track, and the sound level was averaged over a fixed period.

The ***result*** of this was even more disappointing. The lattice-braced dulcimer was not significantly louder than two other standard dulcimers, nor did it have longer sustain. Immobilizing the back and sides in the sandbox actually made the top quieter, but more significantly, the tone was thin and hollow. Eyeballing the spectrograms showed that the harmonic series of the buried dulcimer had harmonics missing, particularly the fundamentals, and reduced in duration and strength compared to the unburied case.

Conclusions I don't think the rigid body-ultrathin top combination is very suitable for mountain dulcimers. The tone I ended up with echoes the comments of many guitar makers about sounding brash and banjo-like. Measuring the buried dulcimer seemed to reinforce one of the principal differences between guitars and dulcimers. Guitars can sound very good with just half the top vibrating and the rest immobilized, but ***mountain dulcimers radiate from all surfaces*** and that seems to contribute considerably to the character of the sound they produce. Take away the back and sides vibration and the character is degraded. It also hints at the greater importance of the wood interaction with the air cavity resonances in a mountain dulcimer compared with a guitar, and the need for the top and back to be coupled in some way by the air resonances to maintain the characteristic dulcimer sound.

This book originally started with me claiming the relative unimportance of the top plate parameters (mass, thickness, species, etc.) in a full fretboard mountain dulcimer. This current experiment has looked at the contribution of ***just*** the top plate, and it wasn't a good one. Maybe I was on the right track after all...

More Lattice Bracing- May 05, 2018

The results of the lattice braced test dulcimer didn't encourage me to make a proper dulcimer in that style. However, I had already set aside some wood for the purpose and decided to complete the instrument, but with some differences from the test dulcimer and to the general philosophy of massive body/ultralight top. I don't think that combination is particularly suitable for mountain dulcimers.

The new dulcimer was made of a Jarrah body, which is a dense and heavy eucalypt, and a Huon Pine top – an Australian softwood very like Alaskan Yellow Cedar (*Cupressus* sp.). The top was still very thin at 1.3mm, but was more lightly lattice braced with Western Red Cedar 4mm square section braces, compared to the 8mm high braces in the test dulcimer – so nowhere near as stiff. The upper bout was not constrained by a massive plate insert, but was reinforced with 2mm strips of Western Red Cedar. The top was very fragile and I easily managed to put a chisel through it – always a risk with very thin panels. Final top weight was 116gm compared to 50gm for the test dulcimer (without fretboard). That weight is not much different to my normal tops, but probably a lot stiffer, and more even along/across the grain. (Figure 11.31). The light strap braces on the upper bout are to add some mechanical strength to the top in that area.

Figure 11.31. Test dulcimer with lattice bracing

The back was braced a little lighter than I normally would, but still with five cross braces, and the back plate was a little thinner than usual at 2mm because the wood was very dense. But the sides were about double the usual thickness at 4mm.

The fretboard was made of balsa wood core with thin overlays on the top and sides of Jarrah. It was not hollowed or arched and was glued to the top plate the whole length, unlike the test dulcimer which had an arch disconnecting the fretboard from the top plate over the lower bout. The final weight of the fretboard was 225gm, which is just a bit lighter than usual. The hollow test dulcimer fretboard weighed 288gm which is a bit heavier than usual, but both were in the same ballpark. The new Balsa-core Jarrah fretboard is shown in Figure 11.32.

The end result was an instrument, #126, that has a nod to the stiff/light/homogeneous top philosophy of lattice guitars, and with very heavy sides so as not to soak up too much energy there. It had a normally braced and reasonably flexible back and a lightish fretboard glued to the top in the normal way. It might be expected that this arrangement would allow top/back/air resonance interactions as in a normal dulcimer, but with a lower bout that would more efficiently act as an air piston than a standard arrangement, because of the lattice bracing. The fretboard would still be the main moderating component, unlike the test dulcimer where the top plate lower bout was disconnected from the fretboard, and the upper bout was basically immobilized.

Figure 11.32. Balsa core fretboard construction

The resulting instrument is one that I like a lot. (Figure 11.33). Whether that is a result of the lattice bracing/thin top I can't say, but it has a clarity and rich warmth that sounds good to me. It is quite loud and with good sustain and dynamic range. The test lattice-braced dulcimer, with its dense fretboard sounds hollow and nasal in comparison.

Figure 11.33. #126 Thick sided, lattice-braced, Balsa-core fretboard Jarrah body

So lattice bracing/thin tops ***can*** be made to work in mountain dulcimers, but whether the extra effort it takes, and the resultant fragility of the instrument is worth the trouble, makers will need to find out for themselves.

Even More Lattice Bracing- July 29, 2018

The lattice braced dulcimer in the previous section had ***4mm thick sides***, of the eucalypt, Jarrah (*Eucalyptus marginata*). The top was thin and lightly, but stiffly, ***lattice braced.*** The ***fretboard was a Balsa wood core*** overlaid with Jarrah. These three factors were all a departure from my standard construction methods, and make it difficult to pin down which factor, or combination, might be most responsible for the resultant very nice sound,

So another lattice braced dulcimer was made, with thin top, Balsa-core fretboard, but very thin sides. This dulcimer was made with another fairly heavy eucalypt for back and sides (Yellow Stringybark), and a thin Kauri Pine top. The lattice bracing was similar to the previous Jarrah dulcimer, but not exactly the same. (Figure 11.34).

Figure 11.34. #127 Kauri Pine 1.6mm lattice braced top

The top of this dulcimer is 1.6mm thick, a little thicker than the Jarrah (1.3mm) and the Test Dulcimer (1.2mm). The braced top weighed 99gm (Jarrah, 116gm) and the fretboard weighed 247gm (Jarrah, 225gm). Overall the weights, dimensions and construction were similar for both the Jarrah and the Yellow Stringybark. The big difference was the sides.

The sides of the new dulcimer were only 1.5mm thick, definitely requiring internal side linings which were absent on the 4mm thick Jarrah sides.

The result of this construction was another very nice dulcimer, and one which shared a very similar sound to its predecessor. (Figure 11.35).

Figure 11.35. #127 Thin sided, lattice-braced, Balsa-core fretboard Yellow Stringybark dulcimer

The conclusion follows that the sides cannot be the principal sound-influencing factor in these two dulcimers. Both side sets are of a dense timber, but one has 4mm thick sides, and the other 1.5mm, and both these thicknesses are at opposite extremes of normal practice, where sides might normally be about 2.5 - 3mm.

Both have light, thin, lattice-braced tops, and a Balsa-core fretboard overlaid with a denser wood —one, or both, of these factors is likely to be the reason for the pleasing and similar sounds of these two dulcimers, which are characteristically different to the usual sound of the dulcimers I make using more standard methods.

To shed more light on this, I made two more dulcimers to complete the combinations of fretboard and top bracing, numbers #128 and #129. The configuration of the four dulcimers is given in Table 11.2.

Table 11.2
Configuration of four lattice-brace test dulcimers

	Dulc #126	**Dulc #127**	**Dulc #128**	**Dulc #129**
Fretboard Type	Balsa core	Balsa core	Balsa core	Standard/ hollow
Fretboard weight	225gm	247gm	226gm	226gm
Top Thickness	1.3mm	1.6mm	2.4mm	1.8mm
Top Bracing	Lattice	Lattice	Standard ladder bracing	Lattice
Side Thickness	4mm	1.5mm	3.6mm	3.2mm
Back and sides Wood Density	High	High	Low	Low
Final Weight	1185gm	1091gm	983gm	959gm

The two new dulcimers are shown in Figure 11.36, and the top bracing in Figure 11.37.

Figure 11.36. Dulcimer #128 Balsa fretboard and #129 standard hollow fretboard

All four dulcimers were very nice sounding instruments, similar in general tonal character to each other, but different (in my judgment) to the general run of my previous dulcimers. So has the lattice bracing/thin sides/thick sides/Balsa-core fretboards made any difference? In careful listening to the four, played at different

Figure 11.37. Dulcimer #128 standard braced and #129 lattice braced

parts of the fretboards, there *are* tonal differences between each of them, however the similarities are greater than the differences. And the differences between any two are no more than I would expect between any two other dulcimers I have made.

Perhaps this could mean that the four are statistical outliers for one or more constructional parameters compared to my previous dulcimers. To see if this might be the case, I calculated the mean and standard deviation of numerous parameters (weights, thicknesses etc) for the previous forty dulcimers and compared them to this current four. If a parameter (e.g., top thickness) was more than two standard deviations from the mean of the previous forty, it might start to look like an outlier.

Only the top thickness of three of the four approached or exceeded two standard deviations, the third (#128) was close to the mean. Other parameters were within one standard deviation from their means. In particular, the weights of the fretboards were very similar for the four, and very close to the mean of the previous forty. However, I would not claim that as the magic factor. So none of the obvious parameters explains the commonality of tone for the four, and their joint difference to previous dulcimers. It remains unexplained, unless all the differences, past and present, are a failure of my own listening judgment, which is, of course, possible.

The end result is that various combinations of thick sides, thin sides, lattice and standard bracing, Balsa-core and standard fretboards and light and dense body woods, can lead to fine sounding dulcimers. And further, that different combinations can result in similar sounding instruments

Chapter 12
Side Linings

The Effects of Side Linings- Nov 23, 2014

I stopped in to visit Terry Hennessy a while ago and had a play of his latest mountain dulcimer, which I liked a lot. It had the sound that I like – mellow enough and with good "ring" and sustain on the upper fretboard. And very well made as are all Terry's dulcimers. It's a new design reminiscent of the one he made for Mimi Farina[19]. It got me thinking about why it might sound that way.

Aside from the shape and design itself which are probably significantly important, there are a number of features that might individually or collectively contribute to its particular sound. It has a very dense Rock Maple fretboard with Ebony overlay and with the bridge not far inward of the end block; the ladder-braced top is still reasonably flexible (pushing down on the strum hollow can bend the notes); the lower bout is a bit wider than most dulcimers and the internal side linings are double laminated and about 1cm wide.

I also install side linings in my dulcimers but have not really given much thought to their function or effect, it just seems like a good idea to put them in. I know many mountain dulcimer makers don't use them, but I don't know of any other thin sided stringed instruments that don't, from ukuleles to guitars and violins. Usually I just use off-cuts of the back or top materials for the linings, or whatever I have around — these are continuous strips of solid wood that I bend with the sides, not the kerfed linings often used in guitars, which are quite flexible and don't add appreciable stiffness to the sides as solid wood linings do.

What then is the function of the side linings, particularly the top lining? Most will say that it allows more leeway to cut into the sides to install external edge bindings, without accidentally cutting the top off! But that can't be the reason in violin-class instruments which don't have edge binding, or mountain dulcimers with a fiddle edge, as mine do. Internal side linings do allow more gluing surface to keep the top from popping off – but how many tops pop off even from very thin sides without linings?

But there's another reason for side linings as Gore & Gilet *Contemporary Acoustic Guitar*

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[19] http://www.richardandmimi.com/dulcimer.html

– *Design and Build*[20] points out. The linings add stiffness and mass to the hinge that is the joint between the top plate and the sides. The more massive that joint, the more of a mechanical impedance mismatch there is and the more energy that is reflected back into the top from the joint, theoretically producing more sound from the top plate rather than it leaking away into the sides.

Gore and Gilet use large continuous laminated side linings on the top plate joint, as Terry Hennessy does. Do they noticeably affect the sound? It's an area I haven't looked at before, so I thought I'd try to see for myself.

My test dulcimer has been called into use again. The top was thin at the edges (from another experiment), so for this experiment it was replaced with a constant 3mm thickness Western Red Cedar top and with a dense Spotted Gum fretboard to replace the lighter Mahogany original fretboard. Spotted Gum is a tough eucalypt, often used for axe and pick handles in Australia. No side linings were installed — the top was hide-glued straight onto the 1/8" plywood sides. (Figure 12.1.)

Figure 12.1. Test dulcimer before and after top and fretboard change

I've used the twin of this Spotted Gum fretboard on another dulcimer and it turned out fairly quiet, as I've noticed with other heavy fretboards, so that's what I expected would also happen here.

But no — I was immediately struck by how similar it sounded to the light/thin edge top it replaced. A bit less brash, and a bit more solid, but still similar. The bridge tap frequency spectra of the dulcimer with the two tops were also fairly similar (Figure 12.2).

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[20] Gore, Trevor and Gilet, Gerard, "Contemorary Acoustic Guitar—Design and Build", Trevor Gore Guitars, Cottage Point NSW 2084 Australia, ISBN 978-0-9781174-(0-3,1-0) 2011

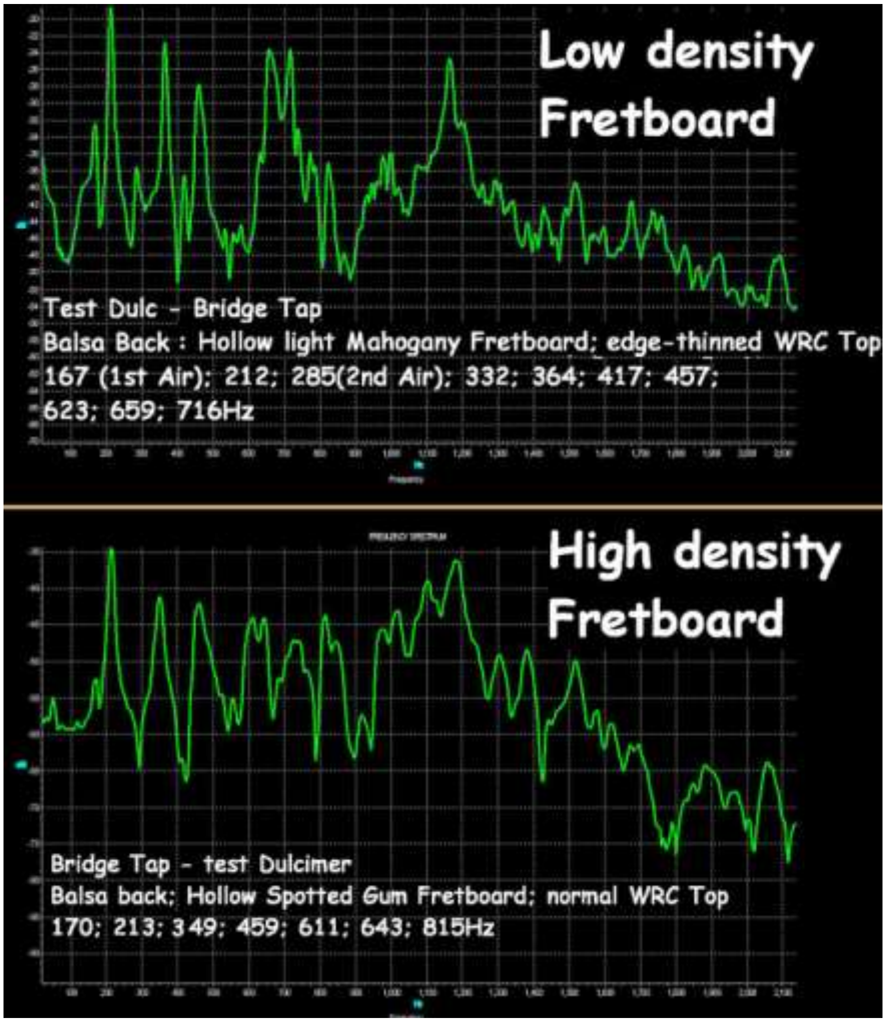


Figure 12.2 Tap spectra effect of fretboard density.

This goes directly against my contention that the fretboard is the main component that sets the tone.

I know from other experiments that changing mass/stiffness of a fretboard , and leaving everything else the same, can dramatically alter the sound. I know from a different experiment that thinning the edge of the top plate didn’t alter the sound, so the actual top plate change from edge-thinned to constant thickness shouldn’t, on the face of it, be relevant here.

So, since the only thing changed was the top/fretboard assembly, and that change didn’t radically alter the sound even though the tops were very different.

Then, it must mean that these two tops are not determining the sound in this dulcimer as much as expected, and something in the dulcimer body is.

My suspicion is that the ultra light balsa-wood back could be affecting the sound more than most backs would – the back might be dictating the tone here as much as the fretboard!

Unless, by chance the total effective mass/stiffness of the central lower bout happened to be similar for the two tops, even though the densities of the fretboards are quite different. The fretboard heights and strum hollow shaping are different. This is speculation, and I didn't make any measurements, but the flexibility of the new (heavy) top seems similar to the old (light) top as measured qualitatively by strumming and pushing down on the strum hollow.

As Jane Austen says, this is all very vexing.

Although heavy fretboards seem, in my experience, to be associated with quieter dulcimers (all on instruments with side linings), it may be possible that very light back woods might counter this. Terry's dulcimer, mentioned previously, has a dense fretboard, with a light but stiffly braced back, and thick top linings, and it is still quite loud.

Do side linings have any part to play in this? That's what this experiment attempts to find out. Currently there are no side linings on the test dulcimer. I'll make some measurements, then take the top off and install heavy top linings laminated from three solid wood strips, make some more measurements, and see what results from the change.

The Effects of Side Linings II- Nov 30, 2014

The aim of this study was to see if the addition of internal linings to the top of a mountain dulcimer side modifies the loudness, sustain, or tone of the instrument.

Method

A new top assembly was installed on a test dulcimer. It was glued to the existing 1/8" plywood sides with a weak hide glue. Recordings and measurements were made. There were no internal side linings at this stage.

The new top was removed, undamaged, and heavy laminated linings were installed to the top edge of the sides. The linings comprised three layers of dense strips of hardwood — one of Sapodilla (Chewing Gum tree) and two of Spotted Gum (axe handle wood). The top was reinstalled on the new linings and the recordings and measurements repeated. The linings were 1cm wide. (Figure 12.3.)

Figure 12.3. Test dulcimer before and after installation of extra wide and dense side linings

Measurements

Three sets of recordings were made, first with no linings, then with the wide side linings.

1. Recordings of ***individual strings*** were made, open and capoed at the 8th fret by the method of looping a filament of copper thread from an electrical appliance cable around the string and pulling with pliers until the thread broke, releasing the string to produce sound. This is a method of producing a repeatable string excitation, but can only be used on single strings. Multiple recordings were made for each string and the results were

averaged.

2. Recordings of ***three strings struck together*** were made by a falling pendulum-rod with a plectrum attached to the end — open strings and capoed 8th fret. This allowed all three strings to be struck essentially simultaneously. It was repeatable but perhaps not quite as repeatable as the thread-pull method. Multiple recordings were made and results were averaged.

3. A ***test tune*** was recorded with and without side linings.

Sufficient time was allowed between each string excitation for the sustain measurements to be made. Care was taken to keep the measurement conditions the same for all cases (Figure 12.4).

Figure 12.4. Two methods of repeatable string excitation

Results

The actual numerical values of these measurements are affected by the recording conditions and so are not absolute; e.g., the sound pressure levels would be different if the microphone was placed further away. However, keeping the methods constant can allow comparison of before and after changes. Recordings made were:
Sustain: This is surprisingly difficult to measure, and there seems to be no agreed

definition about what it is (some call it “decay”). For practical purposes, we might say it is the length of time that a note can be heard after it begins. But as the note loudness descends into the ambient noise it becomes almost impossible to determine the end-point reliably. This is especially true as the higher overtones may be the ones continuing; and then the hearing acuity of the listener becomes a factor.

To achieve some reliability, I used the pitch detection mechanism of the PRAAT signal analysis software to determine sustain. As long as the software could detect any steady pitch, I considered that at least one overtone had some continuing energy. This applied to the pendulum strike as well where there were three notes struck at the same time and hence three sets of unrelated overtones. But PRAAT seems to select the strongest energy candidate for a steady pitch and report that, irrespective of harmonic relationships.

Average Sound Pressure Level: This is the average SPL of the string pluck/strike over the period of the previously determined sustain interval. Higher values would indicate a slower fall off of the sound.

Peak Sound Pressure Level: This is the maximum value of the SPL within the sustain period, generally about 10mSec after the string strike.

Spectral Centre of Gravity (C of G): This measure was used as a proxy to compare tonal balance of two recordings made under the same conditions. From a frequency spectrum of a sound, it calculates the frequency at which the same amount of sound energy is below it as is above it. For the same instrument and recording conditions, a lower spectral C of G after a structural change (linings) would indicate a shift towards sounding more mellow because lower frequencies would contribute relatively more to the total sound energy than before the change. The Fourier spectrum of the target sound was calculated, and the C of G computed from that.

In practice, the use of this measure on single string strikes was not successful. For short period analyses, there are large errors caused by ambient noise and other factors, so in the end it is only reported for the longer duration test tune. The spectrum for the no-linings case, with the Spectral Centre of Gravity indicated, is shown in Figure 12.5. Horizontal scale is frequency, zero to 11000Hz; vertical scale is sound level in decibels.

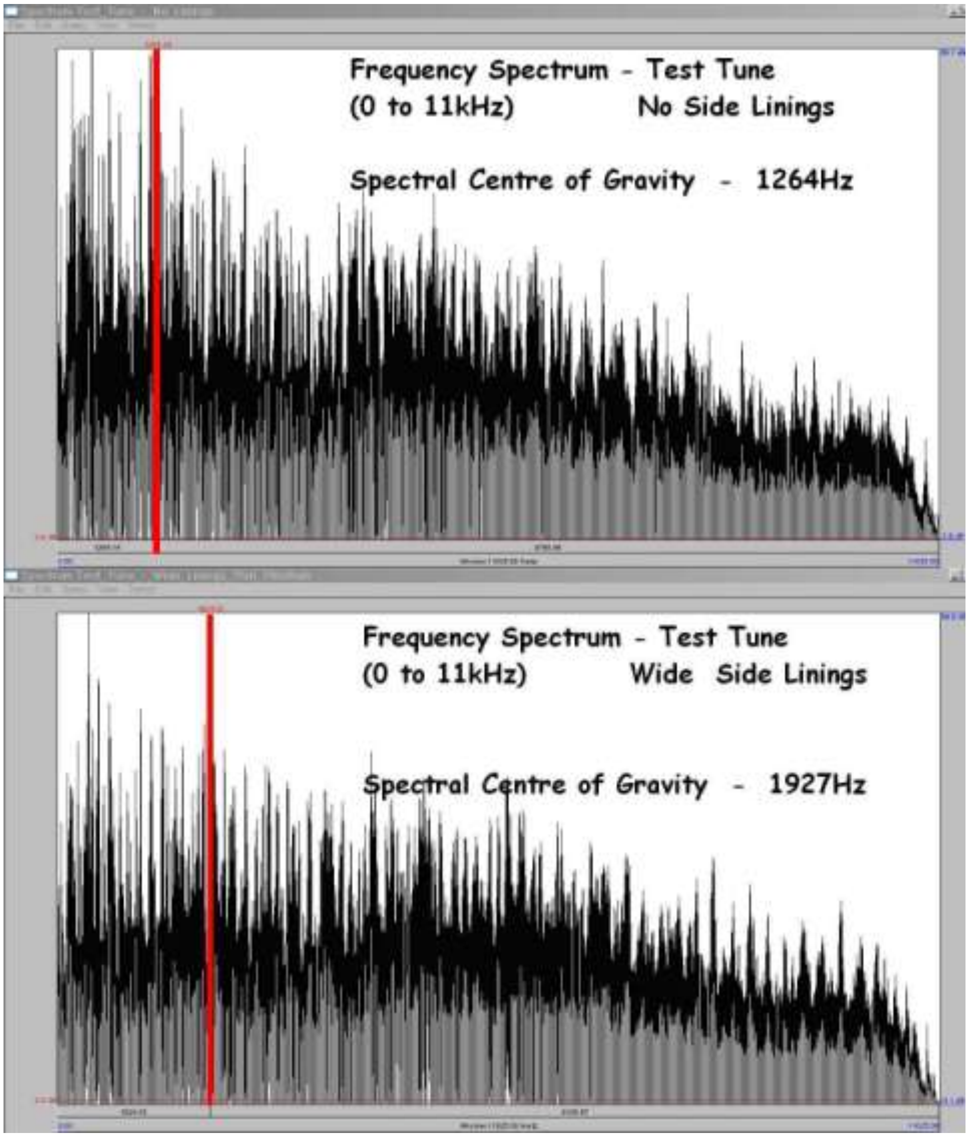
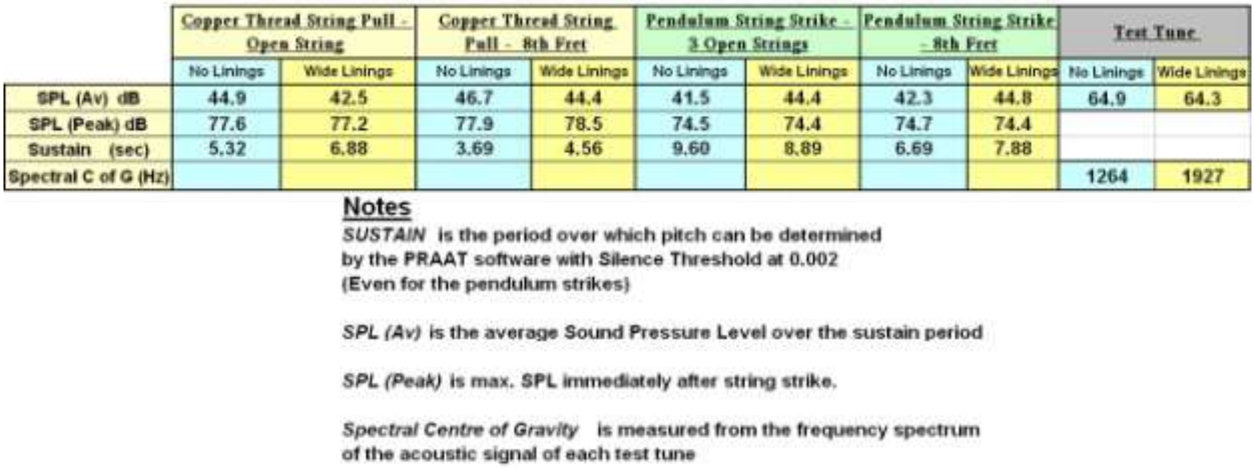


Figure 12.5 Frequency spectrum of sample tune, with Spectral Centre of Gravity indicated, with and without side linings.

Although it looks like there is substantially more activity above the Spectral C o G (1264Hz, 1927Hz), the vertical scale is logarithmic (dB) — there is as much sound energy between zero and 1264Hz as there is between 1264Hz and 11000Hz. It is a reminder that the low frequency activity of the dulcimer contains most of the sound energy.

A summary of the results of the tests is shown in Table 12.1.

Table 12.1
Effect of Side Linings Results



	Copper Thread String Pull - Open String		Copper Thread String Pull - 8th Fret		Pendulum String Strike - 3 Open Strings		Pendulum String Strike - 8th Fret		Test Tune	
	No Linings	Wide Linings	No Linings	Wide Linings	No Linings	Wide Linings	No Linings	Wide Linings	No Linings	Wide Linings
SPL (Av) dB	44.9	42.5	46.7	44.4	41.5	44.4	42.3	44.8	64.9	64.3
SPL (Peak) dB	77.6	77.2	77.9	78.5	74.5	74.4	74.7	74.4		
Sustain (sec)	5.32	6.88	3.69	4.56	9.60	8.89	6.69	7.88		
Spectral C of G (Hz)									1264	1927

Notes

SUSTAIN is the period over which pitch can be determined by the PRAAT software with Silence Threshold at 0.002 (Even for the pendulum strikes)

SPL (Av) is the average Sound Pressure Level over the sustain period

SPL (Peak) is max. SPL immediately after string strike.

Spectral Centre of Gravity is measured from the frequency spectrum of the acoustic signal of each test tune

The increase in the Spectral C of G frequency with the addition of linings is consistent with an increase in overall box stiffness that the linings would add. Increased stiffness tends to emphasise the ***higher*** frequencies. On the other hand, the increased mass of the linings would tend to emphasise the ***lower*** frequencies. Box stiffness increase must have won out in this case, because the overall frequency content of the recorded tune was shifted upwards with the addition of linings.

The Bridge Tap Frequency Spectrum was recorded before(Figure 12.6) and after (Figure 12.7) linings were installed to indicate any change in the resonant characteristics of the dulcimer box (as distinct from the actual sound the instrument made as the strings were plucked).

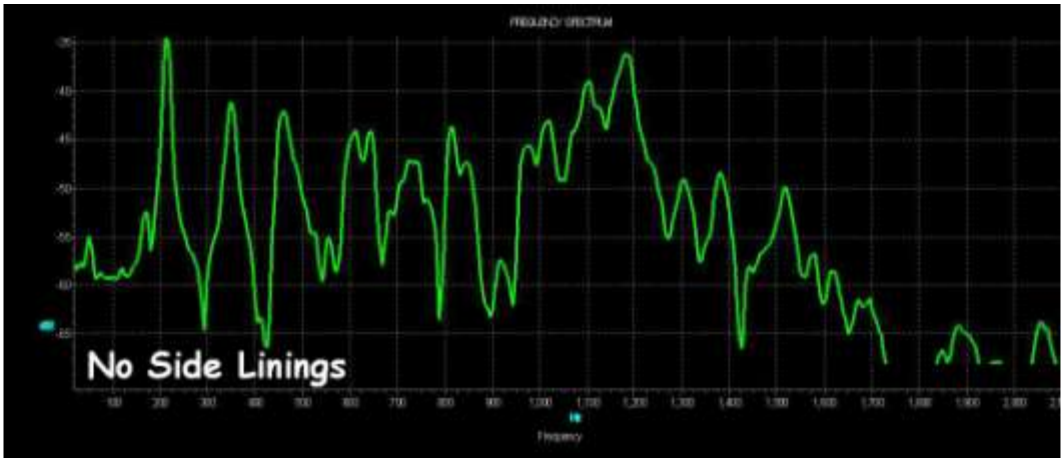


Figure 12.6. Bridge tap frequency spectrum without side linings

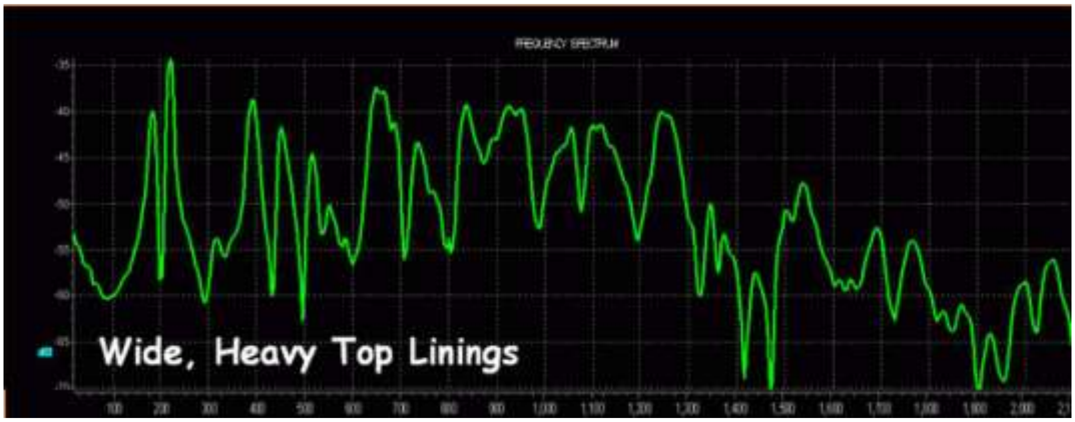


Figure12.7. Bridge tap frequency spectrum with side linings

Conclusions

The addition of these side linings had three other effects as well as stiffening the top/side joint.

First, the 1cm width of the linings immobilised 157cm^2 of top plate that was no longer available to vibrate. That was 17% of the total top plate area including the fretboard.

Second, the heavy linings increased the total weight of the dulcimer by 12%.

In addition, the stiffness of the dulcimer box would have increased with the addition of the linings, although this was not assessed.

Any, or all, of these three effects might contribute to any perceived or measured change in the sound. So it's hard to make one change in isolation.

In addition, as every player knows, using a stiffer plectrum will change the tone of the sound produced. Recording the test tune again on the wide lining case with a heavier plectrum produced a C of G of 1486Hz — down from 1927Hz with the standard plectrum. The difference between linings/no linings was reduced; i.e., the no-lining tune recorded with a standard plectrum was much the same tone as the wide-lining case with a thicker plectrum. So playing styles and accessories can compensate for intrinsic characteristics of the instrument (within reason).

Overall, sound pressure levels didn't change much with the addition of linings, either average or peak. There was a general increase in sustain with the linings, maybe about 25% longer, and the tone, as measured by the spectral C of G shifted towards the higher frequencies.

The effect of the linings on the resonances of the box itself were mainly in the frequency of the fourth resonant peak (the first “wood” resonance?). It increased from 349Hz to 392Hz — two semitones. The 1st air (“Helmholtz”), 1st bar, and 2nd air resonances changed less than a semitone. (With no linings, the 2nd air resonance was hidden in the shoulder of the fourth resonance.)

In my own subjective listening, I preferred the instrument’s sound without linings. The new top/fretboard was similar in tone to the previous light fretboard/thin-edge top, but without the brashness and hard edge to it. The heavy linings seemed to take away some small element of warmth without replacing it with any particular brilliance elsewhere in the spectrum. So, even though it seems like a constructional step backwards to me, I might modify my building process and consider making dulcimers with no linings. Very thin sides would still require linings to provide adequate gluing area. However, anything above, say, 2mm thick sides might well be adequate without linings.

For those who already install side linings, keep in mind that these were very large and heavy; normal sized linings would probably have a smaller, perhaps unnoticeable, effect. Also, this result is only for full length fretboard dulcimers — other configurations might respond differently to the presence or absence of side linings. Kerfed linings, which would be less stiff than continuous ones, may have less of an effect then solid continuous linings.

Overall, side linings might make a dulcimer tone slightly less mellow, but maybe not noticeably so.

Effects of Bracing and Side Linings-Nov 24, 2014

This same dulcimer has also been tested with and without bracing on both the top and the bottom without really noticing any substantial change in tone. Every change will make ***some*** difference of course. However, my conclusions were that bracing made very little difference. The same seems to apply to side linings. That's not to say that in other combinations of wood types, densities, and stiffnesses they wouldn't, but all combinations of everything can't be tested in every experiment. So I am reasonably confident that bracing and side linings are not major contributors to the general tone of mountain dulcimers.

In general, "light and stiff" seems to be a general mantra in the guitar world, and is probably largely true for mountain dulcimers. But although lighter dulcimers might generally be louder, it is not always the case, wood being what it is. Internal wood damping, not easily measured, might have large effects. Top and back bracing is not really necessary in dulcimers for structural integrity, as it is in guitars, because most of the stress is compressive along the length of the instrument. Even really thin unbraced tops and backs (down to a thickness of, say, zero) do not result in a dulcimer deforming badly. But a thumb might easily crack the top or back when picking up in a thin, unbraced instrument. My claimed reason for bracing is to protect against that sort of damage, not for overall structural integrity.

I realize there is another reason I use side linings, and an important one. I bend my dulcimer sides prior to fitting them to the end blocks, which have been previously glued to the back plate. Others glue the sides to the end blocks before gluing to the back. Tops may go on first or last, depending on the builder. Because of scheduling of other activities, the bent sides may sit around for some time before being finally glued to the back. After being bent, and before linings are glued on, the sides usually begin the process of straightening themselves out again —the speed and amount of straightening depends on the wood. If continuous side linings are glued on soon after bending (Figure 12.8), the sides can be left for months without them changing shape and having to be re-bent.

Figure 12.8. Sides with side linings attached

Back Bracing and Side Linings- Feb 16, 2016

In previous experiments, I've looked at the effect of top side linings and also the effect of adding and removing back braces to dulcimers. Recently I acquired some wood that was resawn into a number of homogeneous-looking plates, and I took the opportunity to experiment with the construction regarding bracing and side linings, to see what might result.

I normally install both back braces and internal side linings in my dulcimers — I can afford the time and effort to do it. But for those makers who make dulcimers for a living, the extra day or two per instrument to put these components in decreases their throughput and is a commercial reason to leave them out.

So does it make any practical difference to the sound — braces/linings in or out? The short answer is — maybe, maybe not. The differences in the final sound of the three dulcimers in this experiment can't really be pinned down to the presence or absence of braces or side linings. The differences might be because of those factors, but are just as likely to result from the natural sound differences produced by wood sample variation between the instruments (not wood "species" variation).

The Experiment

In this experiment, I made three "identical" dulcimers with backs and sides of an oak-like wood called *Dillenia papuana*. There was less than 5% weight variation between the three back/sides sets with Sitka Spruce tops and *Dillenia* fretboards and end blocks and less than 2% top-assembly weight and stiffness variation. Final weights varied by less than 5% and most of that was the presence of linings and braces in one instrument. Final weight was 1100gm.

One instrument (#93) had no back braces and no side linings; one (#94) had side linings but no back braces; and one (#95) had both side linings and back braces. All had a back plate center join support strip of *Dillenia*.

Figure 12.9. Three dulcimers with different linings and back bracing

All three had the same top configuration: hollow fretboard; five cross braces. There was a conscious attempt to make these dulcimers sound more on the mellow side than the bright side. The top was thinned to 2mm (a little thinner than normal for me); total sound hole area was smaller than usual (for me). Both of these factors might tend towards more mellow. Strum hollow height was 9mm; side height was 44mm; completed top deflection was 120/1000”; bridge position was 70mm from internal end block.

For most tests, I also tested my own dulcimer (#54) and my Orthey replica under the same conditions. I consider my own dulcimer a superior sounding instrument (to my mind) and it’s the one against which I compare all dulcimers I make. It’s fairly stiffly braced top and back, with side linings. The Orthey is a very nice sounding dulcimer which sounds better without back braces than with, and has no side linings.

Perceived Sound Differences: These are my perceptions only – yours might be quite different.

#54 — Very bright sound with a “sting” to it, strong upper treble cutting power and lower treble “punch”; solid bass, but not exceptionally resonant. Good dynamic range. Middle string a bit reduced in clarity.

Orthey replica — A loud instrument, and with good clarity on all strings over the whole fretboard. Slightly reduced dynamic range and punch compared to #54. Nice resonant bass.

#93 (No linings or back braces) — most muted treble of the three test dulcimers; slightly muffled middle string but nice rounded bass. Reduced “punch” and attack. The least preferred of the three (by me).

#94 (Linings but no back braces) — Characterized by “clarity” on all strings. Reasonably “punchy” but reduced cutting “ring” on upper treble. Marginally the most preferred of the three test instruments.

#95 (Linings and back braces) — Seems loudest, and punchy. Good cutting power on high treble. Slightly muffled middle string. Best dynamic range.

All three test dulcimers seemed to have the same sensitive response to soft playing, none were overly mellow or bright — about middle of the road for my instruments.

Measurements

Measurements were made of sound level output, sound level difference between the top and back, tap spectra, and sound spectrograms.

Sound Level Output: Recordings were made of single strings using the copper thread pull method for repeatability. (look back to Figure 12.4 for the method). Three tests per string; nine string plucks per dulcimer. The first three seconds of each pluck was measured for average sound intensity using the PRAAT speech analysis software.

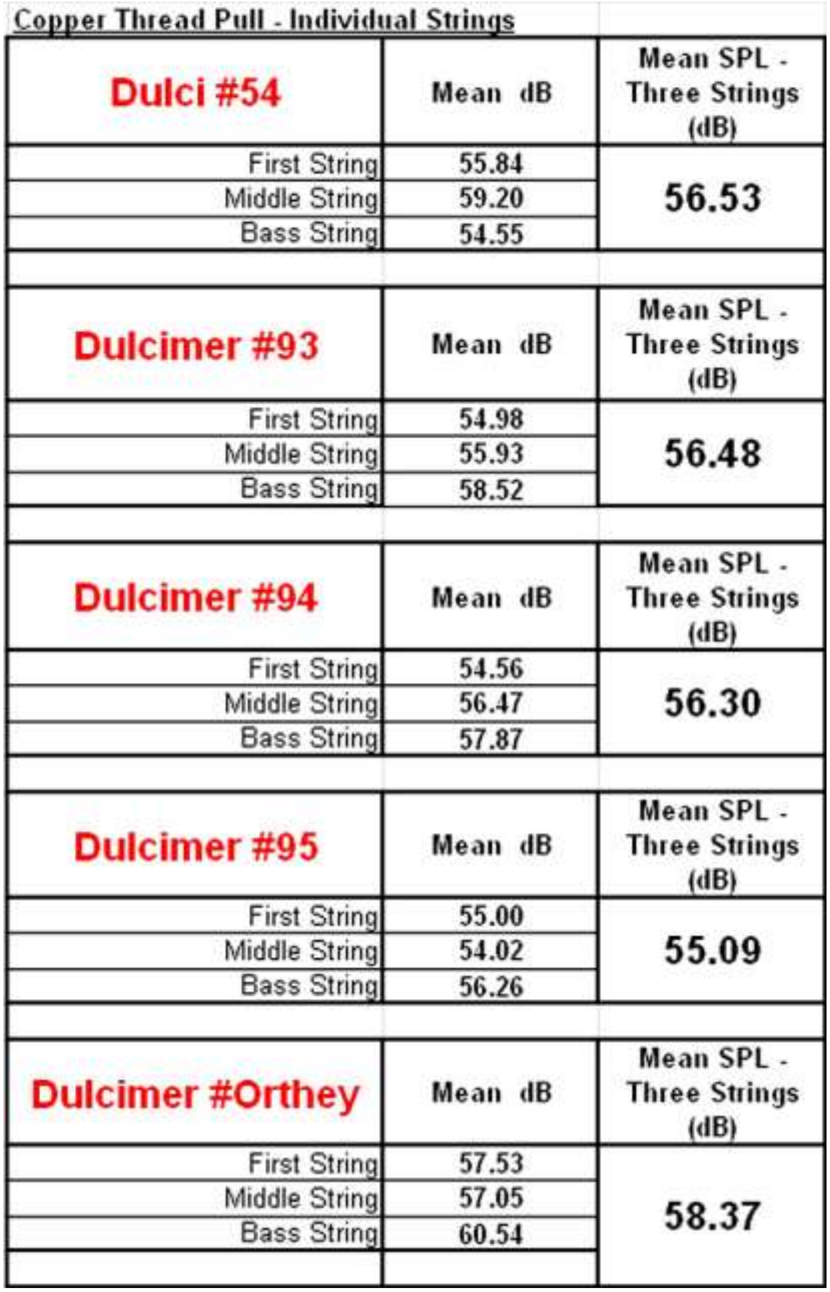
Results are shown in Table 12.2. Despite my perception that #95 was the loudest of the three, it was technically the quietest, so other factors (attack, frequency bias) are coloring the perception of loudness. The Orthey did clearly measure louder than the others, but only by about 3dB, which is not very noticeable. Overall there was not much between the three test dulcimers in terms of absolute sound pressure levels. (The numbers themselves don't mean much, but the test conditions were constant for all dulcimers so relative comparisons should be valid.)

Top – Back Sound Level Difference: I measured the simultaneous sound level of the tops and backs using the method described in Chapter 15 (60 string strikes of all three strings with a plectrum mounted on a freely rotating pendulum wooden rod, dulcimer resting on side, microphone on each side). A small difference in top-to-back sound level (in dB) means that the back plate is vibrating and producing nearly as much sound as the top of the dulcimer.

Since the two dulcimers without back braces should (and do) have much more flexible backs, I thought the backs would probably contribute relatively more to the total sound than a stiffer braced back; i.e., the sound level coming from the back plate would approach the level of that coming from the top plate/sound holes, or maybe even exceed it. But I was wrong.

Surprisingly, for the two unbraced-back dulcimers there was a larger SPL difference between the tops and backs than for the braced-back dulcimer (or the Orthey); i.e, the tops of the unbraced dulcimers were producing more sound relative to the backs. The stiffer back of the braced dulcimer (#95) was vibrating at least as strongly as the more flexible unbraced backs. There wasn't a lot in it, and the loudness of the tops were all very similar, but it points to the fact that a back might vibrate just as strongly as the top, whether it is braced or not. The most stiffly braced of all, my own dulcimer #54, has a louder back than any of the test dulcimers, but not as loud as the unbraced Orthey. Table 12.3 shows the top-to-back sound level differences.

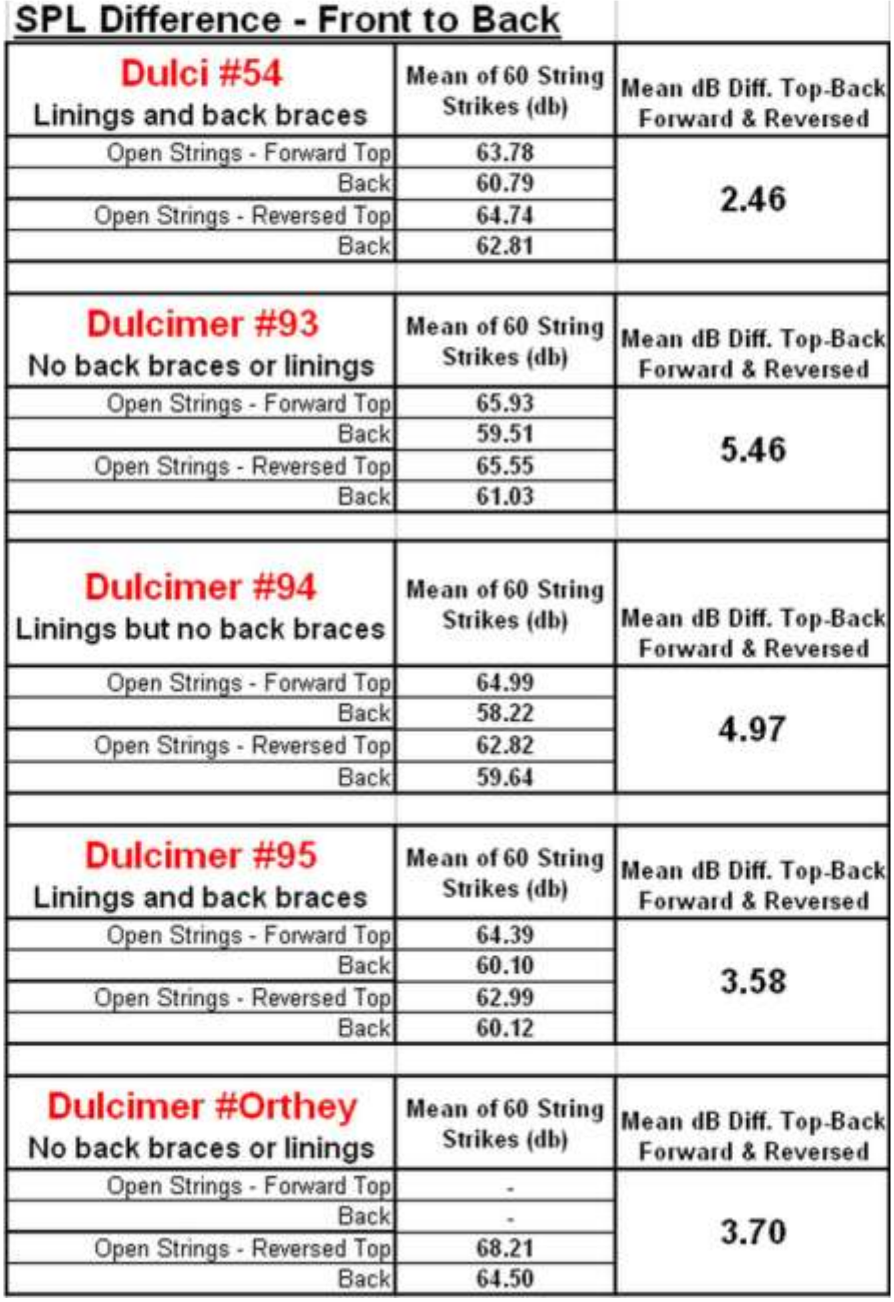
Table 12.2
Sound Level Output Results



Copper Thread Pull - Individual Strings

Dulci #54	Mean dB	Mean SPL - Three Strings (dB)
First String	55.84	56.53
Middle String	59.20	
Bass String	54.55	
Dulcimer #93	Mean dB	Mean SPL - Three Strings (dB)
First String	54.98	56.48
Middle String	55.93	
Bass String	58.52	
Dulcimer #94	Mean dB	Mean SPL - Three Strings (dB)
First String	54.56	56.30
Middle String	56.47	
Bass String	57.87	
Dulcimer #95	Mean dB	Mean SPL - Three Strings (dB)
First String	55.00	55.09
Middle String	54.02	
Bass String	56.26	
Dulcimer #Orthey	Mean dB	Mean SPL - Three Strings (dB)
First String	57.53	58.37
Middle String	57.05	
Bass String	60.54	

Table 12.3
Top vs Back Sound Levels



SPL Difference - Front to Back

Dulci #54 Linings and back braces	Mean of 60 String Strikes (db)	Mean dB Diff. Top-Back Forward & Reversed
Open Strings - Forward Top	63.78	2.46
Back	60.79	
Open Strings - Reversed Top	64.74	
Back	62.81	
Dulcimer #93 No back braces or linings	Mean of 60 String Strikes (db)	Mean dB Diff. Top-Back Forward & Reversed
Open Strings - Forward Top	65.93	5.46
Back	59.51	
Open Strings - Reversed Top	65.55	
Back	61.03	
Dulcimer #94 Linings but no back braces	Mean of 60 String Strikes (db)	Mean dB Diff. Top-Back Forward & Reversed
Open Strings - Forward Top	64.99	4.97
Back	58.22	
Open Strings - Reversed Top	62.82	
Back	59.64	
Dulcimer #95 Linings and back braces	Mean of 60 String Strikes (db)	Mean dB Diff. Top-Back Forward & Reversed
Open Strings - Forward Top	64.39	3.58
Back	60.10	
Open Strings - Reversed Top	62.99	
Back	60.12	
Dulcimer #Orthey No back braces or linings	Mean of 60 String Strikes (db)	Mean dB Diff. Top-Back Forward & Reversed
Open Strings - Forward Top	-	3.70
Back	-	
Open Strings - Reversed Top	68.21	
Back	64.50	

Sustain: I timed the sustain for the pendulum string strikes until I could no longer hear any string sound. The method seemed accurate to about a second. The three test dulcimers had a spread of sustain (or “decay”) from 14 to 16 seconds — basically less than 10% variation. Dulcimer #54 and the Orthey were both about 18 seconds — a bit longer but not much. So, it seems that the presence or absence of side linings and back bracing did not influence sustain significantly in these three instruments.

Tap Spectra – Free Back vs Damped Back: The spectra were recorded of the sounds of tapping the fretboards of the test dulcimers with a rubber hammer (no strings installed). This shows the natural resonances of the box itself and might point to some likely sound properties when strung up and played.

Whilst the three test dulcimers were fairly similar in the top-back loudness tests and the copper thread individual string loudnesses, these parameters were measured with an undamped back. When played on the knee, the two dulcimers without back braces (and the Orthey) were seriously muted compared to the braced-back instrument which was much less affected by knee damping. This was borne out by the tap spectra of a free back (mounted on soft rubber blocks at each end) and a damped back (resting on a towel covering the whole back) for each dulcimer.

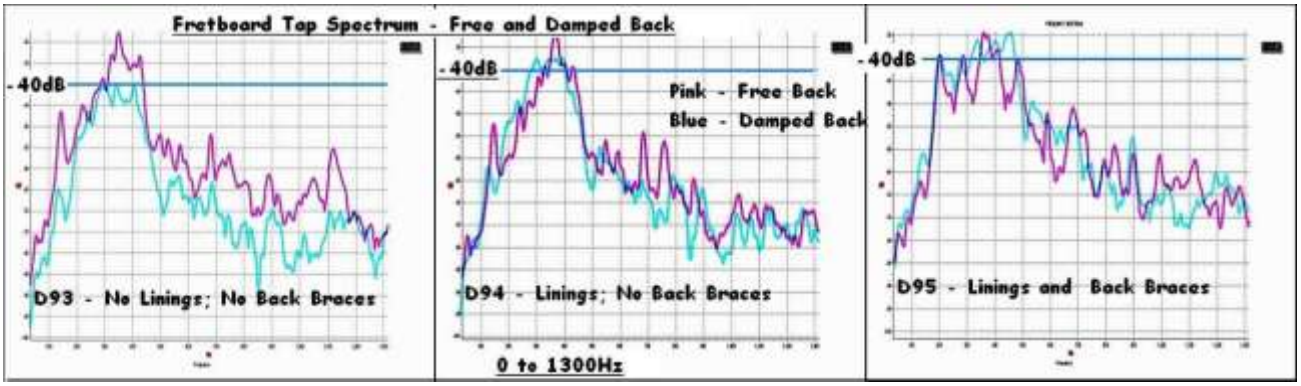


Figure 12.10. Tap spectra for damped and undamped condition

The pink traces in Figure 12.10 are the tap spectra with undamped back (off knee) and the blue is the damped-back (on knee) spectra. Dulcimer #93 (no back braces, no linings) drops about 10dB of sound intensity when damped on the knee — a noticeable fall in loudness; #94 (linings) less so; and #95 (linings and braces) less again. They were all still playable, but if you don't want to mess around with possum boards then table playing or back bracing is worth looking at to minimize sound loss by knee damping.

Sound Spectrograms: The copper thread single string plucks allowed reasonably comparable sound spectrograms to be made for each dulcimer. These show the number, strength, and duration of the partials of the plucked notes and can give an idea of where sound energy might be concentrated or missing in the spectrum. Some suggestions as to the effect of different parts of the sound spectrum on perception are provided from a sound engineering source:[21]

- strong overtones in the 250 – 500Hz region can add ambience and clarity to the sound, and maybe fatten it up,
- too much energy in the 500 – 2000Hz region can sound thin or "tinny",
- energy in the 2kHz – 4kHz region assists with "projection",
- energy in the 4kHz – 6kHz region provides clarity and "presence", and
- energy above 6kHz improves "brilliance".

All the dulcimers tested have sound energy extending up to at least 10kHz. A composite spectrogram for each string of each dulcimer is shown in Figure 12.11.

Figure 12.11. Composite spectrogram for five dulcimers

The top panel is 1st string, middle panel is middle string, and bottom panel is bass string. There are differences in the spectrograms, and hidden in there must be the reasons for the differences in the perception of the different sounds of the test dulcimers. For those who might like to see more detail, the same three individual string spectrograms expanded in height are shown in Figures 12.12 through 12.14. The Y axis is 0 to 10kHz.

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[21] https://pae-web.presonusmusic.com/downloads/products/pdf/AudioBoxUSB_OwnersManual_EN1.pdf

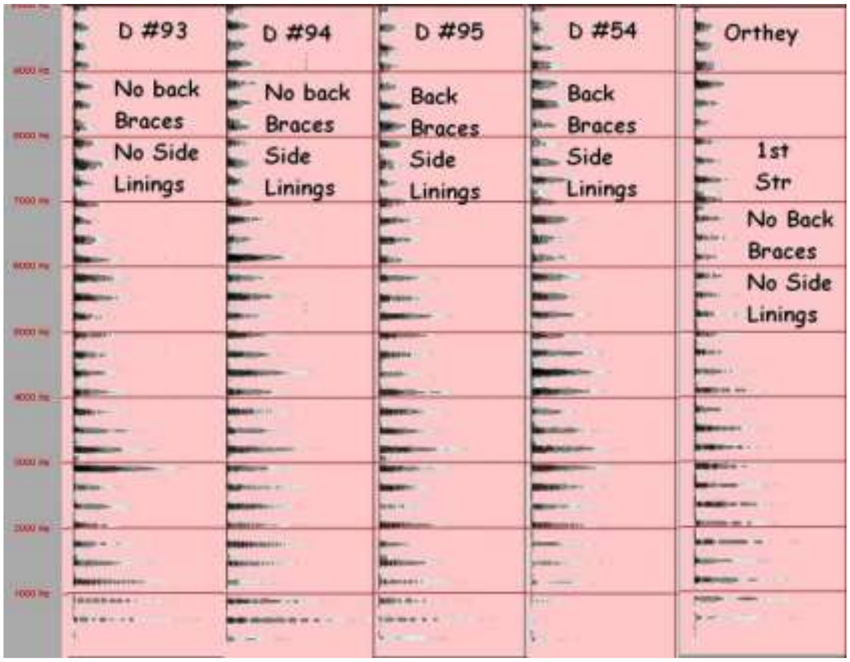

Figure 12.12. First string spectrogram

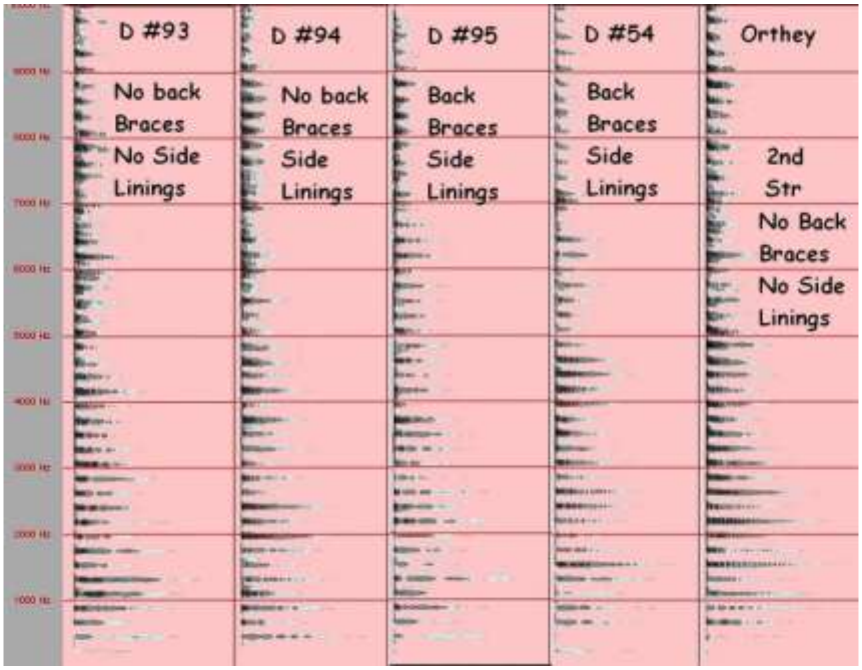

Figure 12.13. Second string spectrogram

Figure 12.14. Third string spectrogram

I think most people over 40 years of age will be unable to hear much of what is going on above about 5kHz. It might partially explain some of the difference in assessing the sound of instruments.

Conclusion

The three dulcimers tested here were as identical as was reasonable without getting obsessive, except for the presence or absence of internal side linings and back braces.

They all sounded good (to me), but the one without braces or linings was my least favorite. However, the variation in sound between them is no more than I would expect if they were all constructed identically with or without braces and linings. So it isn't obvious that the presence or absence of these components affected the sound significantly – the loudness, sustain or general spectral profile. It therefore seems reasonable that a maker can include, or dispense with these components and still expect a good tonal outcome, dependent upon factors other than bracing or side linings.

Chapter 13
Other Design Effects

Wood Under Stress-Dec 13, 2009

The idea of wood under initial stress whilst gluing is an attractive one; something feels right about having it taut and ready to go. I haven't done any serious literature searching about this for stringed instruments, so it may have already been resolved one way or the other — but as with most things, if there is a benefit, it's most likely to be frequency dependent, and also probably involves some trade-off in other ways. That is, its effect will be apparent in some part of the instrument sound spectrum, but not others, and the amount of effect, and the frequencies involved will be dependent on a range of factors such as the amount and distribution of stress, the wood type and dimensions, and the instrument part involved. Getting those factors right so that the frequencies affected produce a "good" sound, is what years of experience might produce. But this is still not to say that there ***is*** a proven benefit of constructing a dulcimer with stressed components. I have seen comments from time to time, from experienced guitar luthiers, that pre-tension in a top is a good thing that leads to improved tone and volume. But most luthiers don't do it and many still produce fine results. In addition, I've read comments from violin makers, and boat builders, that wood that is glued under stress, will, over time, adopt the shape forced on it, and the internal stresses will relieve to zero. If this is true, then it is tantamount to saying that an instrument built under stress, to produce its particular tone, has a definite use-by date, because the stresses will diminish as time goes by. I don't like to think that that is the case for the instruments I make. But, Segovia[22] firmly believed that guitars could become "dead" after a period of time and playing. So if pre-glue stressing does produce a superior tone, a price might be a reduced playing life for the instrument. It would be interesting to do regular follow-up on such an instrument over 5, 10, 15, 20 years to assess whether tone changes over time, and in which direction.

Overall, a dulcimer strung to tension is under considerable and constant stress, and this will distort the stresses introduced at the time of gluing, in gluing sides pressed into a mold for example. And unless there is some hysteresis involved in getting a non-stressed piece of wood moving, I can't think why an initial stress offset might change the dynamics of the vibration.

It might be said that a back plate, pressed into a curved profile when gluing, might

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[22] https://en.wikipedia.org/wiki/Andrés_Segovia

reduce the effect of knee damping in that the back would be less prone to deflection, essentially stiffer, on the knee, which is what I think reduces the knee effect. However internally bracing a back will have the same stiffening effect without requiring the difficulty of maintaining the sides at right angles to a curved back plate.

Curved top and back plates and sides under tension ***might*** modify the sound of a dulcimer, but the effects will be subtle at best, and not necessarily in the desired tonal direction.

Sound Ports - Mar 15, 2010

Sound ports are additional holes placed in the sides of guitars, ukuleles, or mandolins by some makers. The makers who install them are often strong advocates for them, and claim considerable tonal improvement. Double blind listening tests have not supported such claims. I have been asked whether sound ports were worth considering for mountain dulcimers, so I put one in a dulcimer to see the effect – a plain circle about 30mm diameter (Figure 13.1).

Figure 13.1. Sound port in mountain dulcimer side

The port was installed in the side facing a listener – the idea being that since most of the sound of a dulcimer comes from the top, and some from the sound holes on the top, then providing a little more of the sound directly towards a listener, through the sound port, should be a good thing. In this case my general perception was that the sound going towards the listener was probably a bit more “open”, or “full”, but not a lot. As a player I could not really hear much of an effect unless leaning over the instrument, and if I did it again for myself, I would put the port on the side facing me to get that extra bit of feedback. There did seem some enhancement of the upper treble fretboard, which I liked, but at the expense of a slight loss in the lower fretboard bass. In any intervention there are usually trade offs involved.

The lowest air resonance was raised two semitones from 227Hz to 250Hz with the port open, but the second air resonance (blowing across an upper bout hole) was unchanged. The note obtained by blowing across the sound port was 247Hz. I don’t know whether this was just a coincidence being so close in frequency to the lower bout sound hole note or not.

The side height was 50mm.

In Figure 13.2, frequency spectra show the box tap resonances with and without the side port. The peaks in the spectra occur at frequencies of the natural vibrations of the wood of the dulcimer, when tapped with a rubber hammer, some of which are caused by the vibration of the air inside. The top graph is with no side port, the middle graph with no side port but capo attached to the nut, and the bottom graph is with the side port open — everything else the same. The horizontal frequency scale is 0 to 2100Hz.

As expected, the main difference is the raising in frequency of the first air resonance (Helmholz) and its associated vibration coupling with the wood. There are some spectral differences about 550Hz, but this could just be normal test variation. Basically, the only change was to the lowest air resonance. And this was noticed by listeners. Comments were made that the bass response was reduced slightly. Side ports will always do this to some extent because the total sound hole area is increased (which raises the lowest air resonance frequency, hence reducing bass response). Listeners did not comment that it sounded louder or better by directing sound towards them.

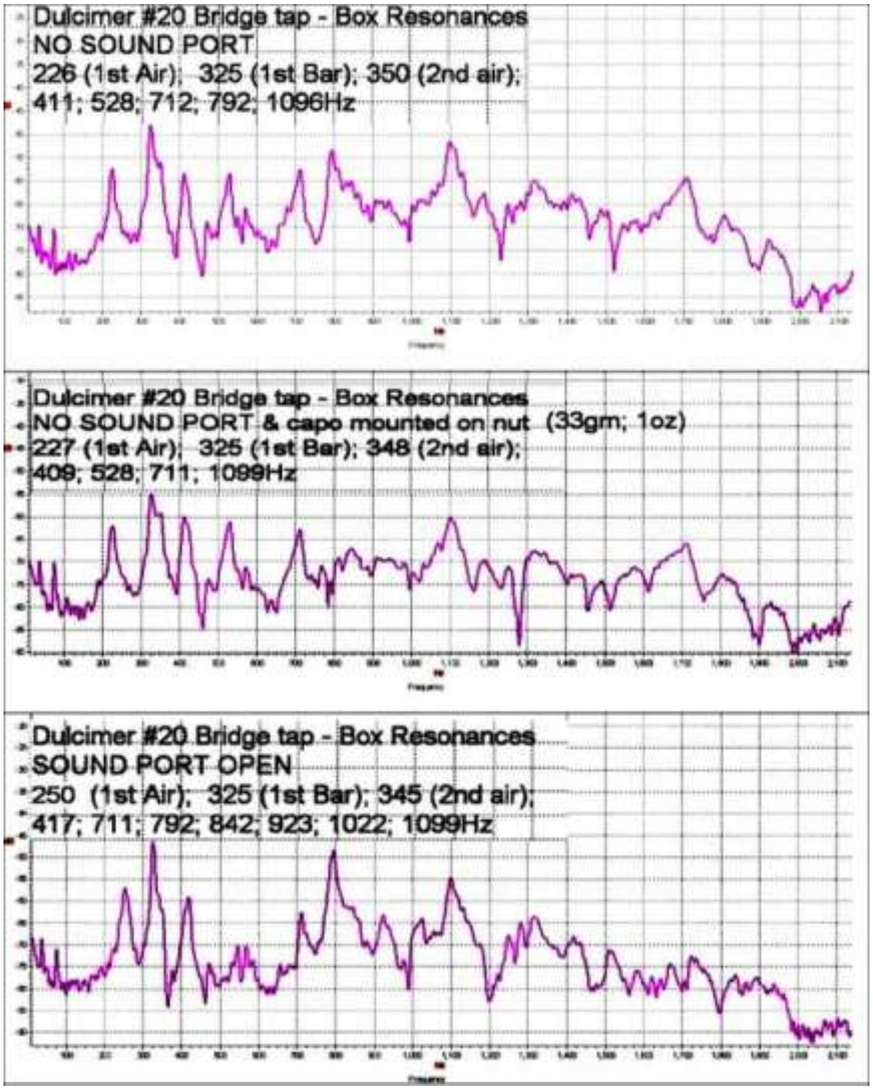


Figure 13.2. Effect of side port on bridge tap resonances

So to my mind, side-ports in mountain dulcimers may be of marginal value in improving or directing sound.

The second graph in Figure 13.2 is for the same instrument (no side port) with a capo, weighing 1oz, clamped onto the nut for storage, of the kind shown in Figure 13.3.

Figure 13.3. Dulcimer capos

It could be argued that this extra weight at the nut will change the tone of the instrument, and technically it will, but not noticeably in practice. The effect, if any, will be to lower the frequency of the 1st bar resonance, which is the second peak in the graph, because of the extra weight near the end of the dulcimer. There is no real difference in the first and second graphs above, except maybe at about 800Hz, which may or may not be related to the extra ounce. So unless you have a capo made of uranium, it's pretty safe to store it at the nut without ruining the sound of your instrument. Perhaps people have already noticed this!

After a while, seeing no particular sound improvement, I blocked up the sound port again.

Double Back-Sep 09, 2010

After installing the soft Balsa back on my test dulcimer, there was such a strong knee-damping that I had to put something on the back to prevent it, and to stop me putting my knee through the soft Balsa wood. So I mounted the Yellow Stringybark that the Balsa replaced, as an outer back (Figure 13.4).

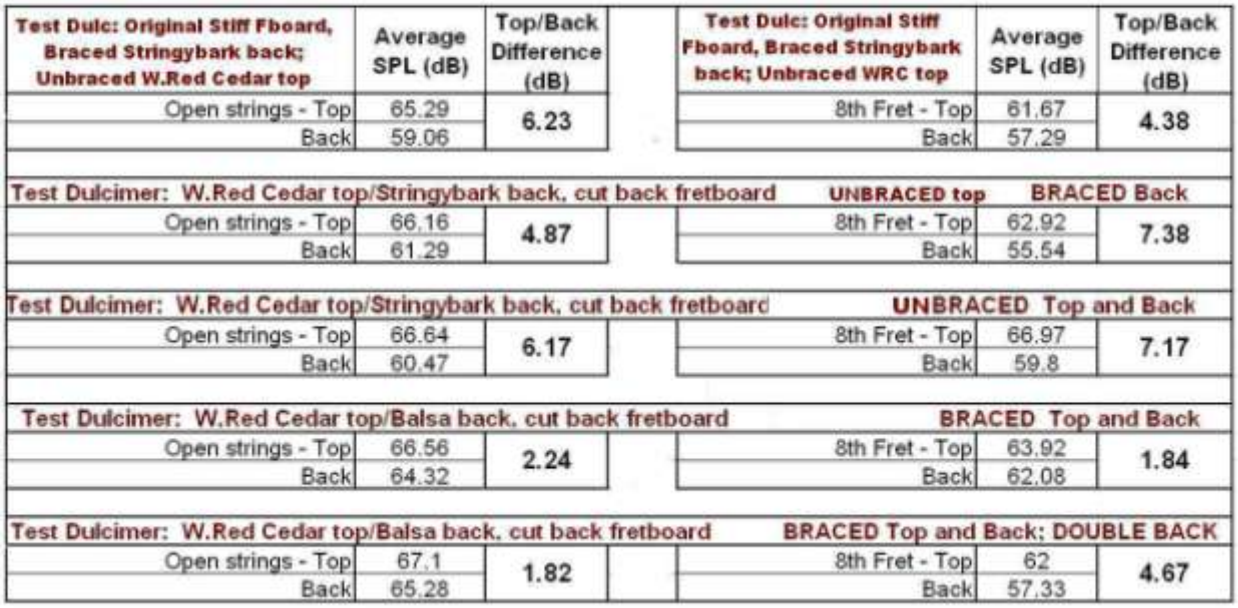
Figure 13.4. Outer back on test dulcimer

This was the first double back that I had installed, and whilst it moderated the knee damping, I was surprised how much the outer back itself vibrated — which meant that it was making sound, and the dulcimer still suffered from some knee damping. In addition, the nasal quality of the sound that was present when the Stringybark was the original back, and which I did not like, returned to some extent. So, the double back was not a full step forward.

Checking the bridge tap spectrum, and the top-to-back sound output (as measured in the set-up in Figure 13.4), revealed that the first bar mode of vibration had increased in frequency by 3 semitones, and the high frequency region covering 1200Hz to 1400Hz was reduced in amplitude. These two things would tend to make the instrument less mellow, and less bright at the same time, the first because the double back made the whole dulcimer box stiffer (less mellow), and the second because, for unknown reasons, the dulcimer is not as loud as it was, in the region 1200Hz to 1400Hz (less bright).

The top-to-back sound output summary for this dulcimer in the various configurations I've tested is shown in Table 13.1.

Table 13.1
Top vs Back Sound Output Summary for Various Dulcimer Configurations



Test Dulc: Original Stiff Fboard, Braced Stringybark back; Unbraced W.Red Cedar top	Average SPL (dB)	Top/Back Difference (dB)	Test Dulc: Original Stiff Fboard, Braced Stringybark back; Unbraced WRC top	Average SPL (dB)	Top/Back Difference (dB)
Open strings - Top	65.29	6.23	8th Fret - Top	61.67	4.38
Back	59.06		Back	57.29	
Test Dulcimer: W.Red Cedar top/Stringybark back, cut back fretboard			UNBRACED top BRACED Back		
Open strings - Top	66.16	4.87	8th Fret - Top	62.92	7.38
Back	61.29		Back	55.54	
Test Dulcimer: W.Red Cedar top/Stringybark back, cut back fretboard			UNBRACED Top and Back		
Open strings - Top	66.64	6.17	8th Fret - Top	66.97	7.17
Back	60.47		Back	59.8	
Test Dulcimer: W.Red Cedar top/Balsa back, cut back fretboard			BRACED Top and Back		
Open strings - Top	66.56	2.24	8th Fret - Top	63.92	1.84
Back	64.32		Back	62.08	
Test Dulcimer: W.Red Cedar top/Balsa back, cut back fretboard			BRACED Top and Back; DOUBLE BACK		
Open strings - Top	67.1	1.82	8th Fret - Top	62	4.67
Back	65.28		Back	57.33	

I would have thought a double back would reduce the sound radiation, relative to the top, more than it did in this case. There was essentially no difference in loudness top to back, with or without the outer back, at the lower fretboard. The isolation of top from back was greater on the original stiffer fretboard, at least for the open strings. This means that in this case at least, the outer back is still vigorously vibrating.

So, I'm not sure how double backs might work. They clearly reduce knee damping somewhat, but certainly not completely. And unless the outer back is super rigid, it will also vibrate and make sound (this one was fairly stiffly braced). Informal listening from the side of this test dulcimer, and my other dulcimer, seemed to indicate that more sound is directed sideways from the inner back of the double-backed instrument; i.e., towards potential listeners, than from a single backed instrument. That might explain the perception that double backs confer some loudness advantage — the sound that was already there is redirected to where people can hear it better. However, my subsequent more rigorous testing of this dulcimer showed that it was not actually louder from the side, so perceptions can be deceiving. The reduction in knee damping is a genuine benefit.

Double Backed Test Dulcimer- Feb 07, 2011

Some time ago, I replaced the back of my test dulcimer with a cross-braced balsa back. To protect the soft wood, I remounted the back I had taken off (a eucalypt, Yellow Stringybark) as an outer or false back, making the dulcimer a double-backed instrument.

I was not very happy with the result — I didn't like the Stringybark sound when it was the single back, and it's use as an outer back wasn't what I wanted either. So, I took off the Stringybark outer back and replaced it with an outer back of good quality 1/8" Hoop Pine ply, with the same cross bracing pattern as the inner Balsa back (Figure 13.5). The ply outer back was heavier and stiffer than the Stringybark back it replaced.

Figure 13.5. Hoop pine plywood back

The edge blocks separating the two backs were about 1/2" high.

To my slight surprise, I didn't much like the sound of the new ply back either; in fact it didn't seem much different to the Stringybark outer back.

I made some measurements and recordings during the process, and these are my findings and speculations – for this one instrument; it may or may not fully apply to other double backed dulcimers.

Measurements

Under identical conditions I made sound recordings and standard box and air resonance measurements for the two types of outer back (Stringybark and Ply), and with the outer back removed; i.e., just the Balsa back. I also made box resonance measurements of the Ply backed configuration with the back and top constrained by placing the dulcimer on my knee and pushing down on the top as hard as I could, whilst tapping the end block with the test hammer. For comparison, I also made the same measurements with a stiff single-backed dulcimer and an unbraced single-back dulcimer.

Results

The bridge tap resonance spectra of the test dulcimer for the three back conditions (Stringybark outer, ply outer, no outer) are shown in Figure 13.6.

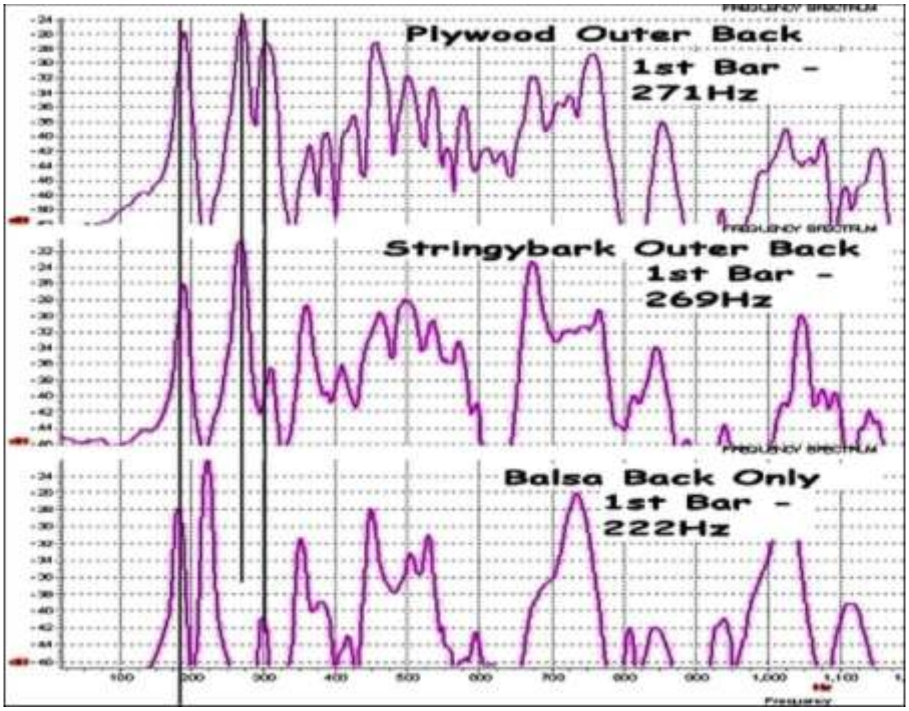


Figure 13.6. Test Dulcimer: bridge tap spectra for three back conditions

The peaks are the wood resonances shown up to about 1200Hz. The three heavier vertical black lines at the left correspond to the first air resonance, coupled to the wood; the first bar resonance; and the second air resonance, coupled to the wood. It’s clear that the addition of the outer back has not changed the frequencies of the two lowest air/wood resonances very much, because they are dependent upon the internal air capacity of the dulcimer, but the frequency of the bar resonance has risen from about 222Hz with a single back to about 270Hz with the double backs – that’s 3 ½ semitones. This is what would be expected because the outer back, mounted on the blocks, effectively increases the total height of the dulcimer box by the height of the mounting blocks, and this in turn raises the overall box stiffness. A stiffer bar (dulcimer box) has a higher first resonant frequency. These spectra were measured with the dulcimer suspended freely in the air.

Figure 13.7 shows the spectra of three different dulcimers when the back is constrained, as when playing on the knee.

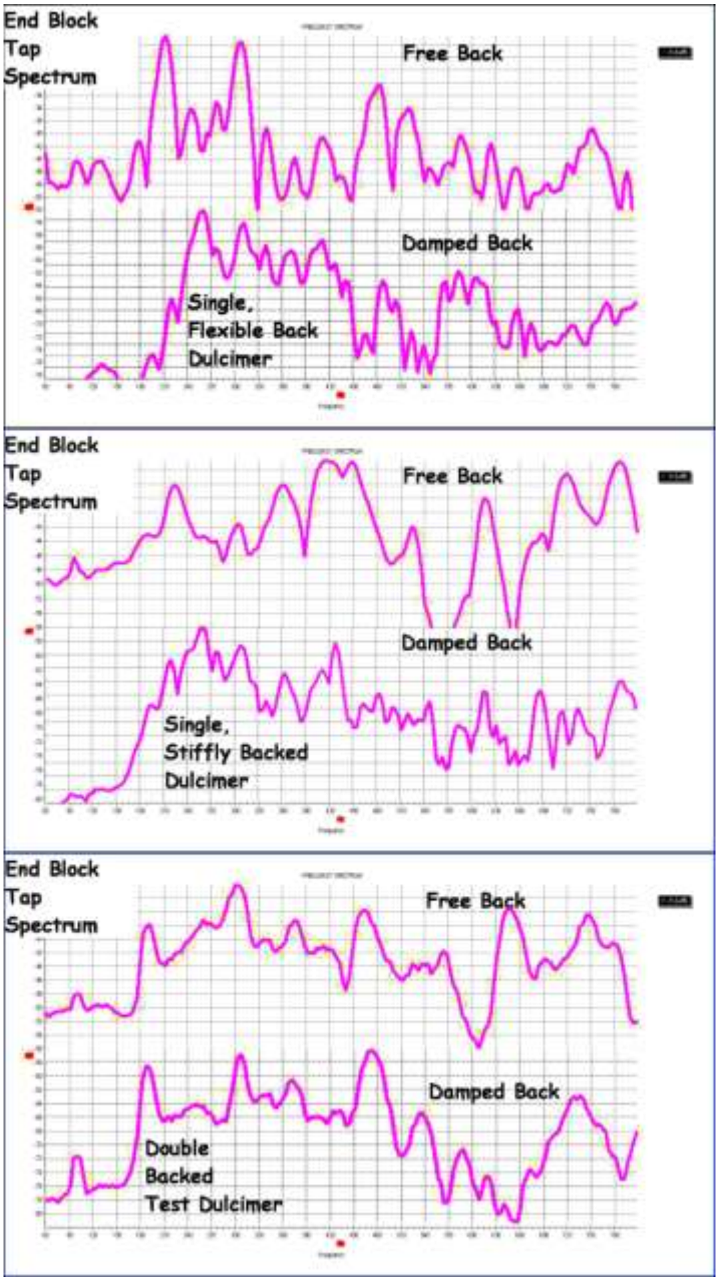
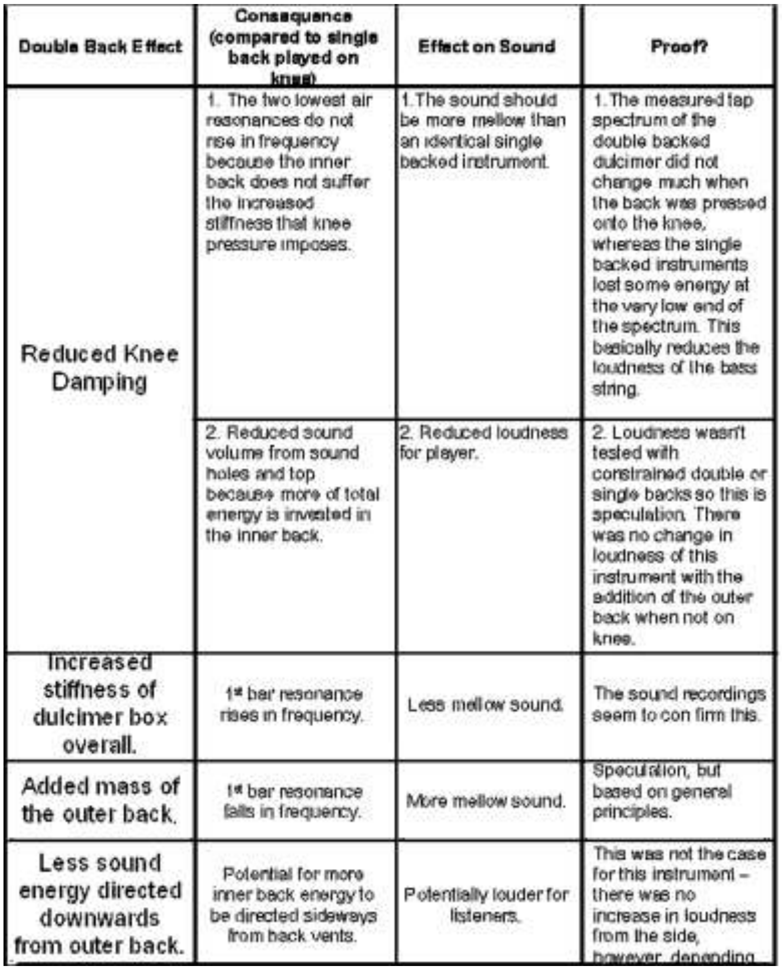


Figure 13.7. Effect of constraining top and back on tap spectra for three dulcimers

The top panel is an unbraced dulcimer with a flexible back; the middle is a stiffly braced dulcimer; and the bottom panel is the ply-double-backed test dulcimer. These spectra are from 60Hz up to 800Hz (30Hz scale increments). Both the flexible single-backed dulcimer, and to a lesser degree the stiffly single-backed dulcimer, have significantly changed the resonant character of the box under the pressure on the knee. But the double backed dulcimer has largely retained its resonance character, with or without knee damping. (The recording microphone was placed above the top plate.)

The relative loudness of the top to the back for the double backed test instrument compared to other configurations is shown in Table 13.2. It is difficult to say if this is typical of all double backed dulcimers.

Table 13.2
Double Back Effects



Double Back Effect	Consequence (compared to single back played on knee)	Effect on Sound	Proof?
Reduced Knee Damping	1. The two lowest air resonances do not rise in frequency because the inner back does not suffer the increased stiffness that knee pressure imposes.	1. The sound should be more mellow than an identical single backed instrument.	1. The measured tap spectrum of the double backed dulcimer did not change much when the back was pressed onto the knee, whereas the single backed instruments lost some energy at the very low end of the spectrum. This basically reduces the loudness of the bass string.
	2. Reduced sound volume from sound holes and top because more of total energy is invested in the inner back.	2. Reduced loudness for player.	2. Loudness wasn't tested with constrained double or single backs so this is speculation. There was no change in loudness of this instrument with the addition of the outer back when not on knee.
Increased stiffness of dulcimer box overall.	1st bar resonance rises in frequency.	Less mellow sound.	The sound recordings seem to con firm this.
Added mass of the outer back.	1st bar resonance falls in frequency.	More mellow sound.	Speculation, but based on general principles.
Less sound energy directed downwards from outer back.	Potential for more inner back energy to be directed sideways from back vents.	Potentially louder for listeners.	This was not the case for this instrument – there was no increase in loudness from the side, however, depending

Conclusions

I suspect that the original thinking for using double backs was to allow the inner back to vibrate more, and more freely, whilst still being played on the knee. I'm not sure that the inner back does vibrate more — sound output doesn't seem to be increased in any significant way over a single back, and a double-backed dulcimer might even be a little quieter than a single-backed version. This might not be important anyway — "more" vibration is not necessarily "better" vibration. But the double back certainly does seem to allow the inner back, and the instrument as a whole, to vibrate more freely, as evidenced by the stability of the box resonances even with a constrained outer back. In addition, the different mass and stiffness of the two outer backs tested did not seem to affect things very much (unlike changes in the fretboard affecting the whole top), so there may be some latitude in what wood is used and how stiff the outer back is made. It may be that a balance is possible between the increased stiffness a double back confers (less mellow sound) and the mass of the outer back (more mellow sound).

Like everything we do in making dulcimers, there is a price to pay for any supposed beneficial intervention, and double backs are not exempt. Table 13.2 attempts to summarize some likely effects occurring with a double back, and the resultant consequences, compared to the same instrument with a single back, played on the knee.

Effects of Sound Posts and Fretboard Overlays- Sep 18, 2010

Some of the old time mountain dulcimer makers installed sound posts in their instruments, and some modern makers use them. Others speculate about their value. It's hard to know what the aims of these older makers were, but some modern makers claim loudness is increased as a result of installing a sound post. In the past I did install a sound post in one of my dulcimers, through a sound hole, but it was such a failure, tone-wise, that I took it out and haven't done it since. However, sound posts are crucial to the operation of violin-class instruments, and the placement of the sound post is critical. So given the historical precedent in dulcimers, and some current claims, I thought a closer look worthwhile

One thing is clear, though — a sound post in a mountain dulcimer cannot function the way it does in a violin; the mechanism of any sound change it causes must be quite different. In a violin the function of the sound post (at least at low frequencies) is to immobilize the foot of the bridge on the treble side, so the bass side foot can rock up and down under the side-to-side influence of the bow on the strings, as in Figure 13.8. It is a means to turn a side-to-side motion of the bowed string into an up-and-down motion of the bass foot of the bridge, hence driving the top plate of the instrument

Because the dulcimer is a plucked instrument, there is no requirement to transform a side-to-side force into an up-and-down movement, as there is in a bowed instrument.

Without having any clear idea how it might work, I tested sound posts on my own dulcimer.

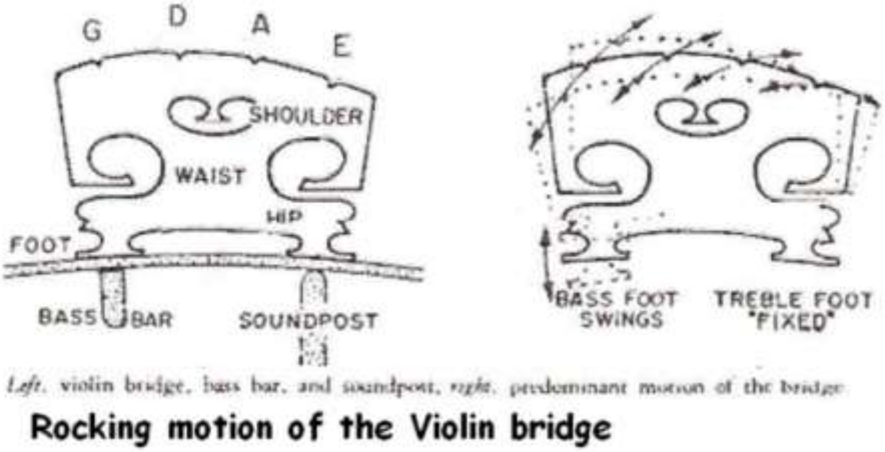


Figure 13.8. Violin bridge motion

Would I install one permanently? If other factors hadn't intervened — yes.
Will I put one in future dulcimers? No (unless other factors intervene).

What Did I Do?

I installed one or more sound posts in the fretboard of my dulcimer in holes drilled through the top, with a screw thread tapped into the fretboard wood, at eight different locations – 2nd; 3rd; 4th; 7th; 13th; 15th frets; after 17th frets; and also in front of the bridge (Figure 13.9).

Figure 13.9. Holes in fretboard indicating location of sound post.

These posts were screwed tight against the join strip of the back plate to physically connect the top with the back, or left just clear of the back to act as a weight on the fretboard, unconnected with the back.

I used metal and wooden sound posts (Figure 13.10) to get an indication of the effect of the weight of the sound post on the result.

Figure 13.10. Wood and metal sound posts

Although I did record the frequency spectrum of the instrument when tapping the bridge, I was really listening for audible improvements to the sound, so I didn't do any detailed sound analysis. The conclusions are my impressions – yours might be different.

This dulcimer has what I call a wolf note at C on the middle string – more likely an over-damped note – loud but of shorter duration.

Sound posts - General Results

1. There were clear improvements in the sound when a post was installed at Frets 2, 3 or 4, but 3 was the best. It didn't matter whether the post was metal or wood. The resulting sound had more sustain, particularly on the upper treble fretboard, more "ring" overall, but with a slight loss of some bass power and generally a reduced "presence" of the sound. The wolf note was gone, but in the Fret 4 post the wolf note was just moved up the fretboard to a new location.

But, the same results occurred when the posts were not in contact with the back plate, just suspended from the fretboard. This leads me to suspect that the effect was not a result of connecting the top to the back, but rather the effect of locally adding weight to the fretboard. The fact that neither the top nor the back vibrates a lot in the upper bout supports this idea — connecting two minimally-vibrating parts isn't going to achieve a heck of a lot in the energy transfer stakes. Nevertheless, the sound improvement at Fret 3 was sufficient that I would consider permanently mounting a sound post there – in this instrument only.

2. A sound post at the waist position seemed to have no effect at all.

3. From Fret 13 to the bridge a sound post unacceptably degraded the sound. In all four positions (13, 15, 17+ and bridge) the resultant sound was significantly muted and bland — basically the life was sucked out of the instrument. At Fret 17+ new wolf notes appeared up and down the middle string.

I tried various combinations of multiple sound posts, but all positions on the lower bout resulted in a very poor sound.

There might be a sound post position on a dulcimer lower bout that produces an improvement in the sound, possibly off the center line, but I don't think it would be predictable prior to building, and unless there is good access through a sound hole, finding the best position might be difficult after dulcimer completion. In addition, knowing what I do now about the vibratory behavior of the tops and backs, it doesn't seem sensible to me to physically connect them. The top is already louder than the back, and they both vibrate in very similar modal patterns anyway. I don't know the relative top/back phase behavior of the vibration, so it is possible that locking them together could reduce some of the air vibration coupling to the wood, but I would have thought that would generally be a bad thing. These tests bear that out, at least.

Overall, the effect of a post in the upper bout seems more related to the weight and its effect on possible wolf notes, and in the lower bout I think a sound post will generally be detrimental.

Fret Board Overlay to Cover Soundpost Holes- Sep 18th 2010

The fretboard of the dulcimer used to test sound posts was softish, and getting worn on the edges, so after the sound post exercise, I took off the frets, tuners and feet, planed the fretboard, and installed a very dense 2.65mm Jarrah (*Eucalyptus marginata*) overlay as shown in Figure 13.11.

Figure 13.11. New fretboard overlay

I couldn't measure the change in stiffness, but the fretboard height changed from 19mm to 14.6mm. That should result in a stiffness reduction of more than 50%. Weight probably went up marginally.

Stringing up immediately after putting the frets back and tidying up, I thought I had ruined the instrument. It had lost its "punch" and altogether had much less character. The wolf note was gone though, so I put aside the thought of a sound post. But over a period of about a week the glue must have hardened up, or I had forgotten what it used to sound like, so although still different, it seemed to be similar to what it was, less the wolf note.

The bridge tap spectra before and after the new overlay show some slight differences after the settling in period as shown in Figure 13.12.

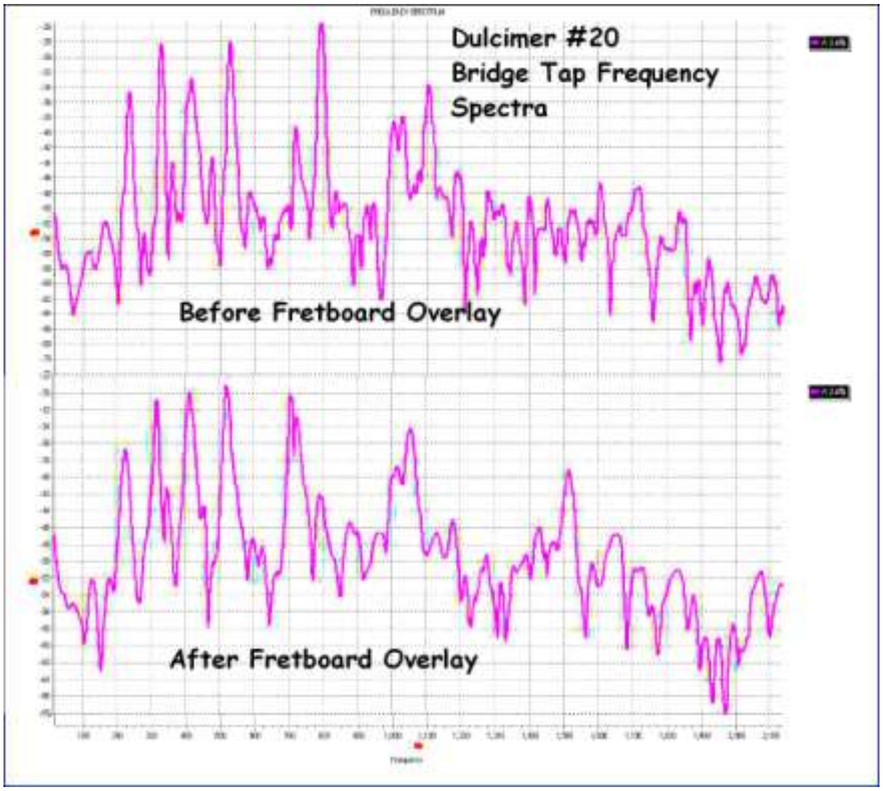


Figure 13.12. Bridge tap spectra before and after fretboard overlay

This was a very thin overlay, and I suppose the message (what I suspect many makers already know), is that a thick ebony fretboard overlay looks very nice, but it may have an unduly large effect on the way the dulcimer sounds, essentially swamping the effects of other structural choices made for the instrument.

Effects of strings and finish/aging- Nov 25, 2011

When I make recordings for sound comparisons I use the same string sets and the same recording conditions, but if the scale lengths are different, then the tensions will also be different - I don't control for the different tensions between two dulcimers with different string lengths. The studies of the resonance characteristics of the box itself are intrinsic to the box and independent of what strings are used, or how they are tuned. For a more rigorous look at how strings vibrate, the interested reader might track down the article “String Theory” by guitar and violin (and dulcimer) luthier Alan Carruth[23].

As to the effect of aging or finish on an instrument, I think the effects are far too subtle and slow acting to be detectable by anything I measure — I'm happy if I can show whether an instrument is louder or softer. Whether the sound is better or worse is a

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[23] www.alcarruthluthier.com/Downloads/stringTheory.pdf

value judgment I might be able to make for myself, but not for others.

"Playing In" a Mountain Dulcimer- Feb 18, 2018

From time to time, people talk about improving the tone and/or loudness of their dulcimer (guitar, ukulele, mandolin…) by the natural means of playing it frequently, or by some artificial means such as exposing it to loud radio music or white noise for an extended time. Anecdotes of dramatic improvement can be found, but information about precisely what has changed in the tone, and what has happened in the instrument, is harder to come by. There is some information, based on experiments, that perhaps the glue joints in a new instrument "settle in" over time, by the mechanism of glue creep, and that process can produce tonal changes. Another suggestion is that the hemi-cellulose in the wood cells degrades with vibration and/or time and this changes the stiffness/mass of the wood plates and hence the tone. Then there is the process of "torrefication"; the heat treatment of the wood prior to construction, that can result in lighter and stiffer panels — "playing in" the wood ***before*** it is used in an instrument, as it were. Nothing seems settled, however, on the ageing/playing in process, most likely because it's very difficult for us humans to agree on what "improvement in tone" means, and also because of our limited ability to remember what an instrument sounded like last week, let alone last year. And recordings can be made to sound like whatever we want them to sound like. Another point to consider— if "playing-in" an instrument actually does result in tonal changes by natural or artificial means, shouldn't there be numerous adverse outcomes as well as favorable ones?

Nevertheless, I thought one of my dulcimers, the Ebony, could use a bit of "opening up" and might benefit from some "playing in" that took less than six months or six years to achieve. I had heard of vibrating devices for musical instruments designed to do this and looked around for what the market had to offer. Surprisingly I could find very few such devices. Most were aimed at violins and could not be fitted to a mountain dulcimer. About the only general purpose device I could find was the ToneRite unit, so I bought one of those; about $130 (In 2018)[24]. (Disclaimer: The ToneRite is a commercial device. I know very little about the company and have no connection to it – I just bought one and used it.)

The device is a household powered vibrator. The small controller box has an adjusting knob to control the nature of the vibration. Inside is an electronic circuit board that, when traced out, appears to be a simple lamp dimmer circuit. The main vibrator unit seems to be a mechanical armature similar to an electric hair clipper. I was skeptical that

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[24] $149.00 U.S at www.tonerite.com

such a simple device could vibrate a musical instrument at other than 50Hz (or 60Hz in the US), and that this single low frequency could adequately “play in” an instrument.

The device itself is quite well made, and clips onto the strings of the dulcimer by means of some rubber covered bars. When switched on it makes a low level hum, but the sound is not obtrusive. It’s easy to get on and off the instrument and doesn’t get hot with extended use. No scientific information is offered in the booklet that comes with it, but there are claims that it should “vastly improve your instruments tone” and that “many users had seen huge improvements”. Feeling the headstock of my dulcimer, with the ToneRite attached, there was a strong vibration, subjectively about double that which would occur by firmly strumming the dulcimer. Figure 13.13 shows the ToneRite attached to the dulcimer.

Figure 13.13. Vibrating ToneRite “playing in” device

I put the device on my ebony dulcimer, resting the ends of the instrument on soft pads, which allowed the back to freely vibrate. I left it for the recommended 72 hours, then, for another 72 hours, then continuously for a month. In between I played and listened to the dulcimer, and recorded the spectra of the bridge tap tone. After the Ebony dulcimer, I attached it to a second fairly quiet dulcimer for the recommended 144 hours.

The questions I wanted to answer were: did the device vibrate the dulcimer in a way that covered a reasonable frequency range; and was there any noticeable difference in tone afterwards?

For the first question I made some recordings from the top plate of the dulcimer with a small piezo transducer and looked at the spectrogram to see the spread of vibratory harmonics (using the PRAAT software package). Figure 13.14 shows the spectra.

The three blue waveforms in the upper panel of Figure 13.14 are audio frequency recordings made with a piezo pick-up attached to the top plate of the dulcimer. They represent the way the top plate is set into vibration by the ToneRite device. The setting of the ToneRite control knob changes the shape of the vibrations.

The second pink panel is an expanded version of the highlighted part of the top waveform. The lower panel is a sound spectrogram of the middle panel waveform, showing the presence and strength of harmonics at the household power frequency. Each horizontal grey line represents a power frequency harmonic.

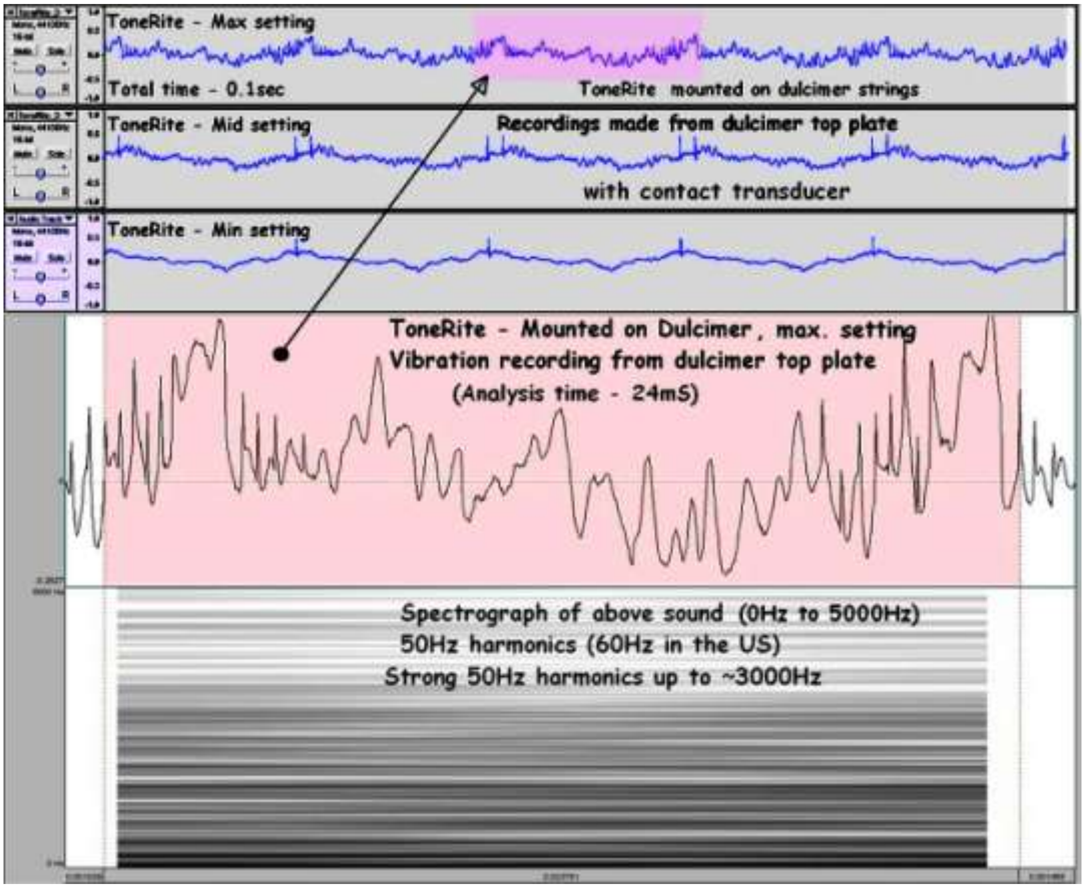

Figure 13.14. “ToneRite”-induced vibrations in a mountain dulcimer

The result was that the device ***does*** vibrate the dulcimer in quite a complex fashion.

There are strong vibration components at 50Hz intervals up to at least 3000Hz. This should give the device a good chance of "playing in" all physical parts of the instrument no matter what their frequency dependence might be. If the play in effect does not depend on frequency per se, but generalized vibration, the ToneRite accomplished that also — the whole dulcimer was vibrating vigorously.

But did the device alter the tone of the ebony dulcimer (32 days continuous application) or the other dulcimer (the recommended 144 hours)? The answer is a fairly definitive ***no***. Try as I might, by different playing styles and careful listening, I could discern no change at all in either dulcimer. I had hoped for a clearly noticeable effect.

The bridge tap spectra (Figure 13.15) for the ebony dulcimer before treatment is basically identical to that after a month of treatment. This means that the gross tonal characteristics of the instrument did not change with treatment. The frequencies, bandwidths, and relative amplitudes of the various resonances below about 1000Hz are unchanged. Any vibration produced changes in the spectra above this are likely to result in more subtle changes to dulcimer tone, but I couldn't hear any — subtle or gross.

Figure 13.15. Bridge tap spectra before and after ToneRite application

So overall, although it does vibrate instruments in a seemingly adequate way, using the ToneRite as an artificial play-in device produced disappointing results for these two dulcimers. What does this mean for the ageing/play-in process and the ToneRite, or any similar device?

1. Both the dulcimers treated were made of high density wood (that's partially why they were quiet in the first place). Maybe tonal aging is less applicable to dense woods, either naturally with time, or with artificial vibrators.
2. Maybe mountain dulcimers don't exhibit marked tonal changes with age/playing-in.

3. Maybe there ***was*** a tonal change, but I just could not hear it (in which case artificial play-in devices are a waste of money for me).

4. Maybe the ToneRite doesn't mimic the natural play in/ageing processes that occur over years and decades — perhaps it's not vibration that accomplishes the effect after all.

5. Maybe tonal improvements by playing in/ageing are all a myth.

Separating Top From Sides – a Free Top Dulcimer -Jun 26, 2017

The Kantele is a traditional Finnish instrument, an unfretted zither, sometimes with an open back and sometimes an enclosed box with a sound hole. Over the past decade studies have been undertaken, by Henri Penttinen[25] and his students, into modifications to traditional construction that might lead to improved sound output and tone. This led them to a Kantele that was an enclosed box type, but instead of a sound hole, there was a narrow gap between the edge of the top plate and the sides. They claim some sound enhancements result from this.

An interesting masters thesis by one of Penttinen's students, Henna Tahvanainen, is available on-line at http://www.researchgate.net/publication/235044019. This has a lot of information regarding the acoustics of stringed instruments, much of which is applicable to mountain dulcimers.

Method

In the past I have done vibration mode tests on completed mountain dulcimer tops in the hope it would allow "tuning" of a top before it was glued to the sides — as some makers do for guitars and violins. No such luck. However, I did notice that the vibration modes of free tops were, in general, more complex than the vibration modes of the tops of completed dulcimers (Figure 13.16).

This led me to wonder if a more "interesting" sound might result if the top edge of a dulcimer was not glued to the sides, but was separated by a small gap. So I cut the top plate of my test dulcimer around its periphery, allowing the top plate edges to vibrate freely (Figure 13.17).

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[25] https://www.researchgate.net/profile/Penttinen_Henri

Figure 13.16. Some vibration modes of fixed vs free top edge

Figure 13.17. Cutting the top edge of the test dulcimer

The resulting saw cut was about 1mm wide and adds about 1500mm^2 to the sound hole area – about 50% more than was there already. Not an excessive increase (total about 6 sq.in, up from 4 sq.in) but it would raise the frequency of the first air resonance by about a semitone. The reason the saw cut is about 1cm away from the dulcimer edge is that the internal side linings are that wide (from a previous experiment).

When I was done with the free edge, I thought I might as well cut half of the actual top plate off, eliminating most of the internal air resonance sound contribution. As expected that didn't improve the sound (but it did seem just as loud) (Figure 13.18)

Figure 13.18. Test dulcimer with free top edge, then half top removed

Results

Results were fairly under whelming. I recorded three tunes with the intact top, then cut a slot in one side, made the same recordings, then cut the other side and made more recordings. My overall impression was that there was no dramatic change in tone for fixed top edge (normal situation), half free/half fixed, or fully free edge top. In blind listening tests (repeated twice), I preferred either the fixed (normal) top or the half free/half fixed edge top. I consistently didn't prefer the fully free edge top. But there was not a lot in any of it — nothing obviously changed for the better or for the worse.

The bridge tap frequency spectrum for the test dulcimer before and after cutting the top free are shown in Figure 13.19. Other than the general trend of the two spectra, the spectral landscape seems completely changed — there are no common resonance frequencies. The usual lowest resonance, the 1st air resonance (Helmholz), has risen from 184Hz to 194Hz, which would be expected because the overall sound hole area has increased because of the edge slot (sound hole area ***up*** — Helmholz resonance ***up***). But in the free top case, there is an additional lower resonance at 135Hz, the origin of which I don't know. Overall, it shows that a dulcimer with a normal fixed top edge vibrates quite differently to one where the top edge is free to move.

Figure 13.19. Bridge tap frequency spectra – before and after freeing top edge

After half the top plate had been removed the tap spectrum was as shown in Figure 13.20, fairly similar to the full free edge case.

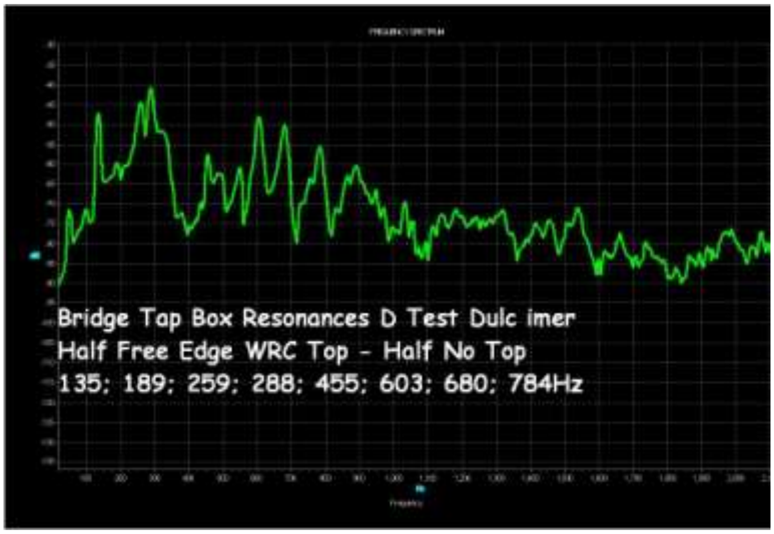

Figure 13.20. Bridge tap frequency spectrum – half top removed

Conclusion

This was clearly not an exhaustive experiment, just a rough attempt to see if there might be a large effect, but there was certainly no improvement in tone. The Finnish group found tonal differences with different air gaps, and even an optimal sized air gap for maximum radiation efficiency (loudness). So, some variation of this idea might still be profitable for mountain dulcimers, but it won’t be as simple as just leaving the top edge free – some tuning would probably be involved. And it won’t be a game changer – improvements would be subtle, as with most other constructional factors.

Chapter 14
Tone Studies

What is Tone?-Feb 19, 2018

What is tone? It's a valid question, but probably doesn't have a universally agreed answer. To me it means the subjective totality of the sound the instrument makes. That total sound has many contributing elements, including factors intrinsic to the instrument itself such as the natural resonant nature of the wood and the enclosed air, the damping of the sound by the wood, and maybe the projection of the sound by the shape of the instrument. But not all of the possible resonances of the instrument might get activated - they require an input, an excitation, and those are provided by the strings which can change the mix of resonances that get excited or even force the instrument to vibrate off a resonance, and that can change the tone. And the strings themselves are put into motion by a player with the aid of some sort of string striking device - fingers or plectrums, both of which greatly modify the way the strings cause the body of the instrument to vibrate (and make sound).

The only parts of this that are under the control of the maker are the first parts about intrinsic instrument factors. That's why when trying to compare the sound of two instruments there is generally an attempt to make common the other factors - playing conditions, type of string strike, environment, etc.

When it comes to making a judgment about the sound of an instrument we might be listening to, we are probably making unconscious assessments about the loudness, the spectral content (bass, middle, treble), the pitch and the sustain, and we mentally translate that into judgments such as "that sounds mellow....really loud.....tinny..." etc. And those mental pictures represent the tone of the instrument and other than general agreement about loud/soft, mellow/not mellow etc. are probably unique to each individual listening.

Construction Factors for Bright or Mellow Sound - Sep 09, 2015

There is a moderate amount of discussion in the dulcimer making community about whether a particular mountain dulcimer sounds mellow or bright, however there is no real definition of what mellow or bright means. Also, some of the construction factors that should make a dulcimer mellow/bright seem to have the opposite effect. The wood won’t cooperate, you know.

Despite the lack of technical definition, we mostly seem to understand what is meant by the descriptions “mellow” and “bright”. Mellow favors the lower end of the sound frequency spectrum, either because the lower pitched harmonics are stronger, or because of the absence of higher pitched harmonics. A bright sound favors the higher end of the spectrum because the lower harmonics are weak or the higher harmonics are strong. There are likely to be other factors involved in the perception, but the relative strengths of the high/low harmonics is probably the main one.

Construction factors that should produce a particular sound sometimes (often?) do not produce that sound. Later in this chapter is the report of three dulcimers that seemed reversed in what they should sound like. I couldn’t really explain why that was.

Factors such as the box cubic air capacity, thickness of the plates, general stiffness, types of wood, size, and shape of sound holes and other factors are often given as influencing whether a dulcimer will be mellow or bright when it is finished and strung up. But no combination of these factors seemed to help me in predicting outcomes for my own dulcimers. Making measurements after they are built is fine, but things can’t really be changed by then, and we are a long way from being able to use theoretical values of resonances; etc., to make accurate predictions about the final sound of an instrument prior to construction.

By now I’ve made a hundred or so mountain dulcimers, and kept detailed records for most of them during construction. I’ve written down my impressions of the sound of each one at the time of construction– some of them I have explicitly noted as sounding “mellow” or “bright” to me. Somewhere in all that data there should be clues as to what is different in the construction of the mellow and the bright instruments.

So I looked back over my records and picked out nine dulcimers I thought of as “bright” and nine as “mellow” and compared the construction details.

And for a change, some practical information seems to have emerged. Some information confirms what seems intuitive, but there were also some surprises (at least to me).

Construction Factors Looked At

I only considered factors that could be controlled during the construction process, meaning that subjective factors such as tap tones, or quantitative factors such as final Helmholtz resonance were not considered. The list of factors is certain to be incomplete – it can only include the things I have measured and recorded during construction.

Other makers might measure different things. Also, the analysis is only for my own pattern dulcimers – I can't say for sure whether the results apply to other patterns, but it's a start. All dulcimers in the analysis were full-length fretboard designs.

The construction factors I looked at were:

- back plate wood density,
- side density,
- top density,
- back thickness,
- side thickness,
- top thickness,
- side height,
- fretboard height,
- fretboard width,
- fretboard density,
- fretboard type hollow/arched,
- completed top/fretboard stiffness (static deflection),
- bracing stiffness – top,
- bracing stiffness – back,
- scale length,
- number of frets – 2 octaves or 2 octaves+3,
- height of fretboard at strum hollow,
- position of bridge from to the internal edge of the end block,
- internal end block length,
- total instrument weight, and
- total area of sound holes.

The values for each of these factors for each instrument were collated into two spreadsheets – one for the nine "bright" instruments and one for the nine "mellow" instruments. In some cases, such as bracing stiffness, I had to rank them on a scale of 1 to 5 based on my knowledge of the wood they were made of and their recorded dimensions.

Analysis of the Construction Factors

I had hoped that just eyeballing the spreadsheets might clearly highlight differences between the construction of mellow and bright instruments, and while some factors did seem different between the two groups, I know enough about comparing small sample sets to realize I had to do some actual statistics. So out came the university statistics textbooks. Some t-tests and F-distributions later and at least I'm satisfied that the comparisons are as valid as the data allow.

In essence, I wanted to see for each factor (height, thickness …), whether there was a statistical difference between the mellow sounding group and the bright sounding group, and if there was, how significant was it.

Results

For the eighteen dulcimers I looked at, the factors shown in Table 14.1 had a statistically significant influence on whether a dulcimer was in the bright group or the mellow group (in no particular order of importance):

Table 14.1
Factors Affecting Bright vs Mellow Tone

Construction Factor	Bright Dulcimer	Mellow Dulcimer
Top Thickness	Thicker; >3mm	Thinner; < 2.7mm
Side Height	Higher; >50mm	Lower; < 45mm
Top/Fretboard Stiffness (End-supported Free Top Deflection @7.6kg, mid f/b)	Stiffer; < 100/1000" deflection	Flexible; >130/1000" deflection
Stiffness of Back Braces	More stiff	Less stiff
Height of fretboard at strum hollow	Higher; >10mm	Lower; < 7mm
Bridge position from internal edge of end block	< 50mm	> 80mm
Total Area of Sound Holes	Larger; > 30cm^2 (4.5 sq in)	Smaller; < 10cm^2 (1.5 sq in)

Other slightly significant factors were:

- Back/side wood density: lighter wood tends to bright; heavier to mellow.
- Height of fretboard: higher (>20mm) tends to bright; lower (< 18mm) tends to mellow.
- Scale Length: longer tends to bright; shorter tends to mellow.
- Length of strum hollow: shorter tends to bright; longer tends to mellow (this may equate to the number of frets: 2 octaves +3frets = shorter strum hollow; two octaves = longer strum hollow)

Factors that did not seem significant for bright/mellow sound:

- top wood density,
- back/side wood thickness,
- fretboard width,
- fretboard density,

- top bracing stiffness,
- length of internal endblock, and
- total dulcimer weight.

Top Thickness: This was unexpected. I have maintained that top plate thickness does not have much effect on the final sound because top thickness variation translates to top stiffness variation, but the fretboard stiffness swamps the top plate stiffness for the normal range of top thicknesses. So, there may be other processes that make a thin top favor the lower pitches, hence a mellow sound. I have conducted another experiment to test just this — the effect of top thickness change in two otherwise identical dulcimers. The thin topped dulcimer did sound more mellow than the thick topped instrument, and I couldn't really explain why. So there is some experimental evidence that backs this statistical evidence, and perhaps supports many makers' gut feeling.

Side Height: This was also unexpected. Since all the dulcimers looked at had the same outline, the height of the sides is really a measure of the cubic capacity of the dulcimer box. Conventional wisdom holds that a bigger box should sound more mellow, but this analysis is saying that for my pattern dulcimers, a bigger box is more likely to sound bright. Two reasons for this spring to mind. Firstly, a taller box gains stiffness, which in general favors the higher frequencies. And secondly, a taller box moves the back plate and the top plate further apart, and this may modify the top/back coupling of the wood plates via the internal air. The examination earlier in this chapter of three dulcimers, where the lowest sides/smallest box sounded the most mellow, supports this current analysis.

Top/Fretboard Assembly Stiffness: This is an expected outcome. As the overall stiffness of the top/fretboard goes up, the ability to support lower frequencies goes down, favouring a brighter sound.

Stiffness of Back Braces: This was another unexpected result, but on reflection one that might seem more reasonable. Fixing braces to the back has more of a relative effect than fixing them to the top with its very stiff fretboard attached. The back can go from very flexible (tending to mellow) to very stiff (tending to bright) by the application of bracing. In contrast the top stiffness will not change nearly as much by adding bracing - it is already very stiff because of the fretboard. Note that the effect of the added mass of the bracing (favoring mellow) is not as important as the increase in stiffness (favoring bright), as expected.

Height of Fretboard at Strum Hollow.: There has been little discussion about this factor amongst dulcimer makers. The reason this factor is significant is not clear although it would tend to increase top assembly stiffness as the strum hollow fretboard height increases. I don’t know when strum hollows came into common use, but Galax dulcimers don’t have them, and they seem to be generally bright sounding instruments.

Bridge Position from Internal End Block: It’s known that moving the bridge off the end block towards the middle of the lower bout can affect the sound quality. This is generally achieved by lengthening the dulcimer whilst keeping the scale length unchanged - the string saddle is then effectively moved inward towards the center of the lower bout. The end block takes up some space within the dulcimer body, unseen from outside, and we usually measure the position of the bridge relative to the end of the instrument body, but the distance from the internal edge of the end block to the bridge may be the more important measurement.

Total Area of the Sound Holes: Again, the effect of sound hole size is generally known – small holes favor mellow; large holes favor bright. I would have thought it was a secondary factor, but in this set of instruments it significantly affected the perception of bright or mellow.

Conclusions

I shouldn't be too dogmatic about these conclusions, but in in general it seems more likely that:

A ***mellow*** dulcimer will have a thinner top; lower sides; a more flexible top/fretboard assembly; lighter (or no) back braces (a more flexible back); a low strum hollow, bridge further from the internal end block; and small sound holes.

A ***bright*** dulcimer will have a thicker top; higher sides; stiffer top/fretboard assembly; stiffer back braces; a higher (or no) strum hollow; bridge closer to the end block; and larger sound holes.

Other factors that are not addressed here, such as the width of the lower bout, may also be significant.

How reliable are these conclusions? Well, the statistical conclusions on this data set are valid. Whether they apply to the whole population of mountain dulcimers is less certain. But that can be said about any constructional advice a luthier may give. There is a spread of values for each factor within the two groups, and the spread of some factors overlap between the two groups, so there are no guarantees.

Effect of Dulcimer Box Size on Tone- Mar 13, 2014

The physical internal air volume of a mountain dulcimer is usually claimed to be a general guide to how mellow the dulcimer will sound. Other things being equal, a bigger dulcimer should sound mellower than a smaller one. But that isn't always the case, and some other factors must be able to counter-act box size to make a larger dulcimer less mellow than might be expected. Or conversely, other factors might over-ride a smaller dulcimer and make it sound more mellow. What might those factors be?

I recently completed two dulcimers and the immediate subjective sound impressions were the reverse of what might be expected given their relative sizes. And as it happens, they were both of a very similar configuration to my own dulcimer. The principal differences were the side heights, and the woods they were made of. Of the three, the largest one sounded the least mellow (D54), and the smallest the most mellow (D75). They are shown in Figure 14.1.

Figure 14.1. Three dulcimers with same outline and different side heights

I had no trouble ranking the three dulcimers based on my own internal definition of mellowness. (the opposite of "trebleness"?), but I made some recordings and did some measurements.

Method and Measurements

Under constant conditions, in DAd tuning, I recorded some open string strums for each dulcimer and a short tune on the lower fretboard. Then I retuned to CGc and did the recordings again to test whether one instrument was just particularly resonant in one tuning. It wasn't.

I listened to the recordings (blinded to the dulcimer number) and ranked them subjectively for mellowness.

The frequency spectra of the short melodies in D and C tunings were analyzed for spectral Centre of Gravity, and the skewness of the spectra. The Spectral Centre of Gravity (C of G) is the frequency at which there is as much sound energy below that frequency as there is above it. For two sounds, the one with the lowest spectral C of G might be expected to sound mellower because more energy is concentrated in the lower frequencies. The Skewness of the sound spectrum is a number that indicates how different the lower part of the spectrum is from the upper part. The higher the skewness number the more dissimilar the upper and lower parts of the spectrum are; i.e., more tonally unbalanced. Table 14.2 lists the measurements or rankings of three dulcimers. Dulcimer 54 was my own dulcimer and 74 and 75 were the new dulcimers.

Comments

In the listening tests, the shallowest dulcimer (75) was always perceived as the mellowest. The other two larger dulcimers swapped places when tuned from DAd to CGc. And in fact, the numbers suggest that the mellowness order is:

- largest dulcimer - middle mellowest,
- middle dulcimer – least mellow, and
- smallest dulcimer – most mellow.

Of the parameters I measured, only the top plate/fretboard weight seems a reasonable candidate to override the box capacity differences and alter the mellowness perception. The smallest dulcimer also had the heaviest top/fretboard assembly. The other parameter that can affect mellowness, the first air resonance (set by the sound hole and box size), were in the wrong order so it cannot be that. If the top assembly weight is not the source of the mellowness perception reversal then it must be some factor other than the easily measured ones I have looked at.

It may be that the idea that a larger dulcimer is generally a mellower dulcimer is just wrong and is a collective perceptual trick on makers and players. A shallower dulcimer, where the back plate is closer to the top plate, might appear mellower because the interaction of the plates with the first air resonance (Helmholz) might be stronger. In addition, because the first air resonance (which is always the lowest of all the resonances) is always higher than the bass string tuning in mountain dulcimers, even a quite large dulcimer is not able to produce the fundamental harmonic of the bass string. This reduces the mellowness of the sound of both large and small dulcimers.

Table 14.2
Measurements of Three Dulcimers

Parameter	Dulc 54	Dulc 74	Dulc 75
Subjective Ranking - Short recorded melody, Dad tuning	Least mellow		Most mellow
Subjective Ranking – plain strum, from recording, Dad tuning	Least mellow		Most mellow
Subjective Ranking - Short recorded melody, Cgc tuning		Least mellow	Most mellow
Subjective Ranking – plain strum, from recording, Cgc tuning		Least mellow	Most mellow
Spectrum Centre of Gravity (av. frequency-energy of spectrum)– Dad tuning, short melody	1654Hz	1793Hz – less lower freq energy	1238Hz – more lower freq energy
Skewness of spectrum (how different is upper sound spectrum from lower spectrum) – Dad tuning, short melody	1.7	1.6 – most balanced hi-lo	2.9 – least balanced hi-lo (lo freqs dominate)
Sound Spectrum Centre of Gravity (av. frequency-energy of spectrum)– Cgc tuning, short melody	1546Hz	1780Hz – less energy in low freqs	1087Hz – more energy in lower frequencies
Skewness of spectrum (how different upper sound spectrum is from lower spectrum) – Cgc tuning, short melody	1.8	1.2 – most balanced hi-lo	3.3 – least balanced hi-lo
Side height	Highest - 50mm/ 1.97"	46.6mm/ 1.84"	Lowest - 42.8mm/ 1.69"
Dulcimer Box capacity	4563cm3/ 278in3	4242cm3/ 259in3	3883cm3/ 237in3
% difference to largest	0%	7% smaller	15% smaller
Sound hole size	Mid	Largest	Smallest
1st Air Resonance ("Helmholz") (spread of 2 semiTones)	228Hz	255Hz	235Hz
1st Bar resonance (of dulcimer box) (all within 1/2 semiTone)	267Hz	278Hz	274Hz
2nd Air Resonance (all within 1/2 semiTone)	335Hz	335Hz	349Hz

Parameter	Dulc 54	Dulc 74	Dulc 75
Fretboard mass	Lowest – 274gm	Highest – 312gm	Mid – 307gm
Fretboard Width	Highest - 36.1mm	Lowest - 33.5mm	Mid - 34.1mm
Fretboard Height	Lowest - 21mm	Mid - 20.5mm	Highest - 22.8mm
Top Plate Thickness	Thickest - 2.9mm	Thinnest -2.1mm	Mid - 2.8mm
Top plate wood	Western Red Cedar	Kauri Pine	Huon Pine - heaviest
Top plate internal wood damping	Lowest damping?		Highest damping? (oily)
Top plate wt (shaped & (braced)	Lightest - 141gm	144gm	Heaviest - 179gm
Fretboard+Top height	23.9mm	Lowest top -22.6mm	Highest top -25.6mm
Top plate/fretboard weight	Lightest - 415gm	456gm	Heaviest - 486gm
Back weight	Lightest - 165gm	Heaviest - 307gm	Mid 218gm
Back & sides density	Least dense	Most dense	Mid density
Total instrument weight	Lightest – 1103gm/ 2.4lb	Heaviest – 1403gm/ 3.1lb	Mid - 1184gm/ 2.6lb
Top flexibility – lower bout	16/1000" - least flexible	19/1000" – most flexible	18/1000"
Base outline shape	Same	Same	Same
VSL	Same - 27 ½"	Same - 27 ½"	Same - 27 ½"
Bridge type	Same - bone	Same - bone	Same - bone
Tuner weight	Same	Same	Same
General Fretboard shape/internal bracing	Same	Same	Same
Strings and tuning	Same	Same	Same

The Contribution of Box Volume to Mellow Tone- Dec 28, 2016

A previous discussion is related to the frequent claim that a bigger dulcimer body leads to a more mellow sounding mountain dulcimer. This makes sense in that a larger capacity body should have a lower Helmholtz air resonance (more strictly, 1st Air resonance which is lower than the Helmholtz because of box flexibility), and that is the lowest resonance of the dulcimer.

However, it hasn't been my experience that this is so. My dulcimers almost all have the same plan outline, but without a standard side height, so there is a wide variation of box volumes, determined by the height of the sides. At one extreme the sides were 62mm/2.4" high on two dulcimers that were noted at the time as having a "sharp" sound, and on the other extreme, two dulcimers at 40mm/1.6", and 38mm/1.5" that were noted as "mellow". This is the opposite to general expectation. So the contribution of the box volume to mellowness-perception must be able to be counteracted by some other factor.

I have also noticed that many of the more mellow dulcimers I have seen have wider bodies, particularly in the lower bout. In addition to that, one of the factors that a prominent dulcimer luthier proposes as influencing dulcimer tone is the distance of the bridge saddle from the side of the instrument. This is equivalent to saying that the lower bout is wider at the level of the bridge.

Method

To gain some idea as to whether box volume is a major contributor to dulcimer tone, or top width/area is more important, I made three dulcimers each with the same internal air volume, but with different plan outlines – the height of the sides being varied to keep the internal capacities the same (Figure 14.2).

Figure 14.2. Three test dulcimer tops with different widths

What might this show? My suggestion is that the width of the lower bout may be more important in determining tone than is the air volume of the instrument. If this is the case then the widest of these three should be the most mellow and the narrowest the least mellow. And it would point to the possibility that when makers have made progressively larger bodied dulcimers, and have attributed increased mellowness to the box volume, it may have been the increase in top width that was the cause instead.

The three dulcimers referred to above are all very nice sounding instruments in my estimation (Figure 14.3). As usual, the outcome of the experiment was not quite as expected.

Figure 14.3. Three test dulcimers – different top areas; same internal volume

Body and top woods were from the same billets and were as similar as is reasonable. The bodies and fretboards are New Guinea Rosewood (*Pterocarpus indicus*, a Padauk) and the tops are Kauri Pine. I spent considerable time matching the mass and stiffness of the three fretboards to within a couple of percent of each other.

The side heights were set so that the three had the same internal air volume of 5525cm^3. This is a little larger than my usual air volume of about 4500cm^3 ; so if the orthodoxy is correct, they all should all be a little more mellow than normal for my dulcimers. The side heights were 60 mm for the standard outline (D#104); 50.5 mm for the wide outline (D#105), and 44 mm for the extra wide outline (D#106).

Sound holes were the same for all three so the lowest air resonance (the Helmholtz, set by internal capacity and sound hole size, might be expected to be the same for all three. However, the boxes of the three are different in flexibility because of the physical size differences and this modifies the theoretical Helmholtz frequency. I expected the lowest air resonances to be different between the dulcimers and they were: 211Hz for standard, 186Hz for wide, and 172Hz for extra wide – a 3 semitone spread.

The dulcimers have no side linings. However, there are top and back braces, the same for all three, but clearly the shorter bracing of the standard outline dulcimer might make the cross grain stiffness of the top and back higher than the longer braces of the two wider instruments.

Figure 14.4. Bracing of test dulcimers

I didn't attempt to match the cross-grain stiffness of the plates because I don't think it matters nearly as much as, for instance, the treatment of the fretboard; although perhaps the back bracing could have been a little lighter. (In the photograph, the braces look somewhat larger than actual because of the angle of the sun causing a shadow).

I made the usual measurements – spectral recordings of the tap tones of the completed top and the completed instruments and also recorded, under standard conditions, notes from each string of each instrument for subsequent display as sound spectrograms.

The main purpose of all this was to see if a larger top area, particularly in the lower bout, translated into a more mellow sounding dulcimer, and especially to see if the fundamental harmonic of the bass string correlated with the perception of mellowness in these three dulcimers.

I also recorded test tunes, and played the instruments live and listened critically.

Results

The frequency spectra of the bridge tap tones were different as expected (because of the different flexibilities of the bodies) and are shown in Figure 14.5, showing the resonances from 0Hz to 1300Hz

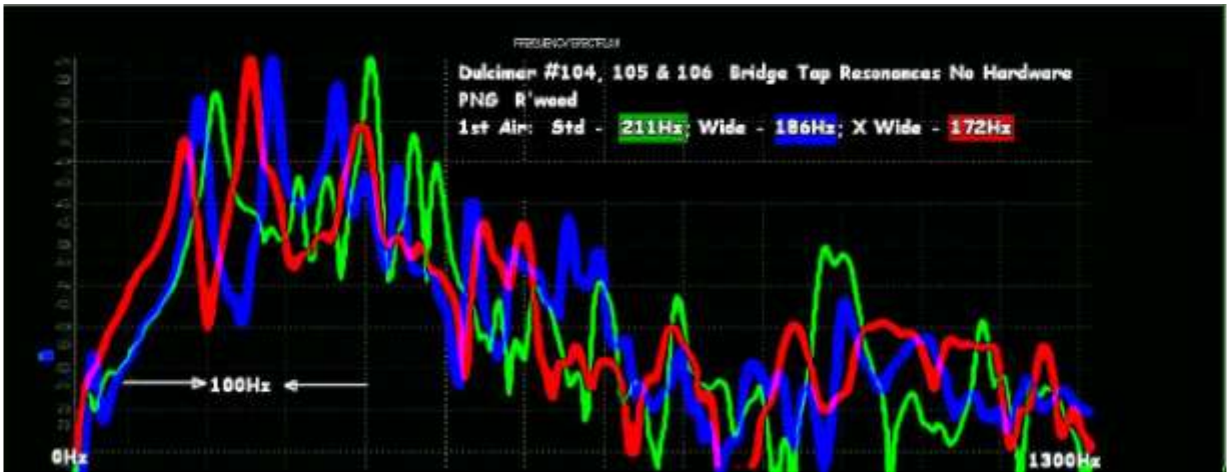

Figure 14.5. Frequency spectra of three test dulcimers

The bridge tap spectra indicate how the dulcimer box “***likes***” to vibrate given its physical structure. The sound spectrograms below indicate how it is ***actually*** vibrating under the forcing influence of the strings.

The sound spectrograms for individual string plucks are shown in Figure 14.6.

Figure 14.6. Sound spectrograms for individual strings

The lowest resonance of all three is still well above the lowest tuned note (C3, 131Hz), so none of them seem to offer support to the fundamental harmonic of the bass string.

But in the general trend of frequency regions of comparable strength, the three spectra are broadly similar.

The horizontal scale for each of the nine panels is 0 to 10 seconds and the vertical scale is 0 to 4000Hz. The lowest of the horizontal flags in each panel is the fundamental harmonic for that string. The wider and darker each "flag" is, the longer and louder is the sound of that harmonic.

In this case, the spectrograms don't show a lot of difference between the three dulcimers. Particularly the fundamental and the first few higher harmonics of the bass strings are similar in strength for the three, although the extra wide dulcimer seems to have longer sustain in the bass string. The same applies for the treble string — fairly similar. The middle strings seem to show the wide profile instrument to be a little stronger in the lower harmonics.

And basically, that was how I heard the three dulcimers — there were no clear unequivocal differences between the three. There are tonal differences, but to the casual listener, they all sound pretty much the same. Playing them live and playing the recorded tunes, the standard outline instrument might be judged slightly less mellow than the other two, but there was not a lot in it. For playing on individual strings the standard outline dulcimer sounds the most mellow of the three on the middle string, while the extra wide outline sounded the least mellow. The bass string tone is almost identical for the three when playing.

Conclusions

The end result is that these three dulcimers, quite different in the size and shape of the top plate, are quite similar sounding instruments. And more than that, the sound is not noticeably more (or less) mellow than my dulcimers generally are.

So the proposition that a larger top plate should lead to a more mellow sounding mountain dulcimer does not appear to be supported by this experiment.

So what has happened here? What are the factors that are common to these three instruments and what are the differences?

What is the same for all three:

- the internal air capacity is the same,
- the stiffness and mass of the fretboards is the same,
- finished weight is close (3.5% spread),and
- plate thicknesses are the same.

- Sound hole size is the same

What is different between the three:

- the side height is different (35% spread),
- lower box/air resonances are different (3 semitone spread),
- the surface area of the top/back is different (35% spread), and
- the major/minor bout width (40% spread).

There are probably lots of other variables that affect the tone, but the ones listed are largely under the control of the maker.

If we say that these three dulcimers sound very similar (and you'll have to take my word for it), then increasing the area, width or shape of the top plate is **not** a sure-fire pathway to a mellower instrument. The fact that these three are about 25% larger in air capacity than my average instruments, and yet are not appreciably mellower, might imply that a larger body is also not a guarantee of mellow tone.

So what does produce a mellower dulcimer might still be one or more of the factors listed in the previous section and summarized in Table 14.3.

Table 14.3
Factors affecting Bright vs Mellow sound

Construction Factor	**Bright Dulcimer**	**Melllow Dulcimer**
Top thickness	Thicker;>3mm	Thinner;<2.7mm
Side height	Higher;>50mm	Lower,<45mm
Top/fretboard stiffness	Stiffer;<100/1000" deflection	Less stiff;>130/1000" deflection
Back brace stiffness	More stiff	Less stiff
Fretboard height at strum hollow	Higher;>10mm	Lower;<7mm
Bridge distance from front edge of end block	Closer;<50mm	Further;>80mm
Total area of sound holes	Larger;>30cm^2	Smaller;<10cm^2

How to square this with the experience of makers over the years who have produced larger bodied dulcimers and noted tonal changes, I don't know.

Finally, this experiment, and the results, are for full length fretboard dulcimers – it may not be relevant to truncated fretboard instruments.

The Bass String Fundamental Harmonic-Dec 28, 2016

Following on from a previous posting (Chapter 8), I made myself two Tennessee Music Boxes (TMB) to see if a larger bodied instrument might produce the bass fundamental better than a normal sized dulcimer. These were made from Radiata pine (same density as Poplar) bought in the local hardware store, with dimensions obtained from David Schnauffer's description of TMBs on a web page[26]. They only took one day each to make.

Dimensions are:

TMB 01 - 31 x 9.8 x 71.5cm; plate thickness 8mm; internal air volume of 16,561cc ; lowest air resonance 80Hz

TMB 02 - 23 x 9.5 x 71.5cm; plate thickness 3mm; internal air volume of 13,954 cc (84% of TMB01 capacity); lowest air resonance 70Hz.

(Compare this with a typical mountain dulcimer - air volume of about 4000cc and a lowest air resonance of about 200Hz.)

For these two TMBs, one had thick plates typical of old TMBs and one had thin plates typical of mountain dulcimers. The larger thick plate TMB01 had a higher air resonance than the smaller TMB02 because TMB02 had thinner plates and was therefore more flexible, which in this case more than counteracted the larger capacity of TMB01. (Increased size —air resonance goes down; increased flexibility — air resonance also goes down)

Both TMB 1st air resonances were lower than the lowest tuned note - C3 (131Hz) which might indicate that the fundamental harmonic could be produced well.

But why bother with this at all? I'm sure there has been a lot of research on the importance, or not, of the fundamental to the perceived tone of a musical note. And it's probably quite complex and theoretical in terms of the psycho-acoustics of it all, but I wanted to see in a simple practical sense whether the strength of the fundamental harmonic matters much to the sound of a mountain dulcimer, and particularly to the perception of the "mellowness" of the instrument.

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[26] http://home.usit.net/~sandyc/mb.html

Figure 14.7. TMB01 and TMB02

Method

To that end I :

- Recorded single note strikes for each open string of eleven dulcimers (and an Epinette), both with the instrument mounted on a wooden bench, and with the instrument on the knee. Two dulcimers were baritones (AEA) and one was a bass (DAD). The rest were tuned CGc. Conditions were standardised.

- Took the sound spectrogram for each pair (bench/knee) of notes for each string of all dulcimers (11 dulcimers; 3 note pairs/dulcimer; 66 sound spectrograms).

- Noted the loudness and duration of the fundamental harmonic of the 66 spectrograms.

Figure 14.8 shows results for two of the instruments – TMB01 and D17, a smallish, but typical mountain dulcimer:

Figure 14.8. Spectrograms for TMB01 and dulcimer D17

The left panel is TMB01, the right panel is D17. Horizontal scale is time (0 to 10sec), vertical scale is frequency (0 to 4000Hz). The "flags" represent the strength (loudness) and duration of the harmonics of the notes. In each of the six-sub panels the lowest harmonic is the note fundamental.

Each note pair (bench/knee) for each string for each instruments was rated for sound preference – which of the two did I like better?

These preferences were then correlated with the strength/duration of the fundamental harmonic of the spectrogram for that note/instrument.

Results

For the 33 note pairs:

- 18 were equally preferred i.e. both bench and knee note sounded equally good to me,
- the bench note sounded better in 8 cases, and
- the knee note sounded better in 7 cases.

In ***all*** cases where there was a preferred note (15 cases), the fundamental harmonic was stronger and/or longer than the non-preferred note.

Conclusion

In some of the 66 notes analysed (6/66), the fundamental was completely absent. in most cases (33/66), it was weak and/or of short duration. In some cases (4/66), it was long, but weak. In only 5 of 66 cases was the fundamental both strong (loud) and of long duration.

It appears that the presence of the fundamental harmonic in a note improves its tone — at least to this listener. And in particular, it seemed that a note was more “mellow” or “full” or “rounded” when the fundamental was present.

So the answer to the question “Does the fundamental harmonic of a note matter in a mountain dulcimer” seems to be a fairly clear— “Yes, it does”.

The next question is how might we increase the strength of the fundamental? I can’t say for sure. However, a clue might be in the construction of the instruments that demonstrated the strongest/longest fundamentals in their notes.

The Orthey replica dulcimer had fairly strong fundamentals on five of the six notes recorded, but of only medium duration (about 5 sec). It is a very lightly constructed instrument with an overall tone that I like a lot.

TMB02 had long fundamentals on five of six notes (about 10 sec), but of medium loudness. I would characterise this instrument as having a “smooth” sound (whatever that means). It is much heavier than the Orthey, and about 1.5 times as heavy as a standard dulcimer, but the plates are also larger and may be relatively as flexible as the Orthey.

The other dulcimers, including the stiff TMB01, were more variable in the strength/duration of the fundamental harmonics.

Longitudinal Waves in Mountain Dulcimer Strings - Twang - Aug 3, 2015

I’ve noticed on quite a few dulcimers, including my own and in recordings and videos, the addition of a particular sort of “twang” to the tone of the open treble and middle strings. To my mind it makes the string sound harsh and a bit unpleasant. The sound generally disappears when the string is fretted.

Reading guitar luthier Al Carruth's paper "String Theory", it's clear that this sound is caused by a longitudinal compression wave in the plain steel strings.

In summary, strings can vibrate in at least three different ways:

1. **Transverse Waves**- the string moves at right angles to the length of the string and can develop multiple harmonics of the fundamental note. This is the vibration we know and love.

2. **Tortional or Rotational Waves**-the string vibrates in a twisting or rolling motion. This is the "squeek" heard on a poorly played violin. This type of string vibration may not be relevant to plucked instruments like mountain dulcimers.

3. **Longitudinal Compression Waves**-the string vibrates back and forth along its length in a stretching and compressing cycle.

All this information comes from Al Carruth's paper "String Theory" at www.alcarruthluthier.com/Acoustics.htm , an excellent discussion about how strings vibrate.

Unlike the transverse string waves, the pitch of the longitudinal wave doesn't depend on the string tension or thickness, only on the length of the string and the Young's Modulus (Modulus of Elasticity) and density, which are properties of the string material. Therefore, if this mode of vibration is excited, the pitch will be the same for both the first and middle dulcimer strings, if they are made from the same material.

It's easy to demonstrate this vibration by applying some violin rosin to a scrap of cloth, squeezing a string with the cloth and rubbing back and forth. If you have no violin rosin, some spray deodorant on a tissue works well.

The squeak you will hear will be in the range of 3000Hz to 4000Hz, but varies from about 3800Hz for 25½" VSL to 3500Hz for 27½" VSL; and 3250Hz for stainless steel to 3550Hz for piano wire strings. First and second strings are essentially the same pitch.

Unfortunately, this annoying vibration can be initiated if one of the normal string harmonics falls at the same frequency or close to it. Then that harmonic is enhanced in strength and may stand out in the sound, particularly in the initial attack. Depending on whether it's the first string or the second, it could be the 12th to 19th harmonic that is affected.

In a real dulcimer the difference in sound with and without a longitudinal wave is quite noticeable.

Figure 14.9 shows a picture of three notes, plucked on the middle string of a dulcimer, with their sound spectrogram below them. An enhanced harmonic at 3663Hz is seen in the spectrograms of the first three string strikes, which is a reinforcement of the string's longitudinal wave frequency. The last three waveforms are the same as the first three, but with the 17th harmonic edited out.

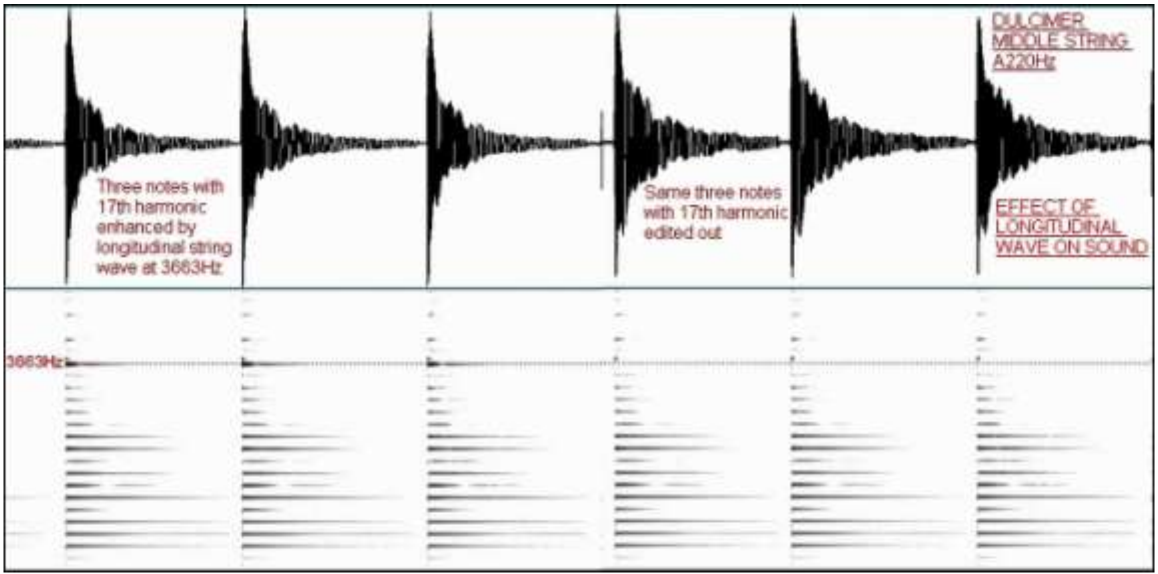
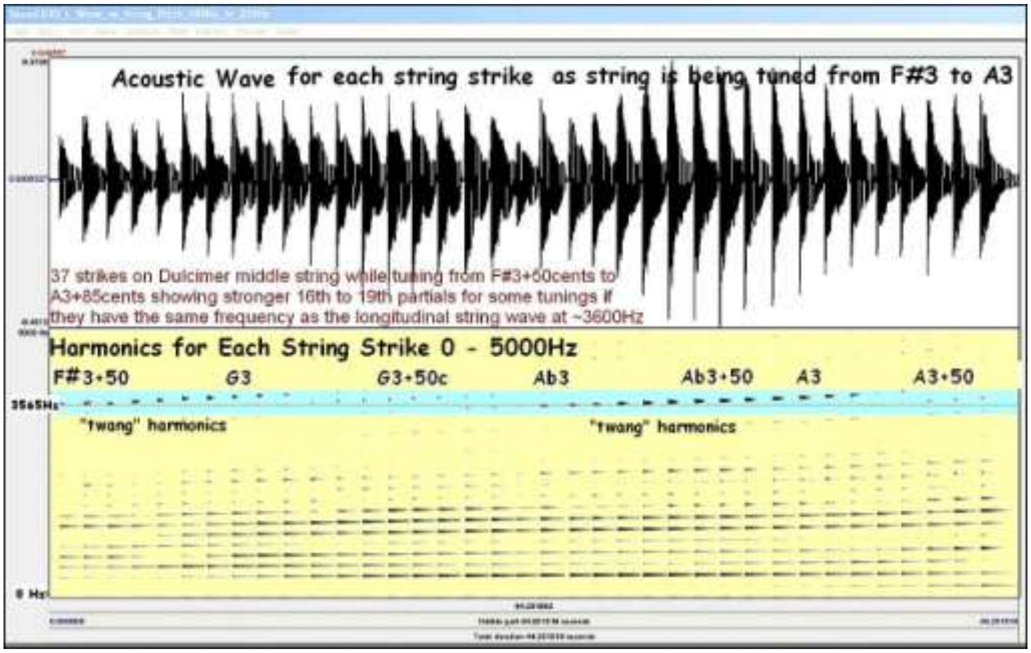


Figure 14.9. Enhanced 17th harmonic by string longitudinal wave.

The effect of the enhanced 17th harmonic is most pronounced at the initial attack of the note. (The display software auto-scales the waves on the screen so the second three look bigger, but just have a reduced initial transient.) When the longitudinal wave harmonic is filtered out of the recorded sound, the "twang" effect disappears completely.

Figure 14.10 is a picture of a string being plucked whilst being tuned from 189Hz (F#3+) to 231Hz (A3+). The harmonics enhanced by the Longitudinal Wave can be seen in the spectrogram as the string rises in pitch and a harmonic falls near the frequency of the Longitudinal Wave (which is a fixed frequency) at about 3560Hz.



37 strikes on Dulcimer middle string while tuning from F#3+50cents to A3+85cents showing stronger 16th to 19th partials for some tunings if they have the same frequency as the longitudinal string wave at ~3600Hz

Figure 14.10. Demonstration of L-wave induced harmonic enhancement as dulcimer string is tuned from F#3 to A3

As the pitch rose and a harmonic fell in the L-wave range, the “twang” was heard. In between those string pitches, the note sounded smooth and pure.

If you can hear the tonal addition of the L-wave-enhanced harmonic, and if it annoys you, then what can be done about it? The short answer is – not a great deal.

The longitudinal wave is inherent in the string, and for the string materials and lengths we use in dulcimers its frequency falls right in the middle of the harmonic spectrum the strings produce. So the potential to excite and hear it is always there. But can this unwanted wave excitation be prevented?

I tried a number of things:

1. changed strings – different thicknesses, different metals,
2. damped the strings behind the bridge and in headstock,
3. changed bridge saddle shape – square, triangle, broad, narrow,
4. changed bridge material – wood, bone, shell,
5. weighted the fretboard (with clamps),
6. changed sound hole size,
7. added weights to top plate,
8. damped the back plate of the dulcimer,
9. made taller bridge by lowering the bridge pedestal, and
10. changed bridge break angle.

None of these moderated the longitudinal wave twang. There were two things that ***did*** reduce the twang effect.

Firstly, the pitch of the string can be fine tuned to eliminate the L-wave, as seen in the picture of the note series above. In other words, tune the string so that no harmonic falls at the L-wave frequency. This is acceptable if you are playing on your own, but not if you must tune to concert pitch.

Secondly, adjust the position of the saddle. On one dulcimer, over a range of saddle positions from 655mm to 670mm, there was a sweet spot at 660mm where the twang was eliminated. Unfortunately the frets were then in completely wrong positions, being a 667mm VSL instrument, and the dulcimer was unplayable. In addition, many dulcimers have fixed saddles which could not be moved anyway.

Another solution is to have a dulcimer that does not produce harmonics above, say, 2000Hz – one that has a reduced high frequency response, perhaps a heavy and flexible one. Such a dulcimer would likely sound muted and muffled, but there would be no L-wave "twang".

Playing style can also moderate the effect to some extent by striking the string in such a position that the 17 – 19th harmonics are not excited. That would generally be further away from the bridge, but is another player input that has to be managed and would reduce playability that little bit more.

This is not a problem peculiar to mountain dulcimers, but is relevant to all stringed instruments, and there doesn't seem a clear solution to eliminating the sound. But now at least you might know what it is when you hear it and won't waste time trying to reduce it.

Effect of Playing on a Table- Apr 23, 2014

There has been some discussion about whether the improvement in sound of a dulcimer mounted on a table is because the table is vibrating, or because the sound from the back plate is re-directed outwards towards the listener.

My contention is that the improved sound is because the dulcimer sets the table (and even the surrounding floors) into vibration. My crude sound measurements seem to support this; i.e., there doesn't seem to be additional sound from the side when mounted on a table, or with a double back, indicating that a small gap between the back plate and the table-top, or an outer back, does not seem to direct any more sound from the gap to a listener.

This section looks at wave simulations that allow us to isolate the sound waves produced by the back plate and see the direction they travel without the complications of vibrations from other parts of the dulcimer. It is hardly a comprehensive study, but it gives an idea of what is happening to sound that's produced by the back alone.

The website http://www.falstad.com/mathphysics.html is a free source for a large number of physics and math simulation applets, with real-time animations. The Ripple Tank applet lets us look at how waves in air propagate around, and reflect from, objects that can be drawn onto the screen.

In the illustrations(Figure 14.11-14.13), I've drawn typical cross sections of a mountain dulcimer box intersecting the sound holes and also a section that doesn't cross the sound holes. The view is one of looking down the length of the fretboard. The back plate is replaced with what the program calls a "plane source"; i.e., a flat source of wave excitement that just moves up and down at a particular frequency — a bit like a flat loudspeaker "cone". The intensity of the waves is indicated by the contrast between the light and dark areas. The lower the contrast, the weaker the sound wave.

Based on a side height of 5cm, the frequency can be calculated from the simulation wavelength on the screen and the known speed of sound in air (frequency = speed-of-sound divided by wavelength). The speed of sound is 330 metres/sec and the wavelength can be compared to the 5cm side height, scaled on the screen.

The dulcimer top plate and sides, and the table it is resting on, are perfectly rigid and do not vibrate in the simulation. Only the back is vibrating and making sound; any waves that are produced in and around the dulcimer are solely as a result of reflections of the plane wave started by the back vibrating.

The four simulated configurations are: dulcimer on table, with and without sound holes; and the dulcimer in mid air, with and without sound holes. The results of the simulation look are shown in Figure 14.11.

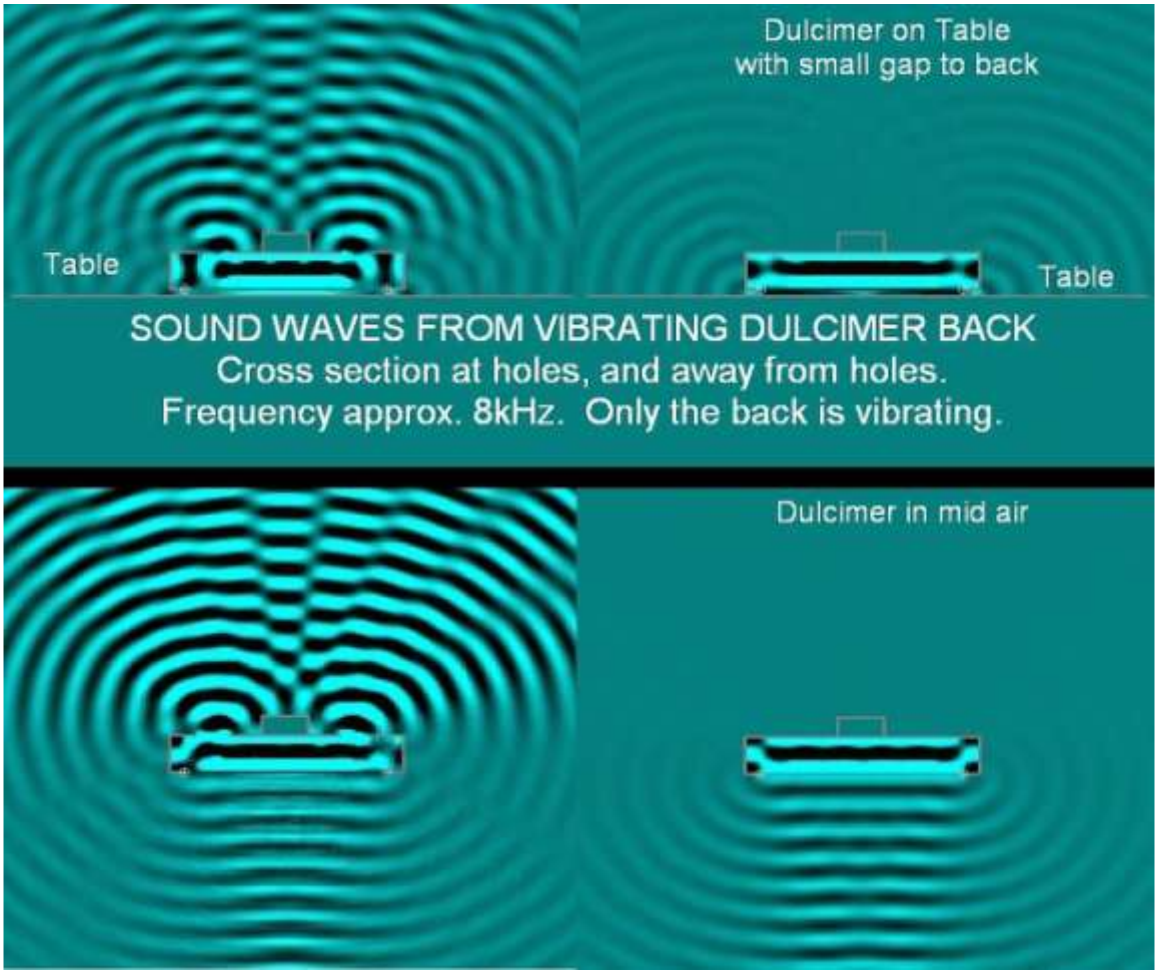


Figure 14.11. Ripple tank simulation. Left is cross section at holes, right is away from holes

In the two upper images in Figure 14.11 there are some low intensity sound waves radiating from the gap between the back plate and the table. So, some sound is capable of being redirected out and up by reflection from the table. But a lot more sound is directed from the back plate through the sound holes.

In addition, the frequency of back vibration in Figure 14.11 is about 8kHz. A real dulcimer produces almost no sound energy at this higher frequency, and even if it did, those of us over about 50 years of age couldn't hear it.

At frequencies lower than about 8kHz, there is very little sound radiating from the table-dulcimer gap, it is only at the higher frequencies that the wavelength is short enough to be reflected out of the gap (Figure 14.12). So, at the frequencies that carry 90% of the sound energy (up to say 2000Hz), almost none is directed out from the gap between the table and the dulcimer. Figure 14.12 shows two simulations at 2kHz and 15kHz. The low intensity waves in the 2kHz panel are emanating from the soundholes and wrapping around the dulcimer body.

Figure 14.12. Simulation of sound radiating from the dulcimer back/table gap

Below about 2kHz very little of the back vibrational sound gets out of the sound holes however – the sound comes directly from the wood.

This effect, of only a small amount of sound coming from a gap between the vibrating back and another nearby surface, also has relevance to double backed dulcimers (Figure 14.13).

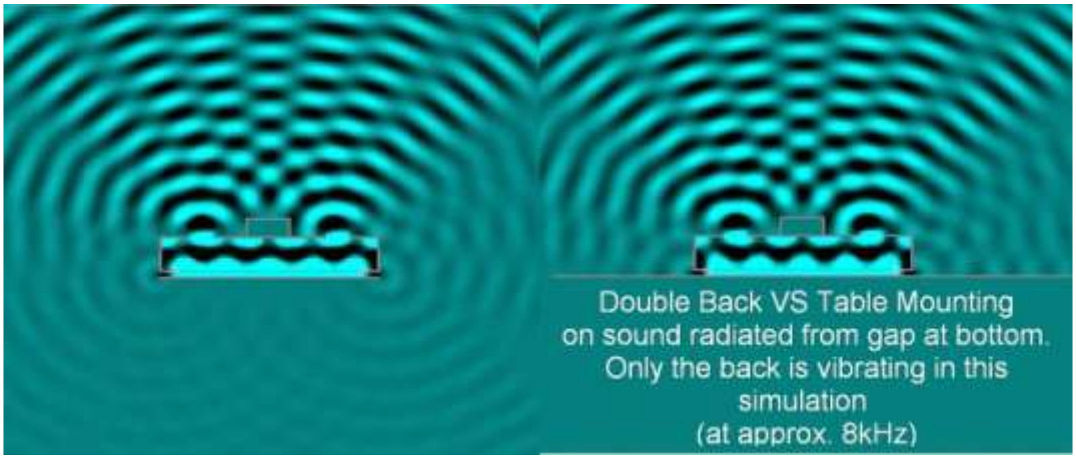


Figure 14.13. Simulation of sound radiating from the inner back of a double backed dulcimer and from the back of a single backed dulcimer with feet played on a table.

Something a Bit Different – The Sound of Top, Table and Floor- Jan 07, 2016

Following on from the previous section, and whilst I was experimenting with a piezo transducer for another experiment I could feel the table that the dulcimer was sitting on vibrating as I was playing.

One experienced player proposes that mountain dulcimers fitted with small feet on the back sound better when played on tables than when on the knee, and that the improvement is because the table is also vibrating and making sound. As it happens, my test dulcimer is fitted with three small wooden feet.

Alternatively, some players have suggested that resting a mountain dulcimer on a table only reflects the vibrations of the back plate off the table and outward, making the instrument seem louder. Others, including me, claim the effect is because vibrational energy is transferred from the dulcimer to the table which then vibrates and makes sound in its own right. Even though the simulations in the previous section supports this proposition, there is an easy way to test the “vibrates the table” idea with a real dulcimer.

A small piezo button transducer was attached to the top plate of the dulcimer, then to the table the dulcimer was sitting on, and finally to the hard floor below another table. Short test tunes were recorded using the piezo as the recording device. The setup and resulting waveforms is shown in Figure 14.14.

Figure 14.14. Piezo transducer recordings – dulcimer top plate; table; floor

Since the piezo transducer is designed to pick up mechanical vibrations, it is clear that the dulcimer is setting not only the table into vibration, but also the floor the table is sitting on.

The vibrations from the table were fairly large, about half as big as the dulcimer top vibrations, and produced a good quality recording. The floor vibrations were only about one tenth the amplitude of the table vibrations, so gain had to be turned up, but the notes of the dulcimer were still quite clear. Because the house current hum was strong I had to filter the floor recording to remove it.

The results are fairly clear – a dulcimer with three small feet, mounted on a table, will set the table (and perhaps the floor) into vibration, and this will usually result in an enhanced sound output from the instrument. The idea that significant sound is reflected out from the gap between the dulcimer and the table (or an outer back) can probably be discounted.

In the process of this experiment, I learned that small weights on a piezo transducer (say about the weight of a plastic pencil sharpener) have a large effect on the sound quality. No weight = lack of bass; too much weight = big boomy bass; just right weight = best balanced sound. I spent some time in matching weight to best sound. This is something to consider when using stick-on piezo pick-ups.

Chapter 15
Loudness Studies

Knee Effect on Loudness-Aug 09, 2009

There might be a possible contribution of the cavity air resonances to the damping of mountain dulcimer sound output when played on the knee. I have noticed in one dulcimer of mine that loudness actually seems increased when placed on the knee. So, I've had a closer look (at one dulcimer) to see if any information might be gained.
The aim was to determine the effect on loudness of placing a mountain dulcimer on the knee whilst playing.

Method

A single dulcimer (No. #20) was used. General characteristics were:

- six string hour-glass shape; three unison pairs, 0.024/0.014/0.014,
- four heart shaped sound holes; two per bout,
- wolf note with a range of influence from about B247 to C#277,
- first air resonance (Helmholtz, lower sound holes) 225Hz,
- second air resonance (upper sound holes) 344Hz, and
- box tap major resonances: 225, 324, 344, 412, 468, 521, 617, 707, 782 Hz (measured with a free back).

Strings were tuned over a range of notes. All strings were tuned to the same note, with the bass strings one octave lower than the 1st and 2nd strings.

Notes used were: E 82/165; F 88/175; G 98/196; A 110/220; B 123/247; C 128/256; D 147/294; E 165/330.

At the lower end of the tuning scale all strings were “floppy”. At the higher end, strings were close to maximum tension.

The dulcimer was placed on the bare thighs for good connection to the wood; lower bout centered on right knee, upper bout centered on left knee, held in place with finger pressure.

Open strings were plucked individually then the dulcimer was:

- lifted free of the thigh by holding the waist, then replaced on the knee,
- then tilted from the head stock so that the lower bout was lifted whilst the upper bout remained in contact with the left knee, and

- then tilted from the bridge end so that the upper bout was lifted whilst the lower bout remained in contact with the right knee.

Perceived changes in loudness and timbre were noted for the three conditions for all eight notes.

Frequency spectra were recorded by analyzing the sound of tapping the bridge saddle under the four conditions: Both bouts on knee; major bout on knee; minor bout on knee; dulcimer off knee.

Results

Perceived loudness ***on*** the knee compared to ***off*** for each string and each note for ***both bouts on knee*.**
+ small increase in loudness ++ moderate increase +++ large increase
- small decrease in loudness -- moderate decrease --- large decrease

Note/Frequency
E82/165 Bass string: Louder (on knee) ++, 1st/2nd string: Louder +

F88/175 Bass: Small effect, 1st/2nd: Softer ---

G98/196 Bass: Softer (on knee) -- ,1st/2nd: Softer ---

A110/220 Bass: Softer --- ,1st/2nd: Softer ---

B123/247 Bass: Louder ++ ,1st/2nd: Louder +

C128/256 Bass: Louder ++, 1st/2nd: Louder +

D147/294 Bass: Louder + ,1st/2nd: Louder +

E165/330 Bass: Softer -, 1st/2nd: Softer -

The results for major and minor bouts are not listed above because major bout was essentially the same for both and the minor bout had a small knee effect.
Whether or not there was a perceived change in loudness, most notes produced a change in the timbre of the sound between ON and OFF the knee. Large loudness changes also usually meant more noticeable timbre changes.

The bridge tap spectra for off-knee and on-knee are shown in Figure 15.1.

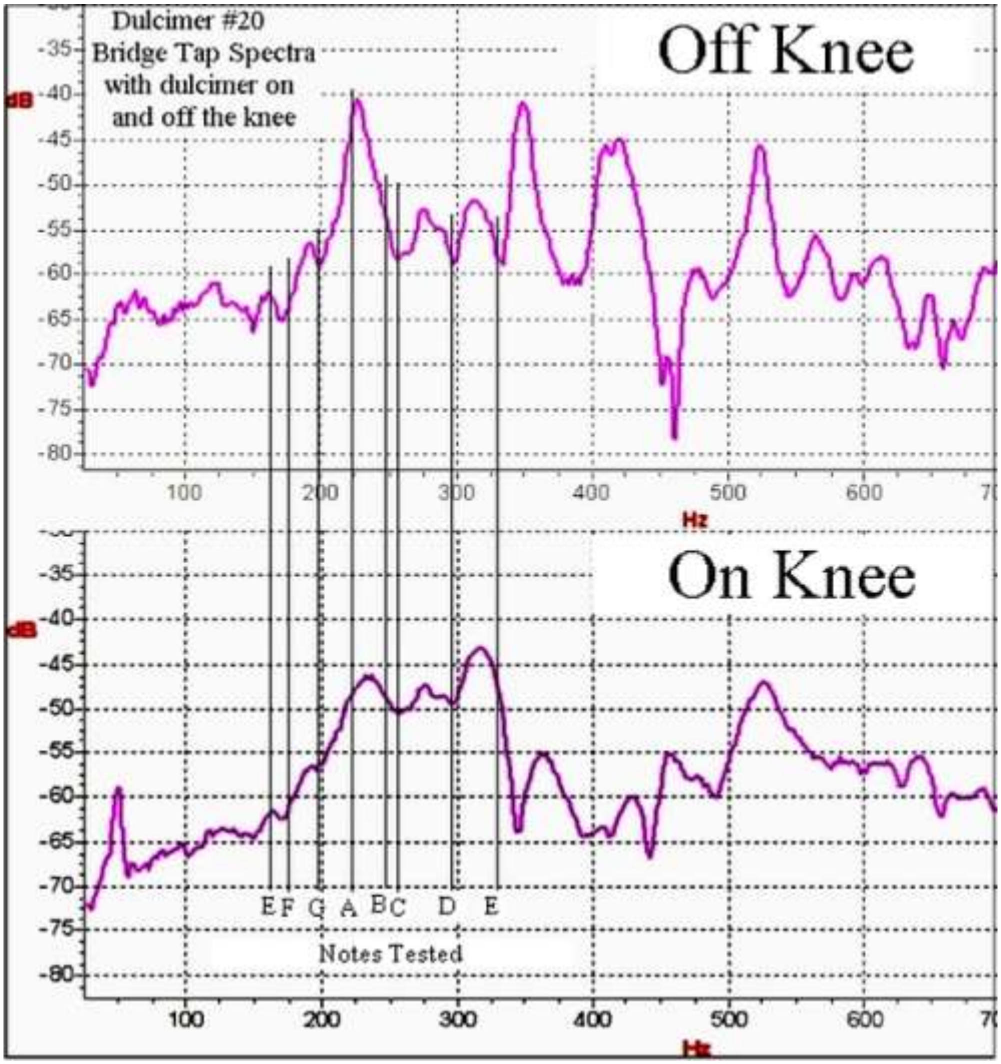


Figure 15.1. Bridge tap spectra for off and on knee for one dulcimer

Multiple trials were performed and the spectra were quite repeatable.

Conclusions

At least for this one dulcimer, a change in loudness by placement on the knee was frequency dependent; i.e., the knee effect changed with the frequency of the note, sometimes softer, sometimes louder.

Most of the effect was produced by the lower bout in both the sound loudness changes and changes in the bridge tap spectra. The upper (minor) bout did not seem to contribute substantially to knee damping. Although there were noticeable timbre changes when lifting off the knee, these were also mainly contributed by the major bout.

The dulcimer had greatest reduction in loudness on the knee around the frequency of the first air resonance (Helmholz), lending support to my observation from another dulcimer (not reported here) that loss of sound radiation of the lowest air resonance might be a significant part of the sound energy lost by playing on the knee (but clearly not the only part). Both 1st (225Hz) and 2nd air resonances (350Hz) were reduced in amplitude in the tap spectra, and shifted upwards in frequency about a semitone. This is as would be expected.

There was a range of notes, broadly covering the wolf-note range for this instrument, where it was actually louder when placed on the knee. In the spectra, the notes B247, C256 and D294 had their tap response increase by about 10db when ***on*** the knee, correlating with the perception of increased loudness in that frequency region. This means that the wood is more vigorously vibrating at those notes when the back is damped. The reason for this is not immediately clear, but it may mean that wolf notes and increased loudness on the knee go together, near the frequency of the note, by an as yet unknown mechanism.

Most of the changes to the tap spectra occurred below about 500Hz. A strong resonance at about 415Hz was lost to knee damping, and since this is a frequency region important to the warmth of a sound, it might have a large effect on perceived timbre change overall

So, a mountain dulcimer can get louder as well as softer when played on the knee, depending on the resonances of the individual instrument and the note being played. To minimize the effect, there are possum boards, tables, and knees spread wide apart. Or at the very least, resting the ***end*** of the major bout on your knee, rather than the ***center*** of the bout.

Top and Back Sound Pressure Levels in Mountain Dulcimers- Aug 31, 2010

Over time there has been a lot of discussion amongst dulcimer makers regarding which part of a mountain dulcimer makes most of the sound – the top or the back. I have made some measurements to try to settle this question, and the fairly definitive answer is:

A mountain dulcimer top is, in general, two to three times louder than the back.

For the fine details, read on.

The Experiment

The aim was to see what sound pressure level differences there might be between sound radiating simultaneously from the top and the back of mountain dulcimers.

Method

Simultaneous recordings were made of the sound radiation from the tops and backs of 7 mountain dulcimers in 12 different playing configurations.

Foam-mounted identical microphones were placed 20cm from the back and top of the instruments which rested on their side on a heavy foam-mounted block of wood.

All three dulcimer strings were struck by a plectrum fixed in a wooden pendulum falling under it's own weight from a vertical position.

Each trial consisted of 15 string strikes. Part of one trial audio recording is shown in Figure 15.2.

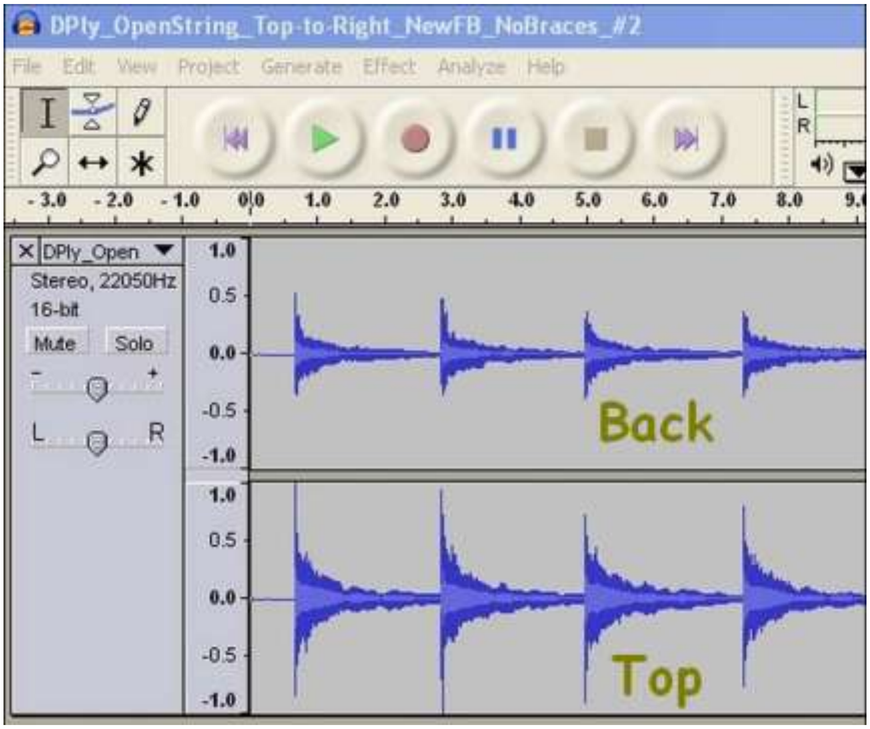


Figure 15.2. Four string strikes of simultaneous top/back sound recording

Five trials for each configuration were recorded and then the dulcimer was flipped over, the string striker moved to the other side and the same number of trials recorded again. This ensured that differences in room acoustics and in the two microphone/pre-amp channels were averaged out. After the forward/reversed trials were recorded on the open strings, a capo was applied to the 8th fret and the forward/reverse trials recorded again. Recordings were saved to a computer for later analysis.

In summary:

No. of dulcimers tested--7
No. of different configurations---12
No. of string strikes per configuration---------------------------------------300
(15 strikes/trial x 5 trials x forward/reverse x open/8th fret)
No. of top/back string strike pairs analyzed-------------------------------3600
Average time analyzed per configuration--------------------------------~600sec

Each of the 240 recorded trials was analyzed using the PRAAT signal analysis software package to obtain the average sound pressure level (SPL) over the approximately 30sec of the trial for both the top and the back recordings — two SPL measures per trial. The top and back SPL measures for the five trials for each configuration/mounting direction/string length were then averaged.

Finally, the average SPL for the two mounting directions were averaged to cancel recording channel and environmental differences, and the difference between the top and back average SPLs were calculated.

The analysis for the recording shown in Figure 15.2, and all the others, took the form shown in Figure 15.3.

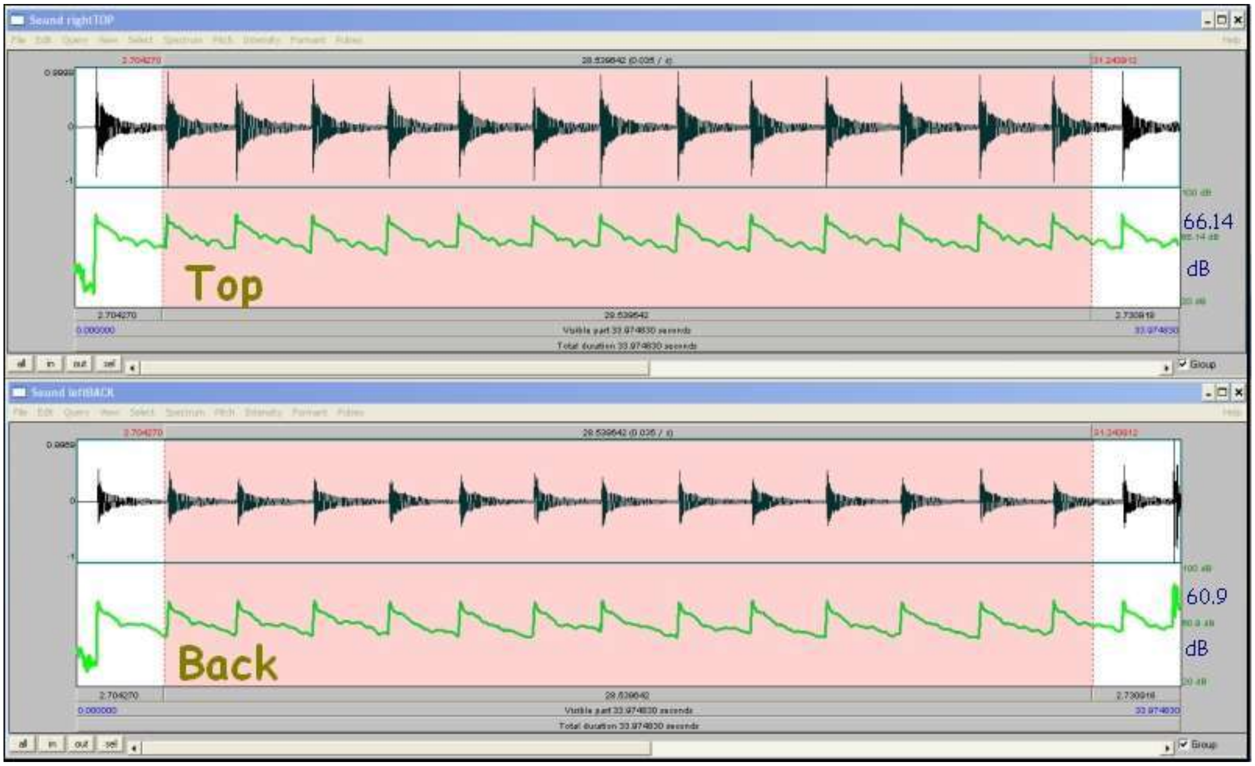


Figure 15.3. Sound pressure levels – top vs back

The upper and lower panels show the simultaneous recording of audio inputs to the top and back microphones. The green traces below the audio waveforms are the running SPL levels calculated by the PRAAT software. The average SPL of the green traces is calculated and shown on the right hand side. This is the value used in comparison between the top SPL and the back SPL. In the case of Figure 15.3, the SPL difference top/back is 66.14 – 60.9 = 5.24dB. Reference to Table 15.1 (following) indicates that for this trial of 15 string strikes, to top would be perceived as about 3 ¼ times as loud as the back.

Two dulcimers were re-tested with their sound holes covered.

One dulcimer was re-tested after its fretboard had been reshaped and again after its back bracing had been removed.

One dulcimer had no top and was tested twice — once with the top-recording microphone 20cm from the internal surface of the back and again with the microphone 20cm from the position of where the original top would have been.

All dulcimers, except one, were hourglass shaped, four sound hole, full length fretboard instruments. One dulcimer was of a teardrop shape.

Two high quality guitars and a ukulele were also tested for comparison.

Set Up. Figure 15.4 shows the top/back audio recording set up.

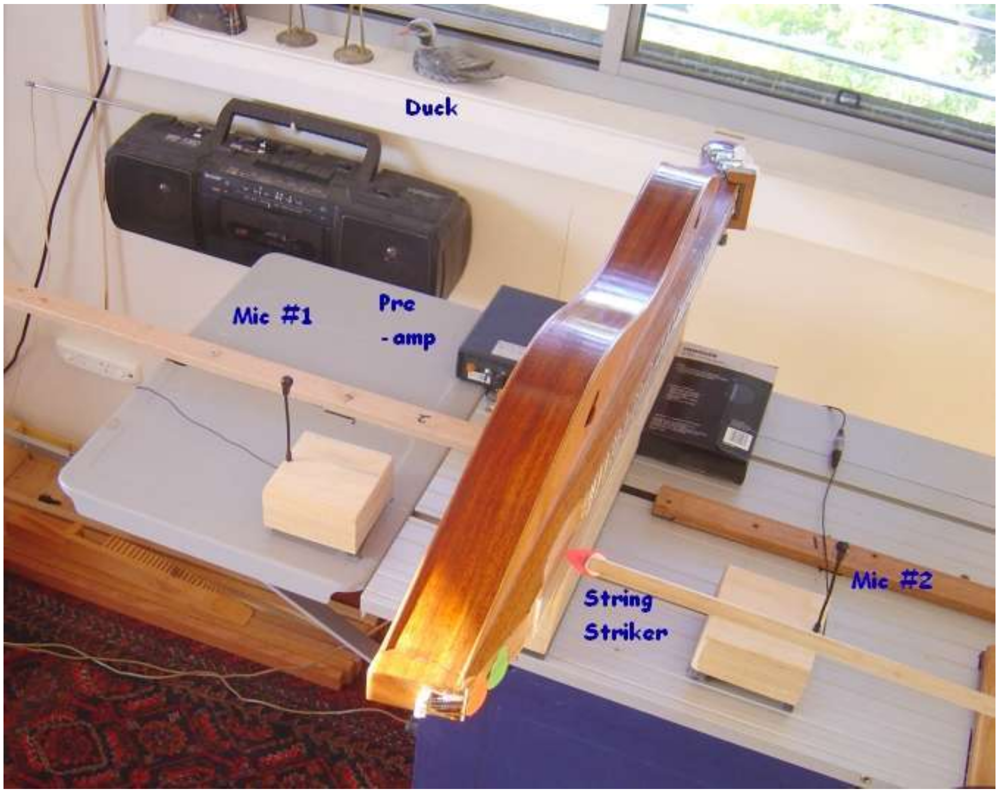


Figure 15.4. Set up for simultaneous recording of top and back string strikes.

Recording Environment: The recording space was a normal reverberant room. Preliminary testing with microphones at 150cm from the instrument showed too much influence from reflected sounds. Measurement of the room surface area and volume allowed calculation of the reverberation time and critical distance between the near (direct) field and the far (reverberant) field. These were approx. 0.5sec and 55cm respectively. Since each string strike lasted approximately 2sec, the recordings would clearly be affected by reflected sound if the microphones were not well within the critical distance (within which the direct sound field dominates). So, 20cm was selected as being far enough from the dulcimer to pick up sound from a wide top/back area, but still close enough to the source as to be largely unaffected by reflections.

Errors: Measurements were made with the same setup, using noise sources, and the background noise, and clicks generated by striking metal bars to try to determine if the right/left recording channels were the same as each other.

Overall, the final dB difference values recorded between the tops and the backs should be accurate to within 0.5dB.

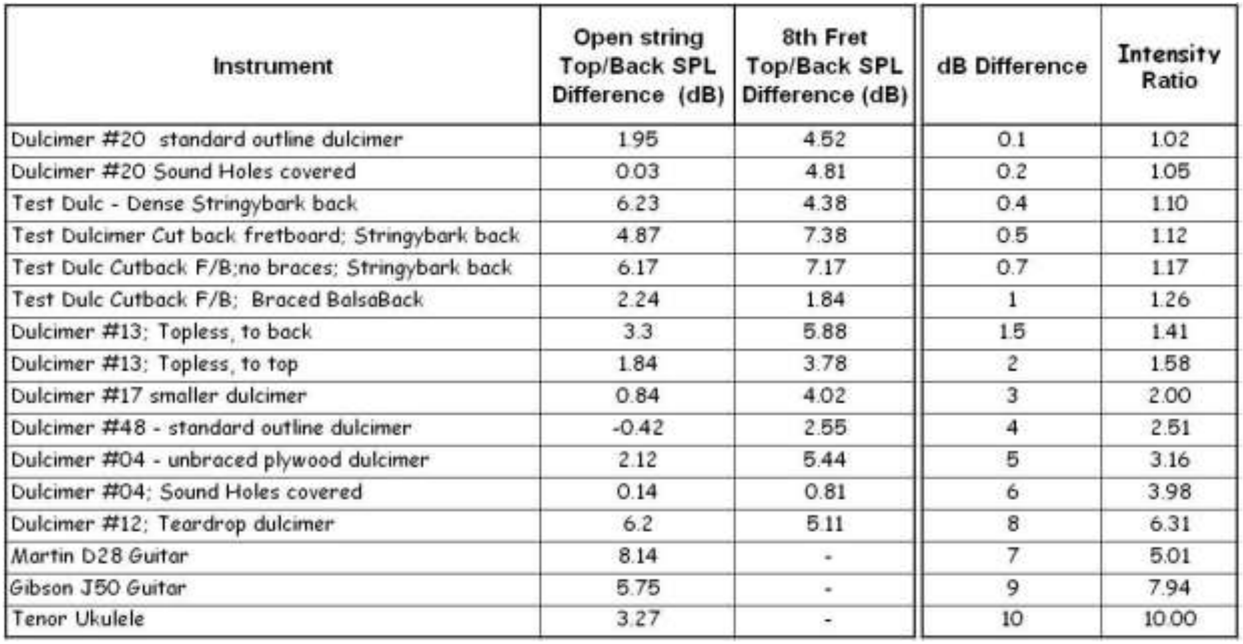
Effect on Results of Plectrum Noise: The plectrum striker made a transient noise of considerable amplitude when it struck the string and this was picked up on the top-side, but not the back-side recordings. There was often more than 10dB difference in the peak SPL values, top to back, of each string strike. But the pick transient lasted only about 10mS, whilst the string sounded for approximately 2 sec. Over the whole string strike, the pick transient added a negligible amount to the average SPL.

Effect of String Striker Stand: The string striker stand was always on the top-side of the instrument, although behind the microphone. Multiple measurements with and without the striker stand showed that any reflections from it back to the microphone increased the top readings by less than 0.3dB.

Results

Table 15.1 summarizes results. The table also shows the intensity ratio for a range of decibel differences.

Table 15.1
Summary of Sound Pressure Level Results



Instrument	Open string Top/Back SPL Difference (dB)	8th Fret Top/Back SPL Difference (dB)	dB Difference	Intensity Ratio
Dulcimer #20 standard outline dulcimer	1.95	4.52	0.1	1.02
Dulcimer #20 Sound Holes covered	0.03	4.81	0.2	1.05
Test Dulc - Dense Stringybark back	6.23	4.38	0.4	1.10
Test Dulcimer Cut back fretboard; Stringybark back	4.87	7.38	0.5	1.12
Test Dulc Cutback F/B;no braces; Stringybark back	6.17	7.17	0.7	1.17
Test Dulc Cutback F/B; Braced BalsaBack	2.24	1.84	1	1.26
Dulcimer #13; Topless, to back	3.3	5.88	1.5	1.41
Dulcimer #13; Topless, to top	1.84	3.78	2	1.58
Dulcimer #17 smaller dulcimer	0.84	4.02	3	2.00
Dulcimer #48 - standard outline dulcimer	-0.42	2.55	4	2.51
Dulcimer #04 - unbraced plywood dulcimer	2.12	5.44	5	3.16
Dulcimer #04; Sound Holes covered	0.14	0.81	6	3.98
Dulcimer #12; Teardrop dulcimer	6.2	5.11	8	6.31
Martin D28 Guitar	8.14	-	7	5.01
Gibson J50 Guitar	5.75	-	9	7.94
Tenor Ukulele	3.27	-	10	10.00

To give an idea of the magnitude of the sound intensity difference between top and back, the intensity ratio on the right of Table 15.1 shows this based on the calculated top/back sound pressure level (SPL) difference for each instrument. For example, the first entry, Dulcimer #20, has an SPL recording from the top that was 1.95dB (deciBels) higher than the back recording for open strings. From the table on the right hand side a 1.95dB difference in SPL corresponds to an sound intensity difference of just less than

1.58. So the top of this dulcimer produces about 1.58 times higher sound level than the back does, as measured by a microphone. At a sound pressure level change of somewhere between 1dB and 3dB we will start to perceive the sound as being ***louder*** (a perceptual variable), so if the SPL difference between the top and back is greater than, say, 2dB, whichever is the higher, top or back, might be perceived as the louder of the two.

Comments

In all cases, except one, the top was louder than the back. The magnitude of the loudness difference varied from essentially zero on the open strings (i.e., top and back as loud as each other), to about 7.4dB on the upper fretboard (i.e., top more than five times as loud as the back). Generally speaking, tops seem to be about one and a half times as loud on the lower fretboard, and about three times as loud on the upper fretboard, as backs.

In one instrument (#48), the back was actually louder than the top on the lower fretboard by 0.4dB, but this represents a difference of 10%, and is within the error margin for the testing. However, it probably indicates that the top and back of this instrument radiate nearly equally at the lower frequencies, although the top is louder at the higher frequencies. A difference in this dulcimer was that the back and sides are very soft and light; the top is actually denser than the back. It also had quite a stiff fretboard. The relative densities of the top and back may have an influence on the sound level differences. The greatest top/back differences occurred in the instruments where the back was much denser than the top (the Test dulcimer and #12). This might imply that if you want more of the energy to radiate from the top, a dense back and sides might be preferred. (But there might be a downside regarding knee damping.)

The dulcimer that had no top (#13) still showed a difference between top and back recordings even though it was the same vibrating plate that was being measured from opposite sides. This is probably explainable as the focusing effect on the sound by the sides, and possibly a significant sound radiation from the fretboard itself (Figure 15.5).

Figure 15.5. Dulcimer #13 — no top plate

In the two dulcimers where the sound holes were blocked, one was stiff with top and back bracing but a soft fretboard (#20) and the other was more flexible with no bracing and a hard fretboard (#04). The sound hole radiation component seemed to be about 2dB in both cases; i.e., the direct contribution of the internal vibrating air to the total sound was about 2dB (another 60%). But this is not straightforward because the loss of the Helmholtz resonances, by blocking the holes, would also modify the sound produced by their interaction with the wood, so the wood sound would also be modified. However, it does seem to indicate that the sound hole radiation represents a significant component of the total sound, at least at the lower frequencies. At higher frequencies the effect was not clear – the two instruments went in opposite directions.

It also seemed generally true that dulcimers with the largest differences between top and back loudness were also the ones where the back was most affected by knee damping, if they had a very thin and/or dense or flexible back. (Test dulcimer and #12). But #04, with a fairly flexible back, did not show this. In this case, the top was stiffer than the back, which may be relevant.

Overall, the stiffer the top and back (and that basically means bracing), the closer they seem to be in loudness (although the top might still be usually louder), and yet the less they are affected by knee damping.

It's worth considering whether part of the increased output from the top is because of sound transmission through the generally softer wood of the top. That idea would be supported by the result of #48, where the back is less dense than the top. But #04 also has a lower density back (but ply, not solid wood), and is louder in the top, and #17 has a very soft top that is not much louder than the back. So it's not clear if this might be a factor or not, but if it is, it seems restricted to the lower frequencies.

A comment should be made about the top/back decibel values listed for each instrument. During the recordings the string strike force could not be controlled accurately – the magnitude of the strike was set by the overlap of the plectrum on the strings and the momentum of the falling pendulum that held it. While I did my best to keep conditions constant between trials and instruments, I have a suspicion that the top/back SPL difference might not be constant with changes in string strike magnitude. Meaning that a harder string strike might give a different top/back SPL difference than a lighter one. So, while the general conclusion that the top is louder than the back is true, the magnitude of the top/back difference might depend to some degree on how hard the strings are struck.

Sound is being made wherever the wood is vibrating, and when it vibrates with greater magnitude (i.e.the wood physically moves more), the sound should be louder (providing it can radiate outwards and isn't locally cancelled out). Which part of the instrument wood vibrates depends upon the resonant properties of the dulcimer – different parts will vibrate at different frequency input from the strings. Sound is also being made inside the dulcimer by the air vibrating in several ways, and some of that sound comes out of the sound holes and some of it forces the wood to vibrate, and hence make additional sound. Some of the internal air vibrations pass through the wood and some is lost as heat energy in the wood. The magnitude of the string strike could vary these components differentially and hence change the top/back SPL difference.

Putting sound holes in the back instead of the top would allow additional sound energy to radiate from those holes and may tend to bring the loudness of the back closer to that of the top. However, such a construction does not make much practical sense. Sound radiating down towards the floor from the back of a dulcimer might be largely lost to a listener or even to the player.

From the study above, the two dulcimers with blocked sound holes both reduced their top output by 60% compared to when the sound holes were open, at low frequencies. I would have to do a few more dulcimers to be more confident that this was a representative result, but because the two instruments have very different construction it might mean that the sound hole component is in the order of 50% of the total sound at the lower fretboard. On the higher fretboard, one of the two increased the sound by 10% with no holes, and the other decreased its sound by a factor of three with no holes. That might indicate that constructional factors interact more variably with sound hole geometry at the higher frequencies in modifying sound hole radiation, whereas sound hole radiation might be less dependent on construction at lower frequencies. All speculation.

<u>An aside: Like most luthiers, I have a sound in my head that I'd like my dulcimers to make. I make constructional variations around a very orthodox theme, as they seem appropriate at the time.</u>

Figure 15.6 shows a picture of the box and sides of a dulcimer of my pattern (on the left), and one that I made at the same time which was a rough functional replica of a Bear Meadow dulcimer from information on the website (on the right).

Figure 15.6. Two dulcimer bodies - Troughear(left) and Bear Mountain replica (right)

The one on the left has 3mm sides and 4mm side linings. The sides of the dulcimers I make are nearly always the same thickness as the backs, and vary between about 2.5mm up to 4mm, depending on the wood density. The Bear Meadow replica has 2mm sides and 2mm side linings. The outlines of these two were the same, the wood species and densities were the same, but the sounds were quite different. The replica instrument was softer, more bassy, and generally sweeter. I suspect the thin 2mm plates were a significant factor in its sound. The thicker sided instrument has a ***very*** loud and robust sound.

Sometimes I cut back the tops of the internal end blocks so that less of the top/fretboard is glued to it and more of the fretboard is free to vibrate. This is prompted by Bear Mountain[27] practice, but I can't say I've noticed any sound change that I could attribute to it. Similarly, I haven't separated the headstock from the fretboard by a gap, which some makers do. I can't think of a reason why it might improve the sound—the dulcimer body would be under increased stress without the compressive strength of the fretboard abutting the headstock. So, I generally do something like as shown in Figure 15.7 at both ends.

Figure 15.7. Dulcimer headstock and tail piece treatment

And finally, whilst looking back at these pictures, I noticed two extra workers, assisting in my endeavors (Figure 15.8).

Figure 15.8. Extra dulcimer workers

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[27] http://www.bearmeadow.com/index.html

Top Loudness vs Side Loudness- Feb 01, 2011

To get some idea of how much the sides might contribute to the overall sound, I've had a look at the loudness of a few mountain dulcimers from the side relative to the top.

The usual caveats apply – these are all full-length fretboard hourglass dulcimers with four sound holes. Also, only seven dulcimers were measured so conclusions are only indicative.

Set Up

The dulcimers were set up as shown in Figure 15.9.

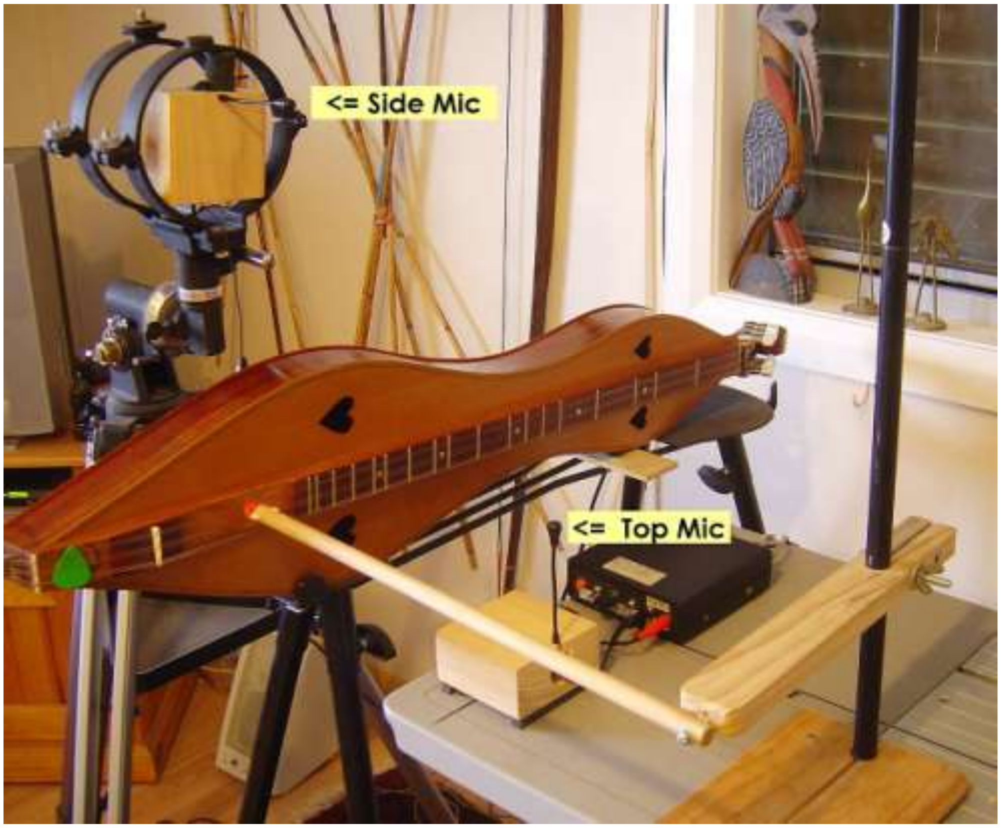

Figure 15.9. Sound recording set up.

The microphones were placed 20cm from the tops, as in the Top-Back SPL study, and 20cm from the widest part of the major bout. If a side did not show up as significantly louder than the top at 20cm, it is unlikely to do so at a greater distance.

The instrument was mounted on foam pads and the strings were stuck with a falling pendulum pick. Twenty-five string strikes were used per test — greater than that number gave no different results. Only open strings were tested —not the capoed upper fretboard as in the top-back study. I expect there would be different results at the higher frequencies.

Once the dulcimer and string striker are positioned, repeated trials gave answers to within about 0.5dB of each other. But I've noticed that if the instrument or string striker is moved slightly, or the pick overlap on the string changed, there is a larger spread of results, about 1dB (although the trend is still the same). This probably means that the relative loudness of the top vs. the back or sides is somewhat dependent on how hard the string is struck, but I haven't investigated this properly. To partially account for this set-up-specific variation, I did two tests for each dulcimer, repositioning the instrument between tests.

In this top-vs.-side test, there was not the opportunity to simply flip the dulcimer over and re-test to accommodate room acoustics and amplifier channel differences, so results here may have an additional result bias which I estimate at less than 1dB based on the top-back study. Overall, I was moderately confident that these results are accurate to with 2dB.

Tests were also done with the sound holes taped over to remove cavity air resonance radiation from the overall sound (and some of their interactions with the wood).

The string strikes were analyzed in the same way as the Top-Back study: sampled into the computer with Audacity and saved as .wav files, then imported to PRAAT where the average Sound Pressure Level (SPL) of the 25 strikes was calculated.

Results

The results are shown in Figure 15.10 (two trials per instrument, three for Dulc #20). In general, the tops were 2 to 6 deciBels louder than the sides ; i.e., about 1.5 to 4 times as loud in sound perception terms. It's interesting to note that the top to side loudness difference was mostly slightly reduced without sound holes. This might indicate that the internal air resonance-induced vibrations in the top and back plates also applies to the sides, but to a slightly lesser degree. This is reasonable given the physically smaller surface area of a side compared to the top or back. When the two lowest air resonances are lost with blocked holes, that component of the top and side sound is also lost, but the top looses more than the sides, thus bringing the top/sides SPL difference closer together with blocked sound holes.

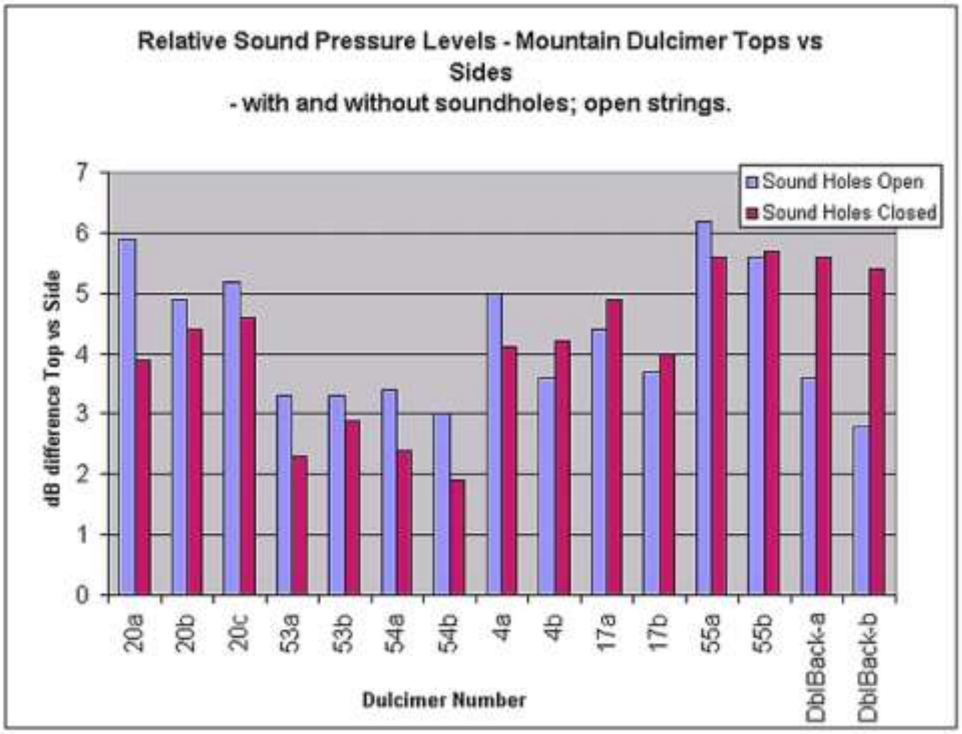

Figure 15.10. SPL differences for tops vs sides for seven dulcimers

These results give support to those players who hold the dulcimer vertically in their lap, Seifert-style. You are actually directing more sound toward the listeners for two reasons—the top is louder than the sides, and the sound hole radiation is directional.

For general comparison with the Top vs Sides graph above, Figure 15.11 shows a similar graph of the Top vs Back SPL differences. (Note: the instruments and their sequence is not the same as in Figure 15.10).

I did not test all the dulcimers in this study with covered sound holes. However, some observations can be made.

First, the SPL difference between tops and backs, with some exceptions, ranges between about 2 and 6 decibels – a similar difference as for tops and sides. We might infer from this, with some hesitation, that the absolute loudness of the back of a dulcimer is similar to the absolute loudness of one side, which means two things: the sides are vibrating significantly, and they probably contribute a non-trivial amount to the overall sound. And that’s only the major bout, so maybe it’s worth thinking about the design of the sides as a significant sound producing element.

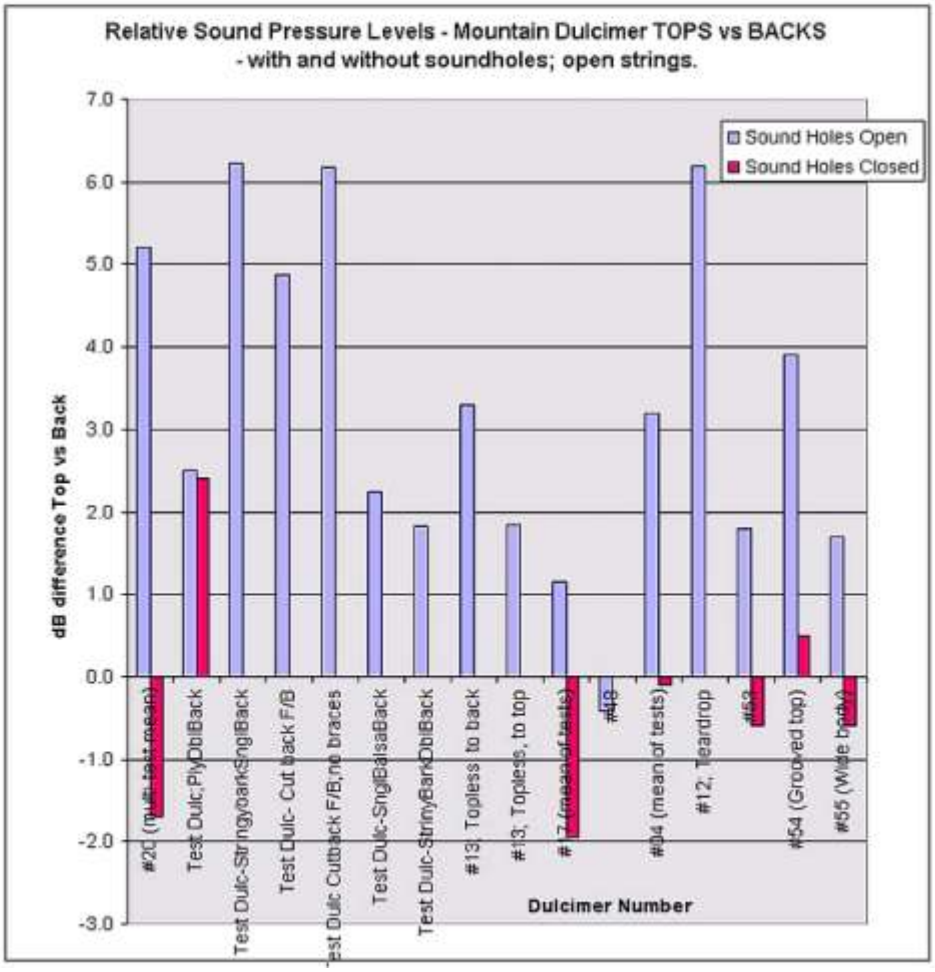

Figure 15.11. Effect of sound holes on SPL difference top vs back

Secondly, without sound holes, the top-back SPL difference appears centered around zero, but as always, with exceptions; i.e., the sound hole radiation may be contributing nearly all the 2 to 6dB difference between the tops and the backs with the wood vibration of tops and backs essentially the same loudness. That's how the graph looks, but preventing the two lowest (Helmholtz) air resonances from developing by closing the sound holes also prevents them forcing the wood of the top and back to vibrate at the same frequencies, and the top and the back may not vibrate at the same magnitudes under the influence of the cavity resonances. So, loss of air resonances may also change top and back wood vibration, and differentially.

Conclusion

At the lower frequencies of the open strings, a mountain dulcimer top might be 1.5 to 4 times as loud as one side. The size of the sound holes might influence the magnitude of this effect. Also the combined sides may be radiating as much sound energy as the back.

The Top-Back SPL study showed that the difference in loudness between the tops and backs is frequency dependent. At the higher frequencies of the upper fretboard, the top increases its loudness over the back. This means that retuning a dulcimer will affect the top to back relative loudness, as will using a capo. In practical terms, it probably means that the higher an instrument is tuned or played, the less relative loss there will be from knee damping.

Relative and Absolute Loudness of Tops, Backs, and Sides of Mountain Dulcimers- Feb 05, 2011

The previous graphs of the loudness of dulcimer tops, relative to backs and sides, only show the ***difference*** in sound pressure level (SPL) between the surfaces, not the absolute sound level which is the sound we hear.

As an indication of how much sound a dulcimer might produce, the absolute sound pressures recorded from the tops of the fifteen or so dulcimers tested in this set-up was about 60dB +/-10dB - depending upon how hard the strings were struck and the intrinsic loudness of the individual instruments. Background level of room noise was usually about 25dB lower than the instrument SPL averages.

So, the dulcimer tops generated an average sound level of about 25dB; i.e.; about 320 times as loud as the background noise. [I know I'm equating "loudness" with "sound pressure level/power" but the purists will have to bear with it.]

Generally speaking, backs and each side were about half as loud as the tops.

All these instruments had fairly standard-sized sound holes.

So, taken together, if all surfaces are allowed to vibrate fully, the total sound contribution coming from the two sides and the back of a mountain dulcimer might be modestly louder than the sound coming from the top alone. How the player and listeners might perceive this will depend upon all sorts of things: how the instrument is held or supported, the room acoustics (reflections, absorptions), how the sound is directionally scattered from the instrument because of its shape, and the frequencies that are being generated (high or low).

And keep in mind that we don't really notice a change in loudness until it roughly halves or doubles.

Aside: The original discussion of this book was of a dulcimer with no top, only a back, sides and fretboard, shown in Figure 15.5. The claim was that removal of the top did not change the measured or perceived loudness of the instrument. None of this current discussion changes that conclusion. The fact that the top removal did not change loudness does ***not*** mean that a dulcimer top adds very little to the total sound output. It just means that the remaining (vibrating) back radiates audible sound in two directions, up and down, whereas with the top in place the internal sound of the vibrating back is largely absorbed by the wood or air and not heard.

The basic difference between the back/sides sound and the top sound is that tops have part of their total sound radiating directly from the sound holes, resulting from the two lowest cavity resonances. How important is this? The measurement method allows some information here.

The recordings with and without sound holes were conducted without disturbing the physical set-up of the instruments. With everything in place, the recordings with sound holes open were made, then the sound holes were carefully covered with masking tape (several layers) without moving anything, and the recordings repeated. Consequently, the absolute effect of removing the sound holes can be observed with reasonable confidence, from one microphone near one surface, rather than the relative difference between two surfaces with two microphones. The results are shown in Figure 15.12. First, the ***absolute*** SPL change in tops and backs with and without sound holes are shown (compare with the SPL ***difference*** top to backs, Figure 15.11).

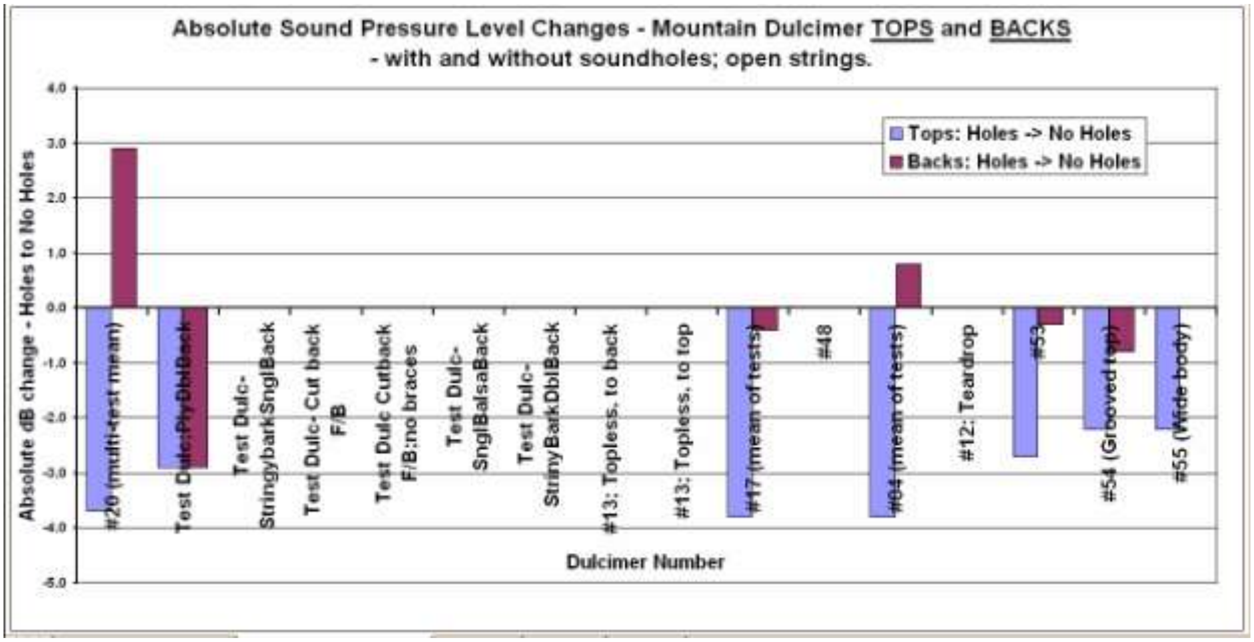

Figure 15.12. Absolute SPL changes for sound holes vs. no sound holes

Then the SPL change in tops (another series) and sides, with and without sound holes, are shown in Figure 5.13 (compare with SPL difference tops to sides, Figure 15.10).

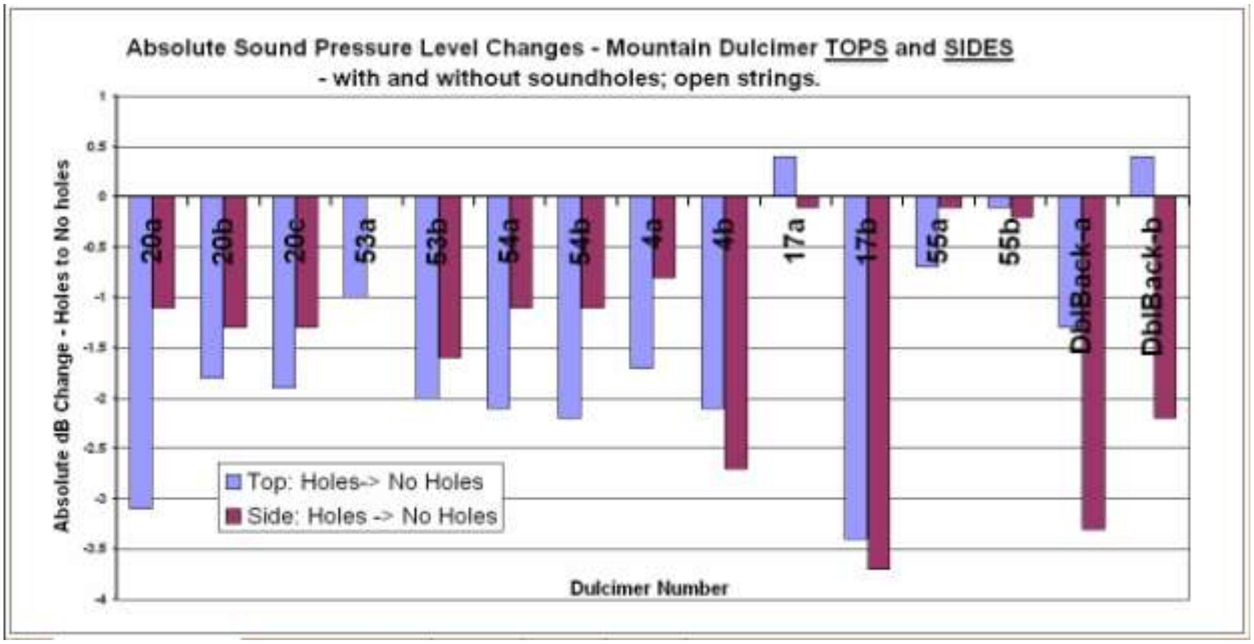

Figure 15.13. Absolute SPL changes for tops and sides with and w/o sound holes for seven dulcimers (two trials each)

(Note: the Tops/Backs graphs and the Tops/Sides graphs are of different series of measurements, and the dulcimers are not in the same order, so don't directly compare a Top/Back graph with a Top/Side graph left to right – look at the dulcimer number if you want to compare. Also the Top/Sides graphs have two sets of bars per instrument for comparison of set-up variation.)

The conclusions I draw from these studies are summarized in Table 15.2. I'd suggest that a "moderate" change might be 1dB to 3dB (1.25X loudness to 2X loudness change) – something we should be able to hear.

Table 15.2

SPL Conclusions

	Holes Open	**Holes Closed**
Top - absolute SPL		Moderate reduction in loudness
Tops vs backs	tops moderately louder than backs	tops and backs ~same loudness
Tops vs sides	tops moderately louder than sides	tops still moderately louder, but a little less than with holes open
Backs - absolute SPL		no real change in loudness
Sides – absolute SPL		moderate reduction in loudness

Or to put things another way:

- tops are nearly always louder than backs or sides, and
- Sound holes add about:
  2dB to 3dB to ***top*** loudness,
  <1 dB to ***back*** loudness, and
  1dB to 2dB to ***side*** loudness.

These loudness increases with sound holes are the sum of direct sound hole radiation and cavity resonance coupling to the wood, which in turn increases sound output from the wood surfaces.

In other words, as holes get smaller, tops and backs get closer to each other in loudness, but total sound output falls. This is in line with expectations, both theoretical and observed, for other instruments; so it just confirms that the same thing occurs in mountain dulcimers. But again, the actual sound radiation pattern is subject to the things listed above – room acoustics, dulcimer shape, frequency – not just the sound hole size.

Loudness - Six Strings vs Four Strings- Jul 06, 2017

If I was asked whether a six-string mountain dulcimer should be louder than a four string one, I might automatically reply that it should be. But on reflection it's not that clear cut.

If we assume that each string contributes equal loudness to the sound if struck equally, then adding two extra strings to a four-string dulcimer should increase loudness by 50%. That translates to 3.52dB increase in sound pressure level (20Log (1.5). (I'm not adhering to proper convention here – loudness is not the same as sound pressure; one is a perceived level of sound strength, and the other is a measured quantity – the output of a microphone.)

It's generally accepted that most people will perceive a 10dB increase in SPL as a doubling in loudness, but a just-noticeable change in loudness is harder to pin down. All sorts of things influence it, but somewhere between an SPL increase of 1dB and 3dB most people will start to hear a sound as louder than it was.

This means that the measured SPL of a six string dulcimer needs to be at *least* 1dB greater than the same dulcimer with four strings, under the same conditions, if it is to be perceived as a louder instrument.

The Experiment

Five six-string dulcimers were within arm's reach, so I measured the sound pressure level of each of them with six strings, and then with four strings, and compared the results. It was expected that the six string recordings would produce higher SPL readings, but would they approach the simple expectation of 50% higher (3.52dB); or if not, would any SPL increase be likely to be perceived as louder?

Method

Each six-string dulcimer was mounted on a stand and six open-string strikes were made of all three strings by a plectrum mounted on a rigid pendulum (Figure 15.14). Recordings were made; then one bass string and one middle string was carefully removed without disturbing the recording set-up and six more string strikes were recorded.

The first four seconds (to 10ms accuracy) of each strike was analyzed with the PRAAT software package for average sound pressure level and the results for 4 and 6 strings averaged for each dulcimer and the two average sound levels compared.

Figure 15.14. Recording set up.

Results

The data are summarized in Table 15.3 . The first dulcimer (#20) actually measured as louder when set up as a four string. However, I think I reversed the direction of the pendulum swing between the 6 and 4 string arrangements; i.e., the plectrum struck the treble string first in one set of recordings and the bass string first in the other. That in itself is interesting, implying that direction of strumming may have an effect on loudness. When I repeated the same dulcimer at the end 6 strings were recorded as higher SPL than 4 strings.

Table 15.3

Six vs. Four String Loudness

Six Strings SPL (dB)									Four Strings SPL (dB)							
Dulcimer	Strike 1	Strike 2	Strike 3	Strike 4	Strike 5	Strike 6	Mean		Strike 1	Strike 2	Strike 3	Strike 4	Strike 5	Strike 6	Mean	Diff 6 to 4 Strings dB
D 20 trial #1	59.4	59.69	59.94	59.55	59.37	59.51	**59.6**		60.06	59.99	60.03	60.06	59.4	59.54	**59.8**	**-0.3**
Ebony	56.41	55.77	54.95	55.57	56.14	56.23	**55.8**		51.31	52	51.05	51.79	51.06	51.7	**51.5**	**4.4**
D 54	55.03	55.52	54.81	55.04	54.67	54.75	**55.0**		54.42	54.2	54.53	54.79	54.17	54.47	**54.4**	**0.5**
Orthey	50.52	51.64	50.51	51.58	50.73	51	**51.0**		49.96	49.8	50.05	49.82	49.48	49.6	**49.8**	**1.2**
Cardboard	52.95	52.96	52.89	52.29	52.9	52.46	**52.7**		51.7	51.83	51.89	51.47	51.42	51.87	**51.7**	**1.0**
D 20 trial #2	58.43	58.02	58.12	57.98	58.13	57.88	**58.1**		57.6	57.79	57.43	57.52	57.31	57.59	**57.5**	**0.6**

Only one of the dulcimers approached or exceeded the 3.52dB necessary for the simple expected 50% increase. That dulcimer was the Ebony instrument. The remainder had a six string SPL increase over four of about 1dB or less.

Conclusion

Most of the dulcimers tested as six string instruments were only about 1dB higher in SPL than when set up with four strings. This is just about the point where some people will start to perceive an increase in loudness. So it seems that, in general, six string dulcimers are not likely to offer a noticeable loudness increase over a four string dulcimer and certainly not a substantial one.

But as with all “rules”, there are clearly exceptions. The Ebony dulcimer was 4.4dB higher SPL when strung as a six string – well within the range where most people would hear it as louder than four strings. In this case, it is quite a heavy instrument and the bass strings seem to carry more of the total power, relative to the treble strings, than in the lighter instruments tested, so taking off a bass string removed more of the original sound power, and made it relatively quieter as a four string.

The two #20 tests demonstrated that the same instrument can produce opposite SPL changes if the strings are stuck differently (but with the same force). (However, neither SPL change would likely be heard as a loudness change.)

Why didn't the six string set-up generally approach the notionally expected 50% increase in SPL readings? Can't say. Perhaps close string pairs interfere with each other and lose energy doing it; perhaps there are more complex couplings at the bridge and nut for double strings; perhaps a plectrum doesn't strike each string equally when they are close together. It doesn't really matter much in a practical sense – generally, a six string dulcimer is clearly not significantly louder than a four string version of the same instrument.

So why make six string dulcimers at all, or have a double first string for that matter? It must have more to do with appealing changes in the timbre of the sound than with producing a louder instrument … with some possible exception

Chapter 16
Wolf Notes and Note Resonance Matching

Wolf Notes in Mountain Dulcimers- Aug 17, 2009

It's probably fair to say that for stringed instruments in general, including mountain dulcimers, it is better to have more strong wood and air resonances than fewer. If there are many resonances, then there is at least the opportunity of modifying them to alter the sound of the instrument and the sound can be richer and more interesting. If there are fewer and weaker resonances, then you are probably stuck with the sound of a more bland instrument.

Unfortunately, an undesirable side effect of many strong resonances can be the presence of wolf notes.

There are numerous working definitions of what a wolf note is, but there seems to be two main types:

- continuous "howling" type notes, and
- "dead" or muted notes.

The first type occurs mainly in bowed instruments (bowed dulcimers might be a candidate), where there is continuous energy input from the bow; e.g., a string tuned closely to a strong air resonance (say, less than 5Hz difference) might produce a beating sound that is strong and undesirable. Cellos in particular seem prone to wolf notes and the better the cello the more likely it is to have a wolf note.

The second type seems more likely in transiently excited or plucked instruments (e.g., Mountain Dulcimers) when a note sounds dull or lacking in sustain, or has a different timbre.

In both cases, the notes on either side of the wolf tone may sound perfectly OK, or there may be a range of two or three notes where there is a noticeable difference from further up or down the scale. Also, the severity of the wolf note can vary from barely noticeable to so bad that the note has to be avoided.

A simple working definition I use is: ***A wolf note is a note that is distinctly different from adjacent notes in loudness, sustain, or timbre*.**

Some explanations for wolf notes say the phenomenon is related to a strong air resonance coinciding with the frequency of a string note or one of its harmonics. Others say it is a wood resonance near a string note. And others suggest it's because of a cancellation effect between wood/wood or wood/air resonances, reducing sound radiation at that note. Still others say it results from a lack of alignment of the harmonics of wood/air resonances with those of the string (or too strong an alignment). Everyone seems to agree that wolf tones are related in some way to one or more resonances of the instrument; i.e., one of the frequencies at which the instrument, or part of it, vibrates most efficiently. A maker can modify these resonances, to some degree, in frequency, strength, and bandwidth during the building process, but it also seems agreed that a wolf note can't be predicted and is only discovered when the instrument is finished. So anything done to eliminate them, or moderate their effect, has to be done after the instrument is completed (although some guitars are proposed as wolf-note-free by design).

From a player's perspective, the cause is not terribly relevant — there is a note that stands out from the rest, and what can be done about it? Suggestions range from using higher/lower tension strings; adding weights to various parts of the instrument; making the air cavity bigger/smaller; changing playing technique; using different tunings.

I only started to think about this at all because wolf notes have occurred on some of my dulcimers. They have shown up on different shaped instruments, some with hollowed and some with arched fretboards. The note is always on the middle string (in tuning Dadd) and has ranged from A220 to D294, which always places them below the 4th fret. Usually only one note is affected, but sometimes there is some "leakage" of the effect to adjacent notes. It's sometimes hard to tell if the note is louder or softer, but there is definitely a timbre difference, and sustain seems reduced.

Which is why I've had a closer look at one instrument (#20) to see if there are any characteristic sound differences, and whether there might be simple interventions that can smooth out the effect of a wolf tone in a mountain dulcimer. It may be that such notes are not common in other makers' instruments; that they develop later in the life of an instrument; that players/makers don't notice or care about them; or that makers already have methods to deal with them. In any case, there has been little discussion on about wolf notes relating to mountain dulcimers.

I wanted to know specifically whether a wolf tone was:

- related to a particular position on the fretboard or to a position-independent note frequency,

- whether there was a difference in the wolf tone between the first and second strings,
- whether string weight and tension played a part, and
- whether I could relate the frequency of a wolf note to an actual resonance in the air cavity or wood of the dulcimer.

Subsequently, I made a number of measurements on this instrument (#20) on the effect on the wolf tone of adding weights to various parts of the instrument and to the sound in general. In all cases, when determining whether a wolf note was present, and judging its severity, I relied on a fairly unreliable measuring instrument - my ear. I justify doing this firstly because I don't know of a technical way to quantify the severity of a wolf note, and secondly - if I can't hear it, then there's no problem, is there?

I had already partially done this investigation on another dulcimer some years ago, by systematically tuning the first and second strings over a range of notes and recording the note at frets up to the 6th. My perception of what I heard is shown in Figure 16.1.

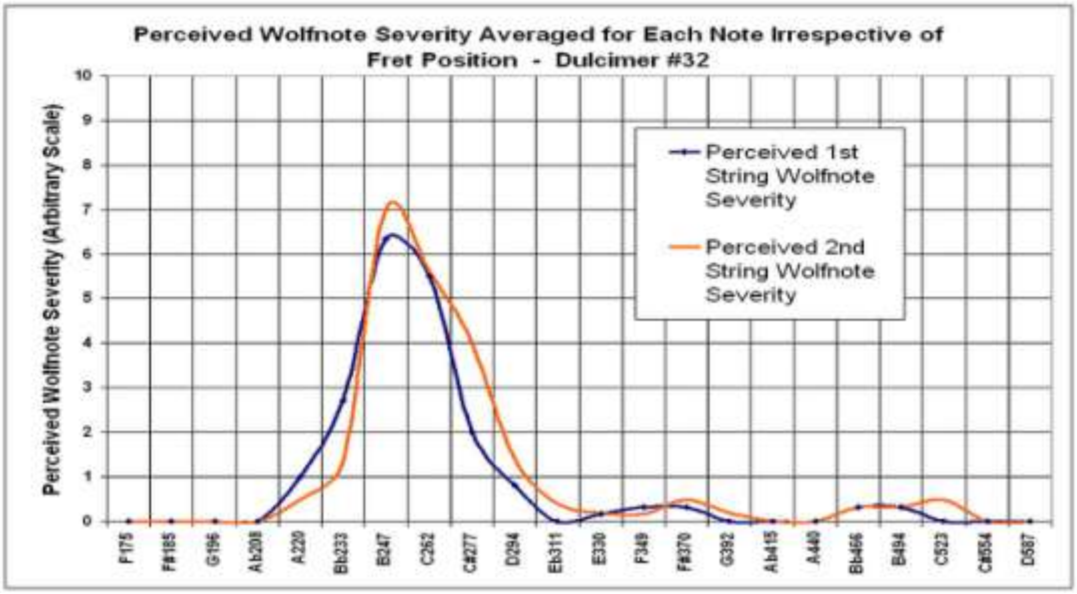

Figure 16.1. Perceived severity of wolf notes vs frequency

This represents the averages of perceptions over 176 fret/note combinations, and was done on an instrument with double first and double second strings (both strings 0.011), a full-length hollow fretboard, and a main air resonance at 212Hz. It shows several things.

1. The wolf note was definitely perceived at a fixed frequency no matter what fret that

frequency occurred on.
2. The octave of the wolf note was not nearly as prominent, if noticeable at all.
3. There was not much perceived difference in tonal quality between the first and second strings under the same conditions.

The perception of a wolf tone covered a note range from about A220 to D294. This is at odds with the fact that dulcimer air and wood resonances are usually narrower than a semitone, so it would require several merged resonances to produce a broad wolf region like this. This resonance-merging was not the case here, so I suspect I was just listening too hard for what I hoped would not be there – like an audiophile, ear to the speaker hoping there's no noise, but not quite sure….

The tap spectrum of the earlier test instrument (#32) and two others (#31 and #33) made at the same time are shown in Figure 16.2. The three pairs of vertical lines encompass the region of the wolf note, its octave, and an octave higher.

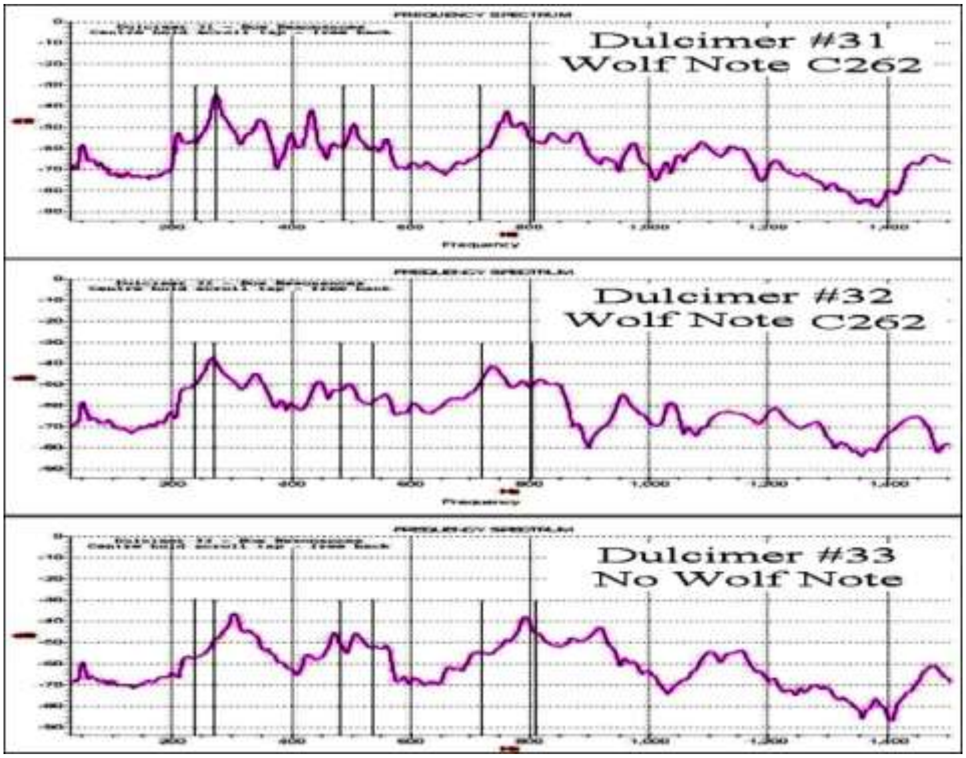

Figure 16.2. Tap spectra of three dulcimers.

The three instruments were identical except for the wood type, and sounded similar, but the top two had a wolf note (#31 and #32) and the bottom one didn't (#33). The first air resonances don't show up well here, but they are all about 210Hz (the small bump, or shoulder). The third air resonance is about 340Hz, so the difference between wolf-note and no wolf-note in these three could be related to the first bar resonance falling between 1^{st} and 2^{nd} air resonance; about 270Hz in the two with a wolf note at C262 (middle string, about 2nd fret); and about Eb311 (middle string 4th fret) in the one without a wolf note.

So in these three (#31,32,33), the wolf tone doesn't seem related to an air resonance, which is one of the claimed culprits in violin-class instruments and guitars. In an earlier experiment, the first air resonance of #20 was systematically raised by filling the instrument with glass marbles of a known volume. The new air resonances could be accurately predicted as each batch was added, but the frequency and severity of the wolf note remained unchanged, even as the air resonance increased and the back plate became more damped. So I'm reasonably confident that in mountain dulcimers it is wood resonances, rather than cavity resonances, that are implicated in wolf notes.

But even that is not entirely clear. The instrument under current test, #20, has a wolf note most noticeable at C277, and my impression is that it is louder at that note, so an anti-resonance is not likely.

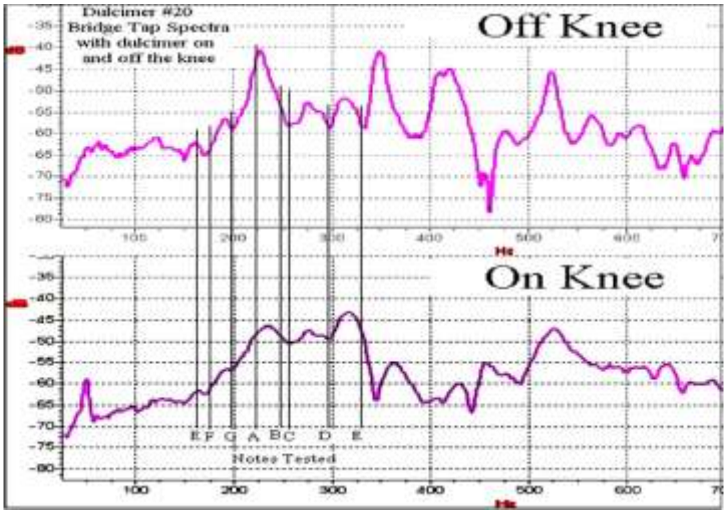

Figure 16.3. Effect on tap spectra of knee damping

Looking at the bridge tap spectra on and off the knee for the same instrument (Figure 16.3, above) there is no major resonance anywhere near the wolf note frequency of C#. And the same goes for the air resonance spectrum (not shown). In addition, when on the knee, the wolf note is not quite as prominent as when the back is free. Maybe there is a clue there.

Overall, these investigations have not satisfactorily explained what causes a wolf note. I think they are probably related to wood resonances in mountain dulcimers rather than air, but clearly there is more than just the fundamental frequency involved.

I tried some interventions on #20 to see if there was a simple way to moderate its wolf tone.

Tests on Dulcimer #20

The instrument:

- 27.5” scale length, six string,
- full length, hollow fretboard of low/medium density,
- first air resonance 223Hz and second at 344Hz, and
- Western red cedar top, all else is New Guinea Rosewood.

Listening Criteria: These tests involved listening to a ***lot*** of notes being played/recorded under different conditions. I found myself homing in on a few subjective criteria for judging the sound and making notes about it. Not everyone will agree with these criteria, but they must mean something to me. I don’t know what the terms mean physically and they aren’t adopted from any industry standard. I listened for:

- lower to mid fretboard “presence” and “punch” on the treble strings. (“punch” might have something to do with the rate of change of sound output from soft to loud.),
- upper fretboard “ring” and “cutting power” on the treble strings. (“ring” probably has to do with sustain, and “cutting” with sound intensity.), and
- lower fretboard “integrity” and “solidity” on the bass string (Who knows? “not fuzzy around the edges”?).

I found I wasn’t so interested with the sound of the bass string on the upper fretboard, perhaps because if I play it up there it’s usually hidden in a chord and not played on its own.

The process was one of making an intervention (weight, string gauge, string tension etc.); deciding if I liked it better or not; judging the quality of the sound; and then measuring the box and air resonances to see if there was some connection that might give a clue about how to produce future instruments with that sound.

Effect of String Position 1st or 2nd string : Under the same conditions of string type, fret position and tension, there didn’t seem any audible difference between the sound of the first and second strings. Even when the strings were of different diameter, but tuned to the same note, there was very little difference in the sound, and the further up the fretboard the more alike the 1st and 2nd strings sounded.

I conclude from this that the nature of the wolf tone and the string timbre in general is not much related to a particular string on the instrument, nor to the fact that it has a hollow fretboard or not.

Effect on Wolf Note of Adding Weight to Parts of a Mountain Dulcimer

Weight was added to various parts of dulcimer #20 by either clamping or attaching with Blu-Tac. Figures 16.4 A and B show the setup for weighting the fretboard. Figures 16.4 C and D show setups for weighting and clamping the top and/or the back plate.

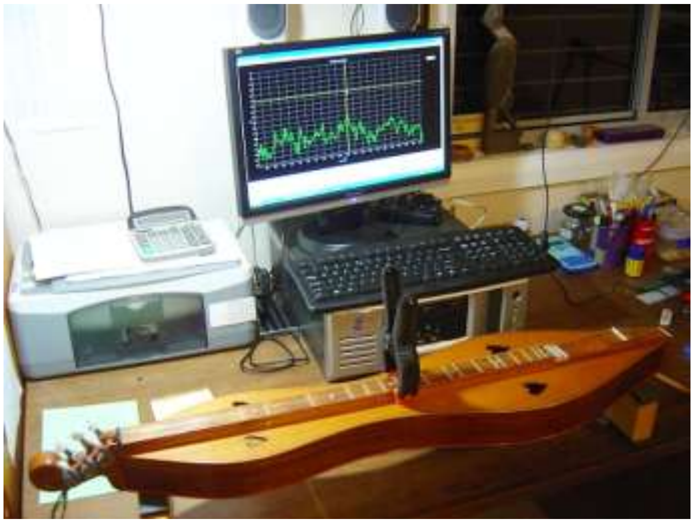

Figure 16.4A. 50gm fretboard weight added

Figure 16.4B. 544gm fretboard weight added.

Figure 16.4C. 544g top plate weight added

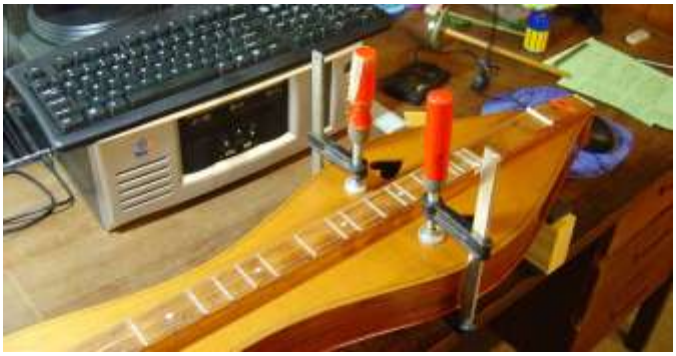

Figure 16.4D. 544gm top/back clamp

Weights were added along the fretboard at 1” or ½” intervals and at various points on the top, back and sides — ranging from metal clamps (544gm), through plastic spring clamps (50gm), to small metal plates (11gm).

General Observations: The observations, based on listening, are very subjective. It was not always straightforward to decide if a result was “better” or “worse”. Even deciding if there was any difference at all was not always easy. However, here are some general impressions:

- A weight as small as 11gm to the back plate or fretboard had a clearly audible effect on the sound. ***Conclusion***: some permanent modification to the sound of a dulcimer can be unobtrusively made after it is finished.

- Adding an11gm weight almost anywhere on the lower bout back plate seemed to improve the sound. Adding a 272gm weight to the back seemed to accentuate the bass, without cutting the treble — however the effect was quite position dependent.

- Adding an 11gm weight to the back of the upper bout seemed to diminish or mute the sound slightly, or even it out (read: make it less interesting); the effect of 272gm was greater, but much less than on the lower bout.
- Adding weight to the sides did not seem to alter the sound much.
- New wolf notes occurred with some placements, particularly on the bass string, when weight was added to the lower bout back, but not the upper bout back.
- Adding an11gm weight to the top plate seemed to have only a slight audible effect, and generally in the "wrong" direction; e.g., loss of upper treble "ring" or general muting. However, adding 544gm almost anywhere on the top improved the tone and increased the loudness significantly. There was more of an effect when the weight was symmetrically placed on both sides of the fretboard. ***Conclusion***: this might point to heavier/thicker tops being acceptable in mountain dulcimers.
- Adding weight to the fretboard had the most beneficial effect on the wolf note and an effective position was about the 3½ fret area, but also the 11th fret area, for a different sound.
- In some positions, whilst moderating the wolf tone, the heaviest weight (544gm) also took the "life" out of the sound. An 11gm weight was enough to improve the wolf note without upsetting anything else.
- Adding weight at or near the bridge greatly reduced the loudness without improving the wolf tone. Not much of a surprise.
- Finger pressure did not have the same effect as firmly fixed weights. ***Conclusion***: the more flexible coupling of the finger tissue still allowed a largely unchanged dynamic wood vibration even though there might be a static deflection.

Whether these conclusion apply generally to all mountain dulcimers is unknown.

However, these tests show that a small weight added after construction ***can*** modify the sound. Larger weights, particularly on the fretboard, have the potential to significantly alter the sound, with even a ½" change in position or the weight producing a large difference. Trial and error is probably the only way to find a preferred position.

Often the solution to reducing the effect of a wolf note, in any instrument, is to remove or add a small weight at some particular spot, usually on the soundboard in the case of guitars. In the case of Dulcimer #20, used in this experiment, I inserted two ¼" brass slugs into the fretboard at the offending 3rd fret. These are shown in Figure 16.5. The slugs extended the full width of the fretboard and did considerably moderate, but not eliminate, the wolf note. The best position for the slugs was determined by temporarily attaching similar weights to various parts of the fretboard.

Figure 16.5. Brass slugs inserted into fretboard to moderate a wolfnote

Effect on Air Resonances of Adding Weight I did a quick check to see if the addition of weights altered the lower air resonances of the instrument and therefore the tone. There was less than a semi-tone variation of the first air resonance and less than ¼ semitone for the 2nd air resonance for weights added to top, fretboard, or back; so I conclude that changes in air resonance radiation was not what was altering the sound for any intervention.

This just confirms that, for a reasonably stiff dulcimer, the air resonance frequencies are fixed by the size and shape of the instrument and the sound hole area, not by what the instrument is made of.

Effect of 50gm Plastic Spring Clamp – at 1” Intervals on Fretboard: The dulcimer was isolated from the bench with foam pads at each end with a free back and tuned to DAdd. A plastic spring clamp was moved up the fretboard from the nut in 1” increments. The sound was evaluated by listening as well as the bridge tap spectrum being recorded at each position.

The sound impressions are shown in Figures 16.6 though 16.9. The X-axis is clamp position in inches from the nut - 0” to 29”; the Y-axis is in an arbitrary rating scale from 1 to 5.

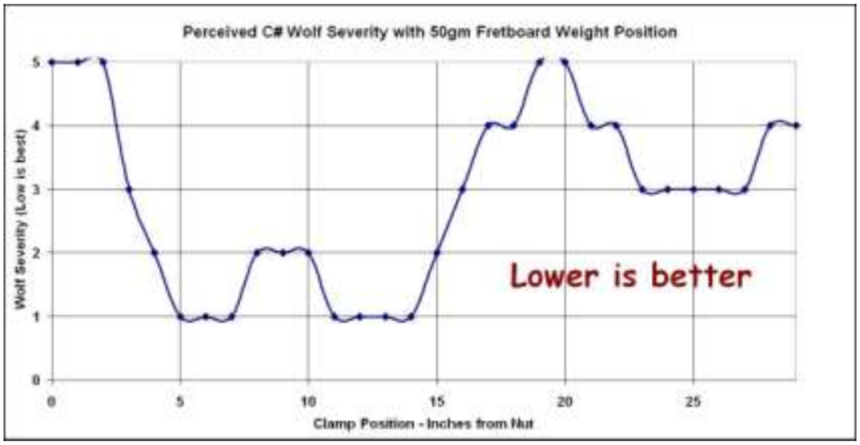

Figure 16.6. C# wolf note severity vs fretboard clamp position

Figure 16.7.Lower treble “punch” vs fretboard clamp position

Figure 16.8.Upper treble “cut/ring” vs fretboard clamp position

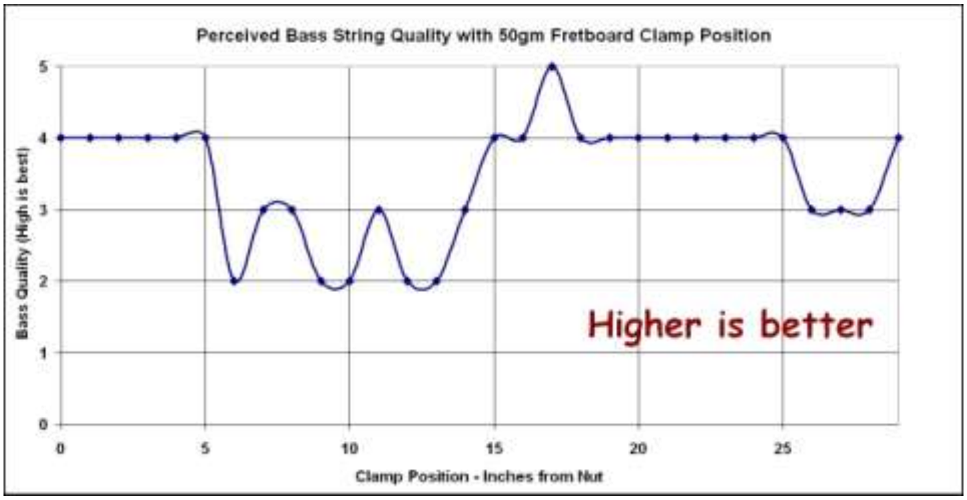

Figure 16.9. Bass quality vs fretboard clamp position

Again, these are subjective personal impressions, and detailed analysis of these charts would be unreliable. However, in general I'd like the wolf severity to be low, and all the others to be high, and there do seem to be regions of the fretboard where adding weight can accomplish one or the other. But it seems that it's more likely a compromise must be made. If a wolf note is moderated or eliminated by adding a weight, it seems likely that the sound will be altered in other ways as well, such as generalized muting, or muting of different parts of the fretboard, reduction of sustain in some parts of the fretboard, or even the introduction of new audible wolf tones.

The bridge tap spectra corresponding to all these 50gm clamp positions shows marked changes in the resonant frequency positions. The spectra and the position of the clamp on the fretboard for some of the clamp positions are shown in Figures 16.10 and 16.11.

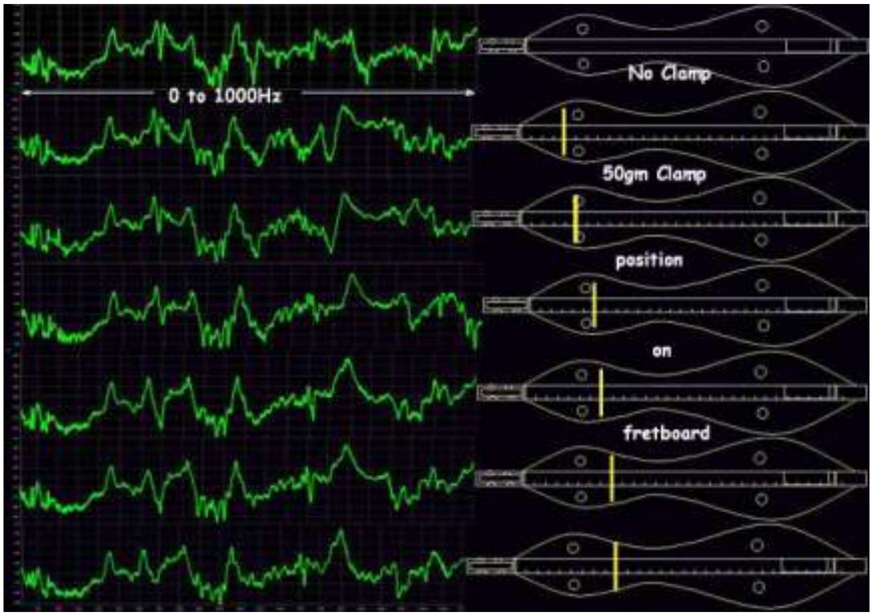

Figure 16.10. Changes in bridge tap spectrum with position of 50gm clamp on fretboard — 4 to 9 inches from nut

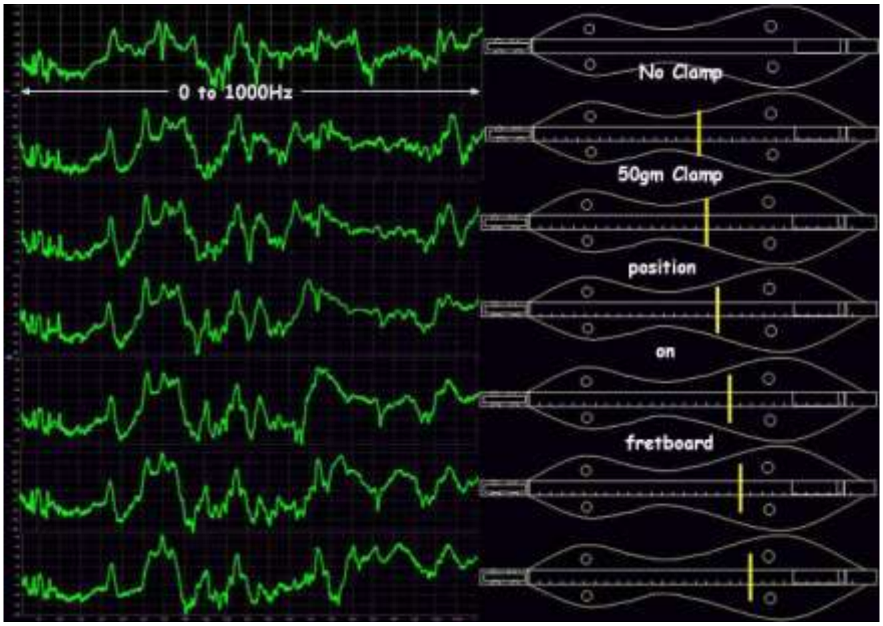

Figure 16.11. Changes in bridge tap spectrum with position of 50gm clamp on fretboard — 15 to 20 inches from nut

The frequency scale is from 0 to 1100Hz. Below 100Hz is just noise, not related to the resonances of the instrument. There is not much variation in the spectra above 1100Hz (caused by adding the weight, anyway). Large changes in the spectrum occurred as the clamp was moved by small amounts, and between 10” and 14” the clamp was moved in ½” increments instead of 1”.

These spectra represent very repeatable views of the vibration of the instrument body and hence the potential for making sound at that frequency, if driven by the strings. However, they don't show ***which*** parts of the dulcimer body is vibrating – that is where "glitter" studies are useful, but not as easily done.

In the spectra in Figure 16.10 and 16.11, each peak represents a frequency at which that dulcimer vibrates efficiently – it "likes" to vibrate at those frequencies. The higher the peak relative to the others, the stronger the contribution of that note to the total mix. The peaks don't stop at 1100Hz but continue up to, say 5000Hz. A maker has no practical control over any individual resonance above about 1000Hz, and it also seems that most of what an instrument sounds like occurs below that frequency. Some of the resonances below 1000Hz can be controlled by a maker – the spectra show that.

The sequence of fretboard clamp spectra from no clamp to a clamp past the bridge at 29" shows some resonances moving in frequency and amplitude, merging with adjacent resonances and also anti-resonances appearing. Some observations are:

- The first air/wood resonance (230Hz, Helmholz) and the second air/wood resonance (350Hz) remain at the same frequency as the clamp is moved. This would be expected because it is the air inside the dulcimer that is causing these, not the wood itself.

- The first bar resonance of the dulcimer box, between first and second air resonances, starts off at about 340Hz, moves down to about 300Hz as the clamp is moved up the fretboard, then rises in frequency again to merge with the second air resonance. Simultaneously, another resonance above 350Hz does the opposite – moves up then back.

- There are regions of major spectral change around 500Hz and from 600Hz to 800Hz as the clamp is moved.

Whether these spectral changes, and hence sound changes, are for the better of not is for the listener to decide.

Again, there seems to be no prominent resonance in the region of the wolf note (C# 277Hz) of this instrument, at least at the fundamental. There are no major resonance changes at this frequency or its 2nd or 3rd harmonic when the clamp is in the 5" to 15" fretboard position, where the wolf note was most audibly reduced.

This must mean:

- there is no wolf note and I'm just hearing things,
- or the wolf note that I'm hearing is not the result of a prominent resonance, although it is related to a particular frequency, or
- the wolf note is more related to sustain or damping phenomenon involving one or many of the harmonics of the wolf frequency. This would not show in the frequency spectra, although a hint might be given by wider than normal resonance peaks around those frequencies – but too hard to distinguish.

Effect on Wolf Note of String Weight/Tension

Vibrating string theory suggests that the best sound comes from long, thin and flexible strings, tensioned nearly to breaking point. That would be somewhere between 10 and 20 kg for a typical dulcimer string. This combination of thickness and tension minimizes errors in the string harmonic series and also the frequency stretch-non-linearity ("twang") for large amplitude vibrations, but it doesn't comment on practical matters such as intonation and playability, just the sound.

For these tests I used new, unwound, single (not unison) strings:
- from 0.011" to 0.020" diameter,
- tuned from F#185 to C#277 on the open string,
- giving a range of tensions from 3.3kg on the lowest tuned 0.011 striing to 24.7kg on the highest tuned 0.020. I used a standard string tension formula.

Each string was re-tuned so that the note C# (the wolf frequency) would fall at each fret up to 4, and listening and recording was done at each fret, and the open string.
Each string size/fret combination was tested on both the 1st and 2nd strings.

No evidence of a resonance/wolf relationship was found here – so in this dulcimer the wolf note was unrelated to sting weight or tension. Maybe not all wolf notes, in the general sense, are caused by prominent resonances as is usually assumed. They are clearly not related to a particular position on the fretboard. Perhaps some are caused by frequency dependent damping within the wood of the instrument rather than the frequency prominence of resonances.

Harmonic Series of Wolf Notes – Time History of Partials- June 01 2010.

In the previous sections, I was trying to find the cause of a tonal difference on a particular note of some of my dulcimers. I have basically ruled out air resonances, prominent wood resonances, or string related factors as the cause. I considered that examining the decay of the harmonics of the notes might show something in the upper partials that could be responsible for the wolf tone, so I looked at the sound spectrographs of notes played on eight dulcimers, with and without wolf tones, but found nothing to satisfy me regarding the matter.

The end result of all this analysis is that I have found no clear origin for wolf notes in mountain dulcimers.

But something did come out of it. I noticed that the wolf tone was most prominent when the string was struck at a quarter of the length of the string, but not near the ends or the middle. This is clear evidence that the first harmonic is somehow involved. So I looked at the spectrographs of the eight dulcimers, fretted at the 3rd fret middle string (the wolf note position, string length 20”) whilst striking the string at 1” increments in position from the bridge to the middle of the string, and about 4 seconds apart in time. This time allows observation of the full decay of the notes. Again, nothing showed up that I could relate to wolf notes – just a huge variety of patterns of harmonic decay between the different instruments.

However, it neatly showed something that may be of interest to players – the difference in tone that arises when the strings are struck at different parts of their length – a warmer sound away from the bridge; a harder sound closer to the bridge. The reason for this is the different pattern of harmonics excited and their strengths. Figure 16.12 provides a representation of one half of a vibrating string from bridge to center, with the first four harmonics shown. The points where the curves cross the zero line are where the string is not really moving; away from those points the string is vibrating increasingly strongly.

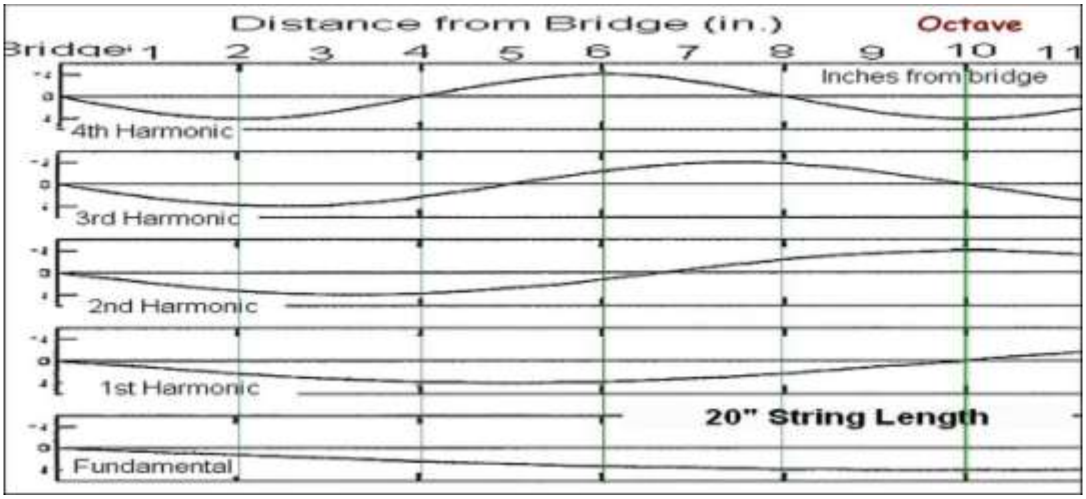

Figure 16.12. Harmonic energy zero-crossings (nodes) as a function of distance from bridge of a 20” string length dulcimer

Figure 16.13 shows the sound spectrograph of a note repeatedly played, but struck at 1” increments from the bridge. The horizontal axis is time, and the vertical axis is frequency. The darker each harmonic “flag”, the louder that harmonic is. Each vertical series of “flags” shows the fundamental and the first four harmonics of a single string strike at a particular position along the string – each harmonic starting off loud, and decaying away to nothing. If you compare Figure 16.12 with 16.13, you’ll see that where the curves cross the zero lines, there is no sound in the harmonic series at that corresponding point along the string. So if you strike the string at a point where one or more harmonics have a zero crossing, then those harmonics won’t be excited, and won’t be included in the total sound – the tone will change because of the position you have struck the string.

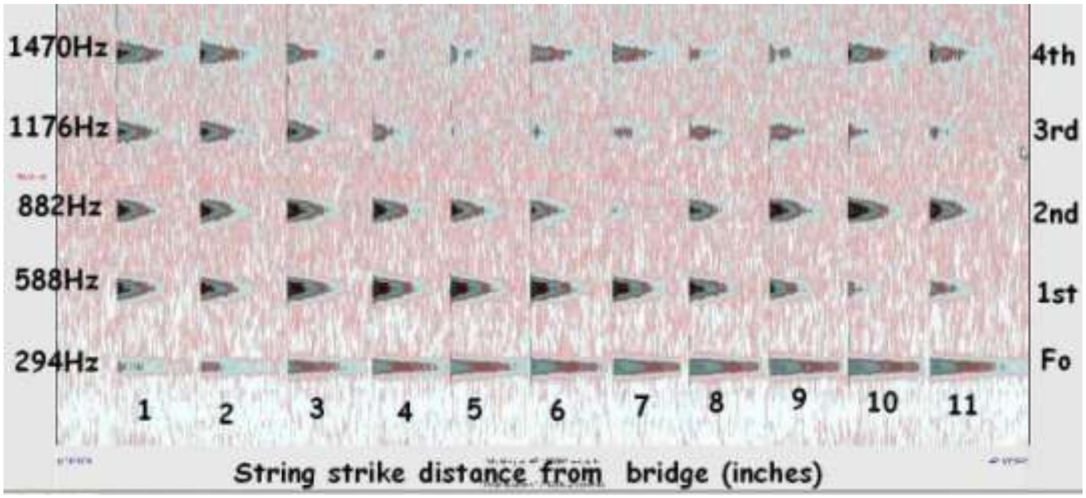

Figure 16.13. Sound spectrograph as a function of distance from bridge – fretted at 3rd fret (20” string length).

Note–Resonance Matching - May 25, 2010

Many players and makers know that an individual dulcimer can sound better if tuned to some particular note – CGcc rather than DAdd for instance. There is often some associated speculation as to why this might be and often includes sentiments such as matching the “resonance” of the instrument to the tuning. It does seem to be a real phenomenon, and I do think it relates to some favorable alignment of the instrument resonances with the notes it is tuned to. (Regardless of the notes the strings are tuned to, the resonances of the dulcimer box and enclosed air remain unchanged.)

A well known Australian guitar maker, Trevor Gore[28], has had some success in tuning the lower box resonances of his instruments to fall between notes in a concert pitched guitar. “Resonance tuning” means the modification of the mechanical properties of the box by standard methods of thinning, bracing etc.; so that the first few wood resonances occur at particular frequencies and fall halfway between notes. I have played a high quality factory-made guitar at his house, which I thought sounded very good, followed by a resonance-tuned instrument of his. In comparison the factory guitar suddenly sounded like it was packed with cotton wool – the difference in clarity and loudness was considerable.

Why might placing the resonances between notes make for a better sound? I don’t know. A couple possibilities occur to me. One could be to do with the smoothing of the lower frequency spectrum so that all notes are more equally amplitude balanced with no stand-out or “wolf” notes. Another possibility could be to do with the “singer’s formant”. This phenomenon, first reported by Swedish speech researcher, Johann Sundberg, is one of the mechanisms whereby superior singers, particularly opera singers, stand out from less accomplished singers, and also successfully compete to be heard over accompanying music. Such a singer introduces an additional resonance, or "formant", into the frequency spectrum of their voice, and this occurs in the region around 3.5kHz – the region at which the human ear is most sensitive to sound. By concentrating extra sound energy in that region, the voice stands out more than it would otherwise. The concept may have some relevance to musical instruments for the same reason, and if the lower spectrum is smoothed by the low resonances falling between notes, there may be more energy available to excite the higher spectral region of the “singer’s formant”, and without as much competition from ragged spectral clutter lower down, allowing it to stand out more - assuming the instrument has a “singer’s formant”. Mountain dulcimers certainly have sound energy extending to 3.5kHz and beyond. Neither of these suggestions are proven.

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[28] www.goreguitars.com.au

I know in only the vaguest way how the resonance tuning is accomplished for the guitars referred to, but I was interested to see if it might be relevant to mountain dulcimers, and whether the alignment of wood resonances between notes might be the reason why some dulcimers respond better at different tunings.

Because I accurately know the resonant frequencies of all the dulcimers I make, a simple way to test this proposition would be to slightly tune the dulcimer up or down so that the frequencies of the first six or so resonances do not fall right on any note, but somewhere between. I did this for five instruments.

The procedure was:

1. **Compare the resonant frequencies of the five dulcimers** with frequencies 50 cents between the series of concert pitch notes. Eyeball the best fit for the lower dulcimer resonances to match those mid-note frequencies, and determine how far up or down each instrument should be tuned so notes fall between resonances.

2. **Tune *accurately* to DAdd**, concert pitch. Then:
    a. Play the instrument and listen to the sound.
    b. Record a standard tune, about 90 seconds long.
    c. Record three repetitions of the three notes of each bar chord from open string to 7th fret.
    d. Repeat (b) and (c) whilst measuring the sound spectrum in real time.

3. **Retune *accurately* to the pitch that sets the wood resonances between notes** and listen and record the same tune and notes, and real-time spectra.

All this was done in one session, under the same conditions, and with as much similarity in plucking as I could manage. For one dulcimer, the trials were repeated five times to see if there was significant variation in data recording for the real-time spectra. Repeatability was acceptable. Later, the spectra were also calculated from the sound recordings and compared with the real-time versions. Two different software packages were used – one for real-time and one for audio recordings. The two results were quite similar (not surprising). Concert pitch and resonance-tuned spectra, recorded and live, were then compared - the aim of the experiment.

Figure 16.14 shows results for one of the dulcimers. It represents the frequencies of individual notes and the first few harmonics, for the note sequences played up the fretboard. Each peak is an individual note or a low harmonic of a note. The horizontal axis is frequency, 0 to 1500Hz, and the vertical axis is sound pressure level in dB.

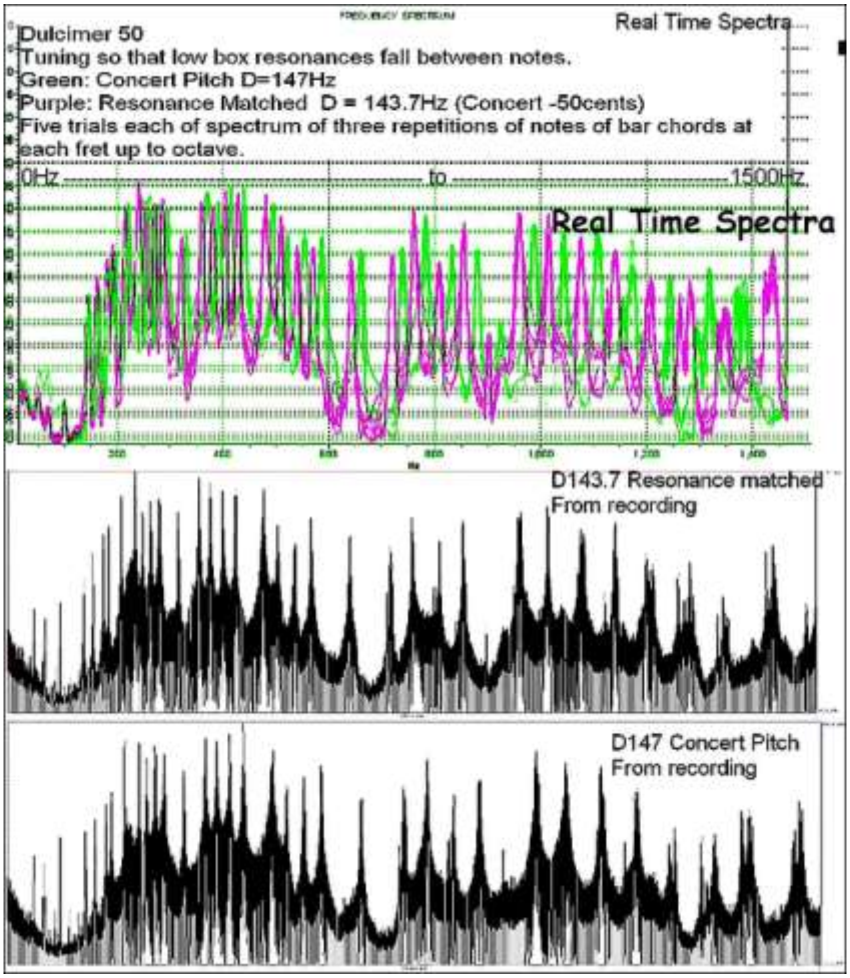

Figure 16.14. Realtime and calculated spectra for concert pitch and resonance-matched tunings

The green spectrum at top is five real-time trials of all the notes of the dulcimer, at concert pitch; then the red resonance-matched tuning, superimposed on each other to give an average idea of the shape of the lower spectrum and repeatability of the measurement; the red spectrum is about 50 cents lower in frequency than concert pitch. The black spectra below are calculated (not real time) from recordings of the same note sequence for the two cases (concert pitch and resonance-tuned).

Overall there’s not a lot of difference between the concert pitch spectra and the resonance tuned spectra at the lower end of the sound spectrum – they start to depart from each other as frequency increases, but this is because of the tuning difference. The amplitudes of the paired spectral peaks (concert/resonance matched) are very similar over the whole of the lower spectrum

So, what of the wider spectrum and frequencies above 1500Hz? I smoothed the broader spectrum, which extended up to 11kHz, to see if there were any spectral regions where the resonance-tuned instrument was different to the concert pitch tuning. Individual notes and harmonics can't be identified in this format, just the frequency regions where the sound has more or less energy concentrated. Figure 16.15 provides an example for one of the dulcimers.

Red is concert pitch; blue is resonance-tuned. The curves are not exactly the same, but that wouldn't be expected anyway because of slight differences in playing, recording etc. But there are no stand-out areas where concert pitch is stronger or weaker than resonance-tuned. This was the case for all five dulcimers.

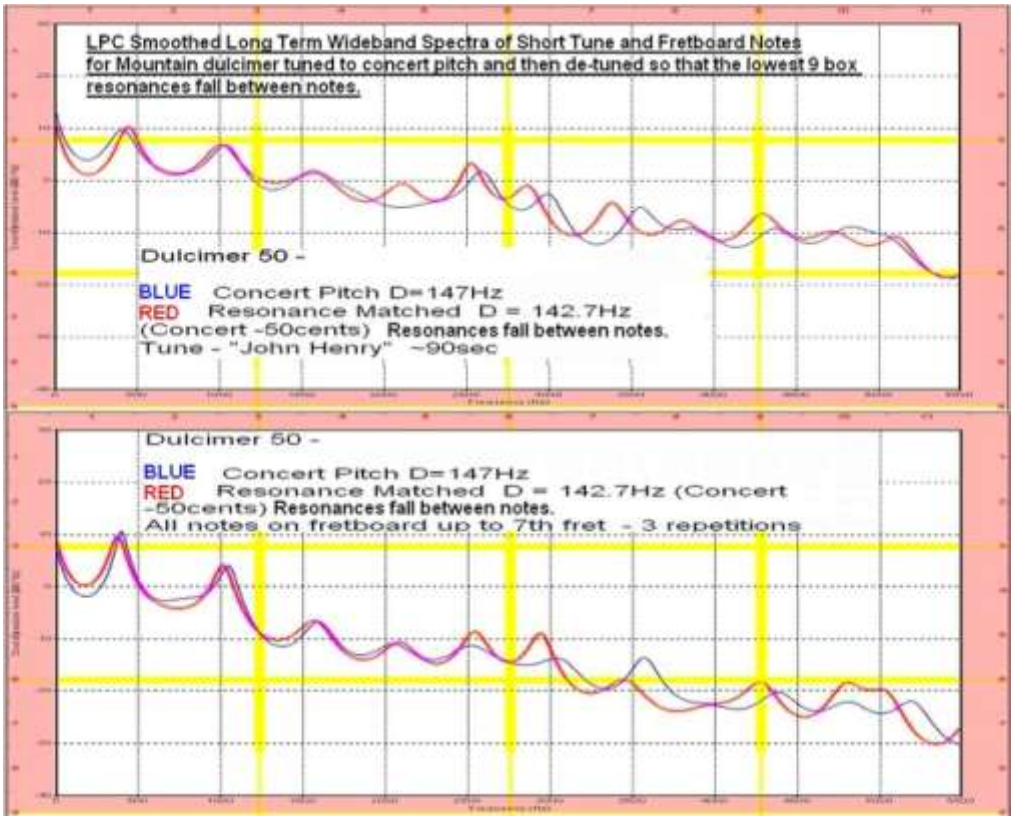

Figure 16.15. Wide band spectra of concert pitch and resonance matched tunings

As far as my own perception of the sound went, I ***thought*** the resonance-tuning produced a better sound in all cases; however, it took some time to retune accurately, and the memory of the previous tuning fades rapidly. There certainly wasn't a significantly audible improvement.

So there seems no strong evidence that interleaving the resonant frequencies of a mountain dulcimer with the notes of the concert-pitch scale produces a better sound. It could be that my dulcimers don’t have the underlying sound quality to take advantage of this resonance-tuning or that my recording and analysis methods were wrong or not accurate enough. Or it could mean that the basic idea has no merit for mountain dulcimers. The mechanism as to why some mountain dulcimers are claimed to (or actually do) sound better if tuned up or down must lie elsewhere.

Chapter 17
Design Process and Other Designs

Design Process-Apr 10, 2010 12:02 pm

For the past year and a half I've been making measurements on mountain dulcimers in a fairly unstructured way; and it might be of interest to some people if I put this work into perspective — specifically in relation to the overall process of designing dulcimers (or any musical instrument) using quantitative methods. However, if you are looking for a formula for producing good instruments you might stop reading now; read on if you would like to know why there is no formula for the perfect dulcimer.

Reading up on the methods used by some guitar-family luthiers who incorporate physics and mathematics into their making, there are numerous approaches, but the overall design philosophies seem to have some common features, which I'll try to summarize below. The sequence below could be varied and some parts could overlap, but all parts would ideally need to be addressed if fine instruments are to come out the other end using these methods. At this point I should also say that no-one seems to have implemented such a process fully for any instrument.

A General Process For Quantitative Musical Instrument Design

1. Determine How To Predict The Instrument Response To A Structural Change.

1.1 ***Examine real examples of the instrument*** to find the main physical parameters that are both controllable by a luthier and which might be useful as guides to predict the performance of new instruments. Variables are such things as dimensions, masses, stiffness, resonant frequencies of wood and air, stresses in strings, wood, etc. In fact, any physical parameter that can be measured might be a candidate. However, those that are clearly controllable and easily measurable by most luthiers might be most useful.

1.2 ***Model the instrument mathematically*** in terms of the experimentally derived important parameters or a subset of them. For example, a combination of masses, with stiffness, acted on by forces to produce displacements. A real example might be how much the top of a dulcimer of certain thickness and stiffness will be displaced vertically by the force of a string under known tension, and how the displacement will vary with the frequency of the string. An equation can be developed to describe this which would give the theoretical displacement of the top as the string tension and top stiffness and dimensions are varied. The equation, or set of them, is called a ***model***, and represents, in mathematical language, a simplified version of how the real instrument works. By putting real values of some of the parameters into the equations, the other unknown parameters can be solved for and then used as a guide in the building process for real instruments. Over the past fifty years, such mathematical models have been developed for violins and guitars, and probably for other instruments as well.

1.3 ***Refine the model*** by comparing the calculated results it gives to measurements on actual instruments, either on a specific make/model or a broad class; e.g., a McSpadden standard hourglass ***or*** all hour-glass dulcimers ***or*** all dulcimers in general. The more a model is refined to match one particular instrument configuration, the more detailed its predictions are likely to be in producing similar instruments.

1.4 ***Use the model to predict the result of structural changes*** in real instruments. Once a model is developed and refined, other luthiers can use it as a starting point without the need to undertake all the work already donen to get to that stage. Only the final input/output relationships need to be dealt with. Actual prediction of instrument parameters may then be made prior to building; or during the building process, and sometimes on the completed instrument to fine-tune its performance. For example, a formula can be used to determine the sound hole sizes that will produce a desired first air resonance. Alternatively, an understanding of the instrument model might provide more general strategies for construction. For example, increasing the size of the sound holes will make the frequency of the first air resonance rise.

None of the above gives any direct information about sound quality, or how to improve it, only how to predict and control some physical and acoustic parameters and how constructional variations might affect them.

2. Characterise The Instrument’s Sound Quality

2.1 ***Develop a sound ranking method.*** This is already done in an ad hoc way by all players and listeners who are usually able to tell the difference between the sound of a poor instrument and of a good one. If a more formal and controlled approach is taken; e.g., via representative listening panels and common descriptive terminology, a basic consensus might be agreed that can be used to rank the sound of instrument from poor to superior; without too much bias from factors such as aesthetic appearance, instrument provenance, and playing context. The difficulty (impossibility?) in obtaining this consensus is probably the downfall of ***any*** general design process, not just a quantitative one. Makers may then have to fall back to the sound ***they*** like, and what they ***think*** the wider population likes – a fairly unreliable situation. This sound ranking process needs to be done only once for each instrument type/configuration. Unless community preferences change….

2.2 ***Determine sound features of “superior” instruments***. The sound of real instruments can be analyzed to determine just what elements of the sound makes them superior. Factors such as general timbre balance, dynamic loudness range, directionality, overall loudness, particular frequency band emphasis, sustain and attack times, and many others might contribute to the overall sound, and certain values for each might combine to produce an agreed “superior” sound. These values might be determined in controlled or general playing situations where recordings of the instrument are manipulated to determine the effect on the sound by general filtering, selective amplification, moving of resonant frequencies, adding or removing harmonics, or any other signal processing action. Finding what parts of a sound makes the instrument “superior” is not a trivial exercise, but if accomplished could result in a set of sound parameters, particular values of which lead to a sound that is generally accepted as superior. For example, the strength of certain harmonics at certain frequencies might be important, as might the musical interval between adjacent resonances or the absolute frequency of some resonances.

2.3 ***Match the model parameters to superior sound requirements***. Knowledge of the model parameters could then be used to manipulate real instruments in construction to reproduce superior instrument sound quality. For example, use the model to predict the mass and stiffness required in a part of the instrument that is known to affect the frequency of a resonance, which in turn has been identified as desirable in a superior sounding instrument.

This is the connection between the mathematical model and the sound of the completed instrument.

The ways to implement this process in the real world are many, but might include:

a) An entirely quantitative approach – high throughput factories might like the possibility of quickly designing instruments by formula with some hope of a better than average sound outcome.

b) A partially quantitative approach – builders with some scientific background might make selective use of a model and sound parameters, coupled with other inputs to the design process.

Many (most?) current builders depend on experience and intuition rather than any quantitative process. In this case, judgments are made on the various construction features, and their effects on the sound, but the connecting reasons are not articulated explicitly, or if they are there may be no verifying proof. This doesn’t mean that the instruments are poor, just that explanations of why are not available.

An alternative approach is the “Make it up as you go along”/ “It seemed like a good idea at the time” approach, which is the method I mainly use.

A final, time proven method is the “reproduction of a known superior instrument” approach – probably a good starting point for beginners.

3. Summary of a Quantitative Design Process

- Analyze real instruments to find the basic operating variables.
- Model those variables mathematically.
- Refine the model against real instruments.
- Use the model to predict controllable physical and acoustic parameters.
- Develop a sound ranking system for the instrument.
- Identify the components of the sound that makes it “superior”.
- Use controllable model parameters to produce an instrument that has those superior sound components.

All of the above still only gets you into the “superior sound” ballpark. At least you are then in a reasonable starting position, but the final sound may still depend on subtle and not easily quantifiable or controllable construction factors including the vagaries of the wood. In addition, the foregoing is only about the sound of the instrument. The value of an instrument to a player, or commercially, may have as much to do with playability (“It practically plays itself”), appearance (“It’s gorgeous”), provenance (“It belonged to my grandfather”), or historical significance (“It’s the only one of these in existence”) as it does to the sound it makes.

In terms of a quantitative design process, mountain dulcimers are still at the first part of the general process; there is a long way to go before a seriously useful design method might be developed for dulcimers.

4. Design Observations

In practical terms however, there are some design features which can be controlled by a maker to definitely modify the sound of a dulcimer, such as the position of the bridge from the endblock. But given a dulcimer design, a maker might also try to guess what effect on the sound will result by varying the physical parameters of the different parts of the dulcimer. Generally, we might start with the instrument layout, or design, and then select the wood, and maybe fine tune thicknesses and heights and areas. I'd like to know why we try to do that fine tuning and what affect it has on the sound compared to if we didn't do it. So far, I have a lot of interesting data from experiments, but no great strides towards understanding much about fine tuning and tonal prediction before or during the building process. I think it is probably not really achievable – for my own part, the first time I have a clear idea about how a dulcimer that I am building might sound, is when I string it up for the first time. But for the design that I mostly use, I'm now reasonably confident of a few things at a more basic level, although not strongly connected with making "better" dulcimers:

1. The fretboard largely controls the way the top plate vibrates, so top plate parameters (thickness, stiffness etc) are less important than in other stringed instruments.

2. The top produces more sound than the back, the difference largely being the amount of extra sound coming from the sound holes, but the back and sides combined contribute about the same sound power as the top.

3. The top and back are strongly coupled in their vibrations, but the vibrations below about 1000Hz take fairly simple shapes in the areas of movement of the top and back plates, often just oval areas of vibration covering the lower bout of the top and back.

4. Varying the thickness of the top plate and the height of the fretboard changes the stiffness of the whole top assembly more than we might realize, and hence the sound.

5. The position of the bridge relative to the end block often has a major effect on the sound, and is something easily designed in. This parameter may influence the warm/bright perception of the instrument.

I think the above statements are also applicable to the wider population of full-length-fretboard dulcimers, and can be used as matters to give thought to in the building process.

This is not much return for a lot of work, and it is not easy to say how to use the information to guide actual building. Above 1000Hz, the way a dulcimer vibrates is too complex to analyze or understand, and that is where most of the overtones of the instrument fall, although not much of the sound power. Prominent resonances above 1000Hz, that happen to coincide with a harmonic of the fundamental frequency, might colour the sound noticeably. Alternatively, frequency regions that have a concentration of resonances might emphasise that region of the spectrum, and modify the tone. Neither of these scenarios can be specifically designed in by the builder, and if they happen naturally, we might reasonably expect that our perception of the tone could be damaged as well as improved.

The best we can do in applying science to our dulcimer building is show that something is more or less likely to happen as a consequence of some physical change in construction. For example, nearly all the experiments I have done confirm the importance of the fretboard on subsequent tone, so the studies tell me it is more likely that a light fretboard will result in a louder instrument than a heavy one. But it will not always be the case – just more likely. Where there is a difference between what one maker has noticed, and what another has seen, the explanation probably has something to do with a maker introducing one change (e.g., hollowing the fretboard to change its mass), but not realizing that this also changes other parameters as well (fretboard stiffness). And the unintended change may over-shadow the intended one in modifying tone. For instance, if you say that different top woods give a different sound, that may be the case, not because of the wood itself, but because you might use different woods in different thicknesses; and very small changes in top thickness, added to the height of the fretboard, results in large changes in top assembly stiffness, and that may be what changes the sound. That seems to be what I've found, but not proved. Mass, stiffness, density, internal wood damping, etc., are all interconnected in the building process, and we juggle them as best we can to produce a sound we like. One thing is certain, we are all dealing with the same Mother Nature – the invocation of mystical forces is not called for.

Builder Comparison-Oct 13, 2010

I called in to Terry Hennessy's workshop in Kangaroo Valley. Terry was making a number of beginner dulcimers to give to people on permanent loan because numerous people in the valley had expressed a wish to learn to play the instrument.

He had just strung up the latest one and when I played it I was struck by how similar it sounded to my test dulcimer (the subject of many of my experiments), which I also had with me. We both agreed that the two instruments sounded almost identical, which was surprising because they could not have been more different in terms of construction.

Terry's dulcimer was made with low grade plywood back and sides, Western Red Cedar top, medium density solid New Guinea Rosewood fretboard, and was elliptical in shape.

My test dulcimer had a double back – a dense Yellow Stringybark *eucalypt* outer back, Balsa inner back, WRC top, good quality plywood sides, a dense and highly arched Alpine Ash (*eucalypt*) fretboard, and an hour glass shape.

The clear message seems to be that a particular sound can be arrived at by more than one constructional route - even very different ones.

The Princess Dulcimer- Sep 16, 2011

I have been contacted several times by singers who have seen the BBC videos of Joni Mitchell singing “California” or “A Case of You”, and it’s been the first time they’ve seen a mountain dulcimer. They want to sing Joni Mitchell songs, and want to know if I can make them a dulcimer like that. I have declined gracefully. However, I contacted Joellen Lapidus[29], who made the dulcimer in the videos in 1969, to ask what her feeling was about people making replicas of the instrument, which she called the “Princess” dulcimer. You can see a picture of it on her website at http://www.lapidusmusic.com

Joellen was quite happy for me to make a functional replica, and even sent me a tracing of the outline of the dulcimer, which saved a lot of time in trying to derive shapes and dimensions from the few available pictures. She also sent some drawings of the sound holes cut from the photocopied sheets she had made in 1969.

I made two replica dulcimers, in different body woods, but the same spruce tops. It was an interesting exercise for me, and because the original dulcimer is an iconic instrument, I thought there might be interest in the acoustics of these two new versions, such as I could measure. It also provided an opportunity to compare results with my standard hour-glass dulcimers and draw more general conclusions. Joellen has played one of the replicas and even though the shape is fairly close to hers, she commented that it sounded different to her Princess dulcimers. As noted in the previous section, the shape clearly does not define the sound. Identical shapes can sound different – different shapes can sound the same.

Joellen has made several “Princess” dulcimers – two of the early ones are shown in Figure 17.1 along with a replica at the bottom. The original shapes appear to have subtly changed in the several made by Joellen, and the outline of the two I’ve made lie somewhere between the later instruments shown in her book “Lapidus on Dulcimer II” and the Joni Mitchell originals in the picture, which I think have very elegant curves.

I couldn’t make exact replicas; you can’t get the wood you know, so the two I’ve made are largely of Australian timbers. One has a body of Mountain Ash (*Eucalyptus regnans*), a fairly heavy *eucalypt*, and the other is Australian Red Cedar (*Toona Australis*), a much lighter wood. The tops of both are Sitka spruce with an Australian Red Cedar hollow fretboard overlaid with Ebony and Swamp Mahogany (another *eucalypt*) at the strum

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[29] https://lapidusmusic.com

Figure 17.1. Pictures of the Lapidus Princess dulcimer and replica.

end. Treatment of headstocks and end blocks is different to Joellen's. I wasn't up to doing the sound holes as originally carved, but the small holes at the headstock end are Joellen's pattern. The holes at the bridge end are a representation of the Australian Lyrebird, which I see frequently near our home (Figure 17.2).

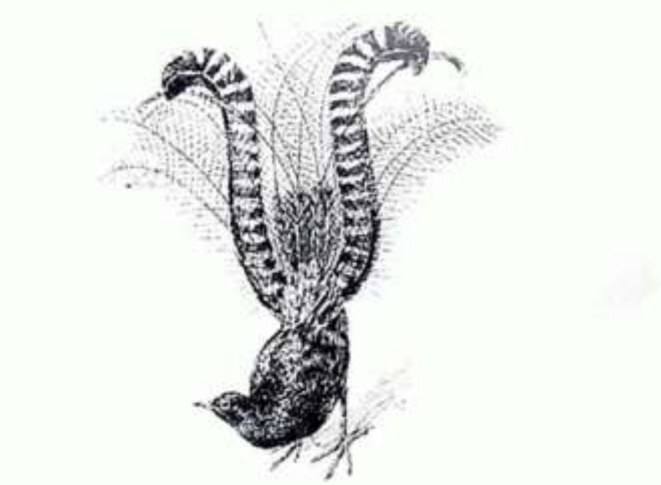

Figure 17.2. Drawing of Australian Lyrebird

This bird is the worlds greatest birdsong mimic – Kookaburra sounds, Currawongs, Black Cockatoos, Whipbirds – you wonder what's going on in the bushes, and out strolls a chicken-sized Lyrebird. The two replica dulcimers are shown in Figure 17.3.

Figure 17.3. Two replicas of the Princess dulcimer design

Aside from the unusual shape, this dulcimer has a combination of a hollowed and arched fretboard. The single arch is where a strum hollow is in most dulcimers, the idea being to allow a larger surface area of free top for vibration. I don't really subscribe to that idea, but it was probably not unreasonable thinking in 1969.

Acoustics and Vibration

Sound: The fretboard treatment of the instruments probably influences sound more than the box shape. Although made of very different body woods, these two dulcimers sounded quite similar, which I think results from the identical tops and fretboards.

The sound is soft and sweet, adequately loud and with nice sustain. They ring nicely on the upper fretboard, and the bass is solid but not overpowering. The middle string could be a bit stronger, but is still adequate. The sound is very different to my own dulcimers, and also very different to dulcimers I have made with the bridge in a similar position – over the inside edge of the end block. I wouldn't call it a traditional sound – it's more mellow than that.

Bridge Position: The bridge position has a major influence on the sound. Sliding the bridge inwards over the strum-arch changes the tone substantially. The further the bridge is moved inwards, the louder and more robust the sound becomes. Moving the bridge towards the end block produces a softer and thinner sound. The original position just over the inner edge of the end block seems to produce the nicest sound. I know there are other factors to consider, such as string tension and break angle, but it does point to bridge position relative to the box end as an important factor in the sound. This has been mentioned many times by other makers.

The difference here is that instead of positioning the bridge on a solid piece of fretboard moved further into the bout, the bridge is set on an arch above the top plate, so energy is not taking the shortest route down to the body, but must go along the arch and down. Yet the effect on the sound is the same as for a solid fretboard end. This says something about how string energy transfers from the bridge saddle to the dulcimer body – I just don't know what.

Sound Holes: The small set of holes in the upper bout of the replicas have an area smaller than I would normally do, and the Lyrebird holes are larger. Never-the-less, there is a lot of sound coming from the Lyrebird holes, and also some from the small holes at the other end. This is interesting, because in this dulcimer the major and minor bouts are reversed compared to a standard hour-glass shape. The bout near the nut is the "major" bout and produces the lowest air resonance, the Helmholtz, or rum-jug resonance ("1st air mode"), about 220Hz in these two dulcimers, which is about the same as in my standard instruments. The small open area of the holes makes the resonance lower in frequency than it would be if they were larger. (The smaller the holes, the lower Helmholz frequency; the larger the box, the lower the Helmholz frequency). The reverse is true of the bout near the bridge, which is the minor bout in the Princess dulcimer. The large area of the Lyrebird holes moves the second dulcimer air resonance higher, about 400Hz, which is about two semitones higher than my usual dulcimers. Both of these air resonances interact strongly with the top and back plates and causes them to vibrate, as in other dulcimers.

It has caused me to wonder why we usually put the larger holes in the larger bout. Perhaps it's mainly for aesthetic reasons of balance, but it may be that if we want to have a subtle shift of tone towards the lower frequencies, reversing the hole sizes might contribute to that. Experiments in partially covering the holes produces an audible, though not dramatic, effect. In these two Princess dulcimers, the loss of loudness because of the smaller holes in the major bout is made up for by the increased loudness from the larger holes in the bridge-end minor bout (sound from the holes increases in loudness as the hole size increases, to an extent).

Top/Fretboard Tap Resonances

I measured the resonances of the completed, but free or unattached, top/fretboard assemblies by holding an edge near the 2nd or 3rd fret and tapping the bridge position with a small plastic hammer. The frequency spectrum of the sound produced shows the tops' preferred frequencies of vibration – their resonances.

Because I had made three pairs of dulcimers recently (including these two replicas), it gives the opportunity to learn something about how much the whole top assembly contributes to the sound of a mountain dulcimer. Each pair essentially comprised two "identical" dulcimers. Figure 17.4 shows the tap resonances of the tops of the three pairs of dulcimers.

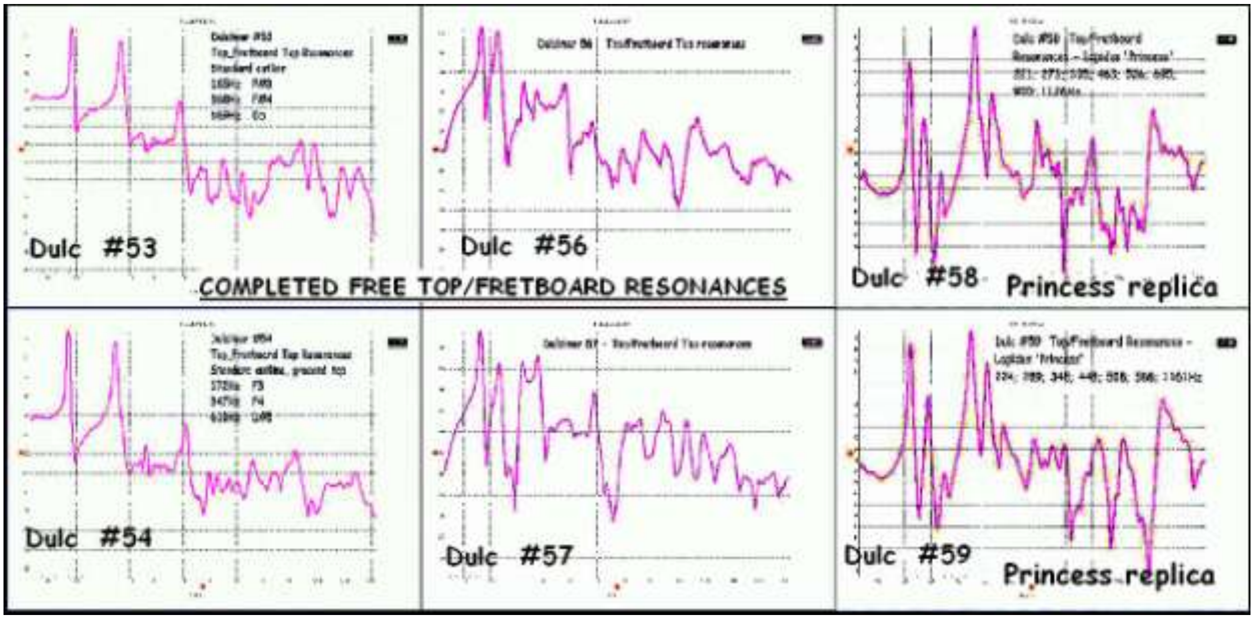

Figure 17.4. Completed, but unattached, fretboard/top resonances of three pairs of dulcimers

The horizontal scale is from 0 to 1300Hz. Each peak represents a frequency resonance, or preferred vibration frequency, of the completed top/fretboard assembly. The right-hand pair, 58/59 are the two Princess dulcimers. The spectra of each pair is clearly different to the other two pairs, but similar within the pair.

Each completed instrument sounded similar to its twin, but different to the two other pairs, and each pair of tops was identical within the pair, but different between pairs. From left to right they are brightest and loudest (#53, #54); to more mellow (#56, #57), to most mellow and softest (Princess replicas). I would not say that the ranking could be predicted from the spectra shown – about 15% of the sound energy occurs above 1300Hz. But it does seem to show that if the tap spectra of two top assemblies is markedly different, then the sound of the completed dulcimers is also likely be different. Keep in mind that these top/fretboard spectra are independent of the dulcimer body – the tops had not yet been glued onto the dulcimer bodies. The back and sides wood of #53, #54, #56 and #57 were all the same – Australian Red Cedar (*Toona Australis*). The two Princess dulcimers were of different body woods from each other – one was of soft and light *Toona*, and the other was heavy and dense Mountain Ash. The fact that the

53/54 pair sounded different to the 56/57 pair, even though they were all of the same shape and same body wood, and the 58/59 Princess pair sounded similar to each other (but not to the other two pairs), points to the tops setting the general tone of the sound. It implies that the fretboard/top plate of the dulcimers contributes a lot to the final sound, and from other experiments, I think the fretboard part of the completed top assembly does most of the contributing, with the top-plate itself of lesser importance. This opens the possibility of tailoring a top for a specific final sound, before it is glued to the box. The challenge would be to link a particular spectral profile to a particular sound, and then determine what to cut off/add on to a top to get that spectrum.

Box Air Resonances

Another major component of a dulcimer's sound is the vibrating air inside the box, and the way it radiates from the sound holes and also forces the wood panels to vibrate at the same frequencies by means of the pressure changes it causes inside the box cavity. This is fairly easily measured in the completed instrument. The internal air resonance spectra of the same six dulcimers are shown in Figure 17.5.

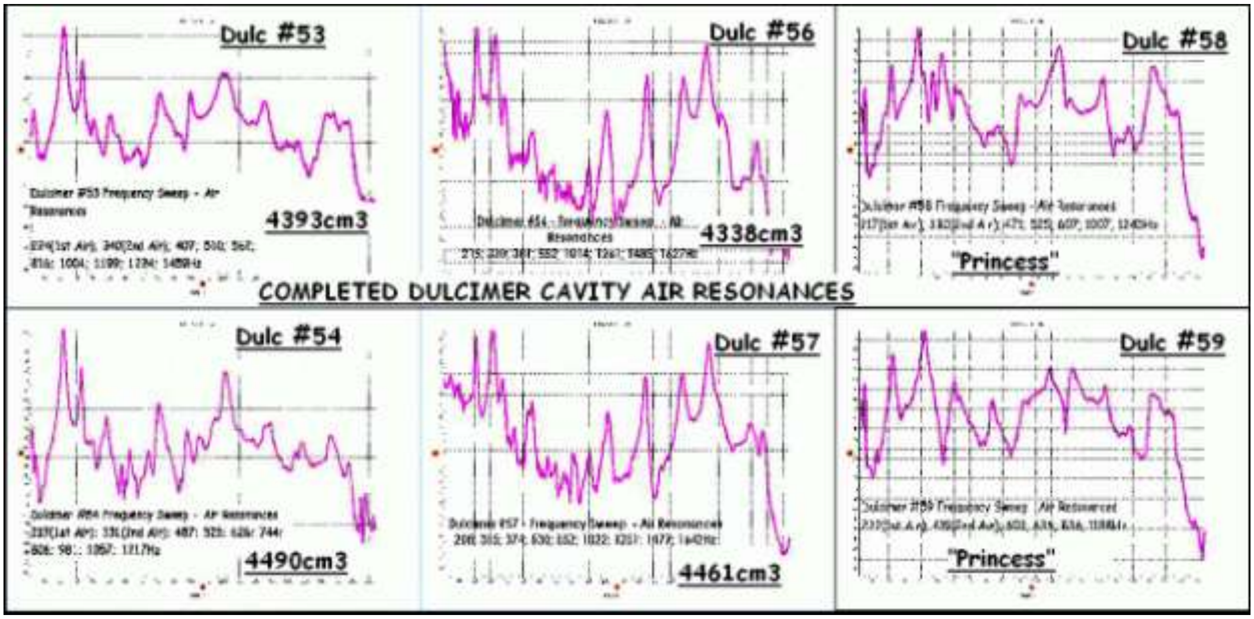

Figure 17.5. Internal air resonance spectra of three pairs of dulcimers

These spectra go from 0Hz to 2100Hz, so the horizontal scale is different to that in Figure 17.4. The air resonances of a box depend on the size and shape of the box, and its stiffness. In these cases, it's interesting that the first four dulcimers (#53 to #57) are almost the exact same shape and size, and made of the same materials. The two Princess dulcimers are very different in shape, and maybe a little smaller in capacity (I didn't measure their volume), and also are made of different materials to each other. So, it would be expected that the first two pairs would have the same air resonance spectra, and that it would be quite different from the Princess dulcimer spectra. If the back and side materials had much of an influence on the air resonances, then the two Princess spectra might be expected to be different from each other. The parameters of the back and side materials and dimensions for the six are provided in Table 17.1.

Table 17.1
Back and Side Parameters

Dulcimer Back and Sides Parameters

Dulc No.	Back &Side Wood	Side Ht (mm)	Side Thickness (mm)	Back Thickness (mm))	Box Capacity (cm3)	Comment
53	Aust. Red Cedar	50	3.1	3	4393	Standard HourGlass
54	Aust. Red Cedar	50	2.7	2.6	4490	Standard HourGlass
56	Aust. Red Cedar	50	2.8	3.2	4338	Standard HourGlass
57	Aust. Red Cedar	51	2.8	3.2	4461	Standard HourGlass
58	Mountain Ash	49	2.4	2.6	-	Lapidus "Princess"
59	Aust. Red Cedar	47	2.7	3.2	-	Lapidus "Princess"

There are some differences in back thickness, side heights and thickness between the 53/54 pair and the 56/57 pair, and in the final box capacities. However, within each pair of dulcimers the air spectra are very similar. If you match up the equivalent peaks in the 53/54 and 56/57 spectra they are also fairly similar between the two pairs, at least in the lower 2/3 of the spectrum (below about 800Hz). I suspect that the detail differences result from the different top/fretboard characteristics between the pairs, and different back stiffnesses resulting from different bracing, which all leads to different air/wood interaction strengths. The air resonances of the Princess pair are quite different to the four hour-glass dulcimers, but similar to each other, even though the body materials were very different. This tells me that it is the shape of the box that most influences the air resonance structure, with the body materials and stiffness differences adding detail, but being of lesser importance. The internal bracing patterns of the three dulcimer pairs is shown in Figure 17.6.

Figure 17.6 Bracing patterns for three dulcimer pairs

Top and Back Vibration Modes

I looked at the way the Princess dulcimers vibrated when vibrated by nearby loudspeakers. Nothing outstandingly different to other dulcimers showed up, and other than the major/minor bouts being reversed, the two dulcimers vibrate in rather similar ways to the other dulcimers I've tested. In particular, the sequence of vibration modes from 1st Air to 1st Bar to 2nd Air was the same as for other dulcimers, and this adds confirmation that these three lowest vibration modes are probably common to all mountain dulcimers (but not to guitars).

The first bar vibration mode of the two dulcimers are shown in Figure 17.7—the whole instrument vibrates like a xylophone bar.

Figure 17.7. First bar vibration mode of two Princess replicas

The frequency of around 250Hz is a little lower than on other dulcimers I've tested and it probably means that the two replicas are a little more flexible. That may be because of the narrow waist. A lower frequency bar mode might tend to make the sound a little mellower. It is interesting to see that the "bar" extends to the top of the arch near where it would be strummed. In other words, the dulcimers are flexing as if the arch wasn't there.

The 2nd air resonance vibration modes are shown in Figure 17.8.

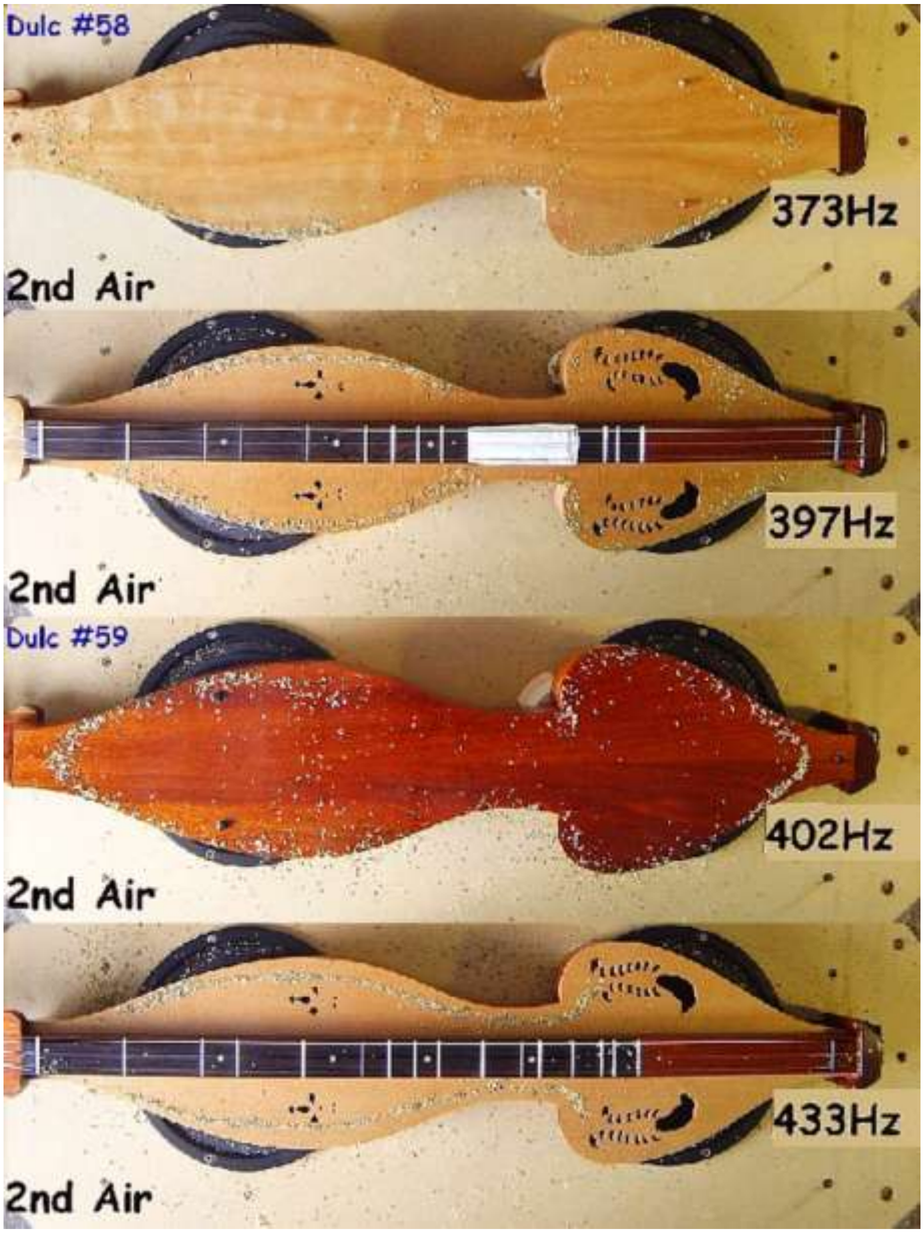

Figure 17.8. Second air vibration modes

As with other dulcimers, the top vibration modes were mostly simple “trampoline” shapes on the “major” bout (nut end of the dulcimer), and were coupled with back vibrations at similar frequencies.

Due to bad planning, the Australian Red Cedar dulcimer had a waist that was 8mm wider than the Mountain Ash instrument. In the picture above, it can be seen that the top vibration on this dulcimer extends across the waist into the Lyrebird (minor) bout, but not in the Mountain Ash dulcimer. I’ve noticed this reluctance to vibrate at that spot on the one other very narrow waist dulcimers I’ve tested. I don’t think this is very significant in the scheme of things, but clearly a very narrow waist modifies how a dulcimer top vibrates.

As with other dulcimers, the backs of these two vibrated at some frequencies in more complex ways than the tops. Figure 17.9 shows a higher vibration mode.

Figure 17.9. A higher vibration mode in one of the Princess replicas.

This must be a wood resonance because there is a resonance in the bridge tap spectrum close to 750Hz for this dulcimer, but not in the air resonance spectrum. It can be seen in Figure 17.10 on the shoulder of a higher peak at about 790Hz.

And as the frequency goes up above about 800Hz, the vibration modes get too complex to distinguish from each other. Some modes do vibrate underneath the strum-arch, as in Figure 17.11. But mostly the arch is treated as if it was not there (vibration-of-the-top-wise).

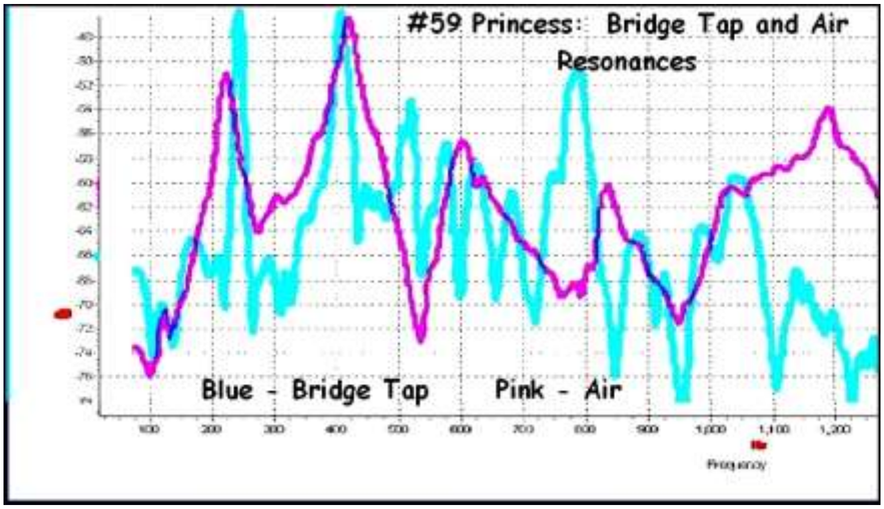

Figure 17.10. Princess replica dulcimer #59 - air and box resonances

Figure 17.11. Vibration under the strum arc

Top/Back Relative Sound Output

In the Princess dulcimers, the tops were 2 to 3 times louder than the backs on the lower fretboard, and about 4 to 5 times louder on the upper fretboard. This is typical of the other dulcimers I have tested, so the unusual shape hasn't conferred any special emphasis to the top over the back or vice versa. Again it may indicate that any general dulcimer shape has the top somewhat louder than the back, and that the difference is mainly in the additional sound coming from the sound holes.

Conclusion

The Joellen Lapidus "Princess" dulcimer has a unique shape and a novel arch over the strum area, but in most respects these two replicas functions in a similar way to more orthodox dulcimers. This is reassuring – the artistic flights of fancy that makers might have from time to time will probably end up producing a work of art that is still a dulcimer in sound and function.

A Different Dulcimer- May 09, 2018

Before we all get too far ahead of ourselves in deciding what the perfect dulcimer is, it might be instructive to consider the following.

Using only parts left over from assembling some furniture purchased from the local IKEA Super Store, I was able to make my own IKEA Dulcimer. No, it wasn't put together with an Allen key – that has already been done (David Beede's Eede Beede octave dulcimer is assembled with an Allen key)[30]. However, there was some acoustically credible packing material supplied in the furniture box (probably specified by one of the many Swedish luthiers moonlighting as IKEA designers, I expect). None of the leftover fasteners from the furniture seemed to fit the packing material, so Titebond was used in the assembly instead, and an old fretboard found lying around was used (not supplied). The honeycomb was hollowed out at the big end, smaller cardboard honeycombs and plates glued together, and the fretboard glued on top. Figure 17.12 shows the result.

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[30] http://www.davidbeede.com/octavedulcimers.htm

Figure 17.12. IKEA dulcimer

It could be a little more scenic perhaps, but at least it was free. And it resulted in an instrument that I like a lot, with a clarity and warmth to the sound that belies its simple construction. It's not particularly loud, but sounds better than some other dulcimers I've made, and others that I've played. In a period when I was away from all my other dulcimers, I was happy to have it with me as my sole musical instrument.

This dulcimer might not be around in a hundred years' time, or even this time next year, but it's OK right now. And by the time it falls apart, I might have purchased some more IKEA furniture.

Is there a message in this? In making mountain dulcimers for fun and pleasure, if all you use is material within arm's reach, you just might get away with it. Keep it light and stiff, and look to the fretboard.

And now, maybe I'll paint this one white and see if I can get it into the IKEA catalog.

Figure 7.13. Side view of IKEA dulcimer

Post Script-August 30th, 2018

I originally started these experiments with mountain dulcimers because I thought they might help me to make better instruments. For reasons I can no longer remember, I had begun to suspect that the top plate of a dulcimer, which many makers call the “sound board”, was not as important in dulcimers as it is in guitars, mandolins or violin class instruments. This led to the no-top dulcimer experiment and to a meeting with guitar luthier, Trevor Gore, who suggested investigating the mountain dulcimer as a vibrating bar. These, in turn, led to the series of experiments that comprise this document.

There was no structured approach to experiment – as an idea came to me, or was suggested by others, I would look into it as best I could, and write a summary for the discussion forum of the *Everything Dulcimer* website. Many other makers contributed comments on the experiment summaries, many of which are edited into the text above, and which help clarify the various results.

One way or another, most parts and aspects of mountain dulcimers were examined – both hour-glass and teardrop shapes, but always full-length fretboards. Still, only the surface has been scratched. Also, much of the experimental results may not apply to more modern configurations where the bridge is attached directly to the top plate. I leave those configurations for others to examine.

A great deal was learned that I did not know before the experiments – mostly about the gross physical character of the instrument and the way it vibrates. Many experiments led me to question the validity of orthodox beliefs about how a mountain dulcimer works and should be constructed, and this often freed me to concentrate less on those areas, in my own building, and more on areas that showed up in experiment as being important to the sound the instrument makes.

Whether this has resulted in “better” dulcimers, I can’t say. What can be said, with some confidence, is that the idea of a “better” dulcimer is itself flawed. A builder might make a dulcimer that he or she likes better than the previous one, however it is almost certain that out in the real world will be a player who ranks them exactly opposite. With my own dulcimers I have observed that even for the ones whose sound I did not like at all, there was a buyer who was looking for just that sound. I’ve had to conclude that there aren’t “better” dulcimers, just “different” dulcimers. The excuse “I couldn’t possibly make a good dulcimer” is not a valid one for not trying.

All of the previous experiments deal with how a mountain dulcimer makes ***sound***. Makers often emphasize the importance of the sound of their instruments, and how they build to get that sound. Yet the quality of construction, the aesthetic appearance of the instrument, the ease of playing, and the instrument’s provenance may be equally as important to a player or buyer as the sound it makes. I leave those aspects of the mountain dulcimer to expert craftsmen and women, artists, music shop instrument-set-up staff, and antique dealers. But ultimately, above all, it is the player who will bring out of any instrument the best of the sounds it can produce.

Appendix

Table A1
Millimeter/Inch Conversion

Millimeter(mm)	Decimal inch (in)	Fraction inch
1	0.039	3/64
2	0.079	5/64
3	0.118	1/8
4	0.157	5/32
5	0.197	13/64
10	0.394	25/64
20	0.787	25/32
30	1.181	1 3/16
50	1.969	1 31/32
100	3.937	3 15/16
1000	39.370	5 29/32

Inch(in)	Millimeters (mm)
.001	0.025
.002	0.051
.003	0.076
.004	0.101
.005	0.127
.06	0.152
.08	0.203
.010	0.254
.020	0.508
.050	1.270
.100	2.540

One millimeter = 0.03937 inch, one inch=25.4 mm
Ten mm = 1 cm

Table A2
Centimeter/Inch Conversion

Centimeters (cm)	Decimal Inches (in)	Fraction Inch
1	0.39	25/64
2	0.79	25/32
3	1.18	1 13/16
4	1.57	1 37/64
5	1.97	1 31/32
10	3.94	3 15/16
20	7.87	7 7/8
30	11.81	11 13/16
50	19.69	19 11/16
100	39.37	39 3/8

Inches (in)	Centimeter (cm)
1	2.54
2	5.08
3	7.62
4	10.16
5	12.70
1	25.40
2	50.80
25	63.50
30	76.20
50	127.00

One centimeter = 0.3937 inches, one inch = 2.54cm

Table A3
Kilogram/Pound Conversion

Kilogram(kg)	Pound(lb)		Pound	Kilogram
1	2.20		1	0.454
2	4.41		2	0.907
3	6.01		3	1.361
4	8.82		4	1.814
5	11.02		5	2.268
10	22.05		10	4.536
20	44.09		20	9.072
25	55.12		25	11.340
30	66.13		30	13.608
50	110.23		50	22.680
100	220.46		100	45.359

I kilogram = 2.2046 pounds, one pound = 0.4536 kilograms
One kilogram = 1000 grams
One pound = 16 ounces

Table A4
Gram/Ounce Conversion

Grams (gm)	Ounces (oz)		Ounces	Grams
10	0.353		1	28.35
20	0.705		2	56.7
25	0.881		3	85.05
30	1.058		4	113.4
50	1.764		5	141.75
100	3.527		10	283.49
200	7.055		2	566.99
500	17.637		25	708.74
1000	35.274		30	850.49
1500	52.911		50	1417.49
2000	70.548		100	2834.95

One gram = 0.353 ounces, one ounce = 28.35 grams

Index[31]

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[31] listings indicating figures or tables are shown in bold italics