The Resonator Banjo Resonator, part 1: Overall Loudness

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(Dated: May 9, 2015)

Among banjos, the resonator banjo is loud, and the resonator back likely maximizes the loudness contributed by its sound hole. Using three different methods of sound production, evaluated using three different criteria of loudness, it is found that the common alternatives, e.g., open back or flat plate back, are equally loud. The *total* banjo sound volume in essentially indistinguishable among these cases.

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I. INTRODUCTION

Many banjo players have strong opinions on the role of the resonator back. Only, they just don't all agree. As part of measuring and understanding the volume of sound produced by different sound holes,[2] I did comparisons with a particular resonator banjo (an old Deering Sierra). In particular, the sound with the standard resonator was compared to three alternatives with that resonator removed. The "sound" was different for each, but simple criteria for what constitutes overall loudness yielded no appreciable difference. I used three different ways to "play" the banjo, each way with its own criterion for loudness.

Some will say, "I knew that!" Others will say, "That's just wrong. Resonator banjos **ARE** louder." And others will add, "The belly behind an open back certainly absorbs more sound energy than the wood of a resonator. So the resonator must be louder." I conclude with a discussion of why the result is both surprising and to be expected.

II. LOUDNESS OF A RESONATOR *VS* ALTERNATIVE BACKS

We can increase the loudness of a recorded sound by turning up the "loudness" or "volume" knob. If the signal is stored as a series of voltages, then that knob increases each voltage by the same factor and makes the output louder. Perceived loudness is roughly a measure of detected acoustic power (energy per time) on a logarithmic scale. The judgment of comparative loudness of fundamentally different signals is more complex. In the end, frequency, duration, timbre, and context all enter into that perception.

To see what role, if any, the standard resonator back (FIG. 1) has on a banjo's loudness, I compared a resonator back to three alternatives, all on the same banjo, using three different methods of exciting the banjo vibration. After describing the details of the experiment, I present the resulting measurements. Anyone can draw their own conclusion, but there really is no clear evidence of the resonator making the overall sound substantially louder.

Suspicious of graphs, computer analysis, and artificial situations? Click here for a sound file sample with open back and resonator back, on the same banjo, with the same set-up (or go to http://www.its.caltech.edu/∼politzer/F-and-A.mp3). The recording quality is not the best, but that is a result of microphone placement chosen specifically to make a fair comparison. Keep this sound in mind. A full explanation of the recording, which should convince the skeptics, is in sections VII and VIII.

III. THE THREE ALTERNATE BACKS

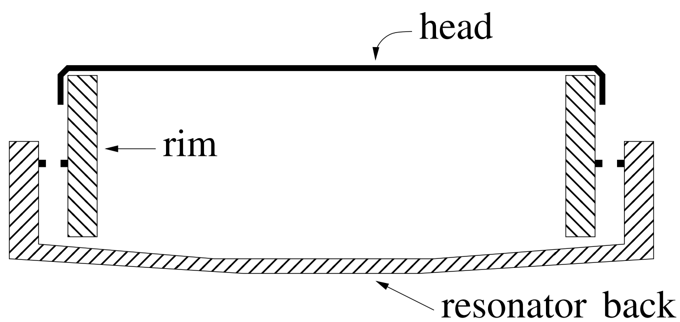

FIG. 1. Standard resonator back geometry

The first alternative back is the “synthetic belly.” That’s what’s shown in the title page photo. It was originally made for a previous project,[3] and its purpose is to behave like the player’s belly when playing an open-back banjo. The virtue of the synthetic belly is that its position can be controlled and held fixed over a variety of measurements. It has a layer of closed-cell foam, which is an outstanding sound absorber; a layer of cork, whose reflection coefficient is comparable to the human body; and a layer of Hawaiian shirt (because that’s how I often play). I previously chose a gap between the belly and the rim to best approximate the sound of real open-back playing.[3] In particular, the belly is angled, with a spacing of $3/8''$ at its maximum (provided by three red rubber washers, visible in the photo on the first page towards the lower left corner) and touching the rim at the point diametrically opposite.

The other two backs are flat, $1/2''$ thick plywood disks. In one case, the disk is mounted parallel to the rim bottom at a separation of $3/16''$. In the second case, the disk is angled, like the belly, going from zero to $3/8''$.

The diameters of all three of these backs match the outer diameter of the rim.

IV. BANJO & MICROPHONE POSITION

Recording the sound of a banjo is an acknowledged challenge. Placing a microphone nearby emphasizes the direct sound over the reflections for walls, ceiling, floor, furniture, etc. However, the near sound field is highly directional and in a frequency-dependent way — rather more so than other instruments.[4] When the mic is placed further away, the room sound becomes apparent. But even that sound, as recorded at a particular place, is sensitive to the placement and orientation of the banjo in the room.

The four different backs clearly produce sound with different directional structure. The standard resonator projects forward. The others project sideways — isotropically for the parallel disk but with a preferred direction for the angled backs.

This is what I did to get a general idea of the overall sound: The banjo was placed on a stand in the middle of my office at work: $14' \times 17' \times 10'$, carpeted floor, acoustic tile ceiling, plaster and concrete walls, and lots of books, papers, and junk. I had a $2' \times 3'$ piece of plywood that I placed halfway between the banjo and the door, at the banjo's height. The door was ajar, open only $16''$. And, finally, the microphone was placed down the hall, $8'$ from the doorway.

I tried different orientations of the banjo, and the sounds were, indeed, slightly different. I present here just one orientation, which is an attempt to put the various radiation patterns on equal footing with respect to the microphone. In particular, the head was at 45^o relative to the direction to the door. That way, the various sound holes were also oriented at 45^o relative to the direction to the door. (That's the "45" in the table and graphs that follow.)

V. SPEAKER-DRIVEN FREQUENCY SWEEPS

For the first comparisons, I mounted a "full-range" $2''$ speaker inside the pot. It was driven by a signal generator, programmed to sweep slowly from 200 to 5000 Hz on a logarithmic scale (of frequency *vs* time). The strings were all damped.

The resulting spectra as computed by Audacity® are displayed in FIG.s 2 and 3 as decibels (vertical) *versus* frequency in Hz (horizontal). The data is divided into 200 to 900 Hz in FIG. 2 and 900 to 5000 Hz in FIG. 3. In the "legend," "res" is the resonator back, "belly" is the synthetic belly, and "parallel" and "angled" are the two mountings of the flat

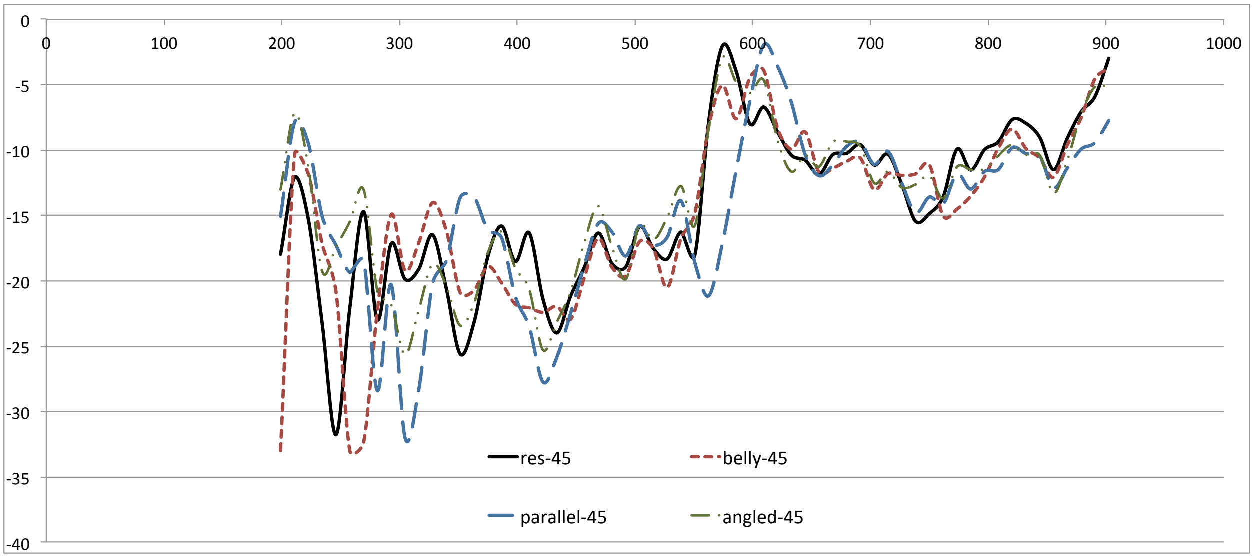

FIG. 2. spectra of frequency sweeps in dB, 200 to 900 Hz; four different backs

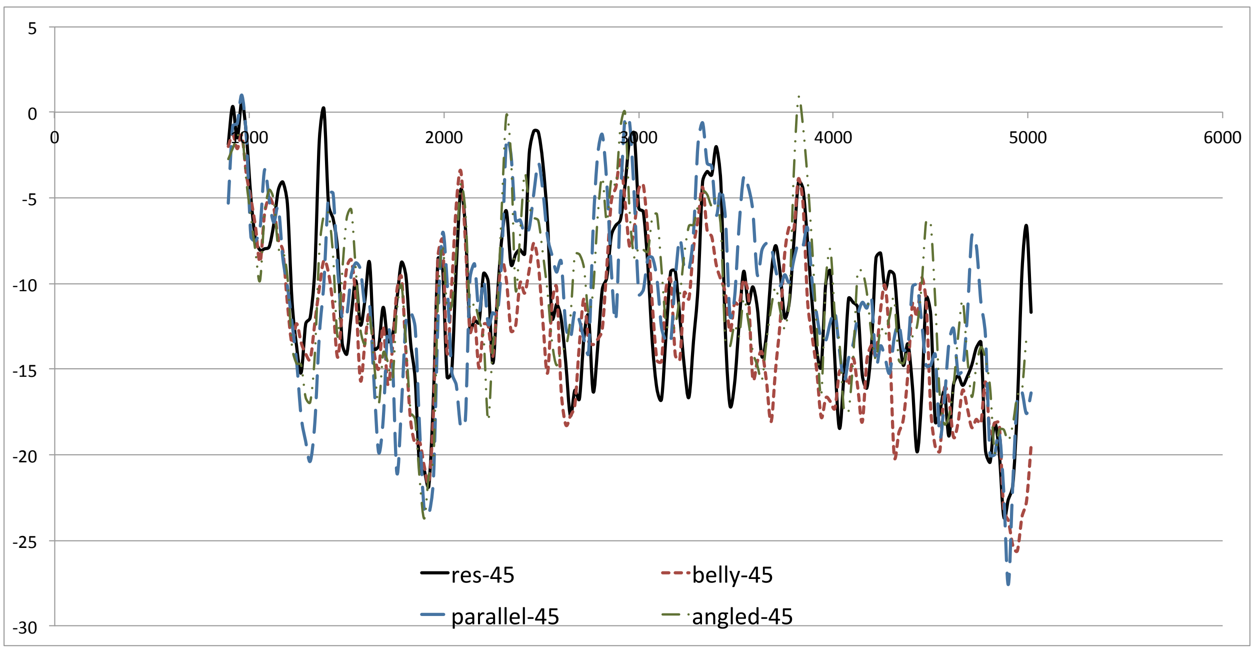

FIG. 3. spectra of frequency sweeps in dB, 900 to 5000 Hz; four different backs

plywood disk. The traces are certainly different, but "res" is not uniformly louder.

{Rae and Rossing[5] identified the 2000 to 4000 Hz region as "the second formant" of the bluegrass banjo — a region of enhanced response relative to the general, steady decrease with frequency characteristic of the plucked string itself. No particular physics story has yet been attached to it, but the present observations show that it is not a result specific to the standard resonator back.}

VI. SINGLE STRING PLUCKS

For another comparison, I recorded the sound of individual plucked strings. The banjo, microphone, door, etc. were all positioned as for the speaker-driven sweeps. With the speaker removed, I plucked the 1st and 4th strings, with all other strings allowed to ring out. The challenge was the reproducibility of the plucks. Repeating the plucks at about one per second, the peak voltages in the microphone record varied by less than ±5%. I could continue that indefinitely. (I used the plastic fork method.[6]) However, on stopping and starting up another sequence after a break, the average of the new sequence might be some ±12% different from the first. In terms of sound, that ±12% is ±1dB, something not normally considered to be perceptible.

I tabulated the average signal peaks for a sequence of plucks, for each back, and for three orientations. The results are displayed in the rather crude FIG. 4.

					FORK		PLUCKS					
	HEAD 1ST	+/-	HEAD 4TH	+/-	45 degrees 1ST	+/-	45 degrees 4TH	+/-	EDGE 1ST	+/-	EDGE 4TH	+/-
RESONATOR 1	205	3	203	5	182	4	197	9	200	5	126	4
RESONATOR 2	207	4	185	4	191	4	206	5	179	8	145	3
RESONATOR 3	198	4	185	6	165	8	193	3	149	8	125	2
RESONATOR AVG	203	4	191	9	179	11	199	6	176	21	132	9
BELLY	199	2	183	5	145	5	159	5	113	5	130	2
3/8 ANGLED FLAT	242	4	247	9	160	7	199	5	185	4	165	5
3/16 PARALLEL FLAT	214	2	201	6	188	6	191	5	175	5	134	3

FIG. 4. fork plucks: 1st and 4th string; resonator, synthetic belly, flat plate (parallel and angled)

The strings are identified in the column labels as 1st or 4th. The orientations are also identified in the column labels as HEAD, meaning head facing the door; 45 degrees, i.e., rotated relative to HEAD; and EDGE, meaning the edge of the head toward the door. The first three rows are three separate runs for the standard resonator back, followed by the average of the three. The last three rows are for the synthetic BELLY and the two ways to mount the FLAT disk back. The numbers are the maximum measured voltage in millivolts per pluck. Their relative sizes are what's important. And the numbers are linear measures of pressure at the microphone. The ± numbers to the right of each measurement are the range observed in a sequence of ten plucks. When comparing entries for different backs with the same orientation, 3 dB would certainly have been perceptible and would have been a factor of 2 in power or a difference of 40% in voltage (e.g., 80 out of 200). But that doesn't arise in the comparisons. As with FIG.s 2 and 3, you can draw your own conclusion from FIG. 4, as well. But I do not see any convincing evidence for "resonator ⇒ louder."

VII. RING THE BANJO

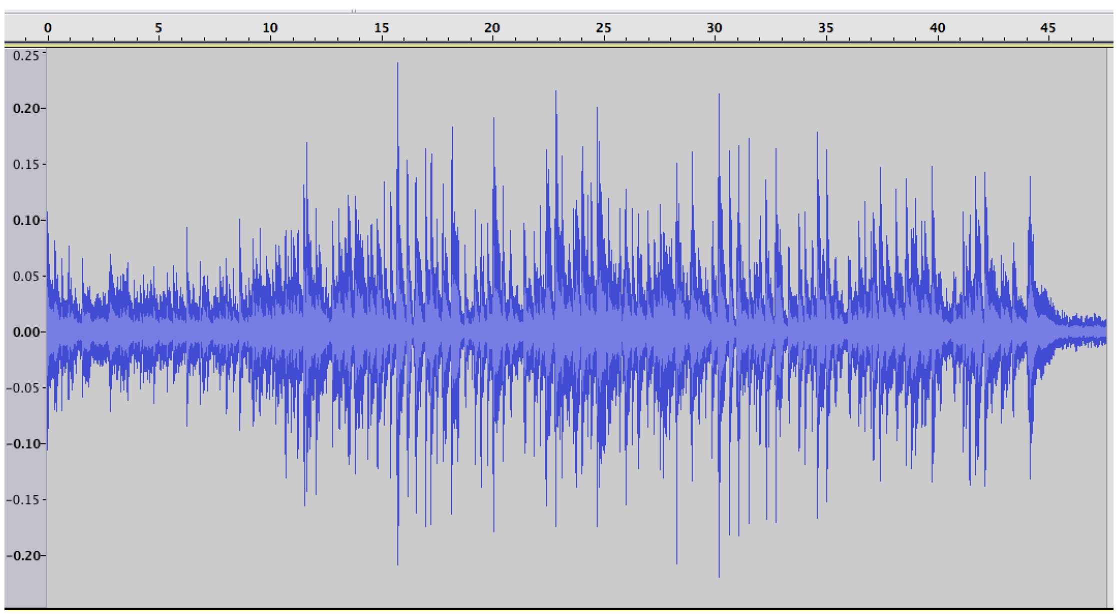

FIG. 5. Sound sample, half open back and half resonator back, (linear) amplitude *vs* time

Here, again, is the sound sample offered at the outset — or go to http://www.its.caltech.edu/∼politzer/F-and-A.mp3. It features the same banjo with and without its resonator. The recording quality is not great because, for the same reasons as discussed above, I recorded in the same way: from the middle of my room, sitting, turned 45^o from facing the door, with the $2' \times 3'$ board in place, through a mostly closed doorway, with the microphone eight feet down the hall. The music selection and style was consciously neither bluegrass nor old-time. (It's my take, more or less, on Mississippi John Hurt's *Frankie & Albert*.) I played twice through with both banjo configurations and spliced the first half of one to the second half of the other.

FIG. 5 displays the waveform of microphone voltage (on a **linear** scale *versus* time) for the half-and-half spliced version. From where I was sitting (as the player) there was a perceptible difference, although not in what I would call loudness. Relative to the open-back version, the resonator back "cracked," to use a phrase from the bluegrass banjo world. That distinction likely lies in the highest frequencies, but it seems to have diminished in the long distance and multiple reflections required to get to the microphone.

Does the sound get louder or softer in the middle for the second time around? Which banjo back is which?[7]

VIII. WHAT'S GOING ON?

It is key that I compared the same banjo with different backs. Typical resonator banjos and open-back banjos have many other differences — and they're usually played differently. Bluegrass banjos have a metal tone ring (over which the drum head is stretched) that weighs $2\frac{1}{2}$ to $3\frac{1}{2}$ pounds. In contrast, an open-back banjo might have no metal in the analogous place, a layer of sheet metal over wood, or a metal ring weighing perhaps $2\frac{1}{2}$ to 3 ounces (e.g., a $\frac{1}{4}''$ diameter rolled rod). The greater inertia of the heavier tone ring increases the ratio of sound production by the head to dissipation in the rim.

To be sure, the resonator wood absorbs much less and reflects much more sound than a belly, real or synthetic. But, if that difference in sound absorption is a very small part of the total vibrational energy budget, then the total sound production need not change perceptibly just because of that particular extra dissipation. Although I do not have an explicit, direct measure, I imagine that most of the banjo's total sound, as measured at a reasonable distance, is generated by the vibrations of the head and not by the flow in and out of the sound hole. That's what makes banjos so loud compared to other stringed instruments.

Also, the sound holes of all of the examples in the comparisons have similar areas, perimeters, and geometries. They are all essentially $10''$ diameter rings. Furthermore, the

Helmholtz/Rayleigh analysis[2] is relevant to musical sound holes when all the air is going in or all the air is going out. That is the case only for the two lowest frequency modes of the banjo pot assembly (the combinations of the Helmholtz resonance and the lowest drum head resonance). At higher frequencies, there will simultaneously be some air going in and some going out, and that's a much harder problem in terms of flow *versus* pressure.

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[1] D. Politzer, *Sound Hole Sound*, HDP: 15 – 4, http://www.its.caltech.edu/∼politzer

[2] D. Politzer, *The Open Back of the Open-Back Banjo*, HDP: 13 – 02

[3] Banjo joke: Q: Where do you recommend placing the mic to record banjo? A: About two miles away works best for me.)

[4] J. Rae, *Banjo*, in *The Science of String Instruments*, T. Rossing, ed., ch. 5 (Springer, New York, 2010); also Banjo Newsletter # 373, November 2004

[5] D. Politzer, *Banjo Bridge Mutes*, p. 20, HDP: 15 – 01

[6] The resonator is on for the first half and off for the second.