Harpsichord & fortepiano

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AN APPROACH TO RECREATING HISTORICAL SOUND: PART II

by Paul Y. Irvin

The first half of this article was published in our last edition. While it posed many problems, this half seeks solutions.

SOUND CONSIDERATIONS

Considering the harpsichord's major role over several centuries of Western European music, I assume that it had reasonably accessible, attractive characteristics that did not depend on education for it to be generally accepted, anymore than people need training to accept the sound of a piano now. It is difficult to imagine why any musical instrument would become popular if it had a sound that was found to be generally unappealing to most listeners,[1] and even to some conductors.[2] Perversity is a well-known human trait, but we must assume that the sounds historical harpsichords produced for four hundred years were found to be generally appealing to their intended audience. There are obviously people now who find the replica harpsichords' sound attractive, but my overall impression is that *if the same percentage of people I encounter now who do not like the sound of the harpsichord had existed historically, the instrument would have had a much shorter history.* I do not believe that this possible difference in apparent level of attractiveness of the replica harpsichord, or the differences in the way it is utilised (discussed earlier), can be explained by any 300-year change in our aural perceptions, or even by any significant cultural change, especially in light of the general level of public acceptance of reproductions of other types of instruments from the same historical period (except perhaps by players of the modern versions).

If we accept my earlier observation that it is natural for players to get the most musical use from their instruments by responding to what those instruments have to offer, and if we acknowledge that modern harpsichord players are using their instruments in ways that make good sense given the sounds they are encountering, I believe we come to an explanation that may explain the previously discussed discrepancy in harpsichord playing: *The reason that harpsichords are being exploited differently now than they were historically is that the sounds we are hearing from most modern harpsichords (and many restored antiques) are not similar enough to the sounds heard historically.* This different sound may also explain the limited enthusiasm that I perceive the public has for the harpsichord. Just as we have accepted non-historical rectangular dampers for approximately the last hundred years, those of us who are involved with harpsichords have also accepted the present harpsichord sound that we have heard all our lives, although there is no historical evidence (of which I am aware) that confirms its basic nature. There does appear to be, however, evidence that conflicts with the modern harpsichord sound and its consequences.

In my assessment, the sound qualities in need of significant improvement in order to achieve a return to historical usage can be understood by a) listening to the tonal qualities and especially the speech-production characteristics of other instruments (including the human voice) played with the harpsichord historically, and b) by analyzing the general sound qualities appreciated in good musical instruments of any era, both informally through the reactions of listeners and more formally by the findings of researchers. The resulting reference qualities can also be effectively applied to analyzing clavichord and fortepiano sound, but here they will be applied to the harpsichord.

Family Sound

One can currently listen to modern orchestras, baroque orchestras, classical orchestras, and occasionally even a romantic orchestra, all equipped with instruments suitable for their specific period of repertoire. Generally, modern violins (for example) would not attempt to play in a baroque orchestra, nor baroque violins in a modern orchestra: and not just because the dates are inappropriate. The Baroque instruments share "family" sound characteristics that allow them to blend and contrast with each other in a musically versatile way. Modern instruments share a different set of characteristics. This

factor was illustrated rather well by Anne Chatoney Shreffler[3] when she compared the spectral characteristics of a baroque flute and a modern flute, both when single notes were played up and down their ranges and when they were being played by Franz Brüggen and Jean-Pierre Rampal, respectively, when performing a J.S. Bach sarabande. Both types of flute play approximately a three-octave range, which we will, for now, designate as Flute Octaves 1, 2, and 3. On the baroque flute, a note produces a relatively evenly distributed set of three octaves of partials which rise and descend along with the fundamental as notes are played up and down its range, resulting in amplifying and reinforcing the movement of the notes. In contrast, no matter in which octave the modern flute is playing, the strength of any note's partials lies in Octaves 3 and 4, resulting in a kind of sonic homogeneity across its range and a reduced ability to reinforce the movement of the musical line. As a result of these sonic differences, the baroque flute's low notes give the impression of sounding lower than the modern flute's, and its high notes higher. A similar sonic difference can be heard when comparing baroque string, brass and wind instruments to their modern counterparts.

These instrument "family" sound characteristics developed along with the evolving music and changing performance venues. Different kinds of sounds were developed and used for various approaches to the solo literature, continuo playing, small ensembles, salons, opera houses, concert halls, etc.

Most current harpsichords I have heard, however, do not share many qualities of tone or speech production with the strings, woodwinds, brasses, or voices with which they play. They often do have a similarity to the modern flute mentioned above, in as much as no matter in which octave, or register, the harpsichord is playing, *its notes generate a substantial number and strength of high partials.* Indeed, about the only instruments that normally produce a similar prominence of high partials are instruments like the celeste, cymbal and triangle, which also cut through the sounds of other instruments very well, but whose intense sound is not one that many people would choose to listen to for a sustained period.[4,5] Ironically, while projecting the presence of a harpsichord perhaps too well, this extensive range of closely-spaced high frequencies also *has the ability to obscure the tones of more musical interest* through an auditory phenomenon known as "masking" which occurs in the basilar membrane of the ear.[6]

It is the excessive abundance of strong high partials that causes problems for most harpsichords whether they are played alone, as continuo, with a small ensemble, or with a larger group of instruments. Alone, there is no relief from the very high overtones, even when low notes are played. Played with other instruments, these high overtones cut through the sounds of other instruments, making it difficult to create a blended sound, whether for continuo, accompaniment, or concerto.

High Quality Musical Sound

Much attention has been paid to the point along the string where a harpsichord plucks. This plucking point determines a basic character of the sound that can be represented graphically by its spectrum. The spectrum presents the relative strengths of the various frequencies which an instrument or voice produces. The sounds of different plucking points can range from the fluty, round sound of a muselar virginal plucking near the centre of a string, to the forward, nasal sound of an English lute register plucking very close to the string's end. With some experience, these spectral qualities are often understood subjectively and can be useful to describe differences between harpsichords, or between their different registers.

There is additional useful information contained in spectra in the form of the relative strengths of the fundamental and overtones making up the various notes produced by an instrument or voice. In 1877 the sound pioneer Hermann Helmholtz formulated general rules concerning tone quality based on spectra, which still hold up today. Two of them are particularly pertinent to the harpsichord sound discussed above: "When partial tones higher than the sixth or seventh are very distinct, the quality of tone is cutting and rough", and, "When the prime tone [i.e., fundamental] predominates the quality of tone is rich; but when the prime tone is not sufficiently superior in strength to the upper partials, the quality of tone is poor."[7] The reason for this assessed "roughness" can be easily seen when viewing a note's harmonic series of partial frequencies. For instance, the first six partials of bass C are C, c, g, c^1, e^1 and g^1 which all are pleasant intervals and consonant with the c frequency. However, beyond those the next partial is a very low $b\flat^1$, followed by c^2, d^2, e^2, very sharp f^2, g^2, very flat a^2, very low $b\flat^2$, b^2, c^3. Six of these next ten partials are dissonant to the fundamental. From the fifteenth partial up they become less than a semitone apart, forming a series of dissonant frequencies which produces

a sound effect that Helmholtz referred to as tinkling. He also observed that when two or more notes with a large number of pronounced partials are produced together the increase in harshness "renders it difficult for the hearer to follow a complicated arrangement of parts in a musical composition."[8] I believe that this phenomenon is evident in many harpsichords.

The spectrum is part of what we perceive as "tone", but our ears hear in more than the average frequency strengths that these spectra reveal. They are sensitive to much more information than is contained in such static spectral analyses. In fact, such an analysis usually does not provide sufficient information to distinguish a high quality instrument from a poor one. It is primarily other sonic factors that enable us to recognize the sound of different instruments,[9] and to distinguish what we do and do not find appealing.

Changing the place on a string where a good harp is plucked will not change it into a bad harp, or a bad one into a good one: only the spectral character of the sound will change. The focus of the further discussion will not be so much on the static qualities of the sound, but primarily its dynamic qualities – how it begins, develops and dies away. It is these aspects of a how a sound "speaks" that give it life, make it interesting to listen to, and, indeed, largely determine its musicality. *In most musical fields, the hearer expects a fine musical instrument to produce a stable and clear voice that starts its tones cleanly and promptly.*

Proposed Changes

I can think of no reason why the sound of the harpsichord should be an exception to the recognized qualities of a fine musical instrument mentioned above. So, in analyzing harpsichord sound with these musical qualities in mind, I believe that the areas needing attention to obtain a good musical, and probably historical, sound are:

a) *A more immediately focused tone,* with less time and energy spent on how the sound is initiated, i.e., less pluck and more musical tone. Most of the sound of the pluck is not musically useful. A good violin, flute or oboe does not make the listener aware that horsehair is being scraped over a string, air is being blown across an opening in a tube, or reeds are buzzing against each other. Similarly, the harpsichord's pluck should just be the means of starting the tone, and should not draw attention to itself.

b) the initial transient sound should seamlessly transform into *an aftersound well related to the initial sound.* Most harpsichords have two rather distinct parts to their plucked tone (producing an "ow" sound compared to an "ah"), and the persistent and obvious timing of the transition from one to the other can limit or even counteract the player's intentions. One significant factor in this effect is the frictional damping by the air of high frequency components of the very thin harpsichord strings that causes them to die away much more rapidly than the lower partials, producing a change in tone colour and an impression of a very short decay. When strong and numerous higher partials are present in a particular harpsichord's sound this "ow" effect can be quite marked. When more of the pluck's energy is directed to exciting the lower partials,[10] fewer and weaker high partials are present and this colour change and impression of short sustain is much less pronounced. Other factors also contribute to this change of tonal colour and short sustain, actual and apparent.[11]

c) *An overtone structure that distributes most of its strength in the first half-dozen partials* so as to emphasise the movement of the musical line through the different registers, as in the earlier example of the baroque flute. The reduction of excessively strong and numerous high partials will also reduce the shrillness, tuning instability and clashing problems that are often encountered. Too many harpsichords I have seen cannot produce the strength of low frequencies that a plucked cello string elicits despite their having a significantly larger soundboard area and enclosed air volume than that of a cello body. Different amounts and strengths of overtones are desirable in different areas of the keyboard range to give clarity, and to distinguish the various registers of the compass, but if similar strong high partials are pervasive everywhere, then all the notes up and down the keyboard start to sound too much alike, their pitch clarity is reduced, and registral differences are diminished. There seems to be a fairly widespread assumption that harpsichord sound quality is primarily the result of the particular characteristics of the "box". Yet small changes to the setup of two seemingly identical violins, for instance, can result in significant differences in sound quality. The harpsichord is even more complex, in structure and mechanics.

d) *Sufficient sustain to allow a wide possibility of phrasing.* Bowed and blown instruments have it easy in this regard, but finger-plucked

instruments like guitars, lutes, harps, theorbos, etc., must have enough sustain to play convincingly the music typically written for them, in order to be considered good instruments. A full, sustaining bass all the way through to a "singing" treble is useful for much harpsichord music. Unfortunately too many harpsichords with a too short sustain require as much imagination as sound for the listener to "hear" the music.

e) *A return to the historical style of damper,* at least in historically derived harpsichords.

Please note that the first four changes proposed above do not involve complete addition or subtraction of a quality that did or did not exist in a particular harpsichord's sound, but involve degrees of change to the amounts and the proportions of the various qualities. The degree of change proposed here, however, is often more than most people have come to expect to be possible, and to achieve this it necessitates a closer investigation and control of energy (routing and losses) in the harpsichord sound system.

Consequences

When a fuller, more focused, immediate tone with more sustain and a well planned overtone structure is achieved in a harpsichord, as found in the design of other good musical instruments, then all the registers will speak with a clearer, cleaner speech, to the effect that,

1. The overall sound of the harpsichord will have *much less "jangle"* (especially noticeable in rapid playing), allowing it to have more in common with the sound character of other types of instruments, enabling it to blend better in a group rather than always sticking out no matter how few registers are playing. A harpsichord combined with a gamba, cello, or bassoon will actually sound like one continuo unit rather than two very different instruments playing at the same time.

2. Adding and subtracting registers while playing will give more of a sense of *creating a new musical sound,* as with an organ, and less of a sense that the amount of jangle changed,

3. The decrease in excess high partials will make *slight mistunings much less obvious* both because there will now be less high energy there to clash, and because with fewer high overtones present, there will be fewer out-of-tune relationships that no action can correct.[12]

4. The 4′ will not scream or clash, and *can be voiced more fully* (which causes the soundboard to produce proportionately more fundamental and fewer overtones), and it can be used as a solo voice, as with the organ. Additionally, it will now greatly improve the impression of increased loudness *when the 4′ is added to the 8′ sound because of the higher partials that the 8′ gains. This increase in apparent* loudness is much greater than can be accomplished by simply adding another 8′ to the first 8′.[13] Also, with historic dampers on the harpsichord, when the lower 8′ is now turned off to play the 4′ solo, the undamped strings will vibrate sympathetically, *creating a 4′ sound more resonant than possible with modern flag dampers.*

5. The front/upper 8′ sound will no longer be too forward in sound, but well-articulated, with a wide range of possible playing touches providing different nuances to the phrasing. All of this will make it a very useful solo voice. Now able to play at fuller strength, *the front/upper 8′ sound will be more useful played against various registrations of the lower manual.* If the front/upper 8′ is voiced while using the lower manual keys through the coupler to give a touch that is similar to the lower/back 8′, then when that register is played through the different geometry of the upper manual keys, the upper manual will give a stronger touch, better matched to the touch of the lower manual's use of multiple registers.

6. The back/lower 8′ sound will still have a mellower timbre compared to the front 8′, but will have fewer articulation possibilities than the front 8′ will now exhibit, leaving it somewhat less useful as a solo voice and more appropriately placed for its historical use on the lower manual (a "la" attack compared to the "ta" attack of the front/upper 8′).

7. With the front 8′ and the 4′ (and back 8′ also) having a more musical sound they can be voiced more fully, providing the whole harpsichord with stronger fundamental and lower overtones for more fullness, with the possibility of *a wider dynamic range and more total output,* and making the harpsichord more useful for a wider range of applications. *The reason that most harpsichords cannot be voiced more strongly than they usually are is that doing so would increase the harshness of the sound.* When the factors contributing to the harshness are controlled, the note can be louder and remain smooth sounding. Due to the plucking position

of the front/upper 8′, for the same plectra force, it will naturally have a stronger voice than will the back/lower 8′, a factor which reveals more of the historical reason/wisdom in choosing the front 8′ to stand alone on its own keyboard.

8. *The stronger fundamental-biased sound will not be so quickly muffled by a buff stop,* giving more of a lute like or harp like sound, a quality which definitely has more musical application than a pizzicato sounding buff stop.[14]

9. If historical dampers are used on all these smoother sounding registers, the lower 8′ register lever will now have much more use through its role of *adding and subtracting resonance to the instrument* by increasing or reducing the number of strings vibrating sympathetically: the upper 8′ can be played solo as usual or it can be played solo with the lower manual stops turned off allowing a more sustaining sound; and it can be played (on doubles with couplers) either on the upper manual or the lower manual for different touches. The upper 8′ can also be played through the lower manual with the 4′ turned on and the lower 8′ off, giving a lusher, less dry sound than the usual lower 8′ and 4′ combination. If a buff stop is present on the upper 8′, then this can also be played two ways: with the lower 8′ and 4′ disengaged for more resonance, or with them engaged and damping for a drier sound. Thus, the historical dampers provide the upper manual with at least three different colours (plus two more if there is a buff stop on the upper 8′), a significant increase over using flag dampers. Some historical French doubles were even equipped with a stop lever for the upper 8′ so that it could be turned off to allow sympathetic vibration for the lower 8′ and/or 4′.[15]

10. A full, strong sounding 8′ often cannot be as completely damped with a single damper as can a weaker 8′ sound. A single damper can easily come down on a string at a particular point that is not moving up and down for an otherwise strongly vibrating frequency. In such cases that frequency will continue to ring after the string's other frequencies have been silenced by the damper. *A second damper on the jack will damp the frequencies that the single damper misses, creating a more immediate and complete silencing of a note upon key release.* By sharing the greater workload, two dampers will also last longer than a single one.

11. *The historically shaped damper will provide both better damping and more sustain and resonance than a modern flag damper will.* An instrument with undamped strings will also provide a longer sustain for those strings that are being played, through the interaction of "string coupling", a phenomenon which can also help pull slightly mistuned strings together in pitch.[16]

12. *A longer sustained tone,* undivided by a pronounced pluck or tonal change, *will give the opportunity for a wider variety of phrasing.* If there is more sustain than needed one just releases the note. If there's not enough sustain, the player has no options, except perhaps to play faster. When enough sustain is available, holding a key down for four beats, as the music sometimes requires, produces more than a finger exercise.

The sonic qualities outlined above will provide a harpsichord sound which:
1. enables, and even encourages, players to use a replica or restored antique harpsichord in a manner more consistent with the historical and physical evidence,
2. has a better ability to blend with other instruments as a single continuo unit,
3. permits the harpsichord to accompany solo instruments such as Baroque flutes or violins, and small ensembles, with a sound which supports rather than intrudes with excessive, unrelated brightness,
4. provides listeners, and players, with fullness, body and depth —attributes appealing in any era.

First Things First

There have always been very interconnected relationships among music, instruments, composers, players, makers, and audience. Only very few people will wish for a sound they have never heard, but any player or composer who has once heard a sound that is more useful for their music making will not want to go back to lesser resources. Makers who survive are, as always, receptive both to the players and to present and changing musical needs. Listeners, as always, vote with their feet. Upon hearing a harpsichord's sound they are either engaged by what they hear or they are not: theoretical and historical explanations do not really change their gut reaction.

The Ruckers were not concerned by the fact that virtually every one of their instruments differed in various dimensions from every other one. If it had been important they would have changed their working methods to control those dimensions more carefully. Every antique Taskin harpsichord of which I am aware is significantly different from every other one. Many of the

differences might be reasonably explained, but no instrument can be predicted from the instrument that was built before it. *The historical makers somehow achieved a recognizable and celebrated sound despite the apparent physical differences, by paying more attention to details that affect the sound rather than the appearance.*

Just as musicians try to exploit all the potential in their chosen instrument to achieve their musical intention, so instrument makers of any era (usually in close dialog with players) try to exploit all the potential within a particular instrument type to achieve the most musical ability for its purpose. Focusing on the primary elements of producing sound (mass, stiffness and damping[17]),on what type of sound is needed for a particular purpose, on the consequences of various types of touch, on exploring which elements control various speech qualities, on searching for where energy is lost and how it is directed[18], and on discovering what potential exists to be exploited in the harpsichord format, brings us closer to recreating the empirical attitudes that originally created and developed the historical instruments being copied. This approach more closely follows the historical direction of designing harpsichords that started with the strings and moved outwards (form following from function), while most copying starts from the outside and moves in (function assumed from form). Focusing on these sound concerns also offers the possibility of revealing additional insights to further direct and stimulate the continuing decades long study of early keyboard instruments, and the further development of designs to satisfy historic as well as modern applications. The fact that there are many fine, extant antique harpsichords of many different designs indicates that there is more than one way to make a good instrument. Doubtless some very good designs have perished over the centuries, while other designs have yet to be discovered.

Making models of food that are inedible has a generally accepted utility for restaurant display purposes. Such copying, however, is not good enough for the chef who wants to recreate a dish he has tasted; first s/he must start with the taste, and then perhaps texture and appearance. Similarly, the first concern in functionally copying a musical instrument would seem to be to focus first on the reason the original was built: the type of sound to fulfil its musical role (given the properties present in the design), and then perhaps the mechanics and the appearance.

Building an enjoyable musical sound that encourages players to use the harpsichord in the same way it was used historically is a better criterion for creating a successful copy than any effort to reproduce dimensional (let alone decorative) characteristics. In aiming to create a sound that fulfils a known historical function, we have a much better chance of fulfilling the expectation that is inherent in the act of copying: that of recreating historical sound.

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1 as evidenced by the sparse attendance at harpsichord recitals, and its rarity on classical radio stations. For years a major classical radio station in Chicago has played 24 hours of J.S. Bach's music on his birthday, with almost all of his keyboard music played on organ or piano.

2 Long after Sir Thomas Beecham's famous comment about harpsichords, a well-known European conductor came to conduct a major American orchestra in a piece using an historical-style harpsichord. After a run through, the conductor said, "Too much harpsichord". They tried again, with the same evaluation. And again. Finally, at the end of the fourth run-through of adjustments, the conductor smiled and said, "Ahhh, just right". Of course at his fourth attempt to reduce the sound of the harpsichord, the harpsichordist had been playing with all the stops turned off!

3 Anne Chatoney Shreffler, "Baroque Flutes and Modern: Sound Spectra and Performance Results," *Galpin Society Journal* 36 (March 1983): 88-96.

4 Researcher Ed Kottick noted over twenty years ago a significant contrast in brightness between new and old harpsichords apparently involving frequencies well over 1,000 Hz. Ed L. Kottick, "The Acoustics of the Harpsichord: Response Curves and Modes of Vibration," *Galpin Society Journal* 38 (April 1985): 64.

5 A professor in the 1970s and '80s used to advise his students, not entirely in jest, that if they needed a harpsichord for their group performance they could save a lot of the money for moving and tuning if they just hired somebody to play a cymbal with wirebrushes.

6 Thomas D. Rossing, *The Science of Sound*. 2nd ed. (Reading MA: Addison-Wesley Publishing Company, 1990), 102-103. Different frequencies excite different portions of the basilar membrane and when frequencies lie close together the excited areas overlap each other which can cause partial mutual masking, or if one tone is particularly loud it may completely mask another nearby tone and our brain will be unable to "hear" that masked tone.

[7] Hermann L. F. Helmholtz, *On the Sensations of Tone*, (New York, Dover Publications, 1954), 119.

[8] Helmholtz, 204.

[9] The fundamental and overtones of a musical tone usually do not all start at the same instant, or develop at the same pace. It is the particular onset timings and developing strengths of these various harmonics that subconsciously give our ears most of the information to identify what type of instrument is playing. In fact so important are the beginning sounds of an instrument that when they are removed from a recording it becomes much more difficult to identify accurately which type of instrument is playing. (Rossing, 130-132)

[10] Arthur H. Benade, *Fundamentals of Musical Acoustics*, (New York: Oxford University Press, 1976), 355-7.

[11] See Gabriel Weinreich, "The Coupled Motion of Piano Strings," in *Five Lectures on The Acoustics of the Piano: given at a public seminar at the Royal Institute of Technology in Stockholm 27 May 1988*, edited by Anders Askenfelt, 73-81. (Stockholm: Royal Swedish Academy of Music No. 64, 1990).

[12] Since the strings of a harpsichord are stiffer than perfectly flexible, the partials are often inharmonic to the fundamental and to each other by various amounts,. Therefore the more partials that are present, the more out-of-tune relationships will be heard. And that is only one note to itself; when more notes are played simultaneously the mistuning is multiplied, giving shrillness to the harpsichord tone and extreme sensitivity to any slight mistuning, especially of the 8′ treble and the 4′ strings. Indeed, it has been discovered that the modern harpsichord with its many high overtones collects about the same amount of inharmonicity as the modern piano does from its much thicker strings, but fewer partials. [Benade, 357] All strings have inharmonicities. That is inevitable, but it is important for the instrument maker to control *how much* inharmonicity is present, *how it is distributed* and *how it is compensated for* in order to get the most musical result. This mistuning can become extreme when replica harpsichords are strung with other than historical stringing schedules, apparently often in the maker's pursuit of more volume in a certain area of the compass. In one instrument I have encountered more often than I would like, the very experienced maker had strung many of the 4′ notes with the same size wire as the 8′ notes and the result was a 4′ that is impossible to get in tune with the 8′ since the stiffness induced inharmonicities are so mismatched. All that can be done in such a case is to make the resulting harshness as even as possible since the notes probably can never sound in agreement on more than one partial at a time.

[13] Instruments with dynamic range, including voice, greatly change their spectral output with increasing loudness. The number and strength of the higher overtones increase much more quickly than the actual loudness of the fundamental pitch, and this spectral change increases the impression of the intensity of the sound. [See Anders Askenfelt and Erik Jansson. "From Touch to String Vibration.," in *Five Lectures on The Acoustics of the Piano*, 55.] This change in the quality of a louder sound is what makes it possible to identify when a person is shouting even when heard on a recording played very quietly.

[14] It is interesting to note that the Ruckers harpsichords, which also used double dampers for their 8′ jacks, always had buff stops, perhaps indicating in both features the presence of a strong 8′ sound. Brass-strung Italian harpsichords, which also often had double dampers, were not usually fitted with a buff stop, but this is probably because they were virtually always played with both 8′ stops together rather than because the brass sound achieved was not suitable for buffing. French harpsichords, which always seem to have used single damper jacks, did not apparently begin using buff stops until about the second half of the eighteenth century when various other expressive devices, like *peau de buffles* registers and machine stops, began to appear.

[15] Edward L. Kottick, *A History of the Harpsichord*, (Bloomington, IN: Indiana University Press, 2003), 262.

[16] Weinreich, 74-80.

[17] *Duplicating the thickness* of a piece will not necessarily duplicate the stiffness of the original unless the rigidity is the same in both pieces of wood or other material being used. *Duplicating the stiffness* is the more direct way of duplicating the original piece's function. If the mass and the damping are also the same, then the vibrational characteristics can be duplicated. If they are not the same, then compensations have to be made so that the copy functions as much like the original as possible. A material's damping quality is a measure of how quickly, or not, the material absorbs the vibrational energy put into it, and is very important to consider relative to the part's function: sustaining energy for musical sound usually benefits from as little overall damping as possible (at least for the lower partials), while noise-bearing components, like keybed, jack registers, and jackrail components probably benefit from a wood that damps the noise quickly. These three elements are also obviously important considerations when dealing with soundboards, ribbing, wire, pins, bridges, relative impedances of soundboard system and case rim, action feel, etc.

[18] In fact, several major factors that contribute to the apportioning of energy to lower or higher partials, and that influence the transient and sustain character of the sound are available for adjustment after the instrument is built, allowing the sound to be tailored to the intended role of the harpsichord and the taste of the owner. Some of these factors are specific manufactured wire; nut and bridge pins (material, diameter, position on crown of bridge/nut, angle, and amount of extension); jack design features, plectrum material; and voicing approach. Setting up these factors in different ways makes possible a broad variety of transient character, clarity/opacity, spectral makeup, and length of sustain.