THE REVERSE ACTION PIANO HARP:

INNOVATION AND ADAPTATION FROM PIANO AND AUTOHARP

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Abstract

The Reverse Action Piano Harp:

Innovation and Adaptation from Piano and Autoharp

The piano is capable of controlling significant polyphony through the detail of voicing and sustain; a unique ability. However it remains a limited and frustrating instrument in terms of its ability to manipulate timbre. Contact with the strings is remote, and timbre inflection limited to note-onset within the capability of its mechanism; its musical output is often likened to visual studies in black and white.

From the standpoint of design all musical instruments compromise musical capability in one form or another in order to align with human physical and sensory capability. A full range of expression may be sought by developing expertise on different instruments, but this is frustrating; in terms of expert performance interfaces such as guitar and piano are mutually exclusive — common theoretical structure must be relearned for comparable performance expression.

This study explores the potential to create an instrument comprising a set of musical compromises comparable to that of the guitar, whilst remaining adaptive to pianistic technique. It begins with exploration of the autoharp and posits a keyboard variant of this instrument.

Practice based research has been undertaken in the form of a prototype series and musical engagement upon the resulting instruments. Five prototypes have been developed, practice engages with aspects of automated design and manufacture, and in the latter stages, working with an exceptional industry based luthier. The resulting instrument has been patented. Musical practice encompasses genres from gypsy-jazz to contemporary experimental music. New works have been commissioned for the instrument and other musicians have played and studied it.

Practice is supported through analysis of related forms of musical instrument (which influence the developing design) and the nature of change within musical technology.

The result is a new, versatile instrument, with demonstrated capacity to gain traction and to propagate within the musical community.

1. Introduction

A Pianist and an Autoharp — A Context for Innovation

Back in the 1970s, when I was a teenager, I loved the piano and practiced it obsessively. But even in those days there was something missing — there are, give or take a few, and depending on the type; 230 or so strings inside that instrument, but somehow I could never quite get at them, could never feel in contact with them in the way that I felt that I should be able to. I did feel that sense of "direct contact with the sound" when I played the violin or the guitar, but I struggled to reach a reasonable standard on violin (I never could stand my own tuning!) and I did not (and do not) really get along with the guitar interface.

It was in this setting that I had my first encounter with a twelve bar Schmidt autoharp. Though short, it left a vivid memory. The instrument looked so much like a small piano soundboard, and at once I felt that it should provide an effective “guitar equivalence” for a pianist, sacrificing one hand in order to gain direct contact with the strings, and sacrificing complexity for portability.

I played the instrument, I loved the immediate and complete changes of chord that it gave and the gratifying changes of timbre that contact with the string surface provided — of course the chord choice was very limited, but surely you could easily change the chord bars? I attempted some melody. A problem: the over damped system did not allow the melody notes that I wanted over the chords, did not seem to allow anything in fact, other than the members of the chord itself. If you wanted another note, you had to change chord. Still, I was not immediately put off, and continued to experiment with the harmonic textures it created.

I grew aware of a second problem; a significant one from my piano perspective; the slick changes of chord very quickly sounded repetitive, and try as I might I couldn't seem to vary the texture as I wanted. Some things, change of register for example, were almost too easy, other things such as stabs and more open-space textures, with silence, seemed impossible to achieve, in fact it felt like the instrument created a momentum of its own. A piano just stops; the second that you allow the sustain pedal up, but ceasing to play this instrument, even for a moment, seemed to cause it to create a cacophonous racket by itself; it just wouldn't shut up!

I fell in love with the potential and possibility the autoharp presented, but I understood the limitations of the instrument and why it couldn't react effectively to the pianistic technique that I had developed. I studied how it worked and saw that because of the over-damped system on which it relied, it was only superficially adaptive to pianistic technique.

Various sources agree on a definition of an autoharp — the following: *a kind of zither fitted with a series of sprung and padded bars which allow the playing of chords by damping selected strings* (Oxford Dictionary) is typical. The definition consists of two components; the "harp" is a fretless zither consisting of a plurality of strings strung over a sound board. "Auto" refers to the damping mechanism where sprung damper bars damp strings extraneous to a particular chord.

Figure 1.1. Autoharp by Oscar Schmidt, Model No. 15a dating from 1961 (Harrison, 2004) with permission

The autoharp is an outstanding interface if the intent of the player is diatonic harmony. Slick changes of harmony can be achieved without significant technical investment on the part of the player, and it lends itself to genres that demand rhythmic accompaniment. Achieving melodic, or combination of melodic/harmonic playing upon the instrument is significantly more difficult.

Players certainly do push the boundaries of the instrument however; in this referenced recording Bob Ellis (Ellis, 2010) demonstrates that he is able to achieve significant freedom in his melodic/harmonic combinations. He achieves this (in addition to very accurate right hand technique) through tuning/spacing compromise. His autoharps have only four chord bars, and his diatonic tuning system provides a series of doubled notes across the compass. This has two effects: firstly the spacing between the discrete pitches in the melody range is increased, providing greater potential for accuracy; secondly, a missed note is not a disaster of dissonance when it does happen. Ellis demonstrates that he is able to ornament melody with harmonic combination effectively. He also discusses the drawbacks of the approach — the instrument plays only in two keys, D and A — a significant limitation when interacting with fiddle players, as Ellis clearly likes to do. With a resigned shrug, midway through the clip he produces a second autoharp set up to play in C and G.

At the other end of the spectrum in this recording Will Smith (Smith, 2012) plays a Chopin Nocturne on his 24 bar autoharp. The timbres are certainly unusual and the playing at times is beautiful, but also contains missed notes, and damping problems (which sound rather like poor piano pedalling). Smith comments after the clip that the chord bars are completely non-standard.

Each approach illustrates the possibilities and limitations of the over-damping system of the autoharp. Ellis achieves melodic/harmonic freedom, but at a price — the instrument is clearly limited in terms of genre engagement by the range of harmonic/melodic possibility. Smith achieves a greater tonal ambition — but at a price of great esoteric complexity in interface.

Surely a Keyboard?

The paradox is that the autoharp interface is initially extremely rewarding to the learner, and therefore very attractive to a beginner musician, but more complex musical combination demands a very significant advance in technique, which few players accomplish. Manipulating twenty-four chord bars in order to produce melodic/harmonic combinations is a feat of technical mastery. Additionally, the technique gained, is locked-in to the esoteric complexity of manipulating damper bars designed for harmony, for another purpose — that of melody/harmony combination. This results in a technical perspective that is rather different from mainstream musicians, and somewhat isolated.

The pianistic perspective on this interface observes that there are only 12 semi-tones in the Western equally tempered scale, and we have an interface (a keyboard) that will accommodate this, ready developed; needing only to be adapted effectively to the autoharp. It would allow access to *all* note combinations providing complete harmonic possibility (24 chord bars is quite simply an unacceptable starting point for a pianist). It also has the potential to allow for effective melodic playing in combination with harmony.

However, we must bear in mind that a considerable strength of the autoharp chord bar arrangement is its essential simplicity from both a mechanical and functional perspective, which leads to a practical, portable instrument capable of considerable timbral variation because the right hand is in direct contact with the strings (a quality lacking in the piano). The chord bars perform a limited musical function — they do not seek to isolate individual strings, and do not distinguish pitch height (octaves); this precision is given by the right hand in contact with the strings.

If the aim is a keyboard equivalence of this arrangement, a typical keyboard/string instrument design strategy of one key coupled to one string is not a good starting point, because the large amount of keys (matching the quantity of strings) will immediately dominate the instrument, removing the focus from the right hand in contact with the strings. In producing such an arrangement we would be well on the way to turning the instrument back into a small piano (there are extant instruments which do provide this kind of interface such as the Dolceola shown below) (Harrison, 2004).

Figure 1.2. Dolceola dating from around 1920 (Harrison, 2004) with permission

Instead we create an effective keyboard equivalence of the function by creating an innovation that follows these principles:

1. Keys are passive; they do not produce sound by themselves — they simply release dampers.
2. A single key is linked to a single reverse-damped bar which damps all octave occurrences of the pitch.

To give a practical illustration of this system; if I depress the key of D (this would make no sound in itself), and then strum right across the string surface of the instrument — all of the D strings would sound — but no others. If I release the key then the instrument immediately damps itself. This arrangement maintains the responsibility for articulation of individual strings to the right hand — in direct contact with the strings. From the perspective of a pianist this interface approximates and enhances that offered by an autoharp, giving reasonable and logical prospects for harmonic/melodic combination, and providing damping behaviour that conforms to keyboard expectation.

The most straightforward aspiration of this study is the establishment of this inventive step and to establish the resulting instrument within a musical community. It is best encapsulated (in refined form) by the patent claim re-write that I provided to the UK Patent Office on 9th August 2011[1].

Claims — Reverse Action Piano Harp (ReAPH)
"Integration of one octave of full sized piano keys oriented towards the toe pin block parallel to the string raised at least 10cm, to provide a left hand keyboard position adaptive to pianistic tradition and right hand strumming/plucking position adaptive to autoharp traditions through use of a pulley string system connecting piano keys to reverse sprung damper bars, damping octave occurrences of individual pitches." (Brissenden P. G., 2012)

The most significant design concern was to create comfortable playing positions for both hands, and the given resulting parallel keyboard position, a pulley and string system is the most obvious coupling mechanism providing the necessary flexibility. Other keyboard positions might provide more direct coupling options, but the optimum keyboard position takes design priority. By the time of the writing of this version of the claims it became clear that this design aspiration should be expressed as evolutionary (and adaptive) to the strengths of both traditions; that is, the adaptive potential and technical strengths of both pianistic and autoharp traditions are identified and preserved within their separate domains.

In the terminology of innovation technology this market is termed *early adopter* — either pianist or autoharpist rather than beginner musicians. Early adopters — ready accomplished musicians, are prepared to make evolutionary steps to assimilate the new interface relatively quickly, because they perceive its advantages, and will contribute to propagation of memes and further enrichment of memes.

The Musical Community

Instrumental players do not normally proceed by completely redesigning their instrumental

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1 This claim is best suited to state the aims for this study, however it was not the version finally accepted by the UK Patent Office.

interface. The learning of a musical instrument is a form of expert performance. Some salient points to note about expert performance are that it is largely non-verbal, automatic and resistant to memory fading. It is highly adaptive within the specific domain of accomplishment, but when transferred to related domains, does not necessarily confer any significant advantage over beginners. Expert performance requires time and repetition; the typical time cited within the psychological literature to acquire it is ten years. Wynn and Coolidge characterize expert performance as reliant "..on a cognitive ability known as long term working memory, in which retrieval structures held in long-term memory, but activated in working memory, enable rapid access to larger bodies of procedural and declarative knowledge" (Wynn & Coolidge, p. 84). The cognitive structures that enable expert performance in different domains are similar, and this human ability has deep evolutionary roots. Wynn and Coolidge argue that Levallois Reduction (a form of flint knapping dating from the end of the Palaeolithic) is an example expert performance indistinguishable from modern day expert performance.

Expert performance is a learned behaviour; not necessarily overly reliant on language for its propagation in a discrete domain — but certainly reliant on demonstration and community. The overwhelming majority of instrumental players expect pre-existing structures to aid them in their development. Pianists have available a vast repertoire of written music and the methodology, through notated and non-notated technical exercises, to acquire a working (motor) knowledge of theoretical framework. They do not, for example generally expect to have to compose pieces, or to have to identify suitable pieces that may be arranged for their instrument every time they want to play a new piece, nor to invent suitable exercises to extend dexterity and/or enhance improvisation skills.

Invention extends outwards from the instrument, to a vision of its accessibility and capability. This vision enables the development of concrete materials for instrumental players to use in order to learn it. Many of these can be adapted. For example, when considering simple melodic material, mandolin repertoire is suggested because the melodic range and tonal characteristics are similar to the autoharp. When considering jazz technique however, left-hand four note substitution exercises are highly appropriate starting points.

In addition to adapted materials, there should be compositions conceived for the ReAPH, which demonstrate its unique properties. The production of all this material, and its availability alongside and contemporaneous with the design development, begins the process of providing an adaptive environment for expert performers, the package which allows the instrument to gain traction, and for a musical community to emerge.

Alternatives to Keyboard

We should be aware however — at the outset, that if we *exclude* all considerations of musical community and focus entirely on function, the issue of musical possibility in relation to the nature and complexity of the instrumental interface is not a simple one. Using the terminology of innovation technology, the argument implied in the opening narrative asserts that the over-damping chord bar system of the autoharp is an example of technological lock-in, to an interface that limits musical possibility (termed a sub-optimal interface within the discipline). A more generalized and flexible interface such as a keyboard would allow for greater musical possibility and range of genre engagement.

This is a reasonable argument to make, but in fact, the situation is not quite so clear-cut. Firstly, it presupposes that a greater range of genre engagement is desirable — clearly dependent on the individual players. Secondly, if we accept without question (for the moment) the idea that there *would* be a net gain in musical possibility and range of genre engagement, for a keyboard-integrated-autoharp over the traditional over-damped system, this still does not necessarily indicate that a keyboard is the *most* advantageous alternative, indeed it is perfectly possible to argue that the keyboard itself is an example of technological lock-in, and that there are a number of different possibilities which might well yield yet greater musical possibility. Yet whilst keyboard alternatives perhaps have a more surprising presence among musical instruments than the non-initiate might suppose, any reasonable assessment of western musical instruments would conclude that the traditional keyboard layout is a market dominant and therefore the most obvious candidate for engaging the interest and acceptance of the musical community. From this starting point we may imagine that ReAPH alternatives might grow to rival the myriad of forms displayed in free reed keyboard interfaces without significantly altering the design constraints.

Fundamental Questions

This opening exposition defines two strands of exploration in order to create a balanced study. The first, practice-based, stems from a desire to create a musical instrument (one that does not currently exist within the spectrum of western musical instruments), the second, theoretical, explores the context of the practice and elements which might inform its development.

Fundamental Practice-Based Questions

We began with a pianist, frustrated (after long experience) with the interface that the instrument provides. The primary stimulus for innovation is the autoharp, the secondary stimulus, the guitar. The guitar best expresses the desired range of musical expression, which is created on the best platform for keyboard innovation; the autoharp.

This raw desire to innovate is summarized in three statements from the pianist:

1. I wish this instrument existed because it would provide different musical possibility to that which currently exists within the range of musical instruments.
2. I wish this instrument existed because it would be adaptive to pianistic skills.
3. I wish this instrument existed because I could carry it around.

The keyboard position on the harp is the fundamental starting point. It was subject to much pre-build experimentation and discussion. The experimentation constituted playing a great deal of air-harp — taking an autoharp and imagining different keyboard/string array arrangements. The position arrived at is determined by constraints learned from experience of piano and guitar; the keyboard position must allow a relaxed left arm, supported from the shoulder and the upper arm, with no twist in the wrist joint and the strum position must allow free forearm and wrist movement, similarly supported by the upper arm and shoulder.

This position is best expressed here by showing a later photograph — the two photographs below demonstrate the unchanged playing position on prototype 3, whose completion is contemporary to the earlier expressed patent claims of 2011 (in refined form).

Figure 1.3. Playing position on prototype 3 (Brissenden P. G., Reverse Action Piano Harp, 2013)

We can summarize this into four statements

Playing interface:

1. Comfortable keyboard playing position for left hand whilst simultaneously providing;
2. Comfortable strum/pluck position for the right hand.

Design considerations

3. Maximizing the playable string surface
4. Providing and effective reverse damping mechanism

And from this starting point the prototype process begins with fundamental questions

5. Can it be done?
6. What are the technical obstacles?
7. How can they be solved?

Figure 1.4. Playing position on prototype 3 (Brissenden P. G., Reverse Action Piano Harp, 2013)

Yet there is a wider context for defining the success of the instrument than the simple raw desire of a single pianist expressed within the exposition. It discusses the potential for wider acceptance within the musical community, and defines further areas of practice (repertoire and method) that must be incorporated in order to make this possible. An all-encompassing question can be expressed as:

1. Can the instrument be established within a musical community?

In order to arrive at a measurement of success we can track various aspects of musical activity, over time the activity should demonstrate:

- Greater variety (this may be of genre, or role within ensemble for example)
- Increased extraversive activity
- Increase in initiatives from others upon aspects of the project

This change inspires a creative momentum and a critical mass should enable:

1. Activity upon the project becoming increasingly independent of the inventor's involvement
2. Increasing musical acceptance and stable (and innovative) propagation of memes.

Practice-Based Methods

The methodology for both practice elements (Design and Musical Engagement) is based in Action Research. Action Research is defined differently according to contextual situations, however there is an underlying principle that is common to all: the method interspaces periods of practice with critical examination of the evidence that the practice has generated; and this guides the planning for the next practice period. It is a progressive problem solving method whereby immediate problems are addressed and results analysed such that they define subsequent undertaking. Action research can be undertaken in groups or as an individual. The method pre-supposes that overall practice-based activity seeks to achieve desired outcomes, but rather than working to inflexible goal oriented schedules, it allows for change at each stage (based on previous results). Crucially, it allows for the fact that different desired outcomes may well exert conflicting pressures, and that resolution and balance will evolve from a progressive approach.

Practice-Based Modes of Engagement

<u>Design Practice</u>

Prototyping

Enhancing and developing skill base (Drawing, 3d rendering, experimentation within the wood workshop, experimentation with the design workshop: computer navigated cutting, laser cutting)

Study of related instruments and forms

Interviews and consultations

Collaborative practice

Critical analysis, reflection and evaluation

<u>Musical Engagement</u>

Composition/arrangement

Performance

Performance Recording

Composition commission and collaboration

Critical analysis, reflection and evaluation

Theory — Fundamental Questions and Methodology

For the majority of the first chapter, I have introduced terminology from the discipline of innovation technology as a framework for analysis with relative confidence that appropriate insight is gained using the ReAPH as a sole model for description. The theoretical framework of innovation technology is itself an application of evolutionary theory, from which it borrows a significant proportion of its terminology — to what extent does it define these terms? I began the process of designing the ReAPH from within a wider research context, exploring the evolutionary origins of our sense of tuning. This cross-disciplinary study was also based on musical practice. I fashioned flutes using materials and technology appropriate to the archaeological record, and compared critical commentary with practice-based observation. I particularly focussed on shakuhachi/quena as a sound producer because it is the simplest and most conceptually obvious, and further because I had no experience of playing it, and therefore the instrument fashioning process proceeded hand-in-hand with learning to play it.

This research led to two conference contributions and a publication on the *Evolutionary Origins of Tuning* at University of Durham conference on *Music and Evolutionary Thought* (2007), and at the City University of New York in (2009). At a conference entitled: *Drawing on the Musical Past, Instrument Making and Experimental Playing in Music Archaeology* run jointly by the Study Group for Music Archaeology and the Research Centre for Music Iconography. The context of this research focussed a great deal on the meaning of evolution and its relationship to cultural and technological change at the point of origins (of technology and culture). I thus began this current study from an unusual position, which had led to the conviction that a Darwinian framework is a necessity simply because it is a truth that cannot be avoided. At the point of origin of technology, analysts are generally comfortable with describing the process of change as evolutionary, because it is intimately entwined with physiological change; both are described as evolving. Later, more complex cultural systems pose a challenge for evolutionary theory, but there is a growing body of research that explores its use as a governing framework. Significantly, evolutionary theory is the only frame of reference that allows a pluralist approach to analysis.

The problem for achieving a successful implementation for *this* study is balance. This study is not about evolutionary theory; it is about a specific technological innovation and its context within a range, and therefore it cannot afford to devote more text than necessary to the intricacies of evolutionary theory interpretation. A significant obstacle is that the framework is complicated and takes a great deal of explanation; further, a fundamental aspect of its power to illuminate, lies in the differences in interpretation of individual studies. Though there is a growing literature on the subject, we are not yet at a stage where this unusual framework can be simply applied without a good deal of support and cross-disciplinary commentary. The success of its inclusion within this study can be measured using the following criteria:

1. *Has the terminology and analytical framework been defined sufficiently?*
2. *Have all obvious arguments against the application of such a framework been identified and rebutted convincingly?*
3. *Has the terminology and analytical framework been consistently applied within the remainder of the study and has it added value to the study?*
4. *Has the footprint of the framework of evolutionary theory been minimized within the study as a whole?*

Another significant deviation from mainstream innovation technology terminology is the use of the term “musical community” within the exposition as an alternative for the “market”. This suggests that there are at least sufficient individualities that distinguish a “musical community” from a standard definition of a market, and that this demands further, discipline-specific analysis.

The exposition begins the process of interrogating the merits of the proposed musical instrument innovation: the standard keyboard (market dominant and obvious starting point to a pianist) alternative to the chord bars of an autoharp — is it the best alternative? What constitutes an appropriate balance between market and musical analysis? Equally, the autoharp string array should be treated as a starting point — should it be changed as a result of keyboard integration? Further potential for enhancement can be explored through exploration of similar and related instruments.

The two subsequent chapters, which move through the subject matter in the order described above therefore perform the function of literature review, but they also directly influence and inform the design practice, such that the practice based questions and outcomes can be revisited and refined at their conclusion. The process of literature review is further embedded in subsequent chapters. I have chosen to analyse the hidden history of related keyboard-autoharp invention within the framework of my own prototype series and patent application, and further contextual analysis is provided in the final chapter on musical engagement.

Measures of Success

The overall outcomes of the study are measured by re-integrating the strands above into five overarching questions:

Can a working musical instrument be created?

Can we analyse its strengths and suggest further change/development?

Is there an appropriate range of variation?

Can the instrument be integrated into the musical community?

Can the instrument be made available to the wider musical community?

2. The Nature of Change

Research Context Within Innovation Technology

The commonality of process driving evolutionary and technological change has been commented on from a number of perspectives. The discipline of innovation technology uses evolutionary terminology freely, but sometimes lacks the precision of the original discipline. Evolutionary commentators such as Dawkins, Gould, Patel (from a musical perspective), and even Darwin also comment within this domain. We should not be at all surprised at this. Darwin (whose research was funded through the fortune amassed by his maternal grandfather, the great entrepreneur and social reformer Josiah Wedgewood) was clearly influenced by Malthus and the emerging academic study of macroeconomics. (Darwin C. , 1969, p. 120) *All* point out the similarity of the process of change within large complex systems. Whilst drawing on analytical structures from the discipline of innovation technology in what follows, I wish to retain the precision of the definitions from evolutionary thinking established within its original framework.

Evolution — Original Context

Evolution as defined within its original biological framework states that variation between generations within a species is purely random. Adaptation occurs because, over accumulated generations those variations best suited to local environment (which might well change) will survive and reproduce — this is the principle of survival of the fittest. These principles are paraphrased directly from Darwin, and can be found in the opening pages of the “On the Origin of the Species” (Darwin C. , 1859, p. 10).

However, evolution was a term used only once by Darwin in the closing paragraph of “On the Origin of the Species”, other than this single usage Darwin avoided the term in favour of the more precise “descent with modification”. The term itself predates Darwin, and its popularization as an encompassing term for “change due to the process of natural selection” is variously attributed to the geologist Charles Lyall, Herbert Spencer and Ernst Haekel. It was said to be disliked by Darwin because it carries with it connotations of “progress” or “development”, and it is easy for these connotations to spill over into situational analysis, when viewed over longer periods of time. It becomes tempting to view an individual lineage as “progressing” or “developing” to a greater perfection of adapted form, but the notion of progress is an illusion; in reality the perceived increase in “perfection” happens as a result of random change in response to changing local conditions. When the lineage is placed in a wider context, this change is more accurately described as a fact of statistical certainty that variety and complexity within a system will increase (assuming we begin from a point of simplicity). Unfortunately this increase in variety and complexity further suggests notions of progression — but in fact if we begin from the opposite — a point of complexity, the evolutionary process will provide statistical variation towards simplicity with equal probability. Thus, within the biological domain change is most certainly random.

Technological Change

Application of evolutionary thinking and terminology to human culture provides an opportunity for further confusion. The unit of transmission, the cultural "replicator" equivalent to a gene within evolutionary biology was coined by Richard Dawkins and is called a meme; and this provides a unit of natural selection within culture. Dawkins chooses to define this term through use of a list: "Examples of memes are tunes, ideas, catch phrases, clothes fashions, ways of making pots or of building arches" (Dawkins, 1976, p. 206). The list demonstrates that a meme may be discrete, or imply an entire technology. It may be concrete or abstract — the common factor is cultural environment, transmission through learning.[2]

There are differences in possibilities for propagation between memes and genes. Memes have the potential to cross cultural boundaries — there is no equivalent to the complete isolation that speciation provides, and cultural change is faster by many orders of magnitude than evolution within its original context, because it involves learning, and transmission through learning, rather than through genetic inheritance. Dawkins, remorselessly Darwinian, unrelentingly provocative, dismisses the difference in speed of transmission as an irrelevance. The memes themselves are the propagators, he says — acquiring their own heritability; their own life if you will, and transmitted within their own environment — human culture (Dawkins, 1976, pp. 208–210).

Though the mechanisms of replication are entirely different, memes and genes are subject

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[2] This in fact closely follows Dawkins unusual definition of the word gene: within The Selfish Gene, "A gene is defined as any portion of chromosomal material that potentially lasts for enough generations to serve as a unit of natural selection. ... a gene is a replicator with high copying fidelity. Copying-fidelity is another way of saying longevity-in-the-form-of-copies and I shall abbreviate this simply to longevity." (Dawkins, 1976 p. 30). It is unusual because it argues that disparate areas of code can become linked because they share heritable properties.

to the same fate. They may replicate perfectly (reproduce), they may undergo modification (mutate) or they may disappear (extinction). Memes might take a number of different forms, from ideas to concrete objects, and at times distinction is a matter of perspective. Consider, for example the ability to transduce sound into an electrical signal. The concept of variable resistance underpins all microphone designs and is unchanged — but the technology that enables this transduction in today's microphones is utterly unrecognisable from the original Bell/Watson apparatus which, though it may exist for historical study, has long since vanished from the meme pool of technological reliance.

Perhaps the most common and profound objection to direct application of theories of evolutionary change to human culture is that change is consciously directed and therefore *not* random. Clearly, musical instrument invention is not random from my subjective perspective; it takes a great deal of conscious direction. It is, however an adaptation to local conditions (the local condition is a frustrated pianist, who longs for direct contact with the strings) and depending on musical perspective, the change from autoharp to ReAPH represents progression, or not — the randomness is a matter of analytical perspective.

The ReAPH itself represents a potential increase in complexity from the point of view of manufacture, though the instrument remains essentially simple when compared to, for example, a piano. It is a decrease in complexity from the perspective of musical interface, especially when compared with the esoteric intricacies of the 24-bar autoharp. When viewed from a systemic perspective, contextualizing the ReAPH within a spectrum of variation of “fretless zither type string instruments” the change is seen clearly as a local adaptation to a local condition — a random variation.

A more complete response is given by fully understanding the implications of Dawkins’ assertion that the memes are themselves the replicators. In order to see why this is so, we need to drill down two levels in our perspective on the mechanisms of change. Firstly, human capacity to engage with and to innovate within technology provides significant evolutionary advantage, such that learning and culture have eventually placed evolutionary pressure upon our species and effected change upon it. An obvious example is language capacity, which has had a demonstrated and proven effect upon our physiology (Patel, 2010, p. 367) and this shows in turn, that a significant proportion of our environment is provided by each other, rather than the wider environment. Drilling down this first level changes our perspective with regard to learning and technology — we see the meme environment is dynamic, and our relationship with it is also dynamic, it influences and changes us (in terms of behaviour, and even physically) just as conscious direction can produce change in the memes. A second level can now be appreciated; from the perspective of an abstract meme the evolutionary environment *is* consciousness. Conscious direction is the means by which memes replicate themselves. From a systemic perspective, we might critically examine the replication potential of a given meme such as a variable resistor, or a keyboard, in terms of its environment – consciousness, just as we examine heritable characteristics such as tooth, claw and speed in carnivorous animals.

A final, often highlighted difference between technological and biological change is the issue of speciation. New technology may emerge through recombination in different, possibly more complex systems. But this form of change is, less obviously, also present within the biological domain; we would not, for example be the complex beings that we are without the crucial assimilation that allowed eukaryotic cells to emerge. We would not be able to digest the food we eat without a host of symbiotic bacteria with which we co-exist; we cannot exist without a compatible ecosystem of inter-linked organisms.

Inter-linked systems of technology produce conflicting pressures in their design configurations. Recall within the first chapter that the pressures exerted by the design considerations (each to be considered an individual meme) with regard to maximizing the playable string surface of the ReAPH for left hand, keyboard position for right hand on the string surface *and* providing effective damping — these are conflicting pressures because the movement by even a few millimetres, of one measurement renders disadvantage to the other, and over-prioritization of one of these memes might well bring about a useless musical instrument. Thus even when an invention is the product of one mind alone, a given meme is under selective pressure. Conscious direction is the very fabric of the selective pressure upon memes.

As the number of contributors to, and stakeholders within a system increases; the presence of a given meme may be a product of collaboration, debate, competition, compromise, revision — the list of descriptors for possible processes involved is very large indeed. The complexity of the conflicting and overlapping interests of groups and individuals and their increasing temporal and geographical separation renders conscious direction by individuals or even groups of individuals, largely invisible and irrelevant, and this produces another correlate with evolutionary process — that of stasis. Gould states that stasis is the norm for complex systems, change, when provoked at all, is usually rapid and episodic (Gould S. J., 1991, p. 69). Stasis suggests resistance to change. This may surround an entire system or components within a system.

Technological Lock-in

Linked systems — sets of memes, are likely to contain one or more examples of technological lock-in. Technological lock-in, systemic stasis challenges the assumption that memes interact more freely than genes. A technological lock-in refers to a component of a system, which has become resistant to change because all participants in the system have standardised to it. It is different to speciation, because in principle there is no rigid barrier to change as with a gene pool — simply systemic resistance, however examples of technological lock-in are certainly pervasive and difficult to break.

There are well-documented examples within the discipline of innovation technology. A subject is most often selected for study because the lock-in is undesirable, and solutions for change are sought. The internal combustion engine is an example of this; reliant on a host of surrounding systems that perform functions such as oil refining and mechanical maintenance, society is locked in to this interface despite the maturation of rival technologies, and this state of affairs is extremely difficult to challenge. Musical instruments abound with examples of meme-sets, which are locked together. At this point in the narrative we need to understand the concept from discipline standpoint, so we will interrogate a commonly cited example within the discipline of innovation technology that has an interesting resonance with the memes that comprise the ReAPH.

The QWERTY type-writer keyboard layout has survived all technological change to other component aspects of meme-sets that surround it, and nearly 150 years after the original patent was filed (1867 by C Sholes), the same basic keyboard layout is to be found on windows and Macintosh PCs as on the original Sholes-Remington typewriter. This is so, even though other keyboard arrangements such as the Dvorak Simplified Keyboard (DSK) claim to offer advantages in terms of typing speed. QWERTY therefore is cited as an example of standardisation to an undesirable sub-optimal interface. Professor Paul David, Professor Emeritus and Senior Fellow of Stanford University is the author of the seminal paper on this subject (David, 1985). David asserts that the QWERTY layout itself was largely a product of Sholes research during the time between the initial patent (1867) and the first production model (1874). Sholes sought a layout that would maximise key separation in order to slow down the operator and even out the rhythm of keystrokes, in order to minimise key jam. The original thinking behind the layout was therefore to maximise efficiency for the original technical specification. David argues that this arrangement very quickly became unnecessary as the 1880s saw a host of competitor typewriter models with both technical advantages and alternative keyboard layouts. However by 1895 QWERTY had complete market dominance and has retained this position ever since and continues as an integrated component within the overwhelming majority of personal computers.

David argues that the factors that led to this decisive standardisation, are all incremental steps, but together deliver a decisive probabilistic advantage:

1. QWERTY was first to market: the result of sustained experimentation and thinking on the part of Sholes, by 1881 it was a very narrow market leader, but by no means dominant.
2. The development of eight fingered touch-typing and training methods for touch-typing took place upon the QWERTY keyboard.
3. Given a narrow market lead in hardware, and a similar initial lead in operator training the decisions of all individuals within the system were more likely to move the balance in favour of, rather than against QWERTY even though individuals do not have strong preferences in favour of any particular keyboard layout. In detail: would be operators are likely to choose to train to the QWERTY standard because the training method was most widespread and well developed — thus enlarging the pool of operators.
   For similar reasons would-be trainers and educators are likely to choose QWERTY. Companies purchasing typewriter stock are likely to standardise to QWERTY because this is the largest pool of operators from which to draw employees. Finally and decisively, typewriter manufacturers producing models with alternative keyboard layouts see that market share can be increased in one step by producing a QWERTY compatible model (David, 1985, pp. 334–336).

Complex systems of human interaction such as this arise as a result of heterotechnic (asymmetric) co-operation. Heterotechnic co-operation is not completely unique to humans; specialized roles have been observed, for example, in some of the hunting patterns of dolphins. But the degree of complexity and of dissociation of individual stakeholders within large interacting systems within society *is* completely unique to human culture. This dissociation of individuals, and interests of individuals, renders the case for systemic randomness unanswerable. No one person or group of people can be said to have “planned” the market dominance of QWERTY; it emerged because of probabilistic pressures.

Interrogating the Concept of Sub-Optimality

David's paper adeptly illustrates the concept of technological lock-in, but appears to be only partially correct in its analysis of the development of the QWERTY layout and does not interrogate the central claims of the DSK alternative.

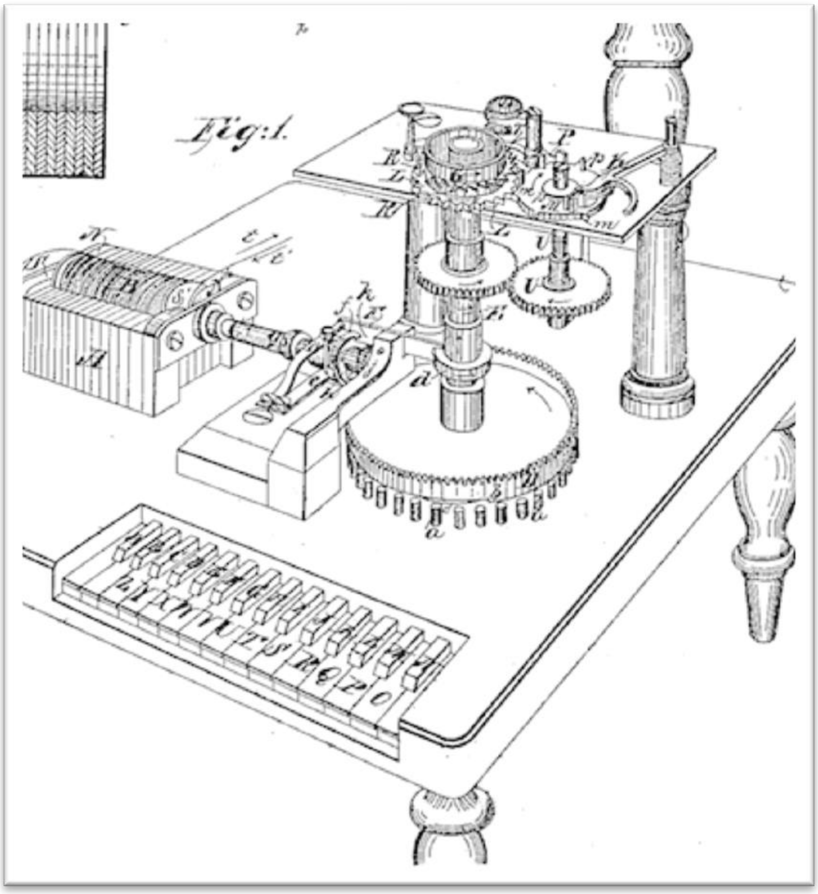

Figure 2.1. Phelps Printing Telegraph Keyboard (Phelps, 1859)

Status: Public Domain

Sholes did not spend six years wrestling with a keyboard arrangement that rendered his invention workable for typing; he was instead heavily engaged with collaborative development with his first customer base. The Sholes & Glidden Type-Writer, which began its manufacture in 1874, represents second-generation technology, identifying a new and potentially much larger user base (the public), but the much smaller first market was of profound importance because it addressed and engaged the relevant professional community in the initial collaborative development of the technology. This first market identified by Sholes and his colleagues was in fact the telegraph industry, and the first prototype was shipped to Porter's Telegraph College, Chicago as early as1868 (Yasuoka & Yasuoka, 2010, p. 162). The keyboard of this typewriter (above right) is clearly based on a piano keyboard arrangement, with keys in alphabetical order rendered to white and black keys in mirror image of each other. By 1870 Sholes was engaged in full developmental work with the American Telegraph Works, and various representatives from this industry contributed to the debate on key arrangement including one Thomas Edison.

The debate centred on optimal discernment and transcription of Morse code with respect to key placement. Debate was detailed and wide ranging, with conflicting pressures resulting in heated argument over minor changes in placement of groups of keys and individual letters. Thus for example S was moved in between Z and E because of the ambiguity of the rhythm coding — receivers are often unable to discern whether Z or SE is correct until the subsequent letters are sent. Yasuoka & Yasuoka argue that it was *never* the intention of Sholes to slow down the typing speed through the QWERTY arrangement; and that the opposite is true: in contrast to the history constructed by David, QWERTY is a standard arrived at through debate and compromise and is collaboratively *optimised* for the aural transcription of Morse code.

Figure 2.2 Scholes Type writer (and enlargement)

(Scientific American, 1872) *Status: Public Domain*

The images are taken from the front page of *Scientific American,* August 10th 1872 showing the typewriter keyboard demonstrated to Western Union Telegraph Company, Chicago. Though there are some differences, the QWERTY layout is clearly discernible from the enlargement.

The scale of the keys is very different to a modern typewriter or computer keyboard, and the original relationship to a musical keyboard is apparent. The orientation and placement of the hands within the picture support this view. Hand movement is clearly dynamic — like a piano player as opposed to the static hand position and independent finger movement of later typewriters. It is therefore less of a surprise that touch typing, and the development of its instruction and training emerged centred on the QWERTY standard, because the professional community was collaboratively engaged with its development. Second generation operators were likely to be short-handers, but were a part of the same professional community and systems of training. Overall it would seem from this that the dice were in fact more heavily loaded in favour of the market success of QWERTY than David might suggest.

On the other hand the central design principles of the Dvorak Simplified Keyboard are:

1. Typing should alternate between hands when possible (all the vowels are under one hand and all the common consonants are under the other)
2. The load between hands should be kept fairly even, with a slight emphasis on the right since most people are right-handed
3. Typing should be kept on the home row when possible
4. When typing cannot be on the home row, it should be on the top, because the bottom row is the most difficult to reach
5. Typing should go from the outside to the inside of the keyboard (the principle of inboard stroke flow)
6. Using the same finger for two letters in a row should be avoided whenever possible.

This set is considerably reduced from that generally expressed by DSK supporters, because principles are commonly expressed in the form of arguments (The Technical Geekery, 2011):

> "8. Words should not be typed with one hand while the other remains idle. Particularly egregious examples of this on the QWERTY keyboard include 'minimum' and 'greatest'. This effectively halves your typing speed, as well as overworking that hand.
> 9. "Hurdles," where the hand has to jump over the home row to reach the top and bottom rows in sequence (or vice versa), should be avoided whenever possible. This problem is greatly reduced on Dvorak layouts by both making sure far more keystrokes are on the home row and by encouraging hand alternation. An example of a bad hurdle on the QWERTY layout is 'minimum' (yes, again—it's a nasty word). There are far fewer hurdles in Dvorak."

These two arguments are re-expressions of previous principles, and the flaws are immediately obvious: both arguments reduce the perceived problem as compared to QWERTY rather than eliminate it, resulting in variable adherence to the central principles. The principle benefits (similarly reduced) are held to be:

1. Dvorak is more comfortable
2. Dvorak is faster
3. Dvorak is easier to learn.

Each claim is contentious, hotly debated by aficionados from both sides, and evidence is conflicted. This does not negate the central theme of David's paper — QWERTY *is* a technological lock-in, but not necessarily sub-optimal, dependent on perspective.

Yasuoka & Yasuoka identify David's paper and a subsequent response by the evolutionary commentator Stephen Jay Gould as resulting in a worldwide meme propagation that has mis-recorded the facts of the initial development of the QWERTY layout (Yasuoka & Yasuoka, 2010, p. 172). Within his paper on the subject, Gould — conciliatory and inclusive (in contrast to Dawkins), seeks not the direct application of evolutionary principles, but rather to establish “whether both systems record common, deeper principles of organization” (Gould S. J., 1991, p. 66). The distinction is a fine one, and perhaps has more to do with his great historical sensitivity to the facts of the mis-appropriation of evolutionary theory by right-wing political movements than a lack of conviction in the direct application of evolutionary theories.

His point of evolutionary comparison to the technological lock-in of QWERTY is the Panda's thumb; originally evolved for a carnivorous life-style, the motion constraints placed upon it are committed to the limited movements of creatures that run and claw, such that the simplified thumb is locked-in. The panda, adapting to a herbivorous lifestyle which requires greater dexterity, has evolved a substitute thumb from an enlarged radial sesamoid bone of the wrist. Gould describes the sesamoid thumb as a clumsy sub-optimal structure, but functional.

We may observe that the sense of the term sub-optimal is dependent upon a *comparison* point in both technological and biological contexts. Without this reference, the term has no meaning. For the panda, the (unspoken) point of comparison is a true thumb adapted to a herbivorous life-style, an adaptation that cannot get into the “system” of the panda because it is a descendent of creatures with thumbs evolved for carnivorous purpose. For the typewriter keyboard the point of comparison is to a keyboard adapted for maximum typing speed, which is similarly locked out of the system, because the typewriter is a descendent of an artefact with keyboard optimised for aural transcription of Morse code. In each case two value judgements have been made in arriving at this conclusion:

1. The judgement that a facet *is* a sub-optimal adaptation (poorly suited to a particular task). In order to arrive at this conclusion, there must be an alternative for comparison
2. The judgement of what the task of that adaptation *is, or ought to be.*

For a musical interface these two observations are very significant indeed. Technological lock-in, in conjunction with optimization to particular purpose, is integral to understanding the technology of music.

Lock-in and Sub-Optimality Within a Musical Context

From an Innovation Technology perspective, a reading of the first chapter would likely lead to the conclusion that the ReAPH is an evolutionary rather than revolutionary change. Adaptive elements are carefully considered, as is the market of early adoption and its position within musical tradition. But from the perspective of western music in the 21st century, the design is more revolutionary than it first appears. There are several reasons why this is so.

First, as stated in the introduction, expert performance requires at least ten years to develop: instrumental expert performance is acquired through constant repetitive practice, expert guidance and exposure to technique from a master. The systemic resistance to change is therefore endemic, and easy to understand from an innovation technology perspective, because a given generation of musicians has an investment in stasis (and is likely to propagate this investment).

Second, within western music we live in an era of maximal extension towards the right wall of most complexity in terms of variety of forms of musical instruments, when compared to the rest of western music history. The variety of interlinked genres of music is far greater, and this has provided an adaptive environment for a bewildering array of forms of western musical instrument to emerge. Beginning from the industrial revolution, the Victorian era saw considerable and characteristic innovation from a mechanical perspective, and the twentieth century has seen an extension of this into the electronic domain and studio practice. The continuous development of processing and storage capacity, coupled with experimentation upon novel interfaces for human/computer interaction provide a rich environment for musical innovation, and it is this area which demonstrates maximal capacity for change at the moment. A learner musician in the west now encounters a very large choice of musical instruments to learn, a further wide choice of instruments from other cultures (now widely available) and further potential to explore sound and music more freely using studio technology.

Innovative adaptation of instruments remains common where it extends the domain of expert performance — particularly in relation to genre change. Hence there is an enormous variety of guitars. But whilst specific adaptations lead to variety in the phenotype of the instrument, the underlying structure almost always remains essentially intact, a guitarist is able to understand the design intent, and to play to a certain extent, a particular variety of guitar immediately, despite exterior variation (change is evolutionary with respect to the domain of expert performance). The accordion (and free reed instruments generally) may perhaps be cited as an exception — genre and regional variation render the playing interfaces exclusive to an extent, and this is a subject worthy of later discussion.

Lastly, we must understand that *all* musical instruments compromise musical capability in one respect or another — it is this compromise and corresponding prioritisation that allows the individuality and strength of voice of an instrument to emerge. Adaptation to a particular musical purpose, or set of musical purposes renders the instrument sub-optimal for other musical purpose, and the player is locked-in to a particular repertoire which conforms to this set of purposes, and to a particular role within musical ensemble situations.

Let us first consider this with respect to string interfaces displaying extreme difference. The number of strings on an instrument varies greatly: a piano has approximately two hundred and thirty, the Chinese *erhu* (most often) has just one (sometimes two). The musical intent of the two instruments is very different: The *erhu* is designed to play predominantly monophonic music (melody), whilst the piano prioritizes polyphony (simultaneous note combinations).

For the *erhu*, change of pitch is given by the fingers of the left hand physically stopping the string at different lengths by pressing them against a fingerboard. The fingerboard gives maximal control of pitch; it gives the potential for a continuous spectrum of pitch change; indeed, conforming to a formal tuning system represents the development of a considerable performance technique. Variety of timbre is given by a bow in contact with the strings and controlled by the right hand. The bow provides the potential for rich and continuous variation to the note produced through a combination of pressure, speed, angle of attack (affecting the amount of hairs in contact with the string) and movement between bridge and fingerboard. These parameters continuously affect the amplitude (loudness) and the harmonic content (timbre) giving a rich variance to the detail of the melodic stream.

The 230 strings on a piano are combined to provide an even dynamic range across 88 notes. In the low bass, one string per note is sufficient; the mid bass provides two strings for each note and the treble are combinations of three strings tuned similarly. The intent of the interface is to provide advantageous access for the hands to polyphony — to play combinations of notes across a wide range of pitch. Notes are accessed by a mechanical action, the player pressing keys that results in a felted hammer striking against the strings. The keyboard interface bears no relation to the variation of string length, this is disguised into the shape of the instrument. The linear-spaced keyboard interface is capable of considerable polyphony; commonly combining between four and eight notes in polyphonic streams. The key mechanism is sensitive to varying force that results in both a range of amplitude and a variation in harmonic content (as the strings are struck harder, the tone becomes brighter). This timbral variety is extremely limited however, when compared to the richness of control provided through a bow in continuous contact with the strings[3]. The keyboard is a particular type of adaptation to a large, or very large, digitized array of sound producers, which maximises the potential for random access to varying note combinations.

We may continue this illustration by adding a narrower comparison; for this, we might add to the comparison set; a guitar and a violin. The guitar usually has six strings, though there is some variety, a violin has four (occasionally five). Each is capable of both polyphonic and monophonic playing, and each repertoire contains examples of both, but though each

[3] Various designers such as Andrew McPherson (magnetic resonator piano) and Sarah Nicolls (inside out piano) and performers such as Xenia Pestova do however extend and enhance this timbral capability by reconsidering the nature of the relationship between the keyboard, player and strings.

is capable in both domains there can be no doubt that the guitar is more adapted towards polyphony, and the violin to monophonic playing.

Like the piano, the guitar tone is based on decay rather than continuous energy input given by a bow. Guitar strings are plucked or strummed as a group. Finger contact can vary from a soft-toned finger skin pluck to a brighter nail contact; groups of strings may be strummed using nail, skin or plectrum. Many guitar playing traditions also add finger picks of different materials to achieve particular tonal characteristics. Movement along the length of the string also varies the tonal characteristics of strum and pluck — movement towards the bridge achieving brighter tone. Timbre and tuning can also be affected after the note(s)' onset through vibrato or string bend from the stopping hand (guitars are played both left and right handed). Overall, although both instruments are based on decay, the guitar player has a much wider potential for timbral variation than a pianist.

A guitar bridge presents the strings as a flat array. The spacing between the strings is relatively wide (around 10mm) at the bridge, but varies depending on the type of guitar: steel strung spacing is closer than for the classical, nylon strung guitar. A narrower spacing makes a better strum surface. But the relatively wide spacing allows the strings on *all* guitars to be addressed individually, in combination, or all together. In contrast the bridge of a violin is arched. The steepness of the slope of this arch varies slightly — steeper arches for classical repertoire, allow bowing to address any two of the four strings together, shallower arches are often used for folk playing and, with sufficient bow pressure, allow three strings to sound together. This gives a significant potential for polyphony, but in practice it is difficult to control. The guitar fingerboard is fretted; raised frets are set underneath the strings so that finger pressure behind the fret shortens the speaking length of the string to a set distance between fret and bridge. This assists the production of polyphony because it is easier to control the tuning of complex chord shapes across all six strings — the tuning is provided by the precisely measured fret. The fingerboard of the guitar is therefore digitised and does not provide a constant spectrum of pitch variation. In contrast the violin, like the erhu, has no frets; the speaking length of the strings is given by the finger pressure stopping the string. Tuning by finger position alone, across two strings in combination is very difficult to control for complex music. This is one of the reasons why folk music relies on a great deal of straightforward first position playing, and open drone strings used in double and triple stopping (bowing two or more strings at once). Double stopping (polyphony) is a significant aspect of violin technique, but the repertoire is, unarguably, predominantly oriented towards melody.

All four of these instruments compromise and prioritise musical capability in one respect or another. Each involve the player in complex, co-ordinated movement of both arms and hands together, and expert performance on each produces music at the limits of physical co-ordination. It is not, however, the limit of human appreciative capability, and this is perhaps one of the reasons why music, irrespective of culture, is a communal activity and in more sophisticated musical cultures, always involves specialist roles with respect to the nature of the music. All musical instruments are adapted to a particular musical purpose, and are thus, sub-optimal for other musical purposes.

Conclusions

The ReAPH/autoharp compromise/prioritisation takes a large array of strings and places upon it a damping mechanism played with one hand, whilst the other hand addresses the strings. This is a reasonable musical compromise and is comparable to the guitar. From the perspective of a pianist one hand is sacrificed from adding to the polyphonic capacity in order to produce direct contact with the strings, and therefore to increase the timbral capacity of the instrument. A reasonable balance may be summarised. An optimally adapted instrument should be able to:

1. Provide a significant capability to produce polyphony; this will be more limited than a piano, but should demonstrate comparable flexibility to that of a guitar; ideally this flexibility would be increased
2. Provide a similar range of the timbral capacity to the guitar when engaged in polyphony
3. Provide a similar capacity for individual melody as a guitar, this is expected to differ as it will lack some timbral capacity such as vibrato and string-bend (because the stopping hand is not in contact with the strings). However, access to sequences of individual notes may actually be improved in certain circumstances.

From this context we arrive at a slightly different perspective of what may constitute a balanced instrument, which provides a framework for exploring a range of variation. Significantly, the autoharp interface, even at its most complex fails to achieve any of the aims stated above. Capacity to achieve polyphony is limited to a choice of 24 chord bars, and timbral capacity is also limited by the over-damping mechanism. Excellence of technique might compensate for the damping arrangement, but the limited capacity to achieve polyphony remains.

Having established the balance of parameters for musical compromise and optimization required for the ReAPH/autoharp interface, we may now refine our fundamental questions:

What is the optimal string array/damping mechanism arrangement to achieve these parameters?

To explore this we must interrogate the three aspects that comprise the design; the keyboard, the damping mechanism and the string array, searching for other innovative and comparable solutions, and possible application and development.

We may further ask: *should there be a range of potential interfaces*? And*: to what extent can variation be incorporated into the vision of the instrument?* The autoharp itself demonstrates a considerable degree of variability in its specification, to the extent that as expertise grows, players tend to customise their interface. This wide range of variation seems unusual from a pianist's perspective; as if nobody can quite agree on exactly what the instrument should be. The autoharp is not alone in displaying a significant range of design however, and study of related forms illuminates the different sets of selective pressures that cause this to happen.

3. Related Forms

What is the optimal string array/damping mechanism arrangement?

Should there be a range of potential interfaces?

To what extent can variation be incorporated into the vision of the instrument?

Introduction

This chapter explores the artefacts that comprise the ReAPH design, keyboard and string array in detail, interrogates each, and examines the potential in related musical instruments to influence the design. We arrive at precise notions of optimum configuration, and range of variation at its conclusion. This exploration proceeded contemporaneously with prototyping practice, and whilst it is not the purpose to detail prototyping here, in two cases it is necessary to understand the problems encountered in prototyping in order to assess the potential in related forms. In each case we will document prototype progress from the perspective of the design meme-set itself, focussing on musical problems of interface rather than overtly discussing the detail of the design changes and compromises that resulted: these are the meme-set of *keyboard* as applied to the string array, and evolution of the *string compass and pitch set.*

Autoharp Evolution

The invention of the autoharp is commonly credited to Charles F. Zimmermann of Philadelphia. A US Patent 257808 was granted in1882. Zimmermann certainly contributed much to the popularisation of the instrument in the United States of America, but the instrument that he produced and popularised was based more closely upon the design work of Karl Gütter. Ivan Styles' "The True History of the Autoharp" is considered the authoritative historical re-construction and Styles unhesitatingly credits Gütter as the true inventor (Styles, 1990, pp. 1–3).

A comparison of the patent drawing submitted by the two supports this view (Zimmermann, 1882)

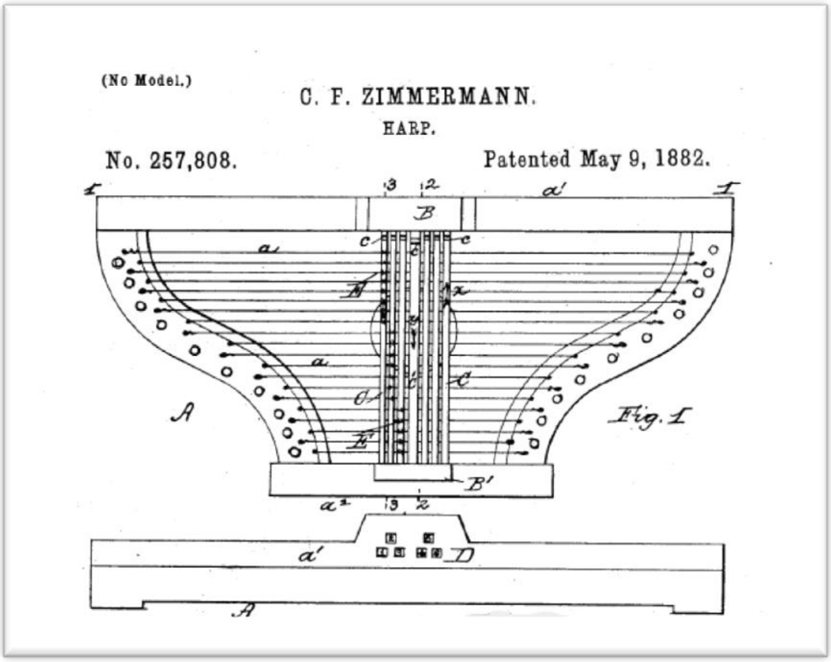

Figure 3.1. US Patent 257808 (Zimmermann, 1882)

Status: Public Domain

Zimmermann's drawing conceives chord bars, which damp *between* the strings by *pulling the damper bar sideways*.

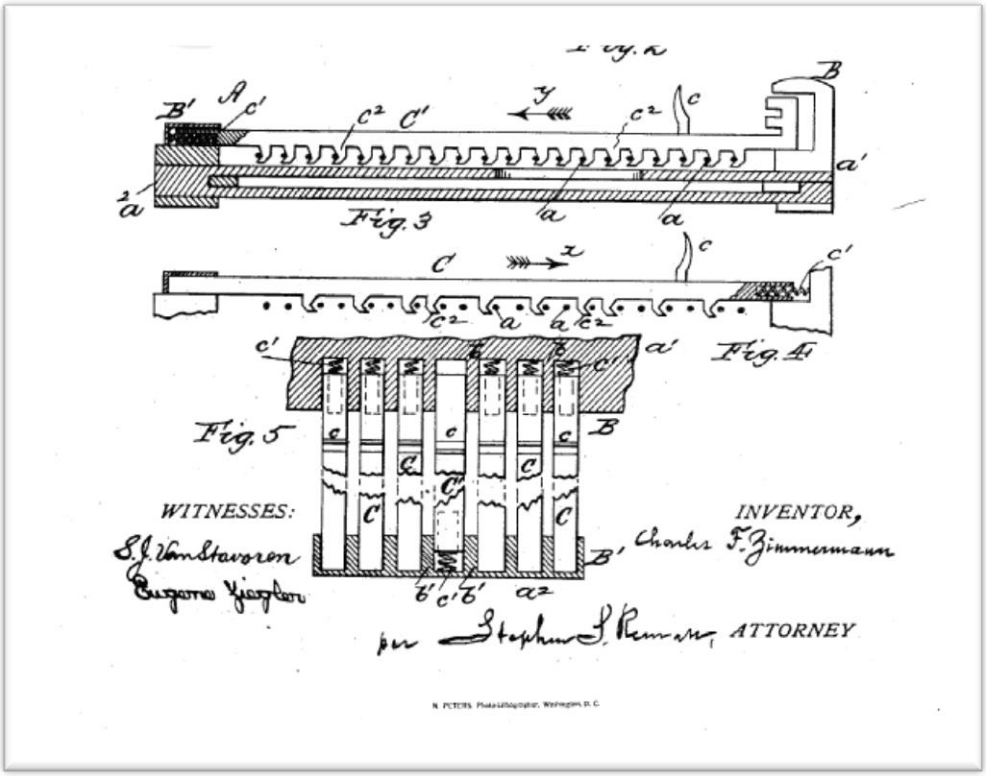

Figure 3.2. US Patent 257808 (Zimmermann, 1882)

Status: Public Domain

Figure 3.3. Zimmermann playing his own invention (Styles, 1990)

Status: Public Domain

A photograph of Zimmermann playing a version of this instrument is also produced within Styles' article.

However there are extant examples of the instrument that Zimmermann actually produced (photograph right). This is a type 1 Zimmermann production model dated at c. 1885–88, it is a diatonic tuning in the key of C, with three chord bars providing IV, I and V7 from the *toe* to *dead*[4] end of the instrument.

Figure 3.4. A Type 1 Zimmermann production model (Harrison, 2004)

With permission

The instrument here is clearly the same as described in the Gütter patent. Styles reproduced these original drawings from his research in the foreign patents section of the US patents office. (The drawings of this patent remain absent from commonly available online databases, and this image is reproduced directly from the Styles article (Styles, 1990).

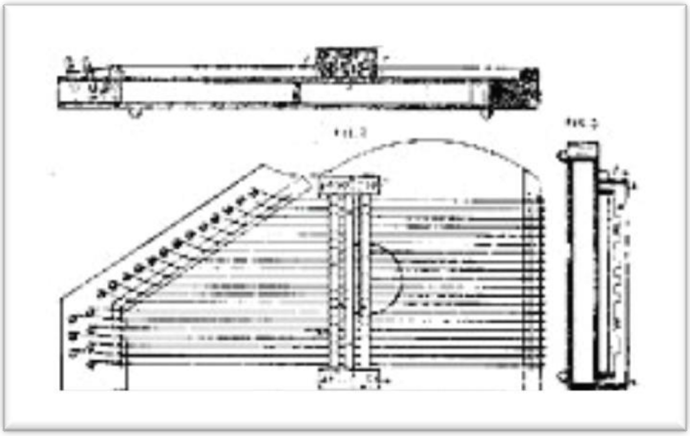

Figure 3.5.

Karl Gütter's original patent drawing (Styles, 1990)

Status: Public Domain

Styles identifies a trip to Germany as a source of Zimmermann's knowledge of this

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[4] The toe end is shaped to string length. The tuning pins are at the toe end. The dead end is usually straight, although it can be angled or contra-shaped to string length to optimise the playing surface. Later models add fine tuning mechanisms at the dead end of the instrument.

instrument. He speculates that Zimmermann might have felt this design to be easier to manufacture than his own.

The design is certainly a more straightforward playing interface; note the playing position in the Zimmermann photograph — the instrument is placed horizontally upon a hard surface rather than held. Whilst there are some autoharp traditions that still use this playing position, precise and virtuosic players more commonly hold the instrument against the trunk of the body, and strum across the surface. This is a far more natural strum/pluck position.

Zimmermann subsequently manufactured Gütter's design under the auspices of his own patent. This sleight of hand was challenged by Herman Lindemann, a German manufacturer who had bought the rights to Gütter's design in 1883. Lindemann issued a statement in 1890 "Warning: I warn hereby especially not to buy or sell the recently sold instrument under the name of Chordzither or Autoharp that are in the market as imitations of my patent 'Volkszither', but the challenge appears to have come to nothing.

— 52 —

Warnung!

Ich warne hierdurch ausdrücklich vor dem **An-** und **Verkauf** der seit einiger Zeit unter dem Namen **Chorzither,** auch **Autoharp** in den Handel gebrachten Nachahmungen meiner *patentirten Volkszither* (Deutsches Reichs-Patent No. 29930) und bemerke, dass ich bereits Anzeige bei der Staatsanwaltschaft gegen den **Verfertiger C. F. Thierfeld** wegen Patentverletzung erstattet habe, alle jene Personen aber auch zur Anzeige und Bestrafung bringen werde, **die sich mit dem Verkauf dieser Nachahmungen befassen.**

Klingenthal, 7. October 1890.

H. Lindemann,

Alleiniger Fabrikant der patentirten und privilegirten „Volkszither".

Figure 3.6. Lindemann's warning notice posted in Der Zeitschrift für Instrumentenbau (Journal of Instrument Construction) (Michel) Status: Public Domain

The first commercially available autoharps had extremely limited chord choice, and the instrument was at once subjected to selective pressure to extend its chromatic capability. We can trace three lineages of design thinking to allow this. One lineage saw autoharps produced with increasing numbers of chord bars, examples of 15 bar and 21 bar

Figure 3.7. Meinhold Autoharp with secondary crooks for damper bars (Harrison, 2004) with permission

autoharps became common; this is the standard contemporary design approach, and these types of autoharps are by far the most numerous.

Another approach introduced a further set of secondary damping control to the system. The Meinhold autoharp (above right) is one of the more straightforward examples. The twelve chord bars can be crooked a semi-tone in either direction, immediately increasing the chromatic potential. The Victoria autoharp, perhaps the closest formulation to Zimmermann's original, is another example of this. Unlike the maximised chord bar approach, extant manufactured examples are limited to 19th-century examples; though these are relatively numerous.

A third approach is to integrate a keyboard in a way similar to the ReAPH. Examples of such instruments do exist, but are exceedingly rare as we shall see. Because of the direct relationship with the ReAPH design, we will study this history as part of the prototype and patent process.

Keyboard Morphology

There are some features of the keyboard, that whilst perhaps not features of the (keyboard) lock-in are nonetheless, decidedly strong expectations that we have of keyboard instruments, and we begin with these because it gives us a general sense of what we think we mean when we speak of a keyboard from a musical perspective.

Dimensions

We generally expect keys to be of certain dimensions. There is a range of key size that to the eye and to an extent the player appears "full size", and this is wider than we might expect. Smaller keys do exist on musical instruments but our tendency is to think of these as toys, or starter instruments for children; the accordion (and possibly the melodica) are exceptions to this.

Historically, keyboard dimensions have varied considerably (125mm–170mm one octave span). Modern pianos present much less variation, but still vary between 164mm and 165mm (Bean, 1999).

Appearance

We generally, though not always, expect a black and white shiny surface to provide contrast, and we commonly refer to notes as “white” or “black” notes, and irrespective of the actual contrast provided by an individual keyboard (for example many harpsichord keyboards depart from this convention) we understand what we mean by black notes and white notes.

Feel

Though keyboards differ, we expect them to fall within a range of resistance provided through a sprung or weighted mechanism, and we expect a key to return automatically and speedily to rest. The amount of resistance always falls within this range — too little and the lack of resistance is disturbing to the player, whilst too much resistance affects the player's ability to play fast.

Kendall Ross Bean defines the current manufacturing standard for pianos as 50 grams key tip weight for minimum depression (Bean, 1999). This is not consistently achieved, and its application results in varying dynamic response across piano manufacturers. There is, as you would expect, even more variation across MIDI keyboard manufacturers, perhaps because there is less pressure to conform to stricter piano dimensions.

Because of the mechanical action of the hammers, piano keys need to deliver considerable power, and therefore pianists have a particular expectation regarding the pivot point of the keys, which is much longer than the size and shape of the playing surface would suggest. Because the black keys are further back, this results in two separate pivot points, for white and black keys, in order to deliver similar power in each case. The overall distance is shortened slightly for the black keys relative to the white keys, which allows for the fact that the most common playing areas are closer to each other than the overall playing surface suggests; we tend to play white keys close to the black keys (shortening the pivot point), and we tend to play on the ends of the black keys — as close to the white keys as possible (maximizing the pivot point). This slight shortening and maximizing of the pivot point results in similar keylever ratio, and from a playing perspective, evens out the overall feel of the keyboard. Whilst the design constraints described are consistently applied, the pivot point does appear to vary across different models (between the range of 215–220mm).

We expect the keys to drop approximately 1cm, again, this can vary slightly depending on the mechanism that the keyboard is coupled to. However variance too far from a narrow range around this measurement is disturbing and affects performance. I derived this measurement empirically through measuring a number of varying keyboards with attractive actions, prior to designing the keyboard for prototype 2. Kendall Ross Bean defines the optimum as 3/8” (9.525mm) (Bean, 1999).

Lastly we generally expect individual keys to trigger a sound through means of its coupling to the sound producer (though free reed instruments do not conform to this principle).

Considering the range of keyboard application, there is a high degree of consistency in the presented playing interface across different keyboards. Pianos, organs and harpsichord particularly, display good consistency in terms of dimensions and weight. However, there is recent interest in variation of key size, and this is relevant to this study. The practical research appears to show that pianists with smaller hands benefit considerably from 15/16 and 7/8 sized keyboards (Boyle & Boyle, 2009). There is one current piano manufacturer, Steinbuhler & Co, Pennsylvania making both upright and grand pianos in these formulations. In principle it would be relatively easy to vary the dimensions of a keyboard as applied to the ReAPH according to the requirements of the individual player.

Keyboard Meme-Set Applied to the Autoharp — Problems with the Musical Interface

If harmony only is the aim, then in principle, you only need twelve keys on the keyboard — each acting as a lever system to an octave reverse-damping bar applied to the autoharp body (as described in the introduction) — all chords are possible from this. In practice, as I built successive prototypes I found that the adaptive potential of the interface was significantly improved from pianistic perspective by adding just a few more keys. The first prototype had only twelve, beginning from C at the bottom and ending at B. This arrangement looked superficially pretty because of the symmetry, but I wasn't satisfied with it.

When playing the instrument there is a problem point for the left hand in turning the bottom of the octave into the top whilst the right hand continues up or down. The direction of play for the hands is momentarily separated as if the pianist were caught in a Shepard tone[5]. This is initially disconcerting, and is true for both melodic and harmonic constructions. For example, suppose the right hand on the string surface is playing a rising passage in A minor from A to E — given twelve keys the left hand must drop a major seventh from B to C to continue the run, whilst the right hand continues upwards continuously. We will call this problem “wrap around”. If we are to limit the number of keys, this problem will always remain, but can be mitigated, to provide greater flexibility. I knew immediately that I wanted at least a top C on the keyboard, which I added to the second prototype. The doubled keys perform the same functions and are connected to the same damper bar. This spoiled the symmetry of the instrument somewhat, and it still didn't feel quite right.

It is of considerable advantage to be able to change the point at which the left hand drops or rises. But any increase in the number of keys has to be balanced against the conflicting selective pressures of increase in complexity of resulting damping mechanism (and overall fabrication) and increase in the width of the keyboard. The width of the keyboard was a particular concern, sometime after the construction of the second prototype; I had modified my playing position to that of the photograph shown in the introduction — I play seated, with the harp oriented at a steep angle with the end of the keyboard held between the thighs.

After deliberating on these conflicting pressures, I decided to reclaim the symmetry of the first prototype when I came to build the third, by adding a doubled C to E at the top. This gives a total of seventeen keys, and this seems to be a good compromise. The keyboard is a little wider, but the key sizes have been compromised slightly from the standard range discussed above. Adding five keys made the damping system more complicated, and this is a subject for later analysis. Crucially, this step allows for a variety of points for the left hand to drop or raise the octave. I was also more satisfied with the harmonic range (the

[5] A Shepard tone, named after Roger Shepard, is a sound consisting of a superposition of sine waves separated by octaves. The amplitudes of the sine waves are controlled by a bell curve, such that (unusually for human perception) the sense of pitch is not given by the fundamental, but by the higher amplitudes at the centre of the bell curve. A typical application developed by Shepard was a series of chromatic tones over the range of an octave where any adjacent tone sounds higher or lower than the previous tone, depending on the context in which it is played. The effect of playing a continuous rising chromatic scale therefore, is that it always rises, but never seems to get significantly higher. This effect is often compared to the visual effects of Escher paintings.

increase in the variety of chord inversions and substitution positions approximates more closely to pianistic training for the left hand) it is therefore much more adaptive than squeezing all of the chord positions into one octave.

Understanding Keyboard Evolution

Our interrogation of the keyboard as an interface should include establishing why it is present in the first place. Keyboard instruments have such dominance in Western music and its education system, that without at least some understanding of the evolution of western tuning systems, we accept without question the division of the octave into twelve semi-tones that the interface suggests. But in fact the governing ratio of the twelfth root of two and the strategy of tuning twelve equal semitones that results, are relatively recent innovations, which arise hand-in-hand with keyboard standardization. Our initial exploration of keyboards therefore will lead to a corresponding focus on tuning issues.

Twelve semi-tones appears to be an unusually high number of divisions of the octave when placed in the general context of human musicality, although there are higher — North Indian classical music divides the octave into 22, for example. The most frequent number of divisions is between five and seven, although the number might be as low as 2 (Blackfoot, North American Indian Music) (Patel, 2010, p. 17). The Complex formal tuning systems deployed in North Indian and Western music however, disguise the fact that number of tones likely to be used in any musical presentation is much less than the overall number of tones in the governing tuning system, and that some instruments within the tradition are not even capable of playing all tones in a single performance without retuning; lever harps and to an extent, the orchestral pedal harps are example of this. Keyboard instruments, as they originated (perhaps surprisingly), were also an example of this.

Such instruments exist and thrive within our musical system because a good deal of western music, as it is written and presented to the listener, does conform to the normal range of human musicality; the major scale and common modes all contain 7 pitches, as (arguably) does the minor scale, despite the variation in the 6th and 7th degree (variation is most commonly a contextual either/or decision). North Indian music also conforms more closely to the human norm in performance deployment; individual *ragas* commonly use between five and seven divisions. These performance sets also conform to another norm across human musicality — they are asymmetrical. The range of between 5 and 7 pitches, in conjunction with the asymmetry, is optimised to human pattern matching capability with respect to pitch — the differences in the asymmetry across cultures account for a great deal of the culturally specific meaning which is conveyed within musical performance and composition (Patel, 2010, p. 314). The differentiation by asymmetry is not localized to pitch systems; it is also present within tonal languages and arguably informs all human ability to classify (Saffran, Hauser, Seibel, Kapfhamer, Tsao, & Cushman, 2008).

An unusual feature of a good deal of Western music however, is its propensity to change key within a piece of music (modulation). This is a process that has become increasingly common through several centuries of musical change; each generation of composers and performers gradually expanding the boundaries of key change, and the range of complexity within individual chords. We might usefully describe key change, as a realignment of the tonal centre for some duration within the piece, such that an alternative set of pitch relationships is now the subject of elaboration. The equal temperament division clearly allows for modulatory procedure, because all intervals except the octave are slightly compromised with respect to Pythagorean whole number ratios based on the harmonic series, but the ideal tuning response to modulation would be a set of divisions based on simple whole number ratios originating from the new tonality. Analogue instruments without frets, such as violins, have the capacity to achieve this accuracy of tuning (though in practice this is highly dependent on the skill of the player) but for highly digitised instruments such as keyboards this is not possible.

This was the problem that faced early makers of keyboard instruments; if we take an octave of keys on a keyboard, and tune simple ratios[6] for a given key centre — then the keyboard will play perfectly in tune for that key. The tuning will also be adequate for related keys, but will sound increasingly out of tune as function of distance from the key centre used for the tuning origin. There is thus a conflict presented to the player, composer and instrument designer. The linearity presented in the keyboard interface suggests that the capacity to modulate freely to all keys is relatively easy to achieve, but tuning simple, whole number ratios does not allow this possibility.

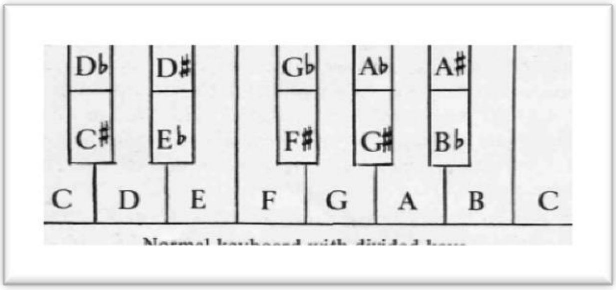

Figure 3.8. Common keyboard arrangement to allow alternative tunings; divided black keys, (Thomas, 1975). Permission Sought

6 For example Pythagorean or Just tuning.

There are three possible solutions, all of which arise in keyboard evolution:

1. Complicate the keyboard interface to allow for greater tuning possibility. A common arrangement is illustrated in the diagram above.

In this arrangement the black keys are divided into two and each connected to a separate sound producer (string), tuned slightly differently.

The height of complexity for this approach is embodied in the 31 note cycle used by Nicola Vincentino (1511–1572) who describes a harpsichord with six rows of keys (Thomas, 1975, p. 150).

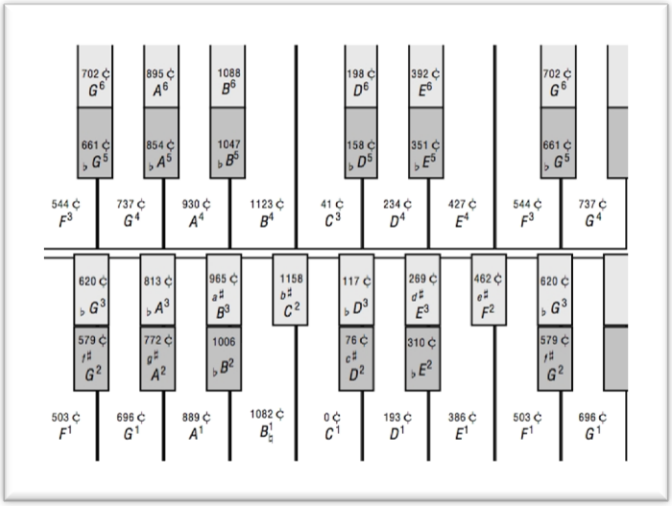

Figure 3.10. The 31 note cycle applied to Vincentino's harpsichord (Lunlunta99, 2007).

Status: Public Domain

The diagram right shows the tuning system (in cents) as applied to the 6 tiers of keys. There are key points to note here: firstly, despite the complexity, the fifth remains a compromised interval throughout the enlarged circle of fifths though it is very close indeed to a simple 3:2 ratio. Secondly, the number of individual stable tunings of strings that need to be achieved and maintained is very large. Lastly and perhaps most significantly, the keyboard interface is very complicated indeed — difficult for the player to interpret, and combinations physically difficult for the player to achieve. The photograph below, an extant harpsichord made by Vito Trasuntino Venice dating from around the same time, with five rows of keys, shows how this complexity actually appears to the player.

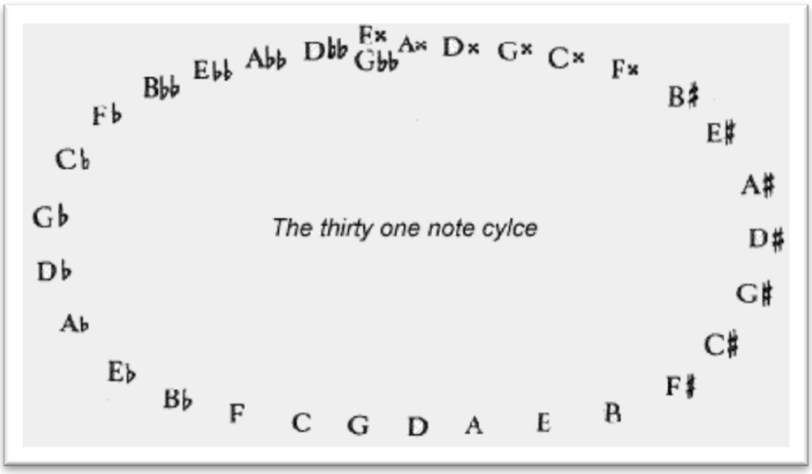

Figure 3.9. The 31 note cycle perhaps for 2/7 comma tunings (non – cycling) (Thomas, 1975). Permission sought

Figure 3.11. Trasuntino's archicembalo (Museo internazionale e biblioteca della musica di Bologna, 2011)

Status: Free Art Licence

2. Another possibility explored by early keyboard makers was to couple the key to alternatively tuned strings. The technology necessary for this was already extant: developed for timbral and dynamic variation, an even more pressing problem than tuning for harpsichord makers. Unlike the keyboard of a piano, harpsichord keyboards are not responsive to key pressure, and dynamic and timbral contrast is affected through terraced introduction of alternative couplings. Accessed through a mechanism at the keyboard; strings plucked closer to bridging points can for example, provide a brighter tone, or a second set of strings tuned at the octave can be coupled in. Utilizing this mechanism for tuning alternative is attractive from a performance perspective because an instrument can be set up at the outset of a musical presentation or modified during a pause, but the keyboard interface rendered to the player during performance is always the same twelve semitones.

3. The third possibility is that the tuning system itself be compromised to match the capability suggested by the linear keyboard interface, and this is in fact largely what has happened within western music. We do not normally encounter divided keys on contemporary keyboard interfaces, nor do we encounter alternative coupling. We also do not normally encounter any of the alternative cycling temperaments that compromise (temper) simple tuning ratios unequally across the 12 semitones. The tuning system which has emerged as standard is equal temperament. It is the blandest possibility, but also offers the most obvious potential for compatibility in different musical situations, and was therefore the most obvious candidate for standardisation for instrument manufacturers.

These historical approaches to increasing the tuning flexibility that a keyboard instrument provides, whilst fascinating to consider, are not advantageous in design terms for the

ReAPH; but tuning flexibility *is* nonetheless well worth considering. Although we expect keyboard and equal temperament to go hand-in-hand, it is only by convention. We encountered diatonically tuned autoharps in the first chapter and equal temperament is clearly not the only, or even the most advantageous tuning choice for this arrangement. If extreme modulation is not necessary and access to diatonic range is prioritised then alternative simple ratio tunings are likely to be preferable.

To what extent is retuning for particular performance possibility a realistic proposition on an autoharp/ReAPH? Guitars with 6 (or the doubled 12 string variation) are often tuned alternatively with reference to a particular key centre; for example, an open G tuning will retune the strings to simple ratios to formulate a beatless G chord using the open strings (tuning DGDGBD). Tuning only 6 (or even 12 strings) for a particular performance situation is a perfectly reasonable proposition. Tuning 36 strings (standard chromatic autoharp specification) is rather more ambitious; with practice, I have found the time taken to accomplish a full tuning to be between 12 and 20 minutes with the current design arrangements. This is a significant interval of time, but not unreasonable when compared to the 230 strings of a piano.

However, there is possibility for considerable enhancement here from a design perspective. Autoharps traditionally rely on friction pins, similar to (though smaller than) those on a piano. Higher end models include a fine-tuning arrangement at the dead pin end. Zither pins, which require a hammer for tuning, are ungainly, imprecise, slow and prone to error, but they have the advantage of being cheap, and fitting easily into a small space that the large string array allows. The fine-tuning mechanism at the dead end of the instrument is ill-suited to the ReAPH configuration (as opposed to the autoharp) because so much of the dead end of the instrument is covered by the keyboard, making access difficult. In terms of the engineering of tuning mechanisms there are certainly better alternatives. Guitars need no fine tuners because the precise movement of geared machine heads renders this unnecessary: precise tuning is achieved with relative ease and stability through one mechanism. A discussion of possible implementation of this device to the ReAPH is given at the end of this chapter.

Later keyboard innovators had no such concerns with the complexities of tuning, and there are a number of 12 semi-tone alternatives to the standard keyboard that offer direct alternatives to the traditional piano keyboard layout that we should consider.

Keyboard Alternatives

An alternative to the traditional keyboard array was proposed and patented in 1882 by mathematician and musician Paul von Janko.

Figure 3.12. Paul von Janko (Doge, 1911, p. 90)

Status: Public Domain

The keyboard layout is shown in the plate below. We may first observe that there is no intention to reference the keyboard from any particular point, as is implied in the layout of a traditional keyboard, because the layout is symmetrical. Each row sets out a whole tone scale, the corresponding row below or above is a whole tone scale, one semitone displaced. The pattern of colouring white – natural, and black – sharp/flat is retained from the traditional keyboard layout, which provides visual clues to translate note meaning.

The design intent of this symmetry is that it leads to a reduced learning time because scales, modes and chords are to be found in similar positions throughout the keyboard.

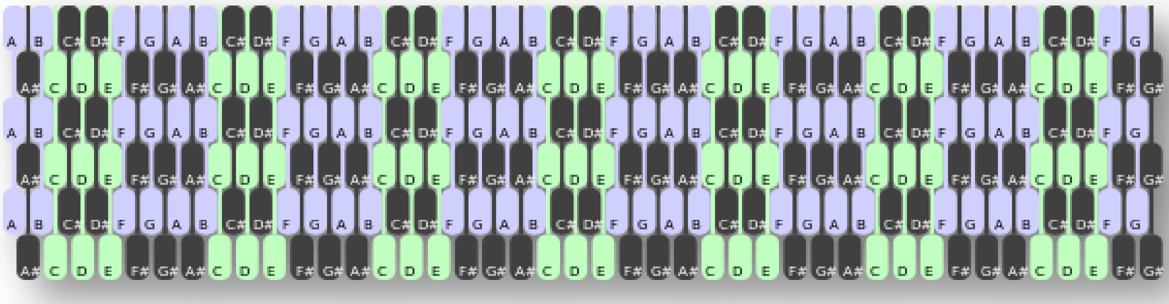

Figure 3.13. The Janko Keyboard Layout (Handige, 2008) Status: Public Domain

Figure 3.14.The Janko Piano (Museum of Musical Instruments Germany, 2010) Status: Creative Commons

Consider a major scale in this arrangement — three whole tones along a row, then a row change to accommodate the semitone between E and F, followed by four whole tones, and lastly a second row change.

Unlike a traditional keyboard this pattern produces a major scale irrespective of the starting note. The learning times of traditional building blocks of technique, scales and chords, are therefore said to be reduced when compared to a traditional keyboard layout. Further, as a direct consequence of the symmetry, transposition (a difficult skill on a traditional keyboard layout, becomes trivial). These properties define the Janko layout as Isopmorphic; self-transposing and symmetrical, such that the same sequence is always accessed by the same shape. Fret boards may also be said to be isomorphic in all but the proportional spacing within the frets and there are similarities to the learning approaches required for isomorphic keyboards and fretted string instruments.

Secondary aspects of the design intent are to reduce the nominal size of the keys to increase stretch potential, and to increase the potential for the hands to interact independently in the same range; this is the purpose of the multiple layers.

A good demonstration of the keyboard in action is given by the musician Paul VanderVoort (VanderVoort, 2012). The video extract presented in this link was recorded in 1986, Vandervoort appears to have become interested in this keyboard design quite early in his career. However, this attraction is highly unusual for a pianist and the proportion of users of the Janko (or any other isomorphic) array on large keyboard instruments, such as pianos, organs or harpsichords, is negligible, and has not reached even the minority user levels of Dvorak typing keyboard layouts. Janko himself spent his final years in exile in Turkey; allegedly fleeing the debts accrued through investing in his invention.

Explanations for the lack of traction within the musical community highlight the immediately obvious features of lock-in, beginning with the earliest commentators. Alfred Doge (*Pianos and Their Makers*), for example, writes in 1911 “The piano virtuoso and teachers of the present day are opposing the Janko keyboard because its universal adoption would mean for them to forget the old and learn the new. The music publishers object to it, because their stock on hand would depreciate in value, as the Janko keyboard naturally requires different fingering than that now printed with published compositions” (Doge, 1911, p. 80). Explanations feature; continuity and compatibility with regard to manufacture, maintenance and expert performance, and pedagogy, as reasons for lack of acceptance; they do not tend to challenge the advantages claimed by the design itself, and they do not seek comparative analysis as to why the range of variation is so narrow within piano design, when compared to, for example accordions.

The case for real and decisive learning or technical advantage remains to be proven for the Janko and the entire story, and resulting debate, has many parallels with the QWERTY/DSK debate. Since information is given by investing in interfaces to a level of expert performance, the debate tends naturally towards polarised positions; evidence is difficult to assess and truly objective evidence is very difficult to gather.

However, there is no technical design obstacle to producing a ReAPH that incorporates a Janko, rather than a standard piano keyboard; compatibility is established from the original design parameters set by Janko (that it works with the standard string layout of a piano). Nor should we dismiss the potential to attract early adopters to this interface, because the interface might prove attractive to players of free reed instruments such as the accordion (where isomorphic interfaces dominate) or even to players accustomed to fret boards.

Free Reed Interfaces — Comparing Range of Variation

Free reed instruments display an astonishing variety of playing interfaces, including a large variety of traditional and alternative keyboard layouts (accordions) which include isomorphic layouts; there are also finger holes and keyed mechanisms similar to woodwind key extensions (*shen*) and direct-access, un-damped arrays (harmonicas). This stands in sharp contrast to pianos, organs and harpsichords, where the playing interface has evolved towards a stable simplicity, and is highly resistant to modification.

Why should this be? Firstly, in evolutionary terms we pre-suppose that we are discussing similar units of classification; a moment's consideration tells us that we are not. Pianos, harpsichords, organs (we might add to this all similar MIDI keyboard interfaces) are natural units of classification from a playing (and design *for* playing) perspective. We draw a lineage through them precisely for this reason, but the sound producers are variable; plucked strings, struck strings, reeds, air reeds and once into the electronic domain; synthesis and sampling. Free reed, is a classification *by* sound producer; a very different perspective.

According to the most used classification system (Hornbostel-Sachs) free reed instruments are classified at 412.132. (Aerophones/free aerophones/Interruptive free aerophones/sets of reeds/*accordion, harmonica (sheng) etc.*) — fourth level classification. Pianos, organs and harpsichords classifications are dispersed, as you would expect because the sound producers can be different, and the secondary interface is the unifying factor. There is however, no reason not to draw a unit of classification by keyboard interface, if it is useful, and as long as we remember that we are comparing different units of classification[7].

A better like for like comparison would be to compare the entire spectrum of string arrays, together with their playing interfaces, to the entire spectrum of free reed instruments and the variety of interfaces that they display — and here we find a comparable level of variation. The comparison seems reasonable because we are now classifying and comparing two types of sound producers and their deployment, and, because the comparison illuminates crucial differences between the two, it enables us to understand exactly why free reed keyboards have evolved differently.[8]

Assuming that we accept (for the moment) that based on the empirical observations above, the comparison between free reed and string arrays is a valid categorical comparison: what differences can be observed in the two spectrums?

Firstly, change of pitch is conveniently addressed in design terms through stopping the same strings at different lengths (*erhu*, violin, guitar). Variable combinations of polyphony are achieved through a mixture of stopping and combining strings in limited numbers — limited to two-at-once and occasionally three on the violin, but with the addition of frets (which may be viewed as a limited secondary interface) increasing to 6 string combinations on the guitar. Digitised arrays with secondary damping interfaces, as we know, range from the medium sized autoharp/ReAPH (36–49 strings) to the extreme piano (230 strings). Such arrays are extremely resource intensive.

In contrast to a string, an individual free reed has a very limited capacity for pitch change; each is a single unit, tuned to a fixed pitch. The (more or less) fixed pitch nature of the free reed means that unlike string arrays we do not expect instruments featuring smaller

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[7] See appendix 1 for a fuller discussion of classification systems.

[8] We might also note that within the same Hornbostel-Sachs classification systems, string instruments are a top level classification (chordophones: *sound is produced by the vibration of a string across fixed point*), so according to the most used system we are *not* comparing like for like. Hornbostel-Sachs however, is one of many proposals for a classification system of musical instruments, and it is riddled with inconsistencies. I do feel that this comparison is at a comparable classification level and to support this Appendix 1 provides a fuller discussion of classification systems.

numbers of reeds. On the other hand, individual reeds are also cheap to produce and highly flexible in terms of design deployment, when compared to strings. They are not under tension, and instruments are free from the design constraints imposed by this. They are also small and require minimal space and thus lend themselves to incorporation in medium, large and very large arrays. Free reed instruments are, therefore, always formulated in arrays, but when compared to a comparable string array, they do not appear to be large instruments.

Arrays, with no secondary damping mechanism are present within the spectrum of variation, but are significantly outnumbered by the number of instruments that do incorporate secondary damping mechanisms.

Figure: 3.15. Guo Yi (郭艺, Pinyin: Guō Yì), a Sheng player beside the River Thames, outside the Tate Modern Gallery, London, England. (Pingstone, 2005) Status: Public Domain

Free reed instruments are thought to have propagated to the west from China. Direct evidence of Chinese instruments dates as far back as 1100 BC, and an even earlier Malaysian instrument might have been the origin within China. Evidence for the existence of free reed instruments is also found in ancient Greek and Egyptian civilisations, which may be independent points of origin.

Figure 3.16. The Sheng (Seasonaldemand, 2012)

Status; Creative Commons

The Chinese sheng has an intriguing secondary damping interface not used in the west, giving the instrument good potential for polyphony, and for melodic/harmonic combination playing, the instrument also looks very impressive.

It is commonly used to accompany soloists, and within ensembles, plays both a harmonic and melodic role. The design consists of up to 21 pipes coupled individually to doubled free reeds tuned to the same resonant frequency (Doktorski, 2000). The second set of reeds are reverse in orientation to the air stream so that the instrument responds similarly to outward and inward breath. Each pipe has a finger hole drilled within its bore, which changes the resonant frequency of the pipe. The pipe will thus only sound when the finger hole is covered, making it the same resonant frequency as the reeds. Pipes can be sounded individually or in varying combinations (Sheng_(instrument), 2011).

Figure 3.17. The modern Keyed Sheng (Taobao (Searching for Treasure, 2012))

Permission Sought

This highly flexible interface has been developed through the second half of the twentieth century with the addition of lever-keyed holes, providing independence between the pipe arrangement and hand access to keys. The number of pipes within the instrument has risen to 36, with a full chromatic range (Sheng_(instrument), 2011). A good demonstration of the varied capability of the instrument was given at the Atlas Academy, Amsterdam in 2009, by the player Wu Wei (Wei, 2009).

Harmonicas — Comparison to String Instruments Designed for Melody

Harmonicas are examples of the less numerous, un-damped free reed arrays, which rely on reed alignment within the array for access to advantageous combinations of notes. The most common reed arrangement (below) is accredited to Richter.

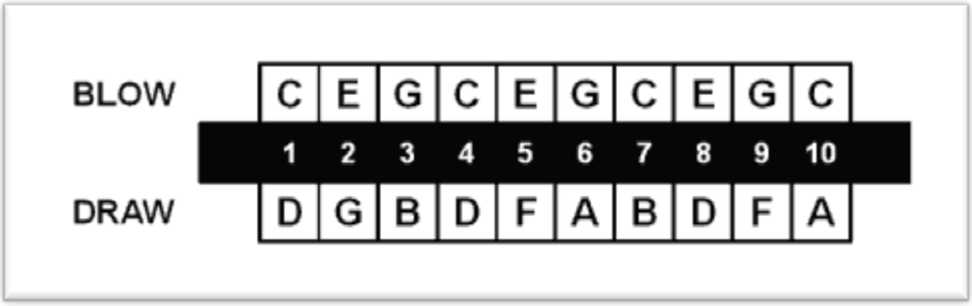

Figure 3.18. The Original Richter Tuning (Bennet-Lovsey, 2012)

Status: Permission granted

The earliest published reference to this invention is to be found in *Zeitschrift für Instrumentenbau* (Journal of Instrument Making) Vol. 3, No. 21, published in April 1883 (Missin, 2008). According to harmonica history, Richter is credited with the invention of blow/draw reeds and the pitch arrangement depicted above. As we have seen, blow/draw reeds were in existence long before this point; but the original application to this particular lineage of free reed instruments is probable. The same is in fact true for the reed arrangement, which was common in other European bisonoric[9] free reed instruments of the time, including the accordion (Missin, 2008).

The harmonic possibility offered by this array is apparent immediately from the arrangement; as are its severe limitations. The chromatic variant provides a full chromatic range by means of a slider, which engages a second set of similarly tuned relationships, a semi-tone higher. This enriches the melodic capacity of the instrument, but its harmonic capability remains limited.

Figure 3.19. Chromatic Harmonica (slider right) (Arent, Chromatic Harmonica, 2005; Arent, Accordion, 2006)

Status: Creative Commons

9 Bisonoric instruments utlise blow and draw reeds of different pitch

In fact, despite the name “harmonica” — the design intent of both instruments is primarily melodic, the chromatic harmonica, most commonly used as a solo instrument in jazz ensemble settings, and the diatonic harmonica as a solo instrument for blues (for blues, the layout above depicted as C would be most commonly deployed for blues played in G).

The first great strength of the arrangement of the instrument is its timbral capacity. The mouth is placed directly behind the reed, and this enables a direct coupling of the mouth (cavity) to the instrument. Altering the shape of the mouth when playing therefore alters the timbre of a note, or combination of notes, to an extent that is unusual within western music. Good demonstrations of the instrument involve descriptions of jaw and tongue movement, and describe shaping of the mouth cavity in ways similar to language. This direct access also enhances the ability of the player to choke the air flow to the reeds to perform analogue pitch bends, adding to the language-like character of the instrument. Access to single notes can be facilitated by damping adjacent reeds with the tongue to enable a single note or melodic strain. A second strength of the instrument, particularly utilised in blues harmonic playing, is its rhythmic capability, facilitated by the learning of suitable vocables. Again, there is a striking speech-like quality to the resulting music, distinguished by accent and timbral variation.

										D		←	**Whole step blow bend**
								F	Ab	Db		←	**Half step blow bend**
	D	F#	A	D	F#	A	D	F#	A	D		←	**BLOW**
D	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**			
	E	A	Db	E	G	B	Db	E	G	B		←	**DRAW**
	Eb	Ab	C	Eb		Bb						←	**Half step draw bend**
		G	B									←	**Whole step draw bend**
			Bb									←	**Step and a half draw bend**

Figure 3.20. Diagram to show blues scale in A played on a D harmonica in second position (Bennet-Lovsey, 2012) *status: Permission Granted*

We can draw a number of comparison points with the string arrays without secondary damping mechanisms previously discussed; violin, *erhu* and guitar — the properties display some convergence. Violin and harmonica display great capacity for timbral variation; the speech-like qualities of the harmonica are very different to the bow of a violin, but the capacity for variation is comparable. There can be no equivalent to the analogue pitch variation of the un-fretted violin within free reed designs, but the harmonica does, like the guitar, display capacity to bend pitch. The capacity to achieve polyphony is present in all harmonicas, but like the violin, is limited. Lastly, though the range of genre engagement is very different, the roles these melodic instruments perform within their respective ensembles have many commonalities.

A significant divergence however is the relative size of the instruments; for reasons already observed free reed arrays require a much greater number of individual sound producers, but despite this, the instruments are relatively small in size. A 16 hole chromatic harmonica has a four-octave range, and to increase this further would not significantly alter the size of the instrument at all. This is a significant difference, which continues through the spectrum of design of free reed instruments.

Even very large arrays of free reeds, comparable in range and possibility to piano or church (pipe) organ remain portable. Considered from a player's perspective, this means that a portable instrument interface can become highly esoteric; adapted to an individual player because the instrument always travels with the player and can be relied upon not to change. Coupled with this, free reed arrays are very easy to re-deploy to the requirements of different interfaces, and unlike the majority of piano manufacturers, makers of high quality free reed arrays are highly responsive to even individual specifications.

In contrast, a pianist, organist or harpsichord player is required to play on the instrument provided at location, often in high pressure situations and without any testing or adjustment time allowed at all. This presents a significant challenge, and the player is reliant on good standardisation. There is therefore, a constant selective pressure to achieve and maintain standardisation across large, none portable keyboard instruments, particularly pianos. This is slightly different to the standard features of a technological lock-in situation, which are often cited as reasons for keyboard resistance to change. It is also *not* a conspiracy of continuity on the part of the establishment, and is *not* related to conservatism of manufacture, which are other factors commonly cited; it is simply a different selective pressure.

Accordions and concertinas, commonly classified together in colloquial terms as “squeeze box” rely on a bellows mechanism to sound the free reed arrays, which is held between the two hands and alternately squeezed and drawn apart. This group of instruments is reliant on a secondary damping interface in all cases, is always portable, and the interface variation is very large.

There are commonalities, and we should begin with these: located on the right hand side of the bellows is an interface designed for melody accessed by the right hand — it is quite common for this to be a reduced size standard keyboard arrangement. The left hand accesses an interface designed for accompaniment (from the left side). The two interfaces are entirely independent, and in the vast majority of cases the playing interfaces are different for each hand. There are references to left-handed instruments, but these appear to be very rare.

The photograph plate below shows seven examples chosen to depict the variety, and to enable us to understand and classify the diversity, in order to draw conclusions as to applicability to the ReAPH.

Figure 3.21. Seven examples of Free Reed interfaces, chosen to depict variety
Top left: Hohner Club II (Woehr J. , Jax RFCB Button Accordion Page, 2009) Status: Permission granted
Top middle: Weltmeister Piano Accordion (Arent, Accordion, 2006) Status: Creative Commons
Top Right: Reuther Uniform Keyboard System (Woehr J. , Jax RFCB Button Accordion Page, 2009) Status: Permission sought
Middle left: Bandonion: (Woehr J. , Jax RFCB Button Accordion Page, 2009) Status: Permission Granted
Middle middle: Mythos No. 27 (Murray, 2009) Status Permission granted
Middle right: Russian bayan (A World of Accordions Museum in Superior, Wisconsin, USA, 2008) Status: Creative Commons
Lower left: Hayden Duet (Woehr J. , Jax RFCB Button Accordion Page, 2009) Status: Permission sought

Top left is a Hohner Club II; this is a bisonoric system similar in capability to the harmonica. There are a great many variations of diatonic instruments and the most significant variation pressures at this level are genre and region. Woehr reports that “there is probably at least one variation for each European ethnic group” (Woehr J. , Jax RFCB Button Accordion Page, 2009)

To the right of this is the Weltmeister piano accordion, the right hand plays the two octave reduced-size standard keyboard, whilst the left hand accompanies. The *stradella* style accompaniment system, at its most flexible, will provide a mixture of chords, with up-to-two rows of single bass notes. A single column from this array will sound; isolated root, the third pitch of the major chord, then, proceeding from the third button; major, minor, dominant 7th and diminished 7th chords. The next column will repeat this pattern at an interval of a fifth. There is variation in chord deployment and the circle of fifth patterning, but the underlying principles can be understood from this description. The instrument is therefore chromatic, but with limited chord choice. In many ways, although the chord choice is wider, this type of instrument exhibits similar limitations to the autoharp, because the harmonic choice is locked-in to standard sets.

The (right hand) piano keyboard (intended for melody) is clearly fully chromatic. This instrument is most usually the image that comes to mind in considering an accordion within the UK, we tend to picture the instrument as a keyboard on one side and a row of buttons on the other. This popular image might lead one to suppose that the chromatic piano keyboard is the most favoured melodic interface. A reading of literature by designers, makers and players of accordions, however, reveals that the opposite is in fact the case; that on balance the traditional keyboard is not considered the most advantageous chromatic interface. There is considerable regional variation; Hans Palm reports that only 10% of Scandinavian accordions incorporate a piano keyboard, whilst in America the figure is 90% (Palm, 2006).

Top right is a similar instrument to the piano accordion, but the melody interface is clearly a Janko keyboard. Brian Hayden attributes the invention of the Janko layout to a much earlier 1811 patent by Trotter, though no known instruments resulted from this patent. He cites Janko as a *re-inventor* in 1885 and reports its incorporation in the accordion early in the twentieth century under the name uniform system (Woehr J. , 2009). This keyboard layout is rare on the accordion. Isomorphic symmetry on the accordion is more commonly created using interlocking rows of minor thirds rather than the whole tone of the Janko keyboard. In the example below, which is common, the rows of minor thirds are transposed by a semitone.

The bandoneon (middle left), the Russian bayan (middle right) and the high end Mythos free bass accordion (middle) all use variations of this system. The left hand manuals of many free bass accordions can be switched to the Stradella chord system described earlier. Good players of the free bass system report that piano and organ music can be read on the instrument with no adaptation. Again, the relative size of the instrument is striking, for whilst these are bigger and heavier than some of the smaller accordions, they certainly maintain portability.

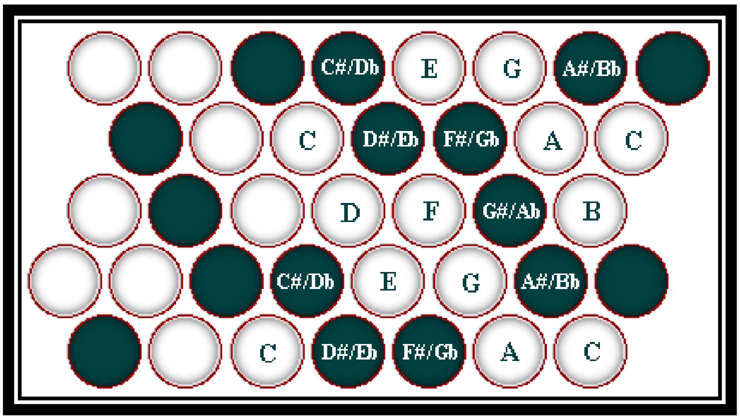

Figure 3.22. Isomorphic Keyboard Layout (Swedish System) based on minor 3rd symmetry (Palm, 2006)

Status: Permission Granted

The lower left concertina is a Wicki-Hayden layout (for both hands). This is a chromatic layout using whole tone steps (like Janko) but with the alternate row displaced by a fourth rather than a semitone. Wicki-Hayden is named after two independent inventors, separated by a century. Kaspar Wicki originally patented this layout in 1896 — again inspired by the Janko layout (Woehr J. , Hayden Duet, 2009).

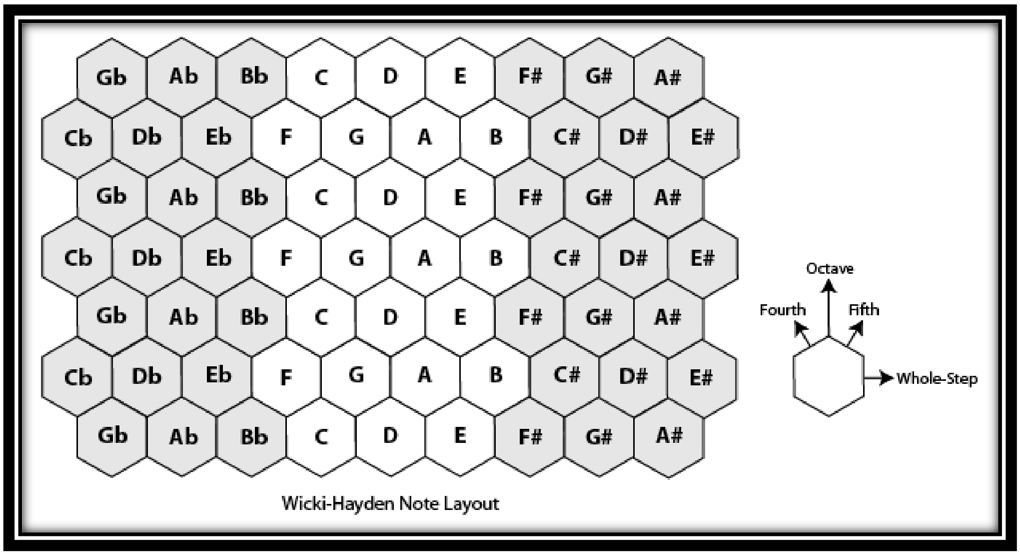

Figure 3.23. Diagram of the Wicki-Hayden note layout used on some button accordions and some isomorphic button-field MIDI instruments. (Waltztime, 2010)

Status: Creative Commons

Facts which become apparent from investigating accordion keyboard layouts, are that isomorphic arrangements are generally held to be superior; the claims for greater flexibility and reduced learning time are accepted. It is also accepted that different interfaces are required for different musical tasks, and that there *should be* variety. Piano accordions are held to be suitable for pianistic adaptation, but are not thought to be the most flexible interface.

The ReAPH, like the accordion, is portable, and the autoharp already displays variation consistent with a lack of selective pressure on standardisation (similar in level of variety to the accordion). So we might expect that a Janko, or other isomorphic keyboard adapted ReAPH, could be a viable and attractive variation.

There are some factors which need careful consideration in assessing their suitability as alternative keyboards for the ReAPH. Although perhaps not immediately apparent, all of the isomorphic layouts discussed are dependent on hexagonal tessellation, and share properties of self-transposition. However, they do differ from each other in several respects. Both the Wicki-Hayden layout, and all of the layouts basing the isomorphic symmetry on a minor third, introduce vertical movement to neighbouring pitches. This is not present in either the standard or Janko keyboard arrangements. To clarify: pitch movement is accomplished not only through movement along the rows (with incidental changes in manuals) it also moves up and down columns of hexagonal tessellation. The

Wicki-Hayden layout develops this concept fully. It is illustrated by the hexagonal icon on the right of the Wicki-Hayden diagram, which denotes the vector of interval travel (vertical and horizontal). Note that direction of travel for semi-tone movement is missing; and is problematic in this interface. The repetition of the first manual is an octave transposition — not a straight repetition like a Janko layout. Movement by octave is executed vertically rather than by moving along the row. To play a major scale in this layout, consider the white hexagons patterned in alternate rows of 3 and 4. The final octave pitch is given by moving up to a third row, this is a very easy repeating pattern.

Minor scales however present more of a challenge. Minor third based layouts need not pursue this vertical movement to the same extent. However, even for simplest case, three distinct rows of minor thirds are needed in order to provide access to all 12 semi-tones rather than the two rows of standard or Janko layouts, the five layer keyboard (figure 3.22), allows movement of five semi-tones in a vertical column, and so similarly introduces vector, as opposed to scalar, interface navigation.

This combination of vertical and horizontal movement is highly suited to the “squeeze box” arrangement because both arms perform double duty on all these instruments; simultaneously maintaining even pressure on the bellows and providing a support platform for hand access to the keyboard. In all, the wrist can be angled easily, but weighted lateral movement from the arm using the thumb as a pivot (the lynchpin of traditional keyboard technique) is difficult.

The combination would be less suited to the ReAPH for three reasons. Firstly, the hand orientation on the ReAPH is designed to be comfortable for a pianist, and to allow full integration of the thumb as a pivot. The keyboard is addressed from a supported position, with a straight, free wrist; as a result, weighted arm movement across the keyboard is not hindered. Too much vertical movement could disturb the carefully achieved balance between the hand positions. Secondly, there are considerable technical design obstacles to the repeating patterns presented in some of the keyboard layouts presented above, in achieving a successful coupling to the ReAPH damping mechanism. Lastly, although accordion keyboards (like the ReAPH keyboard) are passive (they do not produce a sound by themselves), the relationship to the sound producers is different. The accordion player has secondary interfaces under *both* hands, and these act in conjunction with the bellows, whose action is often likened to a bow — the shape and orientation of the reeds (and how they are addressed) is not a technical issue for the player. In contrast, the ReAPH or autoharp player has a secondary interface available to only one hand, which is coupled to a linear chromatic string array — changing the string array to match these interfaces is difficult to imagine, and presents significant technical obstacles.

The piano keyboard provides an intuitive reflection of the linear pitch layout. The Janko layout would provide a similar intuitive reflection, but the non-linear layouts would not; the isomorphic symmetry achieved through a minor third, and the displacement of a fourth integral to the Wicki-Hayden layout would sit uneasily alongside the linear string layout, and the activity of the right hand in contact with the strings.

I am confident in the logic of this particular part of the conclusion, and put forward the traditional keyboard and the Janko layout, as a suitable isomorphic alternative, for implementation on the ReAPH. Assessing the advantage of one over the other is more difficult, and is complicated by the issue of wrap-around when applied to the ReAPH. The most significant claimed advantages of an isomorphic layout seem to be the ease of structure learning and transposition. To what extent would these advantages be preserved in the reduced keyboard arrangement of the ReAPH — with the complication of wrap-around? As a first step I would suggest raising the compass to an octave and a fifth. This would not place pressure on the most significant measurement, which is the keyboard width, because the width of individual Janko keys is less than for a traditional keyboard. This extension would allow a root position placement for every triad (but the full benefit for example for four note substitutions would not be afforded without an extension to two octaves), and keyboard width would not allow this within the current design constraints. Melody is similarly constrained by the issue of wrap-around. In order to play a two-octave major scale on the string surface, it is necessary to repeat the same octave pattern on the keyboard (this is well worth practicing because it mirrors many melodic situations). It is, admittedly, quite difficult to repeat some of these scale patterns on the traditional keyboard. A preliminary assessment leads to the conclusion that this probably would be easier on the Janko keyboard. Clearly the self transposition benefit would be lost for scales above G but the patterns do seem to retain a repetitive quality when compared to the esoteric intricacies of the traditional keyboard.

However, this is extremely difficult for me to compare because the principle claimed advantages (self-transposition and structure learning) appear trivial to me. I compare from a situation of complete familiarity with traditional keyboard to non-familiarity with Janko. It is difficult for me to remember a time when I was not completely familiar with all scales and chords on the traditional keyboard, I am, therefore, continuously transposing familiar patterns into unfamiliar, on the supposedly easier interface.

Further, objectively I consider that much more evidence is needed to support the claims for a reduced learning time for isomorphic keyboards, and treat the claims for this extremely cautiously. Claimants fall into two categories, and neither provides a good evidential platform. They may be proceeding from a situation of a secure knowledge of traditional keyboard — in which case you would expect a reduced learning time, or they proceed from a situation of frustration and incomplete learning of a traditional keyboard — in which case, you would, again, expect a reduced learning time.

Nor do I accept that a reduced learning time, should it be proven, necessarily leads to a more secure or superior technique as a final outcome; and for reasons previously stated, would predict that in fact the opposite might be more likely — that asymmetry, a fundamental factor in human pattern matching within music, results in increased technical security.

However, designers must be pragmatic; and I do accept that there is a strong belief in the technical advantages of isomorphic keyboards within the accordion community, that they are successfully deployed upon this instrument, and that this community allow for, and expect, much wider variety of interface to choose from.

Evidence that this is indeed the case was provided in September of 2014 when I received an approach from an accordion player, Ben Devoy, stating his intention to build a Wicki-Hayden reverse action autoharp using electromagnets as a damping mechanism. The introduction of electromagnets is not attractive to me — I do not want an instrument that has to be plugged in, but it probably resolves the technical challenges of connectivity and is a perfectly viable design approach. I have corresponded with Ben at fairly regular intervals since this time; he is clearly having a frustrating time getting the damping to work, though he seems to be gradually overcoming various problems steadily. I was very glad indeed to hear from Ben. It is one thing to encounter historical patents, but quite another to be contacted by a contemporary, who had dreamed up a similar idea.

Melodica

Before leaving the subject of free reed instruments there is one more instrument that should be considered and classified with the set. This is the melodica (also called the melodion). It consists of a single set of reeds, blown by the player with a reduced standard keyboard layout as a secondary damping interface, much like the right hand manual of a piano accordion, though variations with isomorphic keyboards have been proposed. Smaller instruments are played from a fixed mouthpiece behind the keyboard and raising the whole unit to the mouth; larger melodicas of three octaves can be played through an extended flexible mouthpiece. There is one set of reeds only, oriented to blow, although in principle there is no reason why a draw set could not be added, and it is a common forum discussion topic amongst players. Because of the distance of separation between mouth and reed, the instrument lacks the wide range of timbral variety that a harmonica demonstrates. However, it is highly adaptive to pianistic technique. A good demonstration is given by the Danish multi-instrumentalist Jacob Venndt (Venndt, 2008) demonstrating applied jazz piano technique. Venndt uses right hand alone, his approach primarily melodic, using polyphonic inflections to enhance the melody, as a pianist would. Further, the detail of the rapid accenting and other articulation within the melody also matches that which a pianist would achieve. This is unusual for a free reed instrument; in terms of dynamics and articulation, the accordion is closer to organ technique than piano because the bellows must perform double duty: accompaniment and melody simultaneously. At one point in this clip we see the appearance of the Andes Melodica; based not on freed reeds but an air reed mechanism. This gives a completely different sound, and also a reduced range of two octaves.

The melodica has a history of usage within reggae, and makes occasional appearances in other genres; for example, Steve Reich used the instrument as source sound for *Melodica* in 1966. Generally however the instrument does not tend to be taken very seriously; the cheap build quality of the majority of instruments and the small-sized keys probably account for a good deal of the reasons for this — but there is no principled reason to take the design any less seriously than, for example, the *sheng* or the accordion.

The instrument has a growing following and a number of people working to develop both the instrument, and musical perception of it. The Japanese composer Makoto Nomura is an example of such. The instrument is very popular in South East Asia, where it plays a central role in music education. Nomura describes his early passion for the instrument which developed directly from his primary school experience; his frustration at the lack of availability of professional standard instruments, and his eventual return to developing the instrument for a contemporary classical ensemble setting (Nomura, 2009).

The performances of Jacob Venndt persuaded me to look at the market, and I found three octave examples to be so inexpensive (less than £20.00) that it was impossible to resist buying one. The instrument, when it arrived, played well enough, but with some mis-tuning. Fortunately free reeds can be tuned relatively easily, though it is a time consuming process, and after this it played with an even response and tuning throughout its range.

Playing the instrument was an immediately rewarding experience, which complemented the ReAPH effectively, because it allows expression for the slightly different pianistic training given to the right hand in an effective context of continuous sound. The link between breath and accenting was as precise as the Venndt footage suggested — the keyboard almost feels velocity sensitive. Its appearance (an unfortunate bright blue plastic) left a lot to be desired however. Painful experience of prototyping has taught me of the importance of appearance of musical instruments in gaining acceptance in the musical community. A tone wood housed variant is made and sold from www.melodicas.com, and the sound characteristics described as much improved. Co-incidentally I was at a crucial point in developing 3d rendering skills for ReAPH prototyping when this bright blue plastic instrument arrived, and this seemed like a good opportunity for a start-to-finish test of drawing skills, applying; measuring, rendering in 3d, separating into components and printing 1:1, band sawing all individual components before assembly. This had the desired effect on the appearance, and was also extremely pleasing in terms of improvement in sound quality; the projected tone is richer and the feedback the instrument gives to the player much livelier. The 3d renderings of this design idea are included within the digital assets which accompany this written documents, together with an overdub recording of ReAPH accompanying melodica, which clearly demonstrates the different training given to left and right hands effectively deployed on the respective instruments.

For me, the melodica provided a spur to think about another string instrument, which specifically related to the immediacy of the adaptive environment for the right hand piano technique. The ReAPH, despite its great flexibility, can be frustrating from a melodic perspective particularly for improvising solo material; the left hand at the keyboard is at a disadvantage, because the vast majority of the motor training for melodic control is effected upon the right hand. This proposal is considered in Appendix 2.

String Arrays, String Arrangement and Distinction

Since the patent and general direction of research originated from the idea of a keyboard (a secondary damping interface and its application to the existing autoharp) we did not discuss the detail of the string array in the first chapter. Recall from this account, that the damper bars damp each octave occurrence of a pitch and that the remainder of the accuracy of pitch is given by the right hand technique upon the string face. The string spacing is relatively narrow (though there is variation — average 1/4” or 6.3mm) in order to maximise the number of strings to available space. Further, since the strings are arranged in a flat array, held facing away from the body, there is little to distinguish individual strings. There are two parts to this problem then:

1. Optimising string distinction because of the narrow spacing
2. Optimising orientation within the interface; recognition and isolation of pitches, and pitch groups.

Providing distinction to individual strings is a problem common to all large string arrays, and the purpose of this section is to analyse effective strategies on related instruments, and to assess the potential for their application to the ReAPH/autoharp.

Changes to the Autoharp String Array Meme-Set in Response to Keyboard Integration

The ReAPH prototypes share a common intent with the chromatic variant of the autoharp, which is to provide for the possibility of complete chromaticism. Though described as a large string array, 36 strings is still a relatively small number, and the autoharp takes a strategy of prioritizing greater strength in certain keys whilst compromising others. Through the prototype progression, the ReAPH string tuning arrangement has diverged from the strategy taken by the autoharp, and it is worth prefacing this discussion by understanding the expression of this selective pressure within the prototype series.

Figure 3.24. Diagram of string pitches used on a standard commercial 36 string autoharp

The diagram above shows a pitch range from a 36 string chromatic autoharp. Despite having immediate reservations regarding this system, I decided to retain it for prototype 2. A great deal of thought will have been put into these choices, and it is prudent to innovate from a position of practical experience of the incumbent system, using its design intent as a reference point.

I suspected that I would be dissatisfied with the bass, and this proved quickly to be the case. Secondly, I was rather puzzled by the choice of notes to be omitted from the next octave (above the bass), and once again this proved a frustration — particularly irritating was the missing G sharp below middle C for melodic playing. Lastly, I favoured increasing the number of strings and moving to a system of complete chromaticism. I suspected that the first two points might conflict with this desire, and this also proved to be the case.

The original system appears to be designed to give the impression of a chromatic range by providing complete chromaticism from middle C, and then by gradually removing increasing numbers of notes towards the bass range. Beginning with the G#, notes below are gradually removed to leave strength in a particular range of key signatures. Whilst I share the vision of the design intent, the means of implementation does not suit the ReAPH. The autoharp system is sound, if the intent of the player is primarily oriented to harmony, but the ReAPH needs a fully chromatic melody range to match the increased potential provided by the keyboard, and a stronger bass range.

Prototype 3, based on an Oscar Schmidt autoharp, also has 36 strings; but using slightly different gauges makes a different set of compromises. Instead of gradually removing more and more notes as we descend through the octaves, a distinct interval split is introduced between bass and melody range. The new, fully chromatic melody range begins from g to c''' (using Helmholtz pitch notation) thus matching the common melodic range of a violin/mandolin (to 3rd position 3rd finger E string). This gave access to a classical and folk repertoire from violin and mandolin, which could be read immediately, and it also provided sufficient chromatic melodic compass for jazz. It also reduces potential for “muddiness” caused by closed triads in the lower octaves. Six strings remain for the bass range, and are tuned E, G, A, B, c, d providing half of the circle of fifths (though these could be varied) with an interval of a fourth between bass and melody ranges.

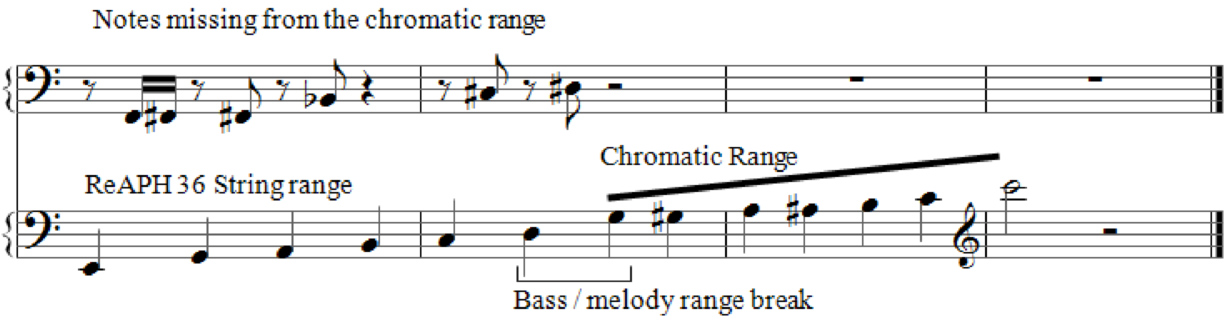

Figure 3.25. Diagram of Pitches used for ReAPH prototype 3 (36 string)

Quick access to the damper bars on this prototype was enabled through a hinged mechanism held with a clip. This quick release mechanism, it was envisaged, would allow alternative damper bar sets and provide the potential for the bass strings to be retuned to an alternative 6. In the event, I did not use alternative damper bars — this particular selective pressure was superseded by the need to prioritise effective harmonic damping (considered in the next chapter), so the clip mechanism was removed on the next prototype and a simpler more permanent mechanism applied.

The plan for Prototype 5 (42 strings) added three more strings to the melody range extending up (D’’’ included) and down (includes F♯), and three more strings to the bass range.

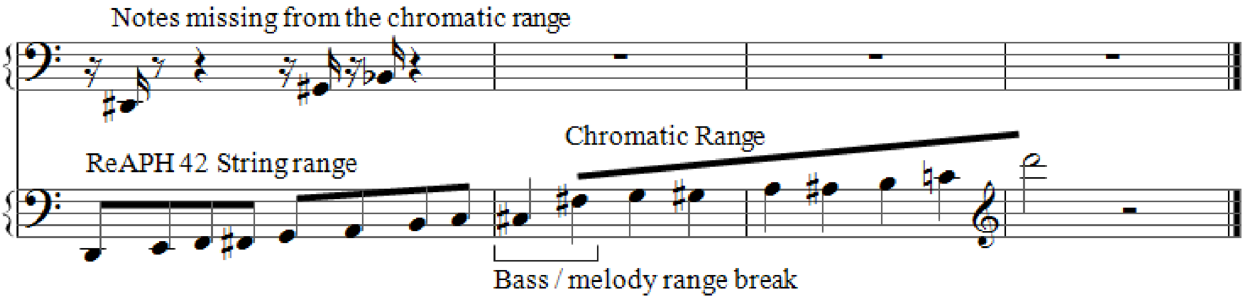

Figure 3.26. Diagram of Pitches used for ReAPH prototype 5 (42 strings)

The eventual tuning turned out slightly different because, upon testing, I considered that the low D had not been well enough achieved, and that the instrument would be better rendered from a low E. The three missing notes are F#, C# and G#.

A further 3 strings would be needed to render the bass range completely chromatic — a total of 45 for a completely chromatic instrument. Complete chromaticism does not necessarily imply a balanced instrument however, because this design pressure has to be balanced against issues of spacing and range. Initially I did not think it desirable at all; a significant restrictive factor is the span of the right hand between bass and melody range using a technique known as a “pinch”, using thumb and (usually) first finger. However, I am more sanguine regarding this factor following the long process of preparing the arrangement for, and recording Debussy's *Clair de Lune* (Brissenden P. G., 2012). The arrangement called for repeated accurate pinches at the edge of my right hand stretch-compass, and the right hand responded by developing a new kind of “spread pinch”, beginning with the thumb and interrupted at a more comfortable stretch by the melody note. The technique felt very natural for the *rubatic* shaping required by this musical material, but might cause rhythm dislocation problems in different repertoire; it brought to mind the playing of Paderewski, renowned as representative of the older romantic generation of pianists, who commonly played with non-co-ordinated hands (most commonly the melodic note was delayed and sounded after the left hand).

In light of this experience I now wonder if a chromatic bass octave might not be viable, even desirable, after all. But a second restrictive factor is my determination to include a low D at some point in prototyping. Low D is highly desirable for folk genres. 11 strings above this pitch, rather than the 8 agreed for prototype 5, might still isolate the low D string in terms of stretch, for playing in the very genre which requires accurate rhythm.

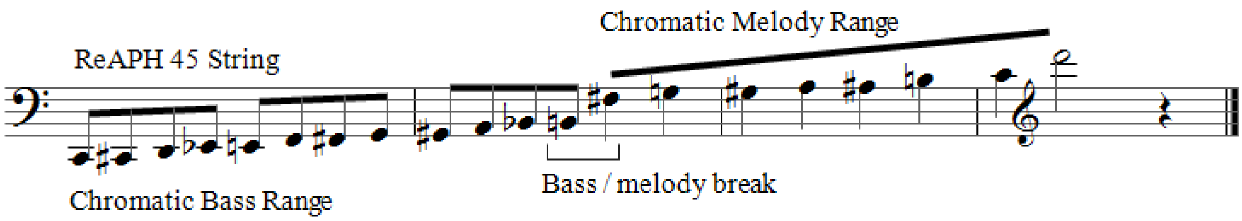

Figure 3.27. Proposed Pitches for Prototype 6 (45 string)

The arrangement above is a compromise, which offers a nine string spacing above the low D, which might be reasonable, but this would depend on achieving the low notes well in light of further improvements to the harp body.

The more I considered this area of practice, the more I concluded that it is likely to continue to display variability across individual instruments, depending on technique, hand size and genre engagement. Commissioned autoharps from luthiers already display considerable variation, and luthiers are used to responding to individual customer demand.

The largest autoharp ever manufactured is the late 19th-century Zimmermann concert grand (shown right); measuring 51cm across, it has 49 strings; and is thus a precedent for an instrument with a compass that would enable a complete chromatic tuning based on the principle of an interval split between bass and treble. This instrument also provides an illustration of the most straightforward way to provide a degree of string distinction (for recognition) — simply draw a keyboard to illustrate the string surface.

Figure 3.28. The Zimmermann Concert Grand: the largest commercial autoharp ever produced (Harrison, 2004) with permission

String Distinction

Though the tuning of traditional autoharps, and my vision of a ReAPH tuning differ slightly, and there is likely to be variation, there is nonetheless, a general principle; all systems seek to optimise chromaticism, the intent (and the ideal) is a linear, chromatic string array, which may be complete (minimum 45 strings for the ReAPH), or compromised, depending on the size and number of strings. As we turn to the issue of string distinction, we can dismiss from the sphere of influence large string arrays that do not conform to this principle, because these arrays provide distinction to individual strings by non linear pitch placement; examples are chorded zithers and the fretted concert zither.

Frame Harps

Distinction of individual strings on all frame harp string arrays is assisted by the advantageous playing position; frame harps are played from a side orientation, giving the player a line of sight across the string with each hand in view, engaging the strings from a different side of the string array. There is also a generous string spacing enabled by the instrument's large size and strings may be coloured differently to provide asymmetric pattern orientation. Instruments are capable of melodic/harmonic combination through isolation of combinations, which are plucked together; strumming is not central to technique on frame harps and is rarely used.

Figure 3.29. Erard Pedal Harp (teatermuseet, 2008)

The intent of the instruments is linear spacing, as it is for the ReAPH/autoharp, but true chromaticism is problematic. Simpler harps (and earlier historical harps) do not attempt chromaticism. The instruments are strung in a 7 note diatonic format, and rely instead on retuning of individual strings for key change.

Figure 3.30. Lever Harp (levers close up).

Selective pressure for the frame harp to achieve chromaticism resulted in two separate lineages. One branch retains a 7 note diatonic string tuning, and is always straight strung, relying on colour distinction of strings to provide recognition within the seven strings, and mechanical means to introduce chromaticism. Greater chromatic flexibility is given by increasing the ease and speed of retuning through moveable bridge mechanisms. This has resulted in two common forms, the lever harp and the pedal harp. Moveable bridges on lever harps (called sharping levers) are coupled to individual strings, and enable each string to be moved up or down by a semi-tone. Pedal harp mechanisms allow a similar three-way movement — the string can be raised up to two semitones, in addition to the open position, but the pedal mechanism is coupled to all octave occurrences of a pitch. The more expensive, orchestral pedal system is often held to be superior to the lever harp, but in fact each has advantages, and is suited to a different range of genre engagement. Because levers engage individual strings, specific combinations that differ across octaves are possible. This is an asset in folk melodic/harmonic combination, for example, where particular ornamentation can be set for the melody range, which is different to the lever settings for the chordal accompaniment. Pedal harps have the advantage of speed, and complete retuning across the instrument given by a single mechanism; this gives the appearance of seamless modulation and engagement with chromatic repertoire.

This 18^{th}-century innovation is slightly predated by a different branch of frame harp evolution, which achieves chromaticism by enlarging the string array to include all of the chromatic notes. Straight strung chromatic harps exist, but are rare because string distinction across 12 semi-tones is difficult to achieve, and difficult for the player to address effectively without disastrous dissonance occurring. The triple harp is one solution: it improves the interface by providing separate rows of strings. Two outer rows of strings are strung diatonically, accessed separately by each hand, and an inner row (the black notes) is accessed by both hands. The formulation first arose in Italy in the 17^{th} century, was subsequently widely adopted within Wales, and became a characteristic national instrument (Bowen, 2011). It achieves string distinction through an interface similar to the traditional keyboard layout. Despite the keyboard-like appearance, the interface has limited immediate adaptive potential for keyboard technique because of the different player orientation. Whilst a keyboard player understands where all the notes are, and is able to translate chord and scale shapes to the new interface, only the left hand is oriented correctly from bass to treble. The interface has many advantages, but its principle disadvantage is that it requires a lot of strings (and a lot of tuning).

A simpler solution built by Pleyel and Wolff in the 19th century is the cross-strung chromatic harp (shown above). The keyboard-like interface is achieved in this formulation through two string courses strung at opposing angles, which cross in the middle. An alternative symmetrical arrangement was also proposed based on cross strung whole-tone scales, providing an interesting parallel with the Janko keyboard arrangement, and would be the logical arrangement for a ReAPH Janko formulation (should application of the technique prove advantageous).

3.31.Modern Cross Strung Harp (Pleyel and Wolff design)

(Maloninski, 2006). Status: Public Domain

Clearly, application to the ReAPH would not look like the frame harp in the picture. The angle of crossover here is very steep indeed, and strumming across both surfaces is only possible at a very small intersection. This is not a problem for a frame harp because technique relies on pluck — the instruments are strummed only very rarely. The ReAPH angle would have to be sufficiently shallow as to allow a large intersection where the strings are nearly level, with a significant distinction appearing to the player only at the toe bridge. Such a small distinction, and the complex measurements needed to create it, might seem to argue against any significant advantage. However, this is a viable design strategy, and has the advantage that it does not rely on line of sight.

The overwhelming majority of string instruments appear to be strung with parallel string courses, such that the spacing between the strings remains constant throughout the length. This appearance is very often an illusion however; guitar, violin have a subtle draw in from the wider bridge, to nut end of the instrument. This can be seen on the violin when viewed directly from above. The variable string spacing provides maximum width and string distinction for the point of sound production (pluck, strum or bow), and a narrower spacing at the fingerboard.

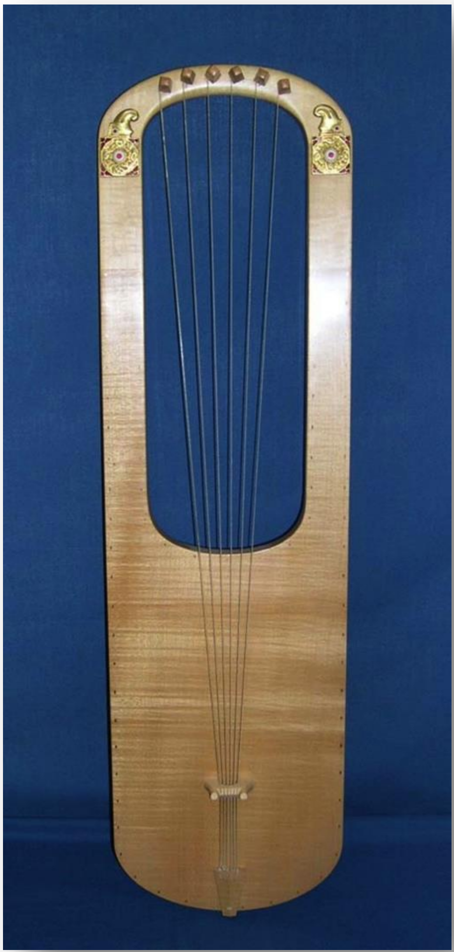

Figure 3.33. Reconstruction of a lyre from the Sutton Hoo ship-burial 1, Suffolk (England). Lyre reconstruction by Dolmetsch. (Plunkett, 2007)

Large string arrays, such as frame harps, tend to be strung in parallel arrays and autoharps follow this pattern. An example of an array that breaks the rule of parallel appearance is the lyre. The purpose of the variable string spacing here, is to provide a strum surface at the bridge, where the strings are narrow, which changes to a string spacing set for comfortable finger width at the nut.

The six-string instrument on the left is reconstruction of a 7th-century instrument; there are also similar examples with 7 strings, and larger instruments with a more subtle variable spacing, and also some examples that display parallel string spacing.

Figure 3.32 String Spacing on a violin (Bill, 2013)

The idea of the interface is that the left hand sits behind the strings and damps different string combinations (like a damper bar). The remaining strings are sounded through a strum much lower down the string face, where the strings are closer together. Corwen

Broch (Broch, 2010) provides a good demonstration of this technique.

The purpose of adopting a variable spacing would be different on the ReAPH. It would aim to provide wider string spacing towards the toe end of the instrument, suitable for more precise pluck technique. The angle of separation needs to be considered carefully against the design constraints of a large string array, and would need to be much narrower.

Overall there are three possible techniques to provide increased string distinction and recognition that are commonly found on large string arrays:

1. Distinction through colour contrast of individual strings
2. Distinction through variable spacing
3. Distinction through cross string techniques

Combinations of Strategies

If we compare an acoustic guitar strum surface of six strings, the string separation at the bridge is around 11–12mm depending on the model. An autoharp typically provides 1/4” string spacing (6.3mm). This quite a narrow spacing, assisting strum but hindering string isolation and a variable spacing might assist here. On a large array, this variable spacing will assist distinction, but not recognition, because continuous variable spacing will not introduce any recognisable asymmetry.

The pianist's instinct is to try to make the black notes stand out from the array, perhaps through colour coding and/or cross string techniques.

The ReAPH player does not have an advantageous line of sight across the instrument as there is for the player of the frame harp, which would seem to argue against a strategy of colour coding for string distinction. It is advantageous to develop technique that does not rely on sight at all with reference to the string interface. But this is true to a very large extent for any musical instrument, particularly where the issue of sight-reading becomes a part of the frame of reference. Good sight-reading is characterised by solid and unbroken engagement with the page with acute peripheral awareness of the instrument, bad sight-reading is characterised by hesitation in the music stream given by a distinct shift in attention from page to playing interface. This is often not noticed by the novice player, but painfully obvious to tutor and audience alike.

Developing sight-reading skills on the piano is highly dependent on the asymmetry of the keyboard interface — without looking down at the keyboard a player can move by touch to the correct position, and no notes need be sounded in this process. Nevertheless, keyboards allow for both the tactile navigation, *and* sight (the keys are colour coded). Isomorphic symmetrical interfaces often distinguish reference keys by indentations on the surface of the keys (there two such on the F and J key of a computer keyboard), and also code using visual stimuli. Guitar fretboards are nearly always inlaid at fret intervals to allow for visual orientation. It seems that many complex interfaces allow for a combination of visual and tactile stimuli.

How precise does the right hand technique need to be on the ReAPH? Given that much of the precision is provided by the keyboard and the damping mechanism, does it matter if surrounding, damped-strings are caught in the strum/pluck action? The answer to this very much depends on the mode of engagement. For rhythmic chord and melody combinations absolute accuracy is not a factor, and this is indeed one of the great strengths of the instrument. But the more melodic the playing, the more precise the right hand needs to be to bring out the true beauty of the melody; catching surrounding damped strings results in added noise — exposed during melodic playing. It is in this aspect that I really benefitted from contact with autoharp players, and particularly from one to one contact with Mike Fenton. For autoharp players, working with chord bars, dissonance is always only a slip of the right hand away — and there is a noticeable difference in the level of precision of good players.

It is fair to say that the linear string array of the autoharp presents poor visual and tactile orientation compared to other large string arrays. To what extent can we enhance the design in order to satisfy the demands of this particular selective pressure?

Distinction Through Colour Contrast of Individual Strings

Despite the lack of a direct line of sight whilst playing, colour contrast may be useful. A potential candidate for this purpose are coated guitar/bass strings manufactured by the company *Dr*. The coating is held to produce desirable sound enhancement characteristics, extend the life of the string and to minimise plectrum noise. These strings have the advantage of providing colour distinction, and are available in a range of colours — including black. However, these strings are extremely expensive, and really prohibitive for prototyping purposes. Acoustic guitar, coloured bronze round wound strings are available relatively cheaply however, sold from a number of different internet outlets as “rainbow” guitar strings. These would provide colour distinction for the bass range, but the plain steel B and top E gauge strings are not coloured, and unfortunately these gauges form approximately half of the ReAPH/autoharp.

Frame harps, based on nylon strings and wound nylon cores, offer an alternative. On these instruments the treble plain nylon strings are readily available in different colours, but the lower steel wound strings are not. This is altogether a frustrating set of findings for prototyping purposes — there seems to be no easy way to assemble a reasonably priced set of strings to provide colour distinction in order to test the effectiveness of the strategy.

Distinction Through Variable Spacing

Even variable spacing (meaning each string is strung to the same variable spacing) is a reasonable principle on a small instrument such as the Anglo-Saxon lyre discussed previously. For a large string array such as the ReAPH/autoharp, with the added complication of damping, the application is difficult, but not impossible. Variable spacing — a different space at the dead end (nut) and toe bridge, always turns the angle of the string away from the origin with respect to the adjacent strings. But variable spacing is also applied asymmetrically on some larger lyres and is used as a strategy to provide distinction of individual strings.

The projection left is the original string specification for prototype 6, using a 1/4”

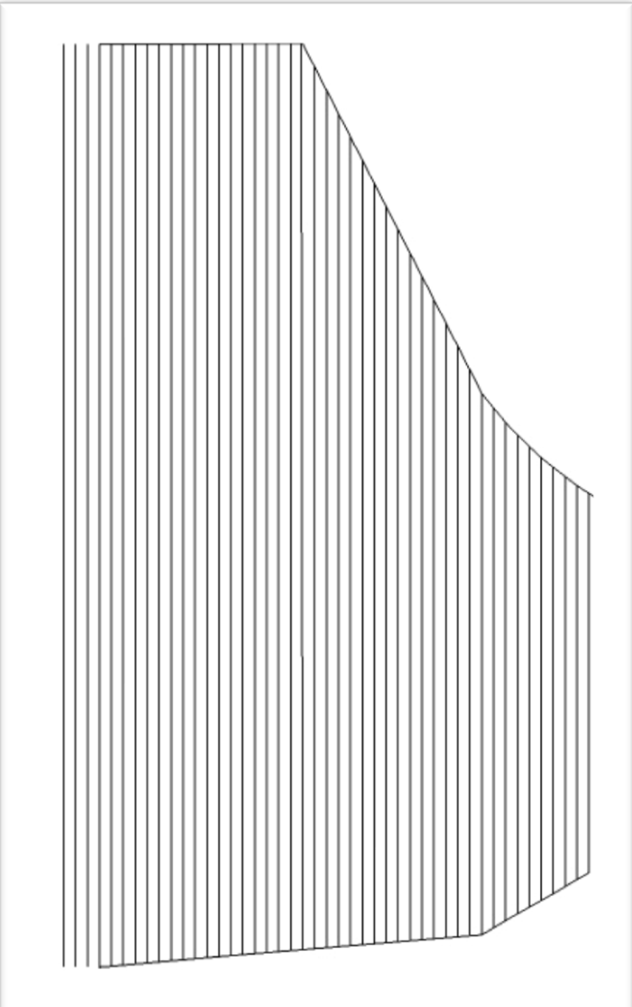

Figure 3.34 The original string specification for prototype 6 (45 strings)

(6.3mm) parallel string spacing and autoharp strings, with three strings added to formulate a fully chromatic range. The scale length of the bass strings is severely compromised and one of the ideas discussed is to use a longer string specification closer to guitar scale length. This change is included in the development of this set of design pressures because it assumed to encompass all of the features (such as improvement of the low notes) so far discussed.

The projection below is an attempt to provide asymmetric variable spacing to increase string distinction and recognition simultaneously, by distinguishing the black notes. The projection begins from the same point — the high D strings are identical on the two projections. Parallel ¼" spacing is then applied between white notes, and when moving white-to-black notes. Each black to white movement uses variable spacing, beginning from 4mm at the dead end and widening to 7.5mm at the toe end.

The scale length is calculated using guitar gauges using a 650mm scale length. The extent of the compromise to the high D string became clear during the process of this calculation; already perilously short, the pitch change from B through D is clearly accomplished as much through an increase in tension as a shortening of scale length. The eventual discrepancy on the high D is 192.4mm (calculated) to 202.2mm (measured). These calculations placed the planning for prototype 5 in a new perspective, and fully explained the flat refusal of my collaborator on this prototype (luthier Alec Anness) to extend above a high D). Some other variances are present in the projection. The lower string spacing — both variable and parallel, allows more space for increased string gauge, and the longer strings have a wider toe measurement for the variable spacing of 8.5mm producing a similar 7.5mm in the playing range. There is also a 9mm gap between the bass and treble range.

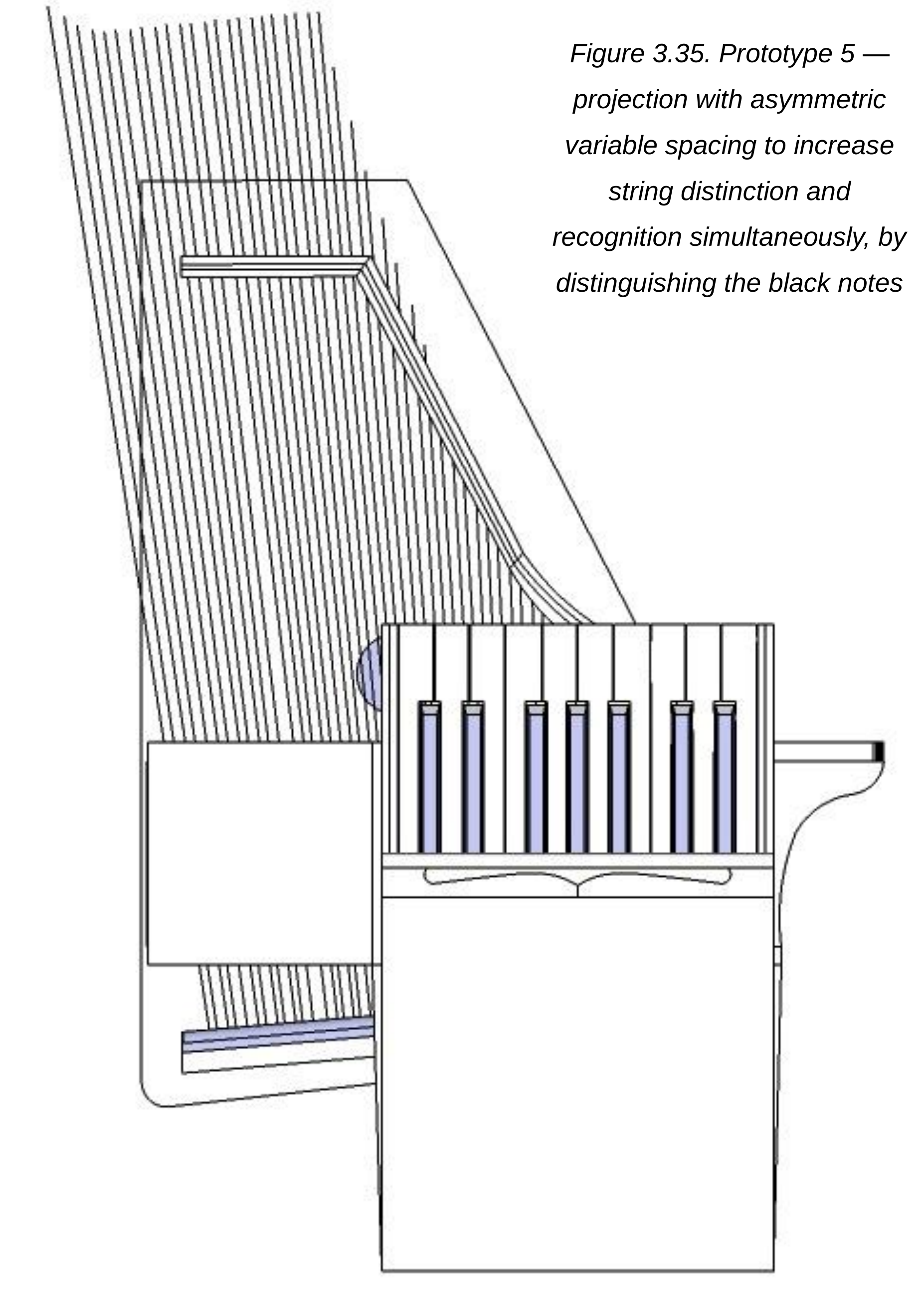

Figure 3.35. Prototype 5 — projection with asymmetric variable spacing to increase string distinction and recognition simultaneously, by distinguishing the black notes

Placing this new specification onto the body of prototype 5 reveals that many of the desired objectives are achieved. The string surface width at the dead end remains comparable to the original measurement, particularly considering that this rendering contains three more strings (prototype 4 specifies 42 strings). The width after the damping mechanism also remains comparable, and the widening at the top of the instrument is as great as can reasonably be expected. The string length at the toe end is extended by the desired amount (specifically: the extension should be minimised because right hand contact should be in the final 1/3 of the string). The success of the specification with regard to string distinction is far more difficult to assess. At the size printed for this text, the black-white patterning can be discerned after study. Printed at 1:1 the black-white patterning does become clear, but perhaps not “at a glance”.

Significantly, as a player, I was attracted to the fan shape immediately, and could imagine it on the instrument during playing. I found it aesthetically pleasing from a playing and visual perspective. There are several disadvantages to this projection from the perspective of distinction only. Firstly, it only widens the spacing 5 times per octave. This could be reversed, and the measurements could be tweaked retaining the asymmetry, so we could widen the spacing 7 times per octave as an alternative.

The asymmetry would be immediately lost however, should we attempt to reflect a whole-tone Janko keyboard layout in the string array, where a 50/50 division between parallel and variable would now reflect the keyboard. Or we might abandon this asymmetry and use this strategy to produce similar variable spacing throughout the array. Overall, the principle that the technique is possible, is established.

Distinction Through Cross String Technique

This strategy produces individual string delineation and unlike the variable spacing, it is almost impossible to illustrate effectively using 3d rendering techniques. The principle is simple, thinking first from a pianistic perspective, the black notes would be cross strung such that a near flat surface is presented to the right hand immediately above the damping mechanism, and raised at the toe end; white note orientation is not changed and is left flat. The optimum position will vary from string to string in order to render the crossover point similar with respect to the end of the damping mechanism. The main problem with this strategy is that the string surface presented to the damper bars is no longer flat and dampers of specific lengths would have to be created for each string. Considering the measurements (likely to be 1, 2 and 3 mm difference) and the nature of damping felt, this is likely to be a time consuming process to implement. It would not be possible to experiment with different damping positions to improve harmonic damping, so this problem would have to be solved prior to implementation. This aspect renders this strategy rather unattractive.

Overall, all three strategies have the potential for incorporation into prototype 6, but implementation is not straightforward. The first (and simplest) method, that of simply drawing in a keyboard, such that it is visible to the player at a glance from the playing position, remains a practical possibility that can be easily implemented.

Alternatives to Zither Pins

Finally we return to the discussion of alternative tunings. The possibility of rapid retuning would be greatly assisted by fitting geared machine head mechanisms as opposed to simple zither pins; machine heads are undeniably superior in engineering terms. Machine heads would be difficult to fit to an autoharp configuration, and would change the look of the instrument considerably. However, such an innovation *is* possible — some recent South American frame harps use machine heads in a double row with the strings fed into the void between them and a similar strategy could be deployed on an autoharp body.

Figure 3.36. Paraguayan Harp using geared machine heads (Griffindor, 2009)

Status: Creative Commons

We must balance the possible gain in design terms against establishment conservatism, because this step would possibly signal a revolutionary departure from expectations of autoharp body design. Prototype 3 was undoubtedly viewed as evolutionary rather than revolutionary at the UK autoharps meet at Mickleover in 2012, but all the tested design changes, excepting the precise pitches to which the compass of strings is tuned are upon the reverse damping action — the prototype is based upon an otherwise un-modified Schmidt autoharp.

Establishment conservatism can be quite extreme within musical systems, and often difficult to fathom; geared machine heads have for some time been commercially available for violin and are clearly superior to the friction pegs that they are designed to replace. Implementation would render the fine tuners at the bridge redundant because the precision is given by the gearing. Manufactures have taken great pains to produce the new mechanism so as to appear exactly like a traditional friction peg, but despite all these advantages, they are rarely implemented. There might be an argument against implementation on the violin from a weight and balance perspective, but no such argument exists for the 'cello, where the device is *equally* rarely implemented. In fact the arrangement of friction pegs at the nut, and fine tuners at the bridge is similar on violin, viola and ‘cello and then changes for the double bass, where geared machine *are* the accepted norm. This change is highly advantageous given the large size of the interface as it allows for simultaneous sounding of the strings whilst tuning.

The disguised violin machine heads would be make a perfect replacement for zither pins, the turning head is in line with the winder, rather than offset at 90 degrees like a guitar machine head, and the “alien” hand-turning heads could be hidden at the back of the toe pin block with only the string turning heads showing — so the appearance to the autoharpist would be relatively unchanged from the top of the instrument. Violin machine heads are however, prohibitively expensive for initial prototyping purposes, and probably for the foreseeable future.

Summary of Design Criteria Expressed as Selective Pressures on the ReAPH Prototypes

During this chapter we have constructed narratives around various design pressures, exploring their expressions upon various instruments, their relationships and their potential for application to the ReAPH. We have seen that many of the design principles that are desirable conflict with each other. The next chapter details the progress of the prototypes and the patent as a historical narrative. In summary, and also in preparation for this, we must now express the key design parameters formally and independently.

At the end of the introduction the fundamental design questions were expressed as:

Playing interface

1. Comfortable keyboard playing position for left hand whilst simultaneously providing:
2. Comfortable strum/pluck position for the right hand.

Design considerations

1. Maximising the playable string surface
2. Providing and effective reverse damping mechanism

As a result of the analysis provided by the previous two chapters, these fundamental questions can be considerably refined into a set of design criteria.

At this point the criteria for inclusion in this list is that the parameter is desirable, can be expressed as an independent meme, and understood as such. We cannot allow the complication of relationship or competition, but we can take account of it by expressing each, in a manner akin to an intended learning outcome. We are then provided with a checklist, and a point of departure for discussion and the prototype series can be measured against each of these through the various stages.

At the end of the prototype process the instrument should provide:

1. The optimum playing position (defined through the patent claim as expressed in the patent claim re-write of 9th August 2011)
2. A keyboard that conforms within the range of expectations of behaviour for a full sized keyboard in terms of appearance and touch & feel (this may allow for a Janko alternative which is compatible with the design).
3. The most efficient and practical pulley and string system.
4. Optimum balance of key movement (and return) providing effective force exerted by the key through a pivot point (and pulley and string mechanism) on the damper bar to un-damp strings and an effective return mechanism
5. The optimum number of keys (range min: 12 max (practical) 18)
6. Effective string and string harmonic damping
7. Minimal noise from the keyboard and damping mechanism
8. Effective integrated amplification
9. Optimised playing space on the string surface (particularly in the high treble)
10. Optimised string tuning, gauges and number of strings
11. Optimised access to mechanisms for maintenance
12. Optimised string distinction, considering variable spacing, visual (colour) spacing and cross string techniques
13. Optimised tuning (winder) mechanisms including geared machine heads

There some other acoustic improvements which are also considered for inclusion in the prototype series. These have not been a focus within the previous chapter because they do not form part of the keyboard and damping interface design, but they do constitute basic improvements to the sound of the instrument, which were studied and considered in some detail in the process of prototyping. For example: on most commercial autoharps the toe bridge is not directly coupled to the soundboard, because both the dead end nut and the toe bridge are placed over the frame material[10]. This provides a poor coupling mechanism of bridge to top plate. Considered together, we can summarize these as:

14. Optimised top plate design (to provide a suitably radiused dome or arched structure).

15. Optimised depth and volume of the resonating chamber

16. Optimised coupling of bridge and top plate; optimised spacing behind the bridge — particularly with regard to the bass strings, to improve the lower bass projection (range: add at least two inches of top plate space around the bridging point of the bass strings)

These design principles are abbreviated below in order to allow quick recognition within tables in the next chapter:

Action

1. Playing position
2. Keyboard: appearance and feel
3. Pulley and string system
4. Key pivot point to damper coupling
5. Key range
6. Harmonic damping
7. Minimal noise
8. Integrated amplification
9. Playing space on the string surface
10. String tuning and range
11. Access for maintenance

Harp

12. String distinction
13. Tuning mechanisms (winders)

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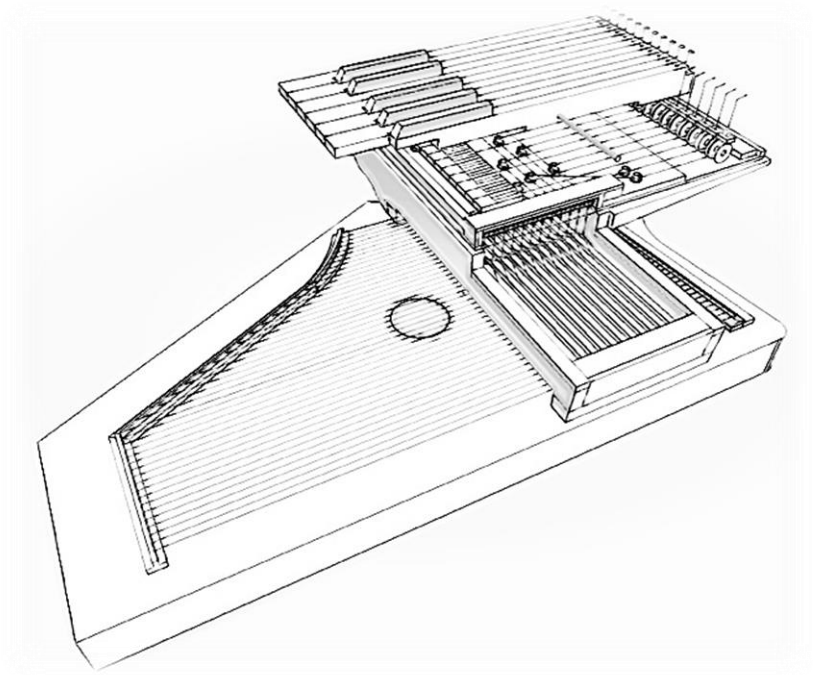
[10] In strict terms a bridge is defined as a member which transfers the vibrations of the strings to the soundboard or other resonant body whilst a nut is defined as a string bearer fixed onto a solid member which is not responsible for transferring vibrations to the resonating body, therefore both string bearers should be referred to as nuts. The application of “bridge” to the toe-end string bearer as standard throughout this text reflects the fact that design practice is mixed, but more ambitious acoustic design results in the toe end string bearer placed over the resonant body (therefore becomes a bridge). This is also the developing design intent for the ReAPH.

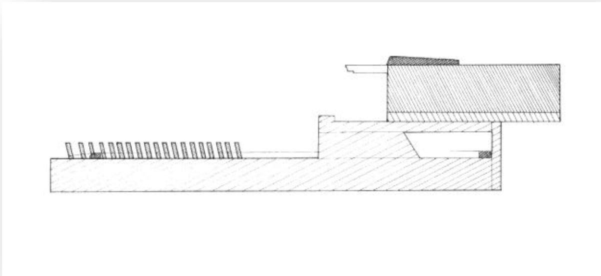
14. Top plate
15. Depth and volume of the resonating chamber
16. Optimised coupling of bridge and top plate

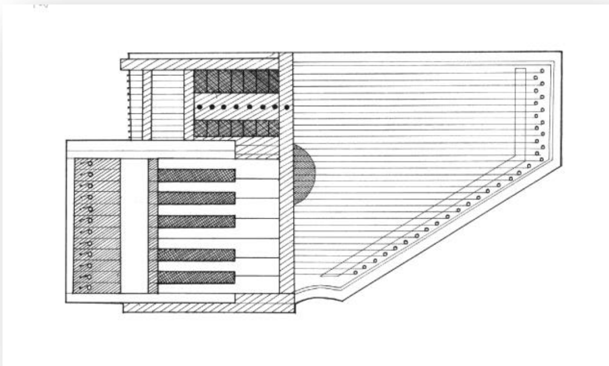
4. Patents and Prototypes



Prototype 1

Year	2007
Considered in Prototype	1
Action	
1. Playing position	Yes
2. Keyboard: appearance and feel	No
3. Pulley and string system	Yes
4. Key pivot point to damper coupling	Yes
5. Key range	Yes
6. Harmonic damping	No
7. Minimal noise	No
8. Integrated amplification	No
9. Playing space on the string surface	Yes
10. String tuning and range	Yes
11. Access for maintenance	No
Harp	
12. String distinction	No
13. Tuning mechanisms	No
14. Top plate	No
15. Depth and volume of the resonating chamber	No
16. Optimised coupling of bridge and top plate	No





No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised, or range understood

Figure 4.1. Drawings of Prototype 1 and Assessment of the 16 Design Criteria

At the start of this prototype build, I had no idea whether the instrument would work at all. No similar designs had been turned up by my own patent database searches and there was no evidence of such an instrument existing amongst the enormous variety of extant fretless zithers. All the evidence at the time indicated that the idea was completely novel.

Therefore design work focussed on the minimum parameters necessary to provide “proof of concept”. It was based on a basic German diatonic autoharp (the cheapest harp body that it was possible to obtain) and utilised a keyboard stripped from a four octave MIDI keyboard. Work on the “proof of concept” prototype ran concurrently with the preparation of the initial patent application, and I did not submit the application until I was sure that the instrument was possible.

Despite the basic nature of the workmanship, there was some good design thinking behind the keyboard action coupling, which allowed for a good deal of testing flexibility in the way that the keyboard coupled to the damper pulleys.

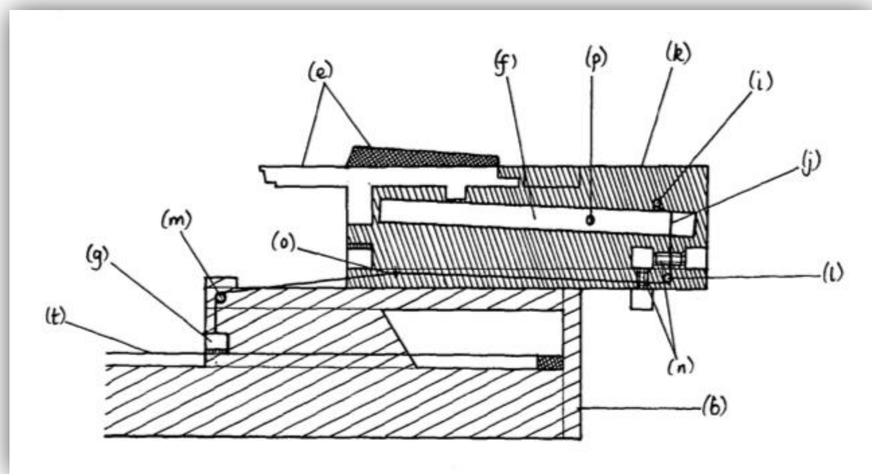


Figure 4.2. Patent Drawing showing the keyboard to damper bar coupling

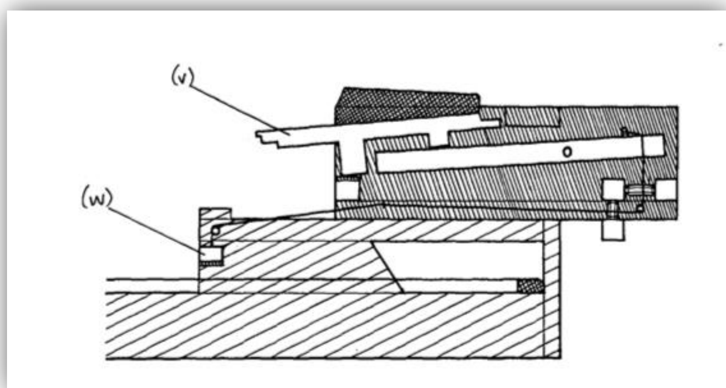


Figure 4.3. Patent Drawing (with key depressed)

Key to Drawings

(a) Toe pin block
(b) Dead pin block
(c) Bass rail
(d) Top rail
(e) Keyboard
(f) Wooden key rod
(g) Damper bar
(h) Spring mounting
(i) Peg
(j) Pulley string
(k) Keyboard housing
(l) Back lateral bar (pulley-wheel)
(m) Damper bar pulley-wheel
(n) Pulley-wheel
(o) Eye
(p) Pivot point
(q) Spring
(r) Washer
(s) Damper bar felt
(t) string
(u) Key crook
(v) Key depressed
(w) Damper bar raised

The drawings above show the keyboard to damper bar coupling. The keyboard was designed to move independently of the key rod, each had independent pivot points and the keyboard could be moved in relation to the damper rods, providing a range of exploration. The stop point for the keyboard was also not added until later, allowing considerable experimentation with the drop of the keyboard. The key aspect explored in this prototype is the *key to damper coupling* (4), establishing firstly that reverse damping was possible, secondly, that it was possible for keys to release dampers (and that they would return to damp the strings effectively) and thirdly, that the instrument behaviour would be as expected and that the musical improvements claimed, which until this point had been theory only, would in fact be possible to achieve.

With regard to the key to damper coupling there were many issues to be considered. The direction of force at the key tip (down) is opposite to that required at the damper bar, so it is logical to design a key that acts a lever, with the pulley string coupled to the far end of the key such that the upward force is in the correct direction. A pulley system, which couples this force to the damper bar, is then relatively easy to envisage.

All keyboards include a mechanism which returns the key to its resting state (not depressed); pianos achieve this through a counterweight at the far end of the key, but counterweights are not conducive to portability, nor to an instrument where the keyboard is likely to be held upright. There are also many examples of sprung action keyboards, including the four-octave keyboard that was adapted for use in this particular prototype. The damper bars themselves require springs to force the damper bar into continuous contact with the strings, and the most obvious candidate for testing would be to utilise the compression springs which are designed for autoharps. Although the purpose is slightly different, the design parameters have commonalities. Autoharp springs are designed to maintain the damper bars above the springs, with force delivered directly from the left hand fingers to depress the bar, and damp the springs, which is a similar action to depressing a key, requiring similar pressure from the fingers on the damper bars. I thus reasoned that if reversed autoharp springs *were* able to provide sufficient force to damp the strings, then in principle the damper bar could be coupled directly to the key (and possibly return it to rest point).

How far do the dampers need to be raised from the strings in order to release them? The release distance must allow sufficient space for the string to vibrate freely without encountering the damper felt. Autoharp designs suggest that this distance might be comparable with the 10mm key drop. However, I felt it possible that that the high clearance found on many autoharps might have more to do with providing an adequate feeling of movement for the left hand and that if string clearance was the most significant consideration then smaller movements would be possible. A calibrating range might be between 2 and 4mm.

If the distance from key tip to pivot point is known, and the desired drop also known, we should be able to get a sense of the desired points to drill the far side of the key to get a calibrating range.

Where the key drop is 10mm and the distance from the key tip to pivot point is 217mm:

$$\frac{10}{217} = \frac{y}{x}$$

Where y is clearance from the damper bar in mm and x is the drill point on the far sider of the key rod.

$$\frac{10x}{217} = y$$

$$x = \frac{217y}{10}$$

$$x = \frac{2 \times 217}{10} = 43.4mm\ distance\ when\ y = 2$$

$$x = \frac{3 \times 217}{10} = 65.1mm\ when\ y = 3$$

$$x = \frac{4 \times 217}{10} = 86.8mm\ when\ y = 4$$

What about the force of the springs? Again, the two measurements necessary for the keyboard are known. Where the ideal key tip weight is 50g (discussed in chapter 2) and the distance to the pivot point is 217mm:

$$Fx = 50 \times 217$$

Where x is the distance from the pivot point on the far side of the key and F is the force required at the spring.

$$F = \frac{50 \times 217}{x}$$

$$F = \frac{50 \times 217}{43.4} = 250g$$

When the damper clearance is 2mm.

$$F = \frac{50 \times 217}{65.1} = 166.6g$$

When the damper clearance is 3mm.

$$F = \frac{50 \times 217}{86.8} = 125g$$

When the damper clearance is 4mm.

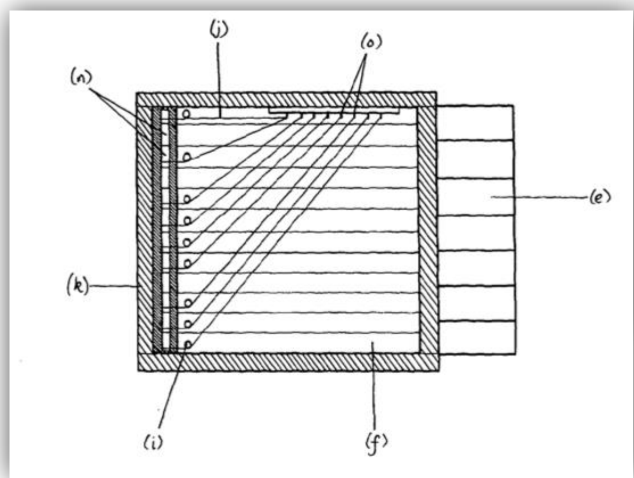
This assumes that the damper bar springs will provide the force necessary to return the key, but another unknown is the resistance a pulley and string system adds to the system and whether force to return the key would be sufficiently fast as to feel natural originating from such a removed point in the system.

After deliberating on these pressures, I decided to build a skeletal model that could be adjusted with ease at as many points as possible. The tested parameters were:

Key drop: range = 7 – 20mm

Far side pivot points: range = 40 – 90mm

Autoharp springs: light and regular (force unknown, but known to be comparable to pressing a key when used as designed in an autoharp) — to prove the principle of reverse damping.



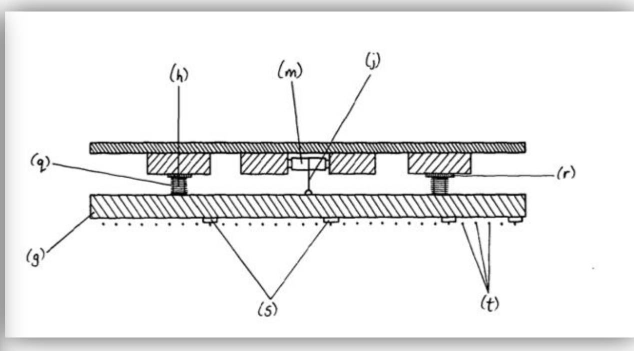


Figure 4.4. Patent drawings showing the pulley system underneath the keyboard and attached to the damper bar

The Figures above show the rudimentary pulley and string system, which relies heavily on hooks and eyes to provide angle correction rather than pulley wheels. The mechanism was built from the lower action up, establishing first that either set of autoharp springs was indeed sufficient to damp the bars — a key finding.

The results from testing the keyboard and pulley system were more confusing. It turned out that the damper bar springs *were* sufficiently powerful to return the keys, but the force required at the key tip in this configuration was excessive — the keyboard felt very stiff indeed. In addition the key return was sluggish. It was unclear whether or not improvements to the pulley system would improve this, but in any case it appeared that the most comfortable integration of keys to pulley strings to damper bars was to be found in allowing a certain amount of free key travel before the pulley strings were engaged, with the damper bar clearance set to a very small distance when compared to that of an autoharp. This is similar in principle to a piano action, which allows for a certain amount of free key travel before engaging the hammers, and in this configuration the damper bar springs cannot return the keys to rest before the coupling is released. The logical consequence is that a set of key springs, which were independent of the damper bar springs, should be integrated on the next prototype. In a practical sense this simplified matters from a design standpoint because the two systems could now be considered independently — the damping springs would not have to perform the task of key return.

The playing position was good, and this was another key (and pleasing) finding. Strumming felt very natural indeed with comfortable access to the keyboard. There could be improvements however; the thinking behind the keyboard position seemed logical at the time, but from the standpoint of playing experience it was clear that the keyboard should be moved towards the toe end and overhang the strings, and that this would maintain optimisation of the playing space (9) on the strings if the right hand could maintain access underneath. It also remained unclear how the instrument should sit and at this time I alternated it between a more horizontal guitar-type orientation and an upright position closer to a traditional autoharp position. I was also experimenting with finger styles, plectrums and finger picks (which were all new to me).

In principle, the key range (5) could be limited to 12 keys because this provides access to all of the strings, but (as discussed in the previous chapter) this did not prove satisfactory; the range of 12 keys felt very limited — I particularly regretted not adding the octave C, and determined that this would be added to the next prototype.

With regard to string range, I had not appreciated how frustrating prototyping on a diatonic autoharp would prove, and similarly regretted not having the confidence to begin on the more expensive chromatic instruments. There were some advantages however, because the range of the diatonic instrument is to the high D, and I could experience the very short playing space that was available to the right hand to reach this. To a certain extent autoharps share the problem of limited access to high strings with the ReAPH; but the problem is worse on the ReAPH because there can be no possibility of the strum/pick right hand gaining access over the damping action — it is wedged against the keyboard block. Playing prototype 1 taught me that maximising the playing space at the high treble was indeed a major consideration.

Overall, a great deal was learned from the ramshackle arrangements of this prototype. It was flexible enough to be dismantled and reassembled many times, and in many different permutations. It was not very robust however, and it came to an unfortunate end in 2008, when my young son trod on it and broke it beyond repair. The preparations for prototype 2 were well under way by this stage, and since its construction was well documented (though unfortunately not well photographed) I did not worry about this unduly.

Request for Grant of a Patent

Despite initial reluctance, I was persuaded that patent application should be a part of this project during completion of the first prototype. There were two reasons for this reluctance: firstly, I am ambivalent regarding the role of patents within the history of musical instruments; the success of a musical instrument depends not only upon its design merits but also upon musical community, and the capacity for both propagation and innovation is ultimately dependent upon a shared vision. Patents are potentially a negative force upon community acceptance and on community innovation upon a musical instrument. For example, Adolphe Sax gained a patent for the saxophone in 1846, and held it for twenty years — an unusually long period of time. Some of the most interesting adaptations took place immediately *after* its expiry: extensions to the bell modified the tone, and a series of modifications to the keywork enhanced the expressive capacity of the instrument. These modifications took the instrument in an entirely different genre direction to that which the inventor had originally intended, and crucially, it was only at this point that genre-based communities were established, ensuring that the instrument became firmly embedded within musical culture.

The second reason for reluctance was that I felt that the innovation was so *obvious*, and that there wasn't anything particularly original about it. Reverse action damping already exists in a number of musical contexts — most obviously the piano, and keyboards are musically ubiquitous. However, various musical colleagues (whose opinion I valued) insisted that they had never seen anything like it. Therefore, I investigated, following the preparation guidelines of the UK Patent Office. The initial searches appeared to show that my colleagues were correct. General and patent database searches revealed that whilst there were examples of keyboard adaptations to fretless zithers[11], none were reverse-damped, and none resembled the ReAPH at all.

However, this raised a question: since none of the design ideas that constitute the ReAPH are in themselves new, and if a reverse-damped keyboard applied to an autoharp is such an obvious and desirable local adaptation, then the evolutionary model would predict that there should be other extant examples of reverse action keyboard adaptations to fretless zithers. A frustrated pianist surely cannot be *such* an isolated “local condition” as to have triggered this chain of events only once in one hundred and twenty years of autoharp

[11] For example The Celestophone (patent 1912), The Marxophone, The Supertone Phonoharp, The Piano Mandolette, Menze's Piano Zither (patent 1898), The Dolceola.

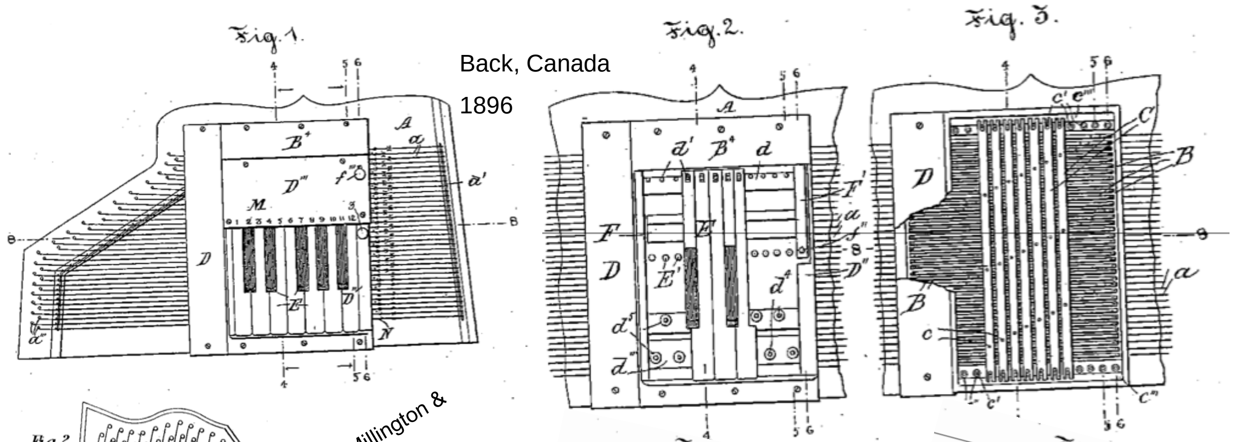
history?

I received the results of the initial search phase of the patent on September 7th 2007 and rather than present the search results in a linear order from the outset, and so that the reader can gain a sense of the surprise I experienced upon receiving the search results, I have assembled a “see at a glance” plate of previous patents.

Initial Search Results

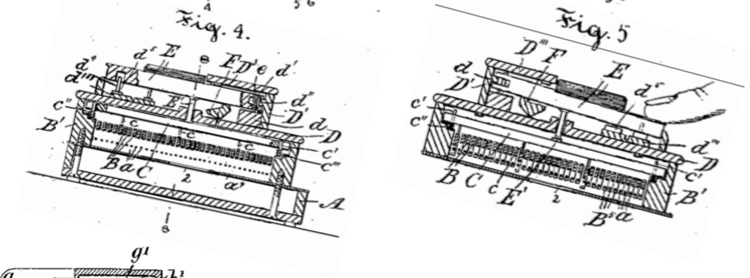
Figure 4.5. Compound Plate assembled from Previous Patent Drawings

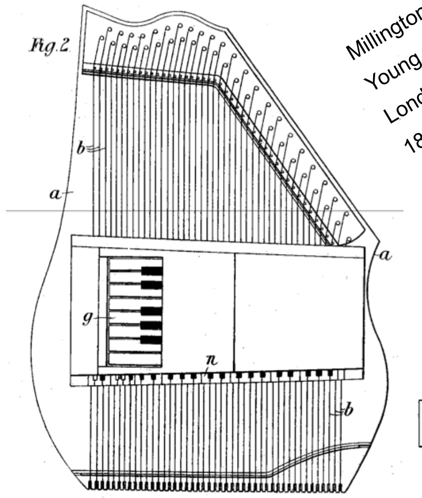
Status: Public Domain (all)



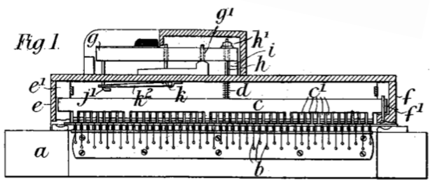
Back, Canada

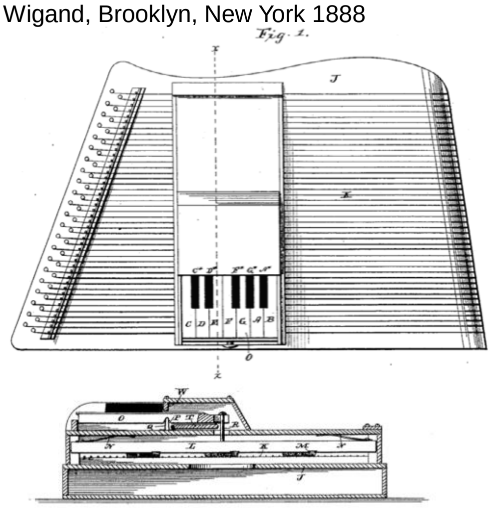
1896



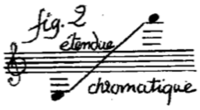


Millington & Young, London 1898

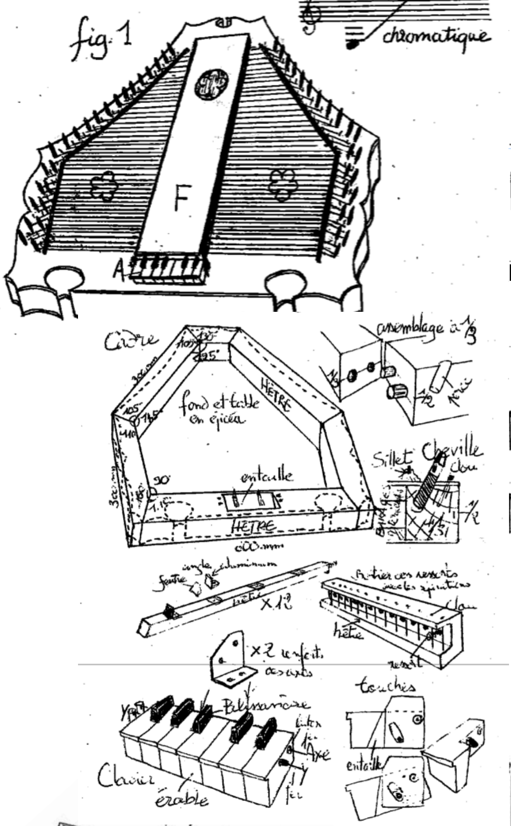


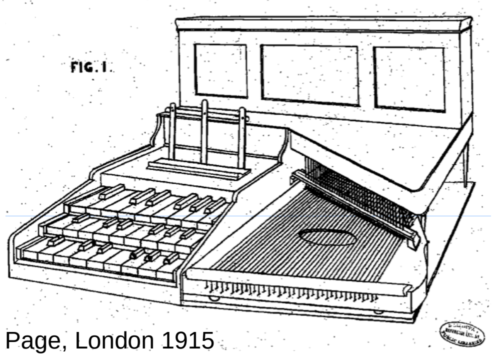


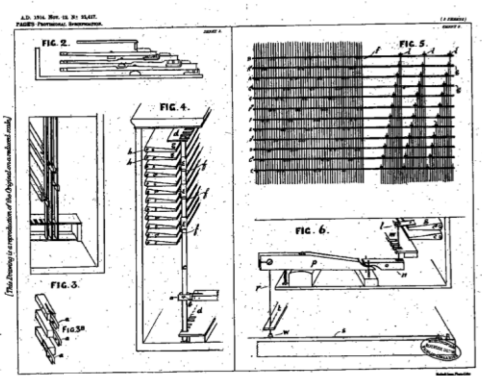
Wigand, Brooklyn, New York 1888



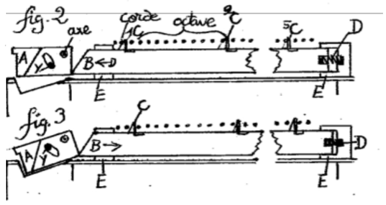
Henner, Strasbourg 1976

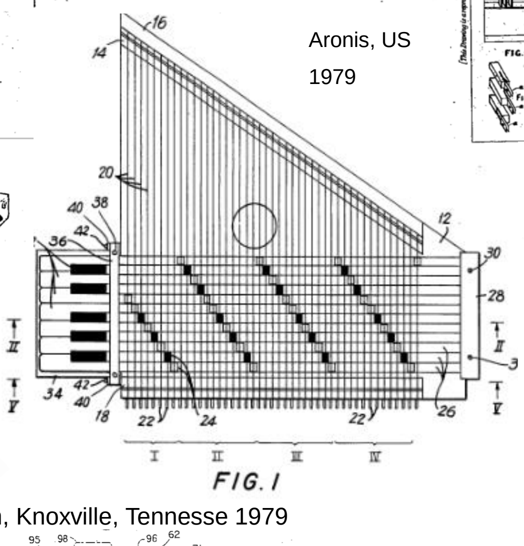






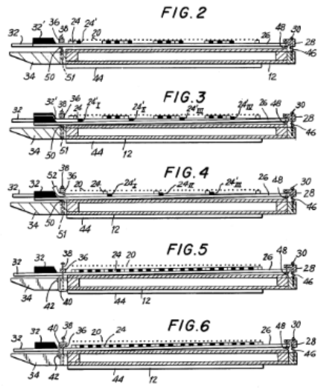
Page, London 1915

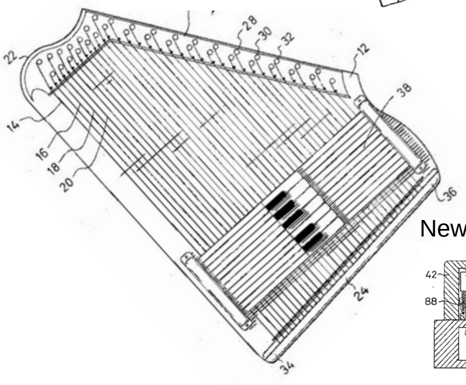




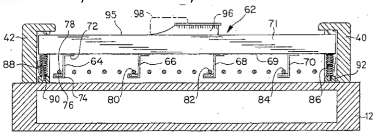
Aronis, US

1979





Newton, Knoxville, Tennesse 1979



The initial search had presented five similar patents. However, upon reading, I found that some of these referred to other patents, not presented in the initial search results. Two of these (Wigand and Aronis), I have added to the narrative list myself, and dismissed other patents cited, as not relevant. One (Henner) appears to remain absent from publicly searchable patent database to this day.

We need to discuss each of these designs in detail, and understand how and why my vision of the instrument is different and eventually merited its own patent. This is the narrative of the patent progression, and it was initially my primary concern, but as I worked my way through these different designs, the initial confusion and doubt was replaced with an enduring sense of pride and kinship and ultimately I was glad that I had pursued the patent because it allowed me to understand this hidden design history.

All the different designs deal with the same set of musical issues and design concerns. To a greater or lesser extent they share a similar vision of the instrument and each idea deserves to be discussed on its own merits. Each contributes different ideas to the vision of how the instrument should be, and is a *truly* related form. So it is with some pride that I present the following, which is, as far as I know, the first analytical commentary on the history of reverse action on the autoharp.

History of Reverse Action Design on the Autoharp

Without doubt, the design concerns of the innovation are in accord with the Victorian ethos, and it is no surprise that the earliest examples date from this time. This was an era of widespread experimentation with mechanical and mechanically enabled musical instruments of all kinds, and this history begins with four designs, covering the period 1888 to 1915, all of which seem to have been written without knowledge or reference to each other. Three of these, Wigand, Back and Millington/Young bear striking similarities in the playing interface (if not in all aspects of the design). Because of these similarities we will consider these three in isolation and subsequently in comparison.

F Wigand 1888

Zithers

US Patent no 390830 Oct 8th 1888

Just six years after the Zimmermann autoharp patent (1882), one Ferdinand Wigand of Brooklyn, New York, filed the first patent for a reverse action autoharp; the patent is simply titled "Zithers". Wigand begins discussion within the patent by outlining the problems with the autoharp damping system, in a foreshortened, but entirely similar manner to the approach taken within this text. He continues by outlining the principle of reverse damping:

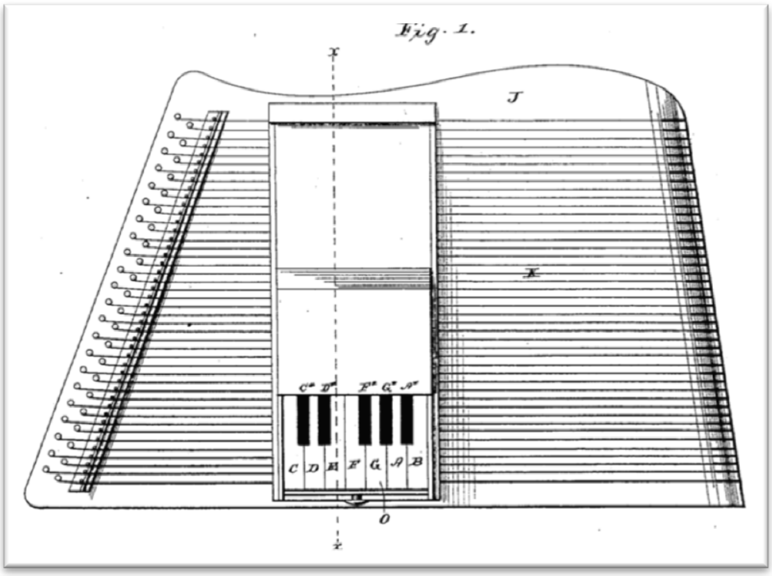


Figure 4.6. Overview of Wigand's Instrument (Wigand, 1888) Status: Public Domain

> "It has been, therefore, my object to produce an instrument with only a limited number of damping-bars, but so constructed that by the various combinations of said bars with each other all the chords possible to be struck upon a piano can be produced.
>
> In carrying out my invention a different principle of construction has been adopted from that heretofore employed in instruments of this class — that is to say, instead of providing each bar with dampers adapted to prevent or shut of the vibrations of all the strings except those of a particular chord, I have provided each bar with dampers adapted to prevent or shut off the strings representing only a certain fundamental note and its octaves, and instead of keeping the dampers normally out of contact with the strings I have arranged to keep them normally in contact with the strings, the result being, when a single bar is operated, to release or leave free to vibrate only the strings representing a certain note and its octaves…"

The keyboard is oriented, keys facing the bass side of the autoharp and we can surmise that the instrument is not designed to be held, but to be played as a table-top instrument (a point we will return to). Wigand describes playing the instrument thus:

> "The manner of using the instrument is very simple. The performer has only to press with his left hand upon such of the keys as represent the notes of the chord he desires to play, which will have the effect of raising the corresponding damper-bars and releasing, so as to be free to vibrate, the strings corresponding to said notes. Then with the thumb or fingers of his right hand he runs over the strings and sets said released strings into vibration and produces the chord. By manipulating the key-board [*sic*] with his left hand as he would the keys of a piano he can produce all the chords capable of being produced on the latter instrument.

This playing position, and orientation of the keyboard, provide the most obvious position from which to integrate a keyboard mechanism (we will also return to this point).

The cross-sections below show that the instrument is reverse sprung (when compared to a standard autoharp) and so an upward force is required to pull the damper bars up, to release the strings. Therefore each key acts as a lever, providing this upward force from the far end of the key away from the playing surface and after the key pivot point, through a direct coupling to the damper bar.

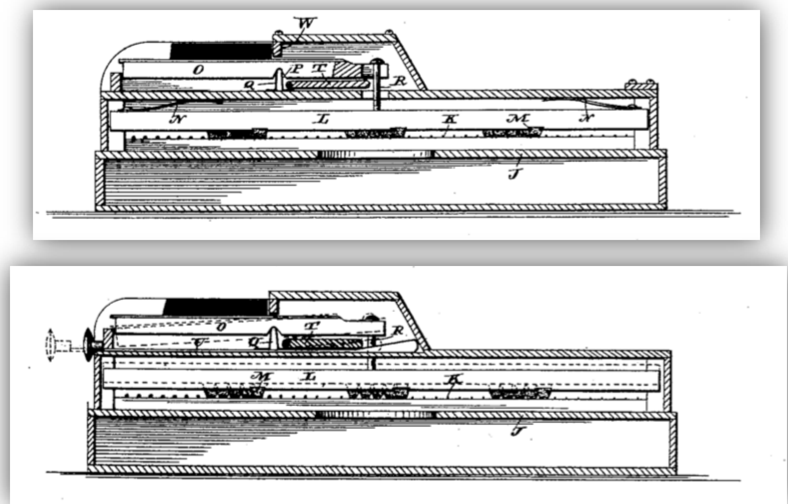


Figure 4.7. Cross-section through the Keyboard Mechanism (Wigand, 1888) Status: Public Domain

Only 12 keys are specified (there is no top C) and additionally a crook mechanism is specified for "throwing all the dampers off the strings" shown in the cross section above. The purpose of this is described as allowing the instrument to be played in the manner of a zither.

The stringing is ambitious: Wigand specifies a 44 string harp with a three and a half octave, completely chromatic range, beginning from a low F.

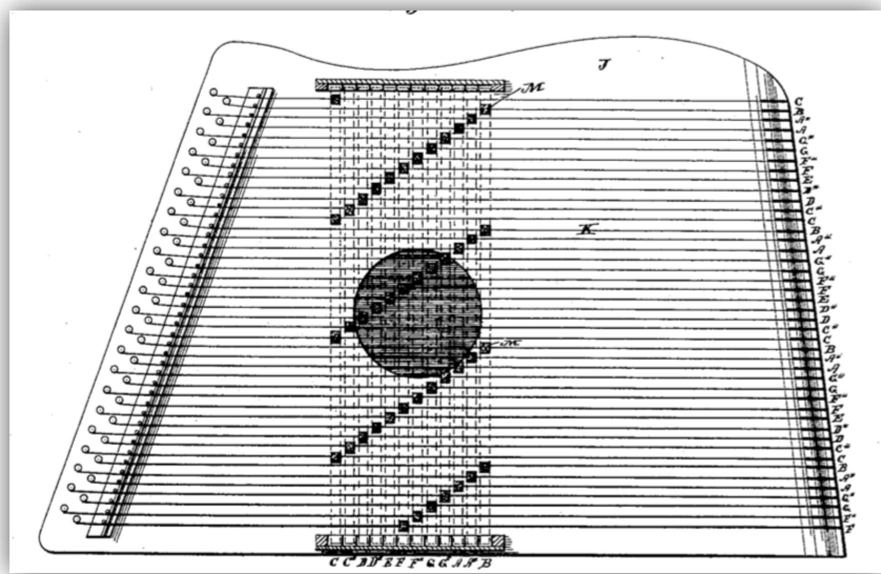


Figure 4.8. Drawing of the Wigand Harp, with Damping Points (Wigand, 1888). Status: Public Domain

The proportions on this drawing are interesting — a huge playing surface is depicted and the string lengths look unrealistic given the pitches of the pitch range. Wigand concludes his patent:

> "My improved instrument can be used either for playing melodies or as an accompaniment to the voice or other instruments, and will be found much more useful and pleasing than instruments of the same class that have preceded it."

James S Back

New and Useful Improvements in Autoharps

Filed September 27th 1895 and

Granted May 5th 1896

United States Patent Office: 559764

"Be it known that I, James S. Back of the city of Ottawa .. in the Dominion of Canada, have invented certain new and useful improvements in Autoharps; and I do hereby declare that the following is a full, clear and exact description.."

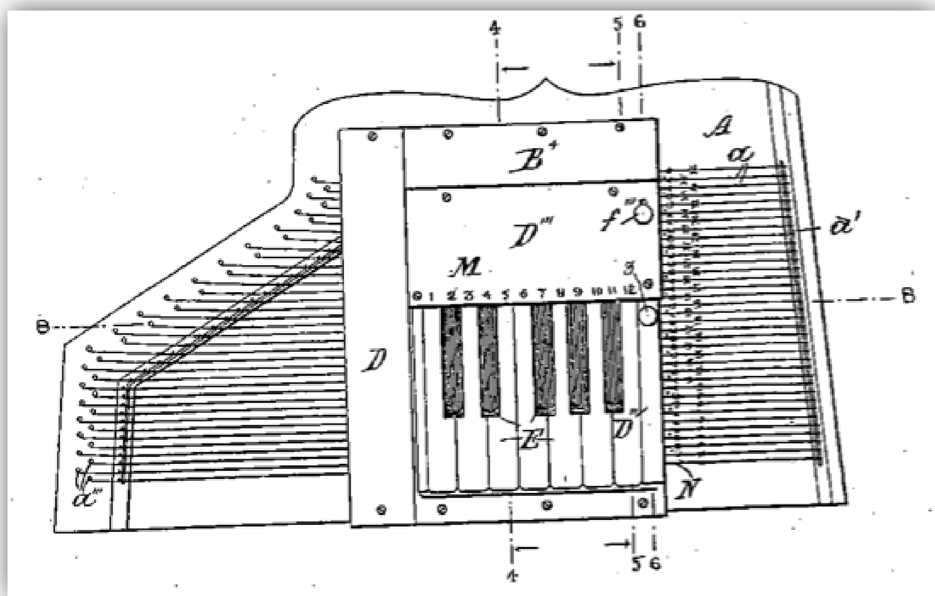


Figure 4.9. Overview Back's Instrument

(Back, 1896) Status: Public Domain

The instrument described by Back innovates upon an otherwise unchanged autoharp, and unlike the Wigand design, the proportions in this drawing do appear entirely realistic. Twelve, full size keys appear on the keyboard and the action is built above the strings of the instrument, and oriented perpendicular to the string face (similar to Wigand).

> "..My improved autoharp is provided with mechanism which by means of a piano keyboard (or, more strictly, an organ-keyboards) permits any chord in any key or the octaves of any single note to be sounded…"

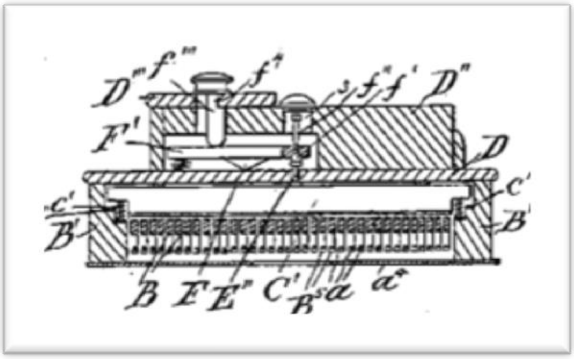


Figure 4.10. Cross-section through the Mechanism

(Back, 1896)

Status: Public Domain

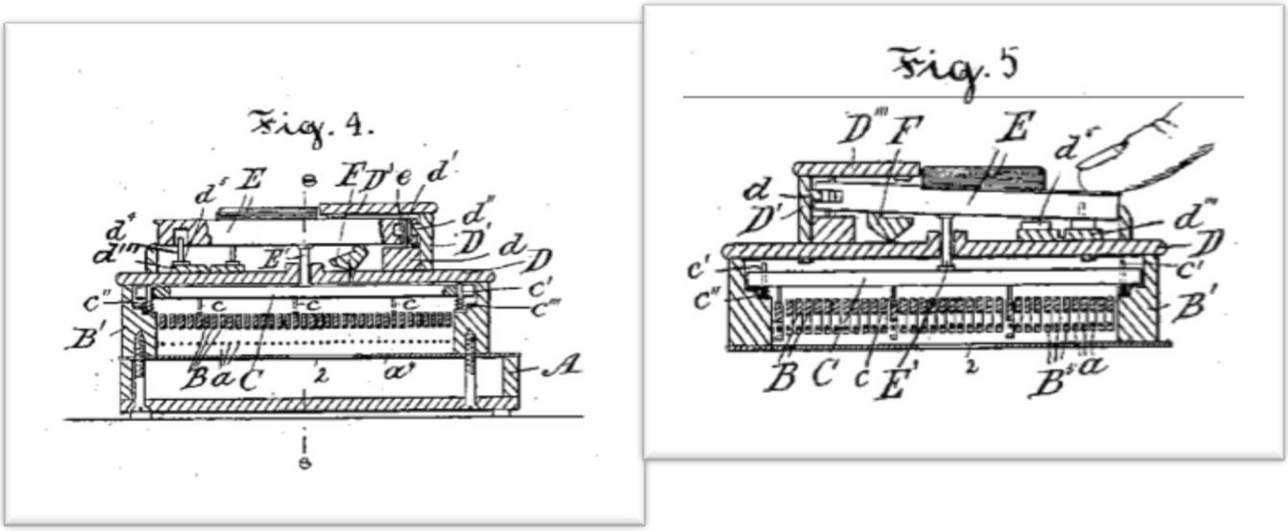


Figure 4.11. Further Cross-sections through the mechanism (Back, 1896)

Status Public Domain

However, unlike Wigand, the damping mechanism is top sprung, in the manner of an autoharp (providing upward force on the damper bars), the reverse action provided by feet, which extend between the strings and damp the underside of individual strings. The drawing above right, shows the mechanism with key depressed and feet extending to undamped position below the strings. The reverse damping is thus provided from underneath the strings, and thus requires a downward force to release the dampers. Keys are coupled directly to the corresponding damper bars, but this time before the pivot-point, and provide the necessary force. From pianistic perspective, an advantage of this design is the long length, key to pivot point — a similar length to piano key length (to pivot point) that would provide adaptive keyboard feel.

There is some sophisticated thinking with regard to adaptation of the piano sustain. The mechanism is more complex than the simple “damp by bar return” of other reverse actions (including mine) or the addition of a key crook which lifts all the damper bars simultaneously (Wigand, Millington/Young). By means of a rocking mechanism, a 13th full damping bar (designed to damp all strings) provides damping and release in combination with the octave occurrences. The effect of this is that in legato mode, strings of the last played keys (or combination of keys) continue to vibrate. A crook changes the instrument behaviour to behave in non-legato mode, where the strings will vibrate as long as the key is held, and then damp on release of the key. Discussion as to the wisdom of incorporating sustain pedals will follow later — suffice to say, at the moment, that this sustain effect adds a lot of complexity to the system.

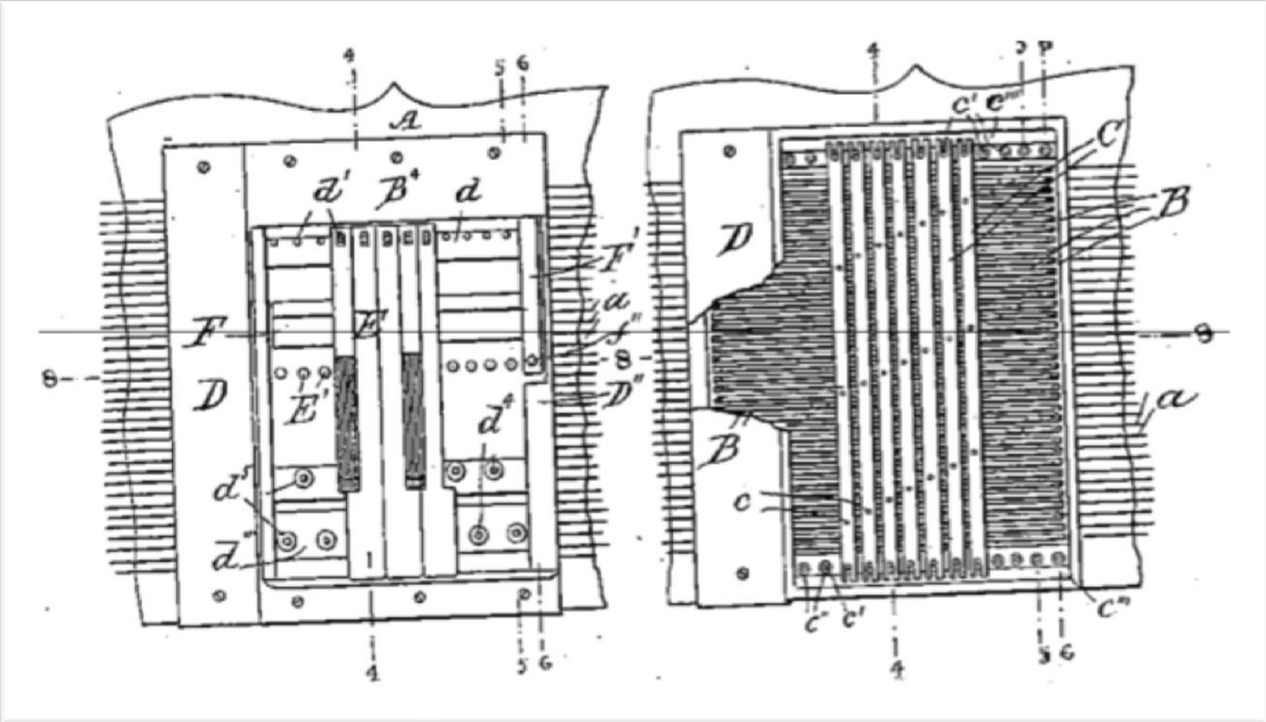


Figure 4.12. Mechanisms viewed from above (Back, 1896) Status: Public Domain

The complexity of the mechanism and also the description renders this device quite difficult to assess. For a flavour of the language consider Claim 1 (the first of 6) below.

> "In an autoharp, the combination with the body of a casing secured above the sound-board, of a series of damper-bars pivoted in said casing at one end above and parallel to the strings and each carrying a damper at the other or free end each adapted to press upward against one of the strings, a cross-bar in said casing carrying a series of springs each holding up one of said bars, a series of presser-bars placed transversely above said damper-bars and provided with pins each adapted to bear upon one of the damper-bars, a spring at each end of each of said presser-bars holding the same up, a board above said bars provided with guides for vertical pins and forming the bottom of a keyboard, a series of pins in said bottom adapted to move vertically and each in contact with one of the presser-bars, a series of keys arranged in the manner of an organ-keyboard suitably pivoted, and each bearing upon one of the aforesaid pins, a muffler-bar similar to the presser-bars but without pins and bearing bodily upon the free ends of the damper-bars, a rocking bar pivoted to the bottom of the keyboard under the rear end of the keys and adapted to have its rear edge depressed by the keys, an arm or lever at one end of said rocking bar bearing with its forward end upon one of the vertical pins which move in said bottom and which is in contact with said muffler-bar and a spring holding up the rear end of said arm or lever, substantially as set forth.

Certainly the design is ingenious, but perhaps over-engineered. The inclusion of the sustain mechanism suggests pianistic thinking, but the keyboard integration on Back's prototype is very involved indeed. Overall this prototype probably contains the most parts and also the most moving parts of any conception of reverse action autoharp design.

Harry Millington and John Young

A New or Improved Stringed Musical Instrument

British Pat No 9698 Application 27th April 1898 Accepted 1899

Us Patent No 625996 1899

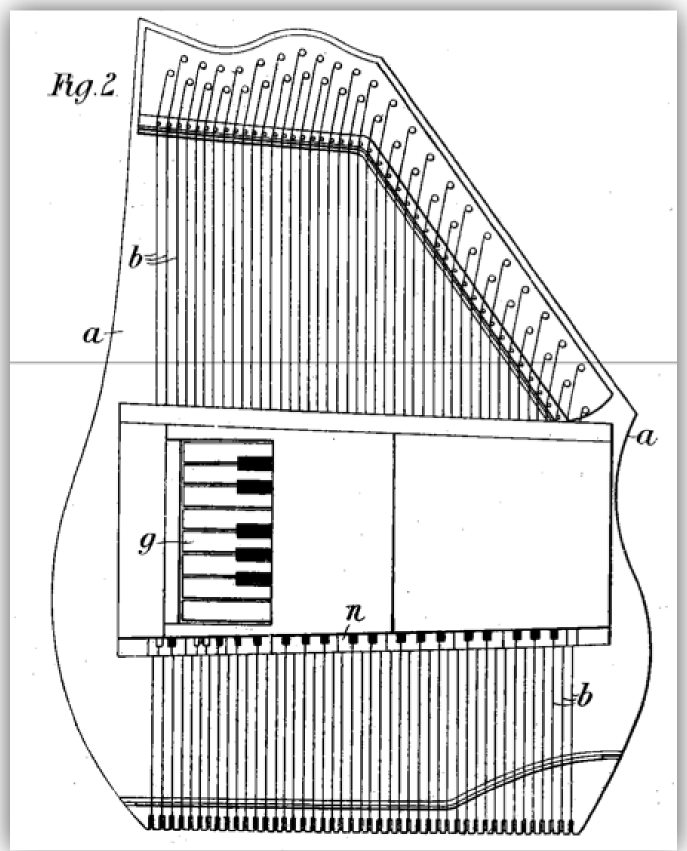


Figure 4.13. Overview of Millington & Young's Instrument (Millington & Young, 1899)

Status: Public Doman

A British patent was granted in 1899 for another reverse action design made by Harry Millington, a piano manufacturer and John Young, a mechanic. It appears that Young then filed for, and was granted, a separate US Patent in the same year.

The damping action deployed here is much easier to understand than that of the previous invention and can easily be discerned directly from the description within the patent document:

> "This invention relates to a new or improved stringed musical instrument… damped by means of damper-bars having dampers which are normally held upon the strings by springs as hereinafter described. Each damper-bar is advantageously provided with dampers of an inverted T shape and is adapted to damper a note and its octaves so that by having a damper-bar corresponding to each note all the notes of the instrument are thereby damped.
>
> The damper-bars are guided at the ends in grooves in suitable uprights which are provided at their upper ends with stops against which the bars can be brought by keys provided in a key board resembling that of a pianoforte, by means of wires which are attached to the damper-bars and to the said keys in such a manner that by depressing a key the damper-bar attached thereto is raised against the action of its spring thus freeing the strings which are normally damped by the particular bar"

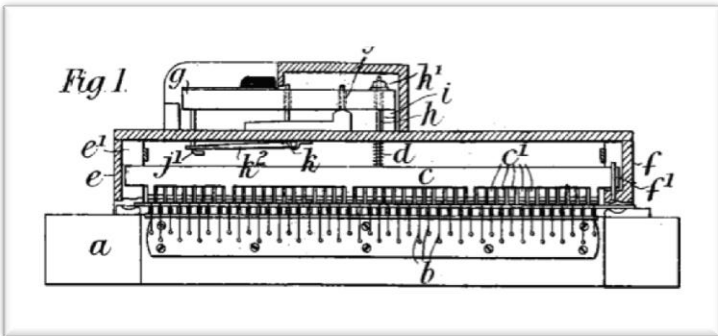


Figure 4.14. Cross-section Through the Mechanism (Millington & Young, 1899) Status: Public Domain

The instrument is reverse-sprung and similar in many respects to the Wigand design. As for Wigand (and unlike Back) an upward force is required to pull the damper bars up.

This is provided through use of the far end of the key (after the key pivot point, rather than before, as in the Back prototype) as can be seen from the cross-section above. The key is directly coupled to the damper bar. Interestingly the inventors have decided at some point that 12 keys are not enough to enable comfortable playing and have added an octave C, which is coupled to the lower C.

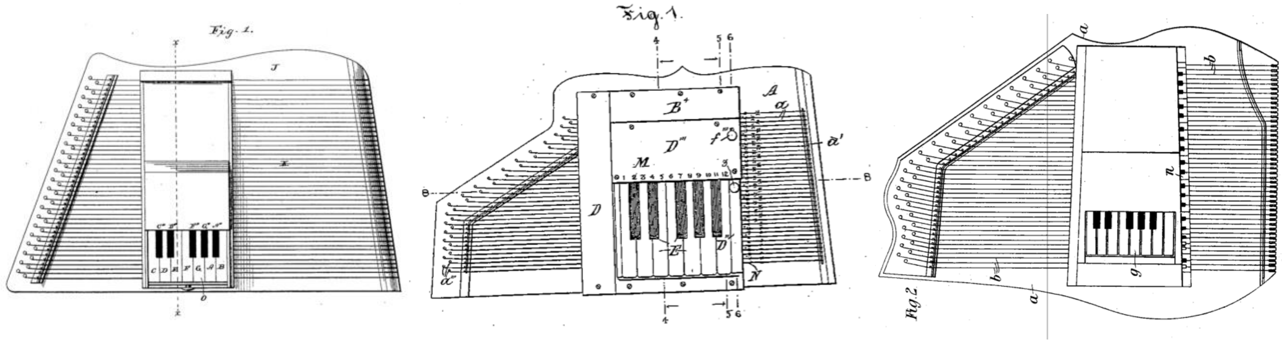
Uniquely among this group of inventions, Millington and Young have considered the issue of string distinction. A second keyboard representation is provided, oriented over the strings on the side of the keyboard oriented towards the dead-end, which is clearly intended to be the playing surface. This is described in the patent as the most convenient solution to string identification, perhaps implying that others were considered.

The playing surface and the overall sound of the instrument are both optimised — and from two perspectives. Firstly, the keyboard mechanism is tapered toward the treble side of the harp (in order maximise access to the treble strings as the speaking length of the string surface narrows), secondly the body of the harp appears to have been lengthened and acoustically improved from original autoharp designs. The description; "..the body of the instrument is made somewhat similar to that of a zither but is provided with a free sounding-board made on the principle of the sounding-board of a piano.." implies a re-consideration of the acoustic properties of the instrument itself. Fretless zithers, unlike the majority of string instruments, are most commonly fashioned with parallel top plate and back plate — an inherent design weakness that, in part, leads to a thin sound characteristic of most commercial autoharps. Piano soundboards, in contrast, are arched to a high point between the dead and toe end of the instrument, and this is probably the first property that has been considered and redesigned according to piano principles. Also the bass string bridging appears to be placed on the top plate itself, rather than on the frame, which would almost certainly lead to an improved bass response. These aspects are not overtly discussed, they could not form part of the patent claims and Millington would likely have been protective of overt discussion. However, they are known aspects of piano design, and it would seem logical that Millington would have wished to apply them to the poorly designed, parallel plated, framed bridged zither design.

A piano maker and a mechanic is an interesting partnership to have formed. The British patent is formulated jointly as Millington and Young, but it was clearly Young who worked on the American patent. I cannot help but speculate as to the nature of this relationship and wonder at the similarities with my own prototype series. I wonder if Young, (perhaps) the originator of the action, at a certain point in his prototyping sought the help of a specialist in piano technology, to improve the sound of his instrument, in much the same way that I sought the help of Alec Anness (with his background in piano restoration, and who routinely applies this design thinking to his autoharps) for the completion of my prototype five. Overall, I am very confident that the harp itself would have sounded very good indeed when compared to contemporary autoharp design.

This design specifies a complete damper-release system similar to that of Wigand; a bar simultaneously lifts the far end of all the keys, thus raising all the damper bars together. This harp has a generous 45 strings, but unlike Wigand, the proportions of the drawings look entirely accurate.

Comparison of Wigand, Back and Millington/Young



Wigand *Back* *Millington/Young*

Figure 4.15. Comparison of Wigand, Back and Millington/Young Designs

(Wigand, 1888) (Back, 1896) (Millington & Young, 1899)

Status: Public Domain

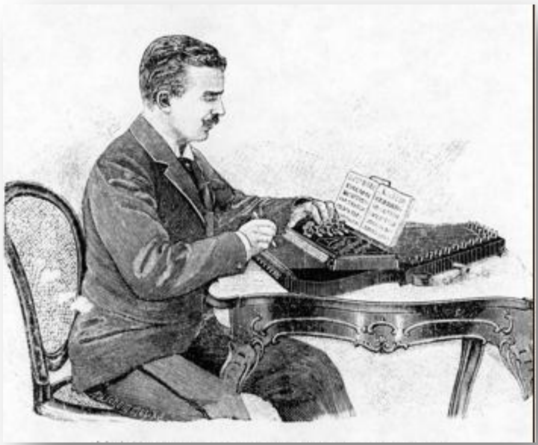
Above, the three instruments are shown together in the same orientation, and the drawings roughly scaled to show the similarities and differences. In terms of difference; the speaking lengths of the strings appear consistent between Back and Millington/Young, the steeper bridging rake to the high treble reflects the simple straight design of the nut at the dead end (Back), whilst Millington has arched the dead end nut to enable a shallower rake. Both illustrate clearly that the remaining playing surface is limited, and requires optimising. Wigand's harp depiction does not appear realistic (given the pitches called for relative to the speaking lengths of the strings). Keyboard size appears to be another discrepancy, and it is entirely possible that the inventors did, in fact, envisage different sizes of keyboard.

Despite the fact that all these three instruments appear to have been developed without knowledge of the others, overall the designs have striking similarities; the design concerns are similar and the presented interfaces are also very similar. Consequently, it is worth pausing at this point to compare them in more detail.

The most striking commonality in all three of the designs is the keyboard orientation with respect to the strings. The keyboard is oriented keys-facing-the-bass-side of the harp perpendicular to the strings. This is the most logical design platform from which to integrate a keyboard because the obvious lever mechanism, the keyboard itself, is placed in line with the damper bars and is available for a direct coupling.

It is evident that this keyboard position must lead to a different playing position of the instrument than the one that we expect on the autoharp today and we can surmise that the instrument was not intended to be held in the lap, but instead, designed to be played as a table-top instrument, in the manner depicted in the photograph of Zimmermann in the previous chapter. Other contemporary pictures also depict players using this playing position.

Figure 4.16. Parlour Scene shows the table-top playing position (Michel) status: Public Domain



4.17. The table-top playing position (Michel) Status: Public Domain

Back describes playing the instrument thus:

> "The strings, as in all instruments of this class, are vibrated with a plectrum, and it is usual to run the latter across all the strings, so that the open ones will be sounded while the damped or muffled ones will be mute"

Which supports this view of the table-top playing position for all these instruments.

Although this does not seem a very sophisticated way of playing the instrument, and would not easily allow for the complex combinations of pinch, tremolo and hammer that are part of today's autoharp finger pick technique, there are advantages. The closest commercially produced autoharp to the Zimmermann original was the Victoria autoharp, (1888), which clearly features the pinch mechanism which results in damping on the sides of the strings; a Zimmermann idea.

I met a player of such an instrument, Keith Holmes, at the UKautoharps meeting at Mickleover in 2012, who did indeed play his instrument as depicted in the photographs.

Keith, in fact, played a replica instrument of the Victoria harp, which he had made himself (his original Victoria model had become too fragile to risk travel). Keith's autoharp was as much of a curiosity to the UKautoharps members as my own and the playing position and extended chord possibility provided by the Victoria formulation produced quite different sounding music to the other autoharps present. It was focussed on melodic and chordal accompaniment, and not on rhythmic strumming. The strum action was pretty much as Back describes; and this particular player, at least, strummed only in one direction (bass to treble) with an emphasis on the final melody note, which was sounded at the top.

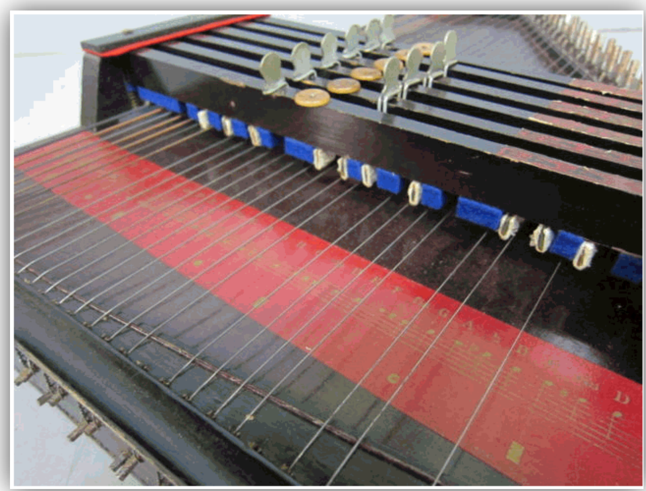


Figure 4.18. Chord Bars and Pinch Mechanism on a Victoria Autoharp (Holmes, 2014)

Status Permission granted

Indeed, a significant advantage of this system is that it is relatively easy to render a precise melody, distinct from the accompaniment, whilst the more flexible chord system adds to the harmonic complexity and provides increased ability to render non-chord tones without having to change to an alternative damped chord. Keith and I played some tunes together, and the resulting blend of the two formulations was attractive. I was sorry that there was not more time to experiment with this combination.

Given that table-top playing was the accepted playing position of the time, and also the most obvious integration orientation for a keyboard, it is evident why none of the three designers questioned this design. I also seriously considered this keyboard position before embarking on this project, but finally rejected it, as I was concerned it would not provide a sufficiently well balanced relationship between the two hands.

With regard to the keyboard designs of the three inventions, Back's is undoubtedly the most attractive to a pianist, and is perhaps the only arrangement that would offer a comfortable and "convincing" keyboard feel to a pianist. Wigand and Millington/Young place the key pivot point at the end of the visible keyboard surface; this may appear to the eye as the obvious pivot point of a key and is indeed a design that is to be found on a lot of electronic keyboards; but it is not so on a piano. The pivot point of a piano key is much further back than the playing surface might suggest. This is not immediately apparent because most of this length is hidden behind the casing. Playing keyboards with a shorter pivot point tends to give a pianist the feeling that there is something “wrong” with the keyboard. Pianists commonly (and mistakenly in my opinion) attribute this wholly to the sprung (as opposed to weighted) mechanism. Shorter pivot points result in steeper angle of key drop, and I believe it is actually this aspect that is most disturbing in the feel of most cheap keyboards — not the fact that they are sprung. This is a key finding, and will be discussed further within my own prototype series.

All three inventors consider the issue of sustain — though the solution is simpler in Wigand and Millington/Young than the complex design suggested by Back (through a bar which simultaneously lifts the far end of all the keys, thus raising all of the damper bars together). I have considered such a device for inclusion in my own prototype series, and had even determined a position — in front of the keyboard to be operated by dipping the left wrist. However, I abandoned it as a primary consideration within the prototype series; I discovered when I imagined the sound and control, whilst away from the instrument, I could hear how an integrated sustain pedal device might enhance the sound, but this perception vanished upon actual musical engagement with any of the prototypes (even prototype 1) and practice sessions invariably led to the conclusion that the device was not necessary. This is a subject for further discussion within the prototype series.

In considering these patent documents, I wonder to what extent the prototypes described were realised and what problems might they have encountered? Certainly this hidden history is no longer obvious today — for the overwhelming majority of the time spent prototyping, I was unable to trace any evidence of instruments that have survived to the current day. The US Patent Office had, in 1870, dropped its requirement that a working model accompany a patent application, so a fully functioning instrument was by no means a certainty. The less than credible dimensions of the Wigand harp body do not inspire confidence that a functional instrument was produced, but overall all the mechanisms appear to be quite robust. I suspect that the feel of the Wigand and Millington/Young keyboards might have been quite heavy, but Young nonetheless successfully pursued his patent all the way across the Atlantic — this suggests that a working prototype was indeed a reality.

In March of 2015 I was approached by Katherine Rhoda hailing from the state of Maine in the USA. This communication included photographic evidence of an extant instrument called a *Gondolin*, apparently dating from 1910, a request for more information, and if possible, identification. My immediate suspicion was that this was a Millington/Young instrument. Though considerably changed from the patent drawings, many of the same design concerns are apparent. The keyboard is tapered to optimise the playable string surface. In order to further assist this, the toe and dead ends of the instrument have effectively been reversed.

Figure 4.19. Gondolin (oriented from bass side) 1910 (Ebay, 2015) *Status: Permission sought*

Figure 4.20. Gondolin (oriented from treble side) 1910 (Ebay, 2015) *Status: Permission sought*

The keyboard depiction above the strings (in order to facilitate string distinction during playing) is another feature unique to the Millington/Young formulation and is also displayed in this instrument (photograph above).

Figure 4.21. Gondolin (side view) 1910 (Ebay, 2015) Status: Permission Sought

This design evidence is confirmed through the marking “Witten, Witten and Co” (shown in the plate above), which is the trading name cited in the Millington/Young patent.

A problem that I suspect all three inventors would have encountered as these mechanisms progressed to finished prototype is that of harmonic damping. Harmonic damping is a problem for autoharp and reverse action harps alike; it happens because damping occurs at points which are in simple whole number proportions to speaking string length; and because single damper bars are used for multiple strings, it is very difficult to calculate appropriate positions easily. Instead, autoharpists mitigate excessive harmonics using two practical strategies, firstly by repositioning the damper bars in different combinations away from the node points, and secondly by extending the damper out from the damper bar (often termed an “outrigger”). The direct couplings of keys to damper bars found in these three prototypes do not easily allow the possibility of repositioning and I consider this to be a factor in the final functionality. The issue of harmonic damping will be the subject of further discussion.

Walton Page
An Improved Means for Operating the Dampers of an Auto-Harp

British patent Application date 12th November 1914 and accepted on 26th August 1915

British Patent No 22417

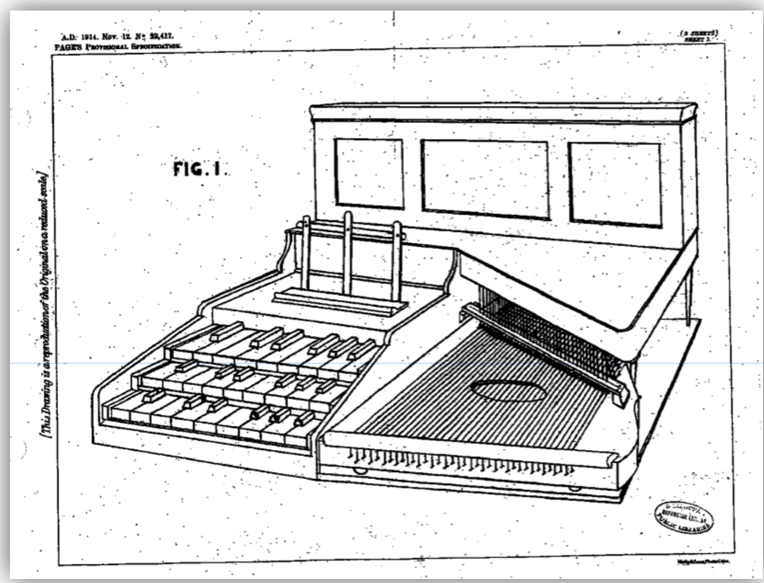


Figure 4.22. Overview of Page's Instrument (Page, 1915) Status: Public Domain

The formulation here is markedly different from all the previous inventions. Perhaps due to the complexity of the keyboard and damping action, Page makes no attempt at an integrated interface. Instead the presentation is side by side; keyboard and strings facing the player, thus effectively doubling the size of the instrument. The complex damping mechanism, housed in the casing behind both the keyboard and harp adds a third bulk area, and overall, it certainly cannot be described as an easily portable instrument.

The introduction states that the intention of this is invention is to enable the autoharp "to be used as an orchestral instrument and to make the playing thereof easy." I wonder what Page had in mind with this seemingly contradictory statement? Did he mean that the unique textures that the autoharp (particularly a reverse action autoharp which enables a level of chromaticism unmatched by any frame harp) would be made available to an orchestra through this invention? This is a possibility certainly, but the design of the mechanism seems to contradict this.

There are few clues from the patent document. Although Page is described as "of no occupation"; his address, described as "The Manor House, Yardley, Hastings", perhaps suggests independent means. There is no clue as to his musical engagement or level of expertise.

However, personally I do not think that the phrase "orchestral instrument" is meant as described above; rather he intended a parlour instrument that retained the characteristics of ease of learning and play found in the autoharp, but which offered a serious progression route to musical engagement. The term orchestral is perhaps used to evoke the richness of the quality of music that the instrument can produce within this setting.

The Page formulation envisages single keys that allow chords to be played:

> "The bottom row of keys releases the strings of the minor chords. Thus on depressing "A" all the A, C & E strings are liberated. The middle row release[s] the strings of the major chords."

Thus, in a manner similar to the autoharp the instrument allows chordal textures to be created from the outset of learning, through use of single keys. However:

> "The top row of keys only operate all the dampers of the particular note depressed. These notes can be played singly (to obtain unison passages) or in combination, by which means discords, or combinations not provided for in the chord-keys can be obtained. They are also used in combination with the chord-keys for the production of sevenths, *etc*."

The design curiously echoes that of a group of modern, electronic instruments commonly referred to simply as "keyboards" in the UK. These are designed as starter instruments (primarily for children) with the thought that (depending on musical aptitude) there will be progression to instruments (or perhaps computer based interfaces) of increasing sophistication. They can play a variety of tones, with (at times) surprisingly good sampling technology. They incorporate an automated rhythm and bass section which allows the player to control the chord progression through use of single keys and two note combinations, thus the player (as with the Page formulation) is not required to fully understand harmony in order to produce surprisingly full sounding music (the equivalent of orchestral textures).

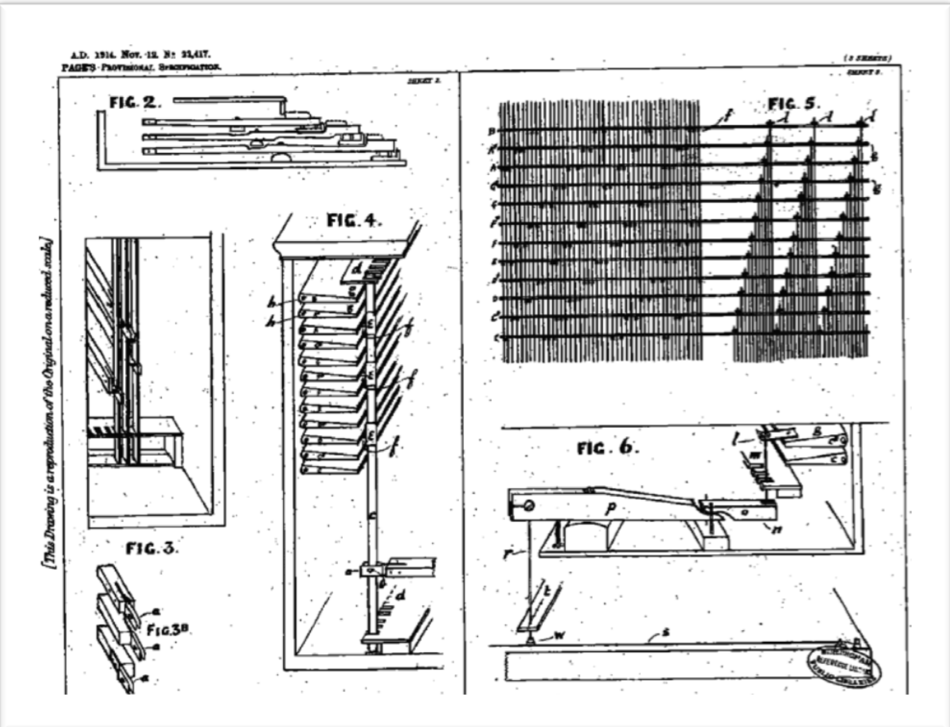


Figure 4.23. Page's mechanisms and Damping Arrangement (Page, 1915)

Status: Public Domain

Page's design conceived 15 keys per row, though he allows for variation. The damping system (shown below) is sophisticated, and one of the claims made by Page; "(3) Arranging the dampers so that each presses the string at a point about one seventh of its vibrating length" suggests that he was aware of, and had largely optimised harmonic damping on this instrument (Wigand, Back and Millington/Young do not display any direct evidence of this).

He does not make reference to any previous reverse action patent. The following reference within the patent

> "I am aware that auto-harps have been proposed in which major, minor and seventh chords could be produced in all keys by means of 3 rows of key buttons on a moveable frame & I make no claim to such an arrangement"

probably refers to the Eschemann patent of 1896 (from which commercial instruments were undoubtedly produced, and examples can still be turned up relatively easily). The Eschemann patent describes an innovation designed for a continuous chromatic strung autoharp where chord bars could be crooked a semitone up or down producing similar chords in different keys. This multi-function facet allowed for a greater number of chords to be produced from a smaller number of chord bars. Overall, Page appears to consider his invention an evolutionary step, which provides logical, but expanded interface for autoharp players. The remaining two claims for this instrument are relatively modest:

> "(1) Operating the dampers of an auto-harp by means of a multiple keyboard arranged after the manner of a 3 manual organ keyboard.
> (2) The method of connecting the keyboard with the dampers by means of adjustable pins and bars fitted with lifters"

Overall, I am confident that this instrument would function well. Page's was one of the patents returned for rebuttal in the initial search phase of my patent application, but this formulation really has departed a long way from the original vision of a portable instrument to the point where I feel that this is really a different instrument from that which I proposed.

Second Tranche — 1976 – 1985

No further reverse action autoharp patents appear to have been filed until 1976. This period follows a revival of interest in the autoharp as a folk instrument in the 1960s and in the UK, concerted advertising campaigns in the 1970s that attested to the ease of learning when compared to other musical instruments. For a time in the 1970s autoharps were relatively common household items in the UK, with many acquired by families as presents for children. I believe that this campaign contributed to defining the autoharp in the mind of a generation in the UK as part instrument, part toy and part education device; a niche occupied concurrently by the melodica and subsequently taken over by electronic keyboards.

In America the picture was different. Respected folk traditions were the foundation of autoharp usage, the instrument gained a large following, and technique became rich and varied. It is no real surprise then that two of the final three patents are American, and the third (perhaps more surprisingly) originates from France.

Pascal Henner (Strasbourg) Cithare D'accompagnement a Clavier

Patent: Republique Francaise No 76 21691

Filed on 15th July 1976 (at 15.55)

"Il existe dans ce domaine un systeme anglo-saxon (autoharp) qui a l'inconveneient de ne permettre que 12 our 15 accords …"
An Anglo-Saxon system (autoharp) exists in this sector that inconveniently does not permit more than 12 or 15 chords..

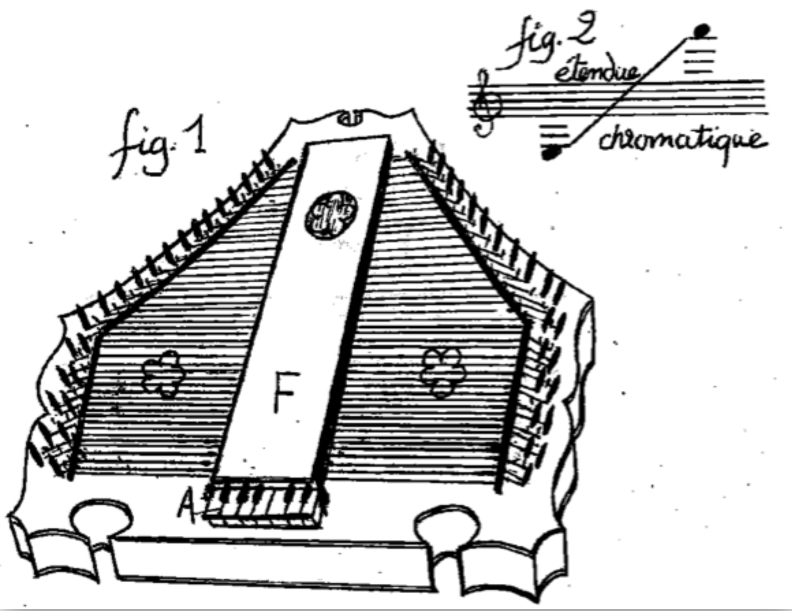


Figure 4.24. Overview of Henner's Instrument (Henner, 1976) Status: Pubic Domain

Understanding the ideas in this patent presented something of challenge; in addition to the language barrier, the drawings are scrappy and there is little or no attempt at scale. Fortunately the description is short, and the ideas expressed begin to sound very familiar.

> *"Chaque touché (A) est en contact libre avec une poutrelle (B) montee d'etouffoirs (C) situes aux octaves de chaque touché…"*

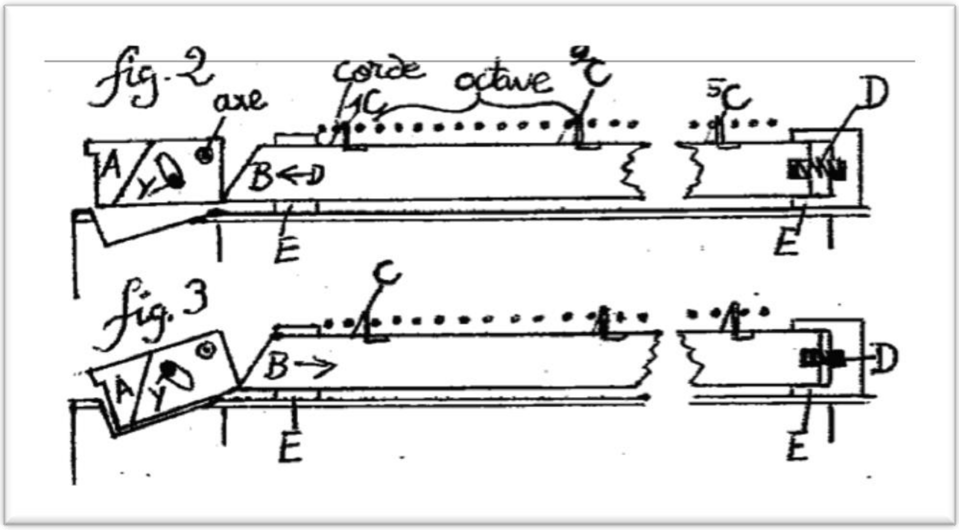


Figure 4.25. Drawings of the Key and Damping Mechanism (Henner, 1976) Status: Public Domain

Despite the changed appearance, which is momentarily disorienting, the keyboard (which uniquely in all the patents begins from F rather than C) remains perpendicular to the strings, and therefore this instrument is another tabletop design.

In this formulation the damping mechanism is placed under the strings and damping is provided at the side of the string through feet extending upwards from the damper beam. Figure 4.25 shows the damper in contact with the string at point C. The downward movement of the key provides force on the beam towards point D, which is sprung, at the treble end of the harp. You can pick out the fact that the damper at point C is not in contact with the string in figure 3 (original patent number within figure 4.25) when the key is depressed. Force from the spring at point D will return the mechanism to rest point. This is a simple and clever mechanism, and has the advantage that it requires only one set of springs that provide force evenly throughout the damping system. Provided that the measurements are controlled strictly, I see no reason for it not to work. However, I am not sure that this arrangement would produce an attractive keyboard action; the pivot points on the keyboard are very short. This issue could be resolved, but this resolution might further compromise the interface as a whole.

The unusual symmetrical harp design is formulated to allow equal access for left and right-handed players. This is a weaker aspect of the design which I consider would not work at all well in practice — there is simply not enough space in the high treble to allow for this symmetrical presentation and the instrument certainly cannot be said to have an optimised string surface.

The issue of handed interfaces is worth considering however. Within the spectrum of western musical instruments as a whole there is mixed practice for left handed implementation; left handed guitars are relatively common, but the violin, for example, is played left handed very rarely — although there are no practical obstacles to this possibility. Whilst I considered the issue of left handed players in the initial stages of prototyping, I quickly dismissed it from my mind as impractical and over-complicated to execute at prototyping stage. Left-handed autoharps do exist, but are quite a rarity; a left handed ReAPH however, would be further complicated, because the keyboard cannot (easily) be reversed, so the access for the respective hands would be completely different.

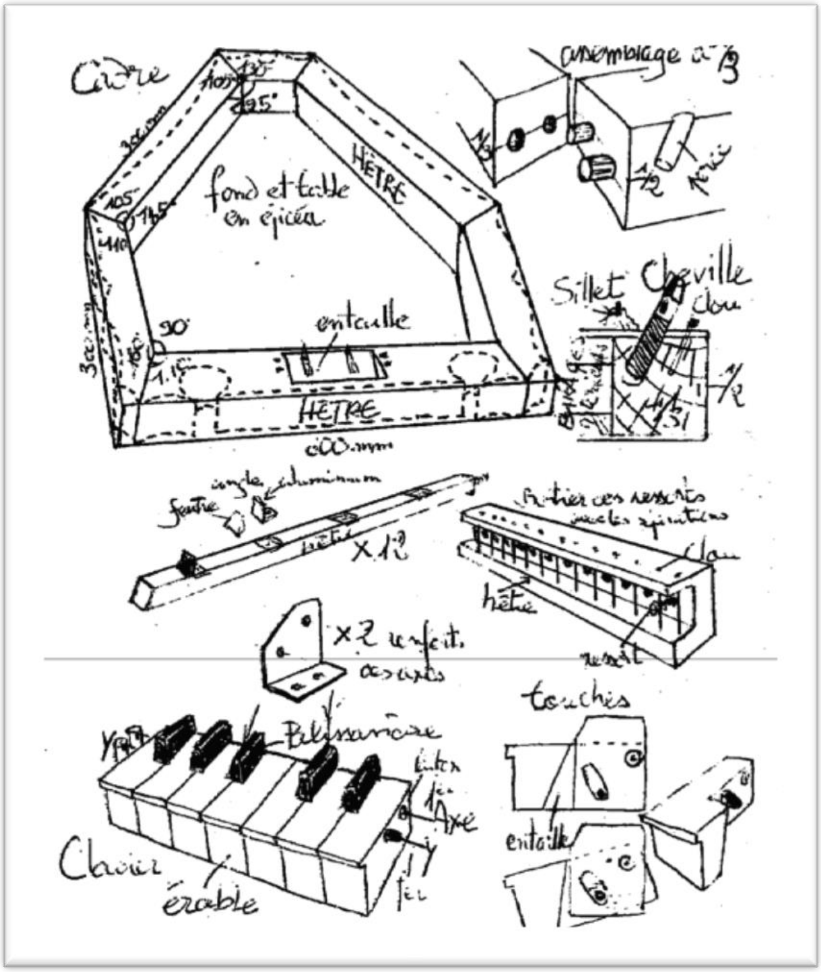


Figure 4.26. The Final Plate of Henner's Patent (Henner, 1976) Status: Public Domain

The final plate of this patent becomes rather scrappy, but you can certainly pick out the defining points of the mechanism: the pivot point of the keys (bottom left and right) the single spring mechanism which receives the far end of the damper beams (centre right), the damper beams and extending felted feet (centre left) and the symmetrical harp shape.

Henner does not refer to any other designs in this patent, which suggest that this patent (like the previous three) was also written in isolation from the ideas of previous patents.

Thomas P Aronis Stringed Musical Instrument

United States Patent

Patent Number 4175466 A

Filing date June 21st 1978 and granted Nov 27 1979

"..Therefore, it is an object of the present invention to provide an improved stringed instrument of the type wherein the strings are arranged in sets of octaves, and a manual keyboard is provided for selecting various strings to vibrate when the strings are strummed, and wherein substantially all of the playing area is accessible to the performer for the strumming of such strings."

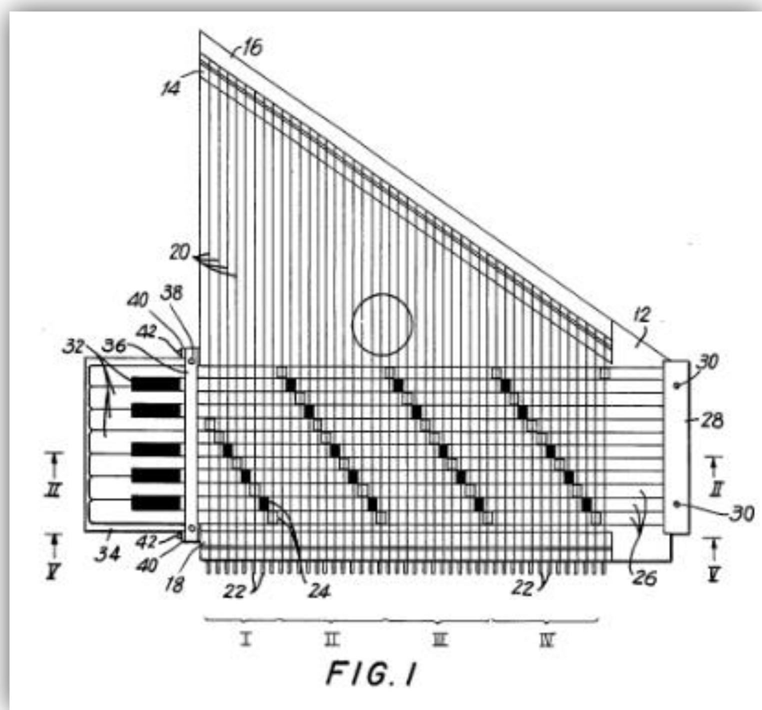


Figure 4.27. Overview of Aronis (Aronis, 1979) Status: Public Domain

The final two patents in this chronology are written in awareness of other US patents, which changes the flavour of the text significantly. Aronis and Newton (to follow) are all about difference: to depict their designs as inventive steps that significantly improve an aspect of a previous design — an approach that was highly informative in formulating my own rebuttal statement.

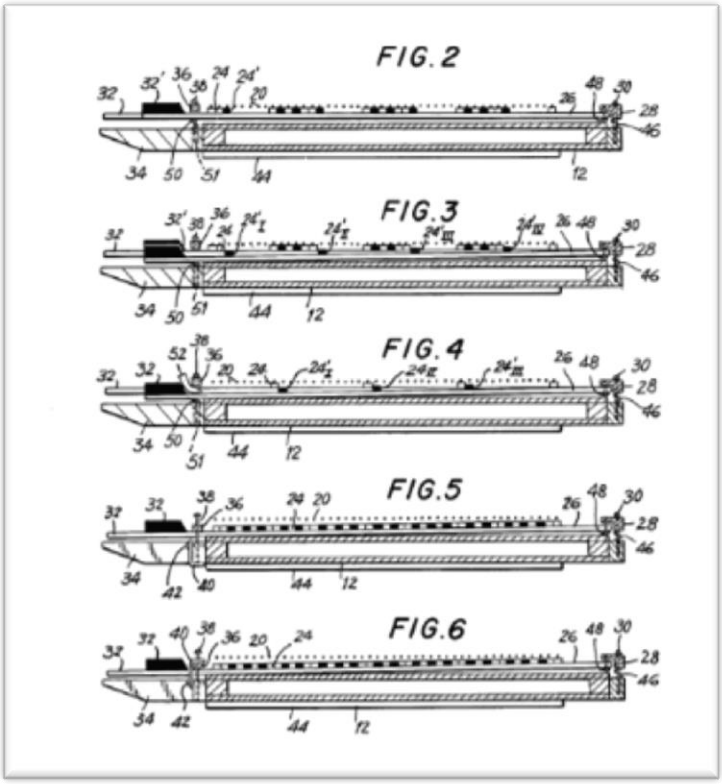


Figure 4.28. Aronis' Keyboard and Damping Mechanism (Aronis, 1979) Status: Public Domain

The Aronis formulation attempts to maximize the playing surface of the strings by placing the entire mechanism underneath. Damping felt is placed directly on top of the key itself and the keyboard is sprung with an extension spring from point 36. Figures 2 through 6 (within figure 4.28) show how the keyboard mechanism will work.

Aronis presents a detailed criticism of Wigand, Back and Young from three perspectives, firstly that the playing surface is too small because the keyboard housing and mechanism are placed above the strings, secondly, that the mechanisms are excessively complicated, and thirdly, because they require greater spring tension.

I disagree on nearly all of these points, but I do think that that the Aronis design has some strengths. In principle it should provide a reasonably good keyboard feel because of the long pivot points on the keyboard (the length is similar to Back) but I do not agree that the spring tension will be significantly different overall; the single spring point in this case might even lead to problems in damping the treble side of the instrument. The design is certainly simpler, but this gain (similar for Henner) must be balanced against the difficulties of placing, and maintaining an action that is positioned directly under the strings — an area that is very inaccessible. Lastly, I do not concur that the playing surface is maximised through this step. A string surface where there is damping felt underneath the strings cannot be deemed playable; it is vulnerable, and would be easily damaged by the right hand strum/pluck actions, and, in my opinion, benefits from the protection of a keyboard action which houses it. Nor do I necessarily agree that access to the entire string surface is desirable at all — there is a relative range of desirable striking points on the string (for all techniques of strum and pluck) which is roughly in the upper 1/3 of each string, and so long as this area of string surface is fully accessible, the playing surface can be said to be optimised.

William T Newton

A New Autoharp Allowing Greater Versatility of Sounds by Allowing Individual Control of the Strings

United States Patent Number: 4,506583

March 26th 1985

"A new autoharp allowing greater versatility of sounds by allowing individual control of the strings of an octave is disclosed. This invention is for use with string musical instruments such as the autoharp…

..Therefore it is an object of the present invention to provide a simple and inexpensive improvement of an autoharp which allows the unrestricted playing of notes and melodies."

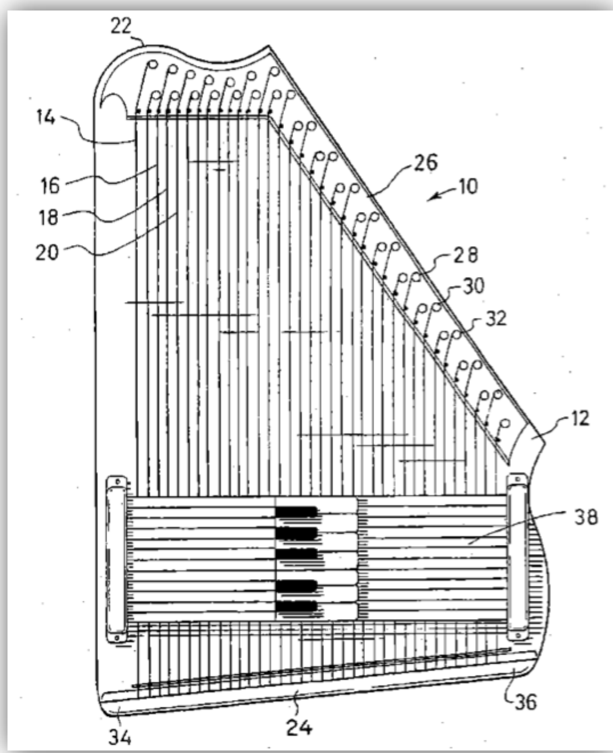


Figure 4.29. Overview of the Newton Instrument (Newton, 1985)

Status: Public Domaiin

Newton provides quite a detailed analysis of previous designs, combined with the simplest of all proposals for a reverse action. The text above summarises the design intent aptly — Newton's design is about providing an easy means to build a reverse action keyboard into an existing autoharp. Assuming a standard 12 bar autoharp — he does not change the damper bar arrangement at all. Instead he begins by depicting a standard autoharp damping arrangement (shown right) and then his replacement (shown below). The replacement is fitted with the now familiar feet (Back, Henner) which project through the string surface and damp from underneath, whilst retaining an over-sprung system. The keyboard depiction is added directly to the damper bars, and no further separation is proposed between keyboard and

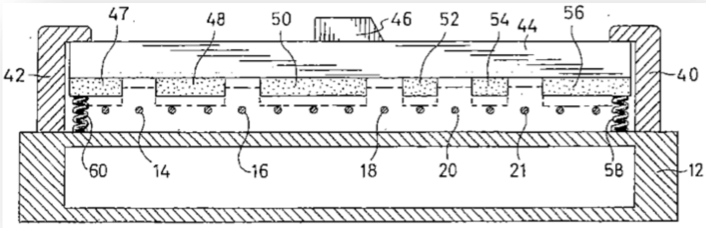


Figure 4.30. Standard Autoharp Damping Mechanism (Newton, 1985) Status: Pubic Domain

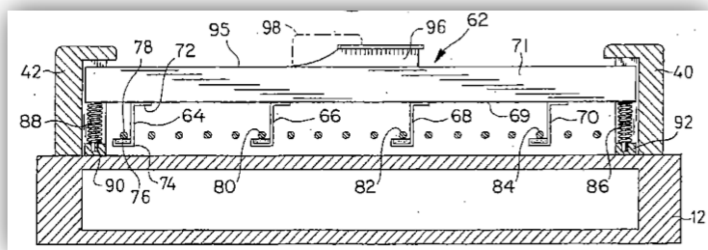


Figure 4.31. Newton's Replacement Damping System (Newton, 1985) Status: Public Domain

damping system.

This “simplest possible” approach offers a practical conversion path for autoharpists which is clearly integral to the design intent, but it is not an attractive proposal to a pianist because the keyboard is so far from the range of expected key dimensions and action. From this perspective it is small, placed poorly, and would provide very poor movement.

All three of these second tranche instruments place the keyboard perpendicular to the strings not allowing the instrument to be played whilst held. The Newton design seems to offer the best possibility for this position for an adaptive autoharpist, because the damper bar arrangement is in principle no different to an autoharp. However playing this instrument in the held position would require the left wrist to twist in order to access the keyboard. This is the position adopted by autoharpists, but autoharpists have only to access one damper bar at a time — a keyboard requires complex finger combinations and this playing position, and the reduced size keyboard is not very attractive to a pianist.

Conclusions and Rebuttal Ground

Overall the range of mechanisms display an interesting spread of variation and commonality, but the language deployed in all of the patents evidences similar musical concerns, proving beyond doubt that “a pianist frustrated with the autoharp” is not an isolated local condition, but one that has recurred on a regular basis since the inception of the autoharp.

The difficulties all inventors face in realising this seemingly straightforward idea have led to a variety of solutions, each of which exhibit strengths in different areas. It also points to the fact that the meme-idea itself occurs with rather more frequency than the number of patents might suggest. Nevertheless this now-illuminated richness of design history cannot obscure the fact that the instrument has little or no presence within the musical community, and extant examples are extremely difficult to find. With regard to the 19th century inventions, the Gondolin (Millington/Young) instrument described above is the only example from the 19th century inventors I have encountered, whilst 19th century autoharps remain relatively common.

20th century examples of reverse action instruments are similarly rare. There are definitely other active players and inventors though — in March 2015 (as a result of the same post [from Bob Ebdon of UKautoharps] that put me in contact with Katherine Rhoda) I was contacted by Steve Brown who plays a Newton style reverse action harp. Steve has quite a few internet recordings which are fascinating. He does indeed play the Newton harp in the "held" position; the twisted wrist does not seem to present a problem to him and he has clearly adapted to the small size of the keys. The approach from the accordion player Ben Devoy (previously discussed) demonstrates that the attraction of the interface is not limited to keyboard players.

But this is a tiny number of dedicated people, and it does not represent acceptance in the wider musical community; there are two groups of potential early adopters; pianists (and other keyboard players) and autoharpists. I would expect that the instrument would only have a limited appeal to autoharpists, the potential new and much larger market is to be found in attracting pianists, but thus far (120 years) it has failed to do so. Answers as to why this is so fall into two categories, the nature of the musical community (the subject of the next chapter) and design issues. Here let us simply summarise the design issues;

1. It is possible that previous prototypes have not worked very well; our analysis has considered the strengths and weakness of each; but one particular issue to re-consider in conclusion is that they exhibited poor harmonic damping
2. The difficulty with previous instruments lies with the perpendicular keyboard integration, and unattractive keyboards from a pianistic perspective

These two points formulate the rebuttal ground for patent application for the ReAPH.

Harmonic Damping Compared

Within the ReAPH formulation, an unexpected benefit of the independence provided by the pulley and string arrangement was that poor harmonic damping could be resolved using the same strategies (but with even greater freedom) as deployed by autoharpists. The fact that pulley and strings can easily be re-coupled effectively enables random access between keyboard and damping systems. The damper bars can be presented in any arrangement without affecting mechanical considerations, or affecting the playing interface in any way — it does not matter to the keyboard arrangement where the damper bar appears if the coupling is flexible. This allows 12! possible combinations[12] of damper bar arrangements and this design property was one of the factors in securing the patent.

[12] 12! (meaning 12 factorial; 12 x 11 x 10 x 9 x 8 x 7 x 6 x 5 x 4 x 3 x 2 = 479,001,600)

Of the historical inventors, only Millington/Young (limited to one additional C) and Page allow cross coupling of keys in their designs, and only Page appears to consider the issue of harmonic damping of sufficient significance to warrant discussion within the patents. This disbars one of the primary strategies to combat harmonics from all of these formulations. But to what extent did these historical prototypes exhibit poor harmonic damping characteristics? Steve Brown's Newton harp certainly does not exhibit excessive harmonics at all by the sound of his recordings, indeed it appears to be very good, and this is clearly achieved without recourse to cross-coupling. In email exchanges, Steve pointed out to me that the different geometry of the feet-through-the-strings design of the Newton (also Henner and Back) allow for easy extension of damping down (or up) the strings as far as necessary from node points without interfering with the movement of adjacent damper bars — a point, the importance of which I had previously missed. The potential to implement the second strategy of producing "outriggers" is therefore considerably enhanced on these instruments, which clearly compensates for the lack of cross-coupling potential. Indeed on further reflection, I consider that the potential to implement outriggers within reverse action formulation generally is enhanced over autoharp formulations because no string has to be damped from multiple positions and therefore there is no practical obstruction to producing a long outrigger even on an overdamped system. Overall, I suspect that harmonic damping was an issue on these instruments and was a surprise for some of the early inventors, but that it was possible to combat it. The extent to which this was executed is unknown.

Keyboard Touch and Feel, Position and Orientation

Various internet sources attribute the adoption of the autoharp as a "held" rather than a table-top instrument to one Sara Carter, some time in the 1920s. Sara Carter was part of the Carter family of folk musicians; cousin to Maybelle Carter (mother in law of Johnny Cash). This story might well be true, the Carters certainly added sophistication to the strum/pick variety of techniques, and were likely the first to adopt finger picks over plectrums, which provided a much wider variety of approaches to the string face.

However, this was not an influence on my own determination of optimal playing position; in fact at the outset of the project, when I was not yet steeped in autoharp, and reverse action autoharp lore, I was a little confused, looking at historical pictures, as to what the dominant position was. Further, I gave no thought to autoharp lineage and considered at first (like many other reverse action inventors) that the instrument was novel. Instead I applied the physiological principles learned from a lifetime at the piano to determine a comfortable keyboard position, and similarly applied knowledge from those frustrating years spent attempting to learn the guitar to determine a comfortable strum position. The keyboard position must allow a relaxed left arm, supported from the shoulder and the upper arm, with no twist in the wrist joint, and the strum position must allow free forearm and wrist movement, similarly supported by the upper arm and shoulder.

Perpendicular keyboard orientation cannot allow both positions to be optimised however the instrument is turned or held — this was the purpose of spending a great deal of time playing “air” harp at the outset of the project. This time determined the optimum playing position and the mechanism evolved from this point. This results in a comparable set of compromises to a guitar — the instrument displays different capability, but similar range in terms of polyphony and timbral variation.

Making an instrument which achieves this guitar-equivalence, but from a keyboard perspective, is perhaps a significant step in gaining market acceptance because there *are* commercial examples of instruments which demonstrate these design aspirations; the electronic keytar and the guitaro.

Figure 4.32. A Guitaro (Harrison, 2004)

Status: Permission Granted

The guitaro (shown left) is a limited instrument from a musical and interface perspective. It offers only 22 strings, and is poorly optimised for hand/arm access; but it aptly demonstrates the aspirations of guitar looks and orientation. The keytar similarly provides a guitar-like interface, but with significant compromises from a keyboard playing perspective — the guitar look and feel, set limitations on the hand access.

The ReAPH formulation, admittedly does not look like a guitar. The first and second prototypes were played at a variety of angles (as is the guitar) to test for optimum position, but always in the same orientation. The more upright position, with the keyboard held between the legs in a seated position (reminiscent of ‘cello) became fixed only at the time of prototype 2 because of the broader repertoire engagement (particularly classical) and greater variety of right hand approaches to the strings, and prototype 3 solidified the position by adding the “spitfire wing”, which enables the instrument to rest on the left leg. The resulting instrument may not aspire to a guitar *shape*, but it is evident to pianists that it will afford a comparable musical interface, and crucially otpimised playing position for both arms.

The adoption of the raised keyboard position, parallel to the strings, leads to a different coupling arrangement — that of pulley and strings. This is more complicated and arguably inferior to some of the direct coupling actions adopted by the historical inventors (from a mechanical perspective), but it had further unanticipated benefits (we have already explored the potential for cross-coupling to eliminate harmonics); it allows the two mechanisms; keyboard and damping actions to be considered semi-independently. A key finding of prototype 1 was that slackening the pulley strings slightly and allowing for a certain amount of free key travel (like a piano) produced a better feel to the keyboard. From this finding, I was confident that a keyboard feel, within the range of pianist expectation could be achieved. The direct couplings to damper bars of all save Page are not conducive to experimentation with the issue of free key travel (before the damper system is engaged by the keys); and there is no evidence that anyone considered this. Moreover my analysis of the historical patents leads me to conclude that only Back and Aronis really considered the aspect of keyboard touch & feel to be of significance, and that the remaining inventors just sought optimal mechanical coupling.

Conclusions

The table below judges all of the prototypes against the 16 design principles expressed as selective pressures within my own prototype series.

Year	1888	1896	1899	1915	1976	1979	1985
Prototype	Wigand	Back	Millington	Page	Henner	Aronis	Newton
Action							
1. Playing position	No	No	No	No	No	No	No
2. Keyboard: appearance and feel	No	Yes	No	No	No	Yes	No
3. Pulley and string system	NA	NA	NA	NA	NA	NA	NA
4. Key pivot point to damper coupling	No	Yes	No	No	Yes	No	No
5. Key range	No	No	Yes	No	No	No	No
6. Harmonic damping	No	No	No	Yes	No	No	No
7. Minimal noise	NA	NA	NA	NA	NA	NA	NA
8. Integrated amplification	NA	NA	NA	NA	NA	NA	NA
9. Playing space on the string surface	No	Yes	Yes	Yes	No	No	Yes
10. String tuning and range	No	No	Yes	Yes	No	No	No
11. Access for maintenance	Yes	Yes	Yes	Yes	No	No	Yes
Harp							
12. String distinction	No	No	Yes	No	No	No	No
13. Tuning mechanisms	No	No	No	No	No	No	No
14. Top plate	No	No	Yes	No	No	No	No
15. Depth and volume of the resonating chamber	No	No	Yes	No	No	No	No
16. Optimised coupling of bridge and top plate	No	No	Yes	No	No	No	No

No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

Figure 4.33. Historical Inventions Assessed against the 16 design criteria of the ReAPH formulation

The harmonic damping simply records the fact that all save Page do not consider the issue within the patent document — it is not a comment on the damping of the instruments themselves. Overall the judgements may appear to be pretty harsh, particularly with respect to the playing position (Note the entire row of red against this criterion). This is, of course, not to say that playing position is not considered in these prototypes (it is) but recall that a conclusion of chapter two was that lock-in to a sub-optimal interface is a matter of perspective, and depends on two value judgements:

1. The judgement that a facet *is* a sub-optimal adaptation (poorly suited to a particular task). In order to arrive at this conclusion, there must be an alternative for comparison

2. The judgement of what the task of that adaptation *is, or ought to be*

From pianistic perspective the keyboard position presented in all of the historical designs *is* a sub-optimal interface in a very real sense. It is my belief that the ReAPH formulation, which places keyboard feel and hand/arm access at the centre of the design constraints really does provide a further balancing in the interface which renders it truly adaptive and attractive to pianists, and to the wider musical community, and that after 120 years of existential obscurity the best years are ahead for reverse action keyboard harps.

Prototype 2

Year	2008
Considered in Prototype	2
Action	
1. Playing position	Yes
2. Keyboard: appearance and feel	Yes
3. Pulley and string system	Yes
4. Key pivot point to damper coupling	Yes
5. Key range	Yes
6. Harmonic damping	No
7. Minimal noise	No
8. Integrated amplification	No
9. Playing space on the string surface	Yes
10. String tuning and range	Yes
11. Access for maintenance	No
Harp	
12. String distinction	No
13. Tuning mechanisms	No
14. Top plate	No
15. Depth and volume of the resonating chamber	No
16. Optimised coupling of bridge and top plate	No

Figure 4.34. Photographs of Prototype 2 and Assessment of the 16 Design Criteria

No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

Prototype 2 was the first instrument to survive until the current time. It was based on a 36 string chromatic Chromaharp, and despite its rough appearance it has proved extremely robust. It travelled through France and Italy with me in the summer of 2008, was used in research and MA presentations during 2009 and 2010 and I played it for hundreds of hours. It spent several months being dissected in the workshop of Alec Anness, whilst he decided whether to take over the task of building the keyboard action, and when it returned after the completion of prototype 3b in 2011, was subsequently adopted by my daughter, and it continued to be played a great deal. My daughter has performed upon it in school concerts, and in school plays. Overall, it has generally travelled, been banged about and proven itself extremely reliable.

This was a significant aspiration for this prototype after the ramshackle arrangements of prototype 1, where I would only dare to attempt ensemble practice with my wife, (and she often commented on the number of interruptions to "..completely rebuild the instrument").

At this time, I took the first tentative steps to improving my woodworking skills with the addition of a drill press, which added precision and strength. This began the slow process of really engaging with this aspect of the project, so that the skill level, and resulting workmanship, really did improve over the next two prototypes.

The keyboard used in the prototype was a very old cheetah 88 note MIDI controller keyboard, which had done sterling service in the University of Salford recording studios during the mid to late '90s but was now obsolete. The photograph left, shows that its design offered the right kind of overhang at the key tip and this aspect was a success, improving the keyboard position without hindering right hand access to the strings in any way.

Figure 4.35. The Cheetah Keyboard used in Prototype 2

Other characteristics of the keyboard were more problematic. The plate also shows that the key tips are weighted, an aspect that at the time, I hoped would counter-effect the shorter pivot point, which is placed immediately after the visible key surface (recall that I have criticised this pivot position as not providing natural keyboard feel to a pianist). The key pivot point could easily be set at a piano key length in prototype one because the keyboard was not directly coupled to the key rod. I had determined this position from measurement of pianos, but at the time of prototype one, I had not fully appreciated the importance of this measurement to keyboard feel. Unfortunately there was no easy way to lengthen it, and so it remained as a random variation. As a result, whilst the keyboard does generate sufficient power to lift the dampers, the feel is wrong for a pianist, and the keyboard is quite heavy. Attaching the key rods to the back of the keys was also problematic because there simply wasn't enough purchase to provide a neat attachment and at this point I resolved that this would be the last prototype to utilise a reclaimed keyboard and that the next one would be purpose built.

The drawing below shows a cross section through the mid point of the damper bars. It illustrates the improved pulley system where three separate pulley wheels each turn the

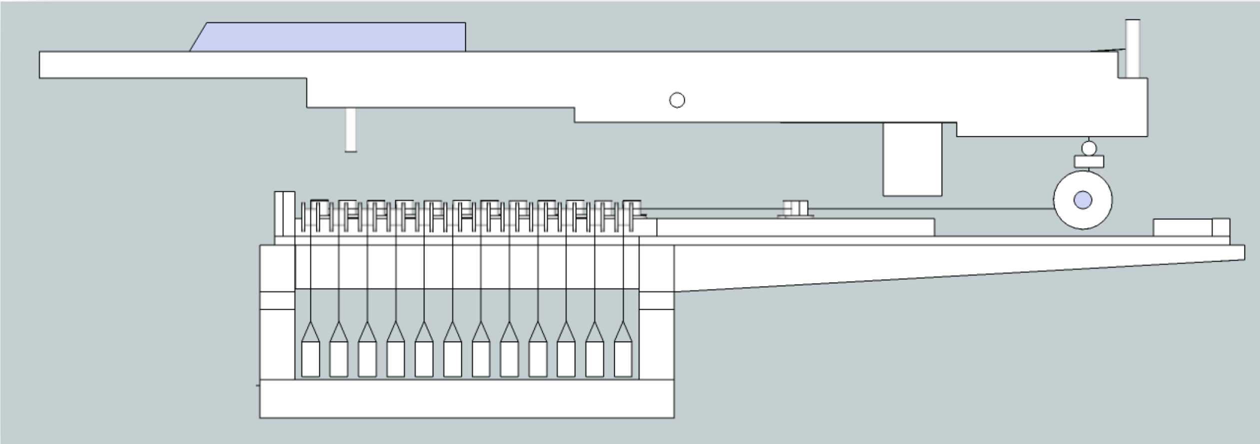


Figure 4.36. Cross Section through the Keyboard showing the improved Pulley Wheel System

string through an angle of 90°. The two following photographs show the pulley wheels realised on the prototype.

The pulley wheels have a 4mm bore and a 10mm outside diameter tapering to a centre groove. The axle is provided through a brass rod (not solid) and this was not sufficiently rigid to prevent it from flexing when playing the instrument, particularly on the longest bar shown in the plate below, and was subsequently strengthened through successive prototypes.

Figure 4.37. The Exposed Keyboard Pulley Wheels of Prototype 2

The best material for pulley strings turned out to be waxed linen thread used in Jewellery making, and the reliability of the system depends heavily on the remarkable properties of this material. It is very strong, and hardwearing — no threads have ever needed to be changed in this (or any) prototype, and it also has properties of shape forming and memory. It wraps itself to the shape of the pulley system and is not easily dislodged.

The photograph below shows the remaining pulley wheels placed under the keyboard and parallel to the strings above the centre point of the damper bars.

The most obvious arrangement was to connect the lowest key to the damper bar closest to the toe end of the harp. This arranges the pulley system such that no string crosses another save for the final top C, which was added to the keyboard at this prototype (discussed in the introduction). This produces the diagonal line of pulley wheels across the matrix that you can see in the photograph. The remaining top C, whose pulley string you can also see in the photograph, crosses all the other strings and is subject to an angle correction in order to allow a final pulley wheel to form a double attachment to the damper bar closest to toe end of the harp. This arrangement proved that cross stringing made no significant difference to the friction, or the reliability of the system, which was a good thing because the cross stringing was about to get significantly more complicated in prototype 3. Overall, the improvements to the pulley system, whilst not perfect, were very successful.

Figure 4.38. The Matrix Pulley Wheel System of Prototype 2

Despite the problems with the pivot point of the keyboard, the double sprung mechanism also proved successful. The keyboard, sprung independently with the springs from the original cheetah keyboard acted independently and was not reliant on the damper spring to return it to rest point. Thus issues of free key travel before engaging the dampers and minimal damper movement were a great deal easier to test for feel. The pulley string tension was controlled using zither pins at the far end of the key rod, and this provided a precise mechanism to produce an even response across the keyboard.

A key problem that emerged from prototype 2 was that the harmonic damping was very poor. The problem was so bad that it demanded urgent attention. From previous discussion it was noted that problems with harmonic damping happen because damping occurs at points that are proportional to the speaking string length. If, for example, we find that a damping point occurs at 1/3 the speaking length, then damping might well result in a pitch of $3 \times f_{\text{fundamental}}$ (octave and a fifth) sounding if the string is strummed or caught in inaccurate pinch or pluck when the string is damped.

Harmonic damping is a problem for autoharp and reverse action harps alike. In both it is compounded by the fact that each damper bar damps several strings from the same point and therefore solutions such as the one patented by Walton Page are not appropriate mitigation strategies — the damper bar cannot simply be moved to a suitable calculated point in relation to a single string. Moreover, the manifestations are so complex and unpredictable as to seem to bear little relation to the simple calculation above — in practice, I quickly gave up calculating and predicting in order to solve this problem; I simply tested and noted results. The problem on autoharp manifests slightly differently, because each string is damped from multiple damping points according to the particular chord bar, two mitigation strategies for autoharp (previously described) are adaptive to the ReAPH. A third, “in play” strategy is also described — the player simply presses the bar harder, which can be effective (but is often not); this strategy cannot be utilised on the ReAPH because the damping pressure cannot vary — it is determined by the strength of the damper spring.

The strategy of widening the damping felt to the toe or dead end of the instrument (termed “outrigger”), seemed possible to apply, but was not attractive to me at this time, as the remaining strategy (the most extreme strategy for autoharpists), that the damper bar order is changed, seemed to offer greater potential to solve the problem completely. Autoharpists do not like to change damper bar order, but are sometimes persuaded to do so in order to mitigate harmonics, but the order of the damper bars is of no consequence to the ReAPH player as long as the keys are connected to the appropriate damper bar.

Commission of Prototype 5 Harp

In the summer of 2010 I arranged the first meet with luthier, Alec Anness, to discuss a possible collaboration. Alec has an interesting blend of skills. His original training is in woodworking; cabinet making, bespoke furniture and particularly in finishing (French polishing). He is also a musician, and this blend of skills met in piano maintenance and restoration. Alec still works in this capacity but seems to work increasingly on commissioned instruments; every time I visit, his workshop is filled with a greater number and variety of instruments. He makes banjos, autoharps and dulcimers. The testimonies to his instruments were without exception excellent, and to me he seemed the best harp maker in the UK. His special interest in the autoharp and his blend of musical and luthier skills, together with his ability and willingness to innovate, made him an excellent potential collaborator for the project.

The first aspects discussed were the acoustic properties of the autoharp itself. The quality of the three commercial harps that I had purchased was frankly, poor. This experience now constituted a reasonable spread of variation; in addition to the diatonic German harp, a Chromaharp (prototype 2) and an Oscar Schmidt chromatic harp (in preparation for prototype 3). The Schmidt harp was the best of these, but still poor when compared to even the most basic guitar that I had owned. I wanted to talk through some ideas on improving the instrument's sound. My ideas centred around a study of guitar shape, design strategy and acoustic properties compared to the relatively small shape of the autoharp. I had therefore determined that I wanted extra volume within the cavity, better bridging and top plate shaping. Alec listened to all this politely, and simply replied that it was not necessary; citing a recent harp by D'Aigle that integrated many of the properties that I had put forward, he talked of how it changed the nature of the weight and balance of the instrument and stated his opinion that this was a shame because it was departing so far from the autoharp tradition. On testing, I had to agree. I found his harps fully lived up to expectations — they sounded astonishing compared to commercial harps. The issue of musical tradition and its relationship to community and market had become a concern by this stage of the project and I knew that there would be considerable advantage in innovating upon an instrument whose outward appearance placed it within the accepted phenotype of autoharp.

Alec was more circumspect about how he achieved this considerable improvement in sound without marked change in outward appearance; saying only that piano design was much more applicable than guitar design. Since I had not approached the problem from this perspective, and in any case all my knowledge was theoretical, I was unable to formulate the right questions to gain a significant understanding of the issues and reluctantly had to leave this question for a later date.

We first agreed that I would commission a harp from him, of unusual proportions (we agreed on 42 strings, a high D and low D and the interval break between bass range and melody range discussed in the previous chapter). Overall we spent several hours in his workshop discussing all aspects of the project. Alec was very interested in its progression. He agreed that the principle of reverse action was sound, and though not really a keyboard player, understood exactly what the successful completion of such an instrument would accomplish. He had an interesting perspective on the autoharp; he felt that the best players of the instrument (and in contrast to other instruments) were around at this point in its history and that this aspect was still developing. In contrast that there was a recognition that no one quite seemed to know how to develop the instrument further. He was reserved about the idea of taking on the making of the reverse action keyboard, feeling that whilst a lot of design issues had been addressed in prototype 2, a great deal still remained, and that it was too early to hand over from prototyping to the expense of engaging a luthier. Not least because the keyboard and damping action were still skeletal and there was a good deal of design to be done to provide a finished housing, which simultaneously provided maintenance access. We therefore agreed that I would make a third prototype, which would place appearance and finish amongst its design priorities, and we agreed to meet after the completion of both projects, at which time we would consult once more and decide how to proceed in order to finish the project.

One more thing that Alec asked was that he be allowed to keep and study prototype 2, a request to which I acceded very reluctantly, as I knew that I would be without a harp on which to engage in any musical practice for some time. It did provide a considerable spur to complete prototype 3 though.

Prototype 3

Year	2010	2011
Considered in Prototype	3a	3b
Action		
1. Playing position	Yes	Yes
2. Keyboard: appearance and feel	Yes	Yes
3. Pulley and string system	Yes	Yes
4. Key pivot point to damper coupling	Yes	Yes
5. Key range	Yes	Yes
6. Harmonic damping	Yes	
7. Minimal noise	No	No
8. Integrated amplification	No	No
9. Playing space on the string surface	Yes	Yes
10. String tuning and range	Yes	Yes
11. Access for maintenance	Yes	Yes
Harp		
12. String distinction	Yes	Yes
13. Tuning mechanisms	No	No
14. Top plate	No	No
15. Depth and volume of the resonating chamber	No	No
16. Optimised coupling of bridge and top plate	No	No

Figure 4.39. *Photographs of Prototype 3 and Assessment of the 16 Design Criteria*

No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

Prototype 3 was built in two intense periods of activity: the first took place in June and July of 2010, and consisted of work on the lower action (including solving the problem of harmonic damping), the pulley system and integrating a temporary keyboard similar to prototype 2. The second took place in January of 2011. Looking back, I realise that I should have taken account of the increased build time (which corresponded exactly with the increase in complexity of the mechanism and the build standard of the prototype) and understood that the time of completion of prototypes in intense periods was over, and a different set of strategies needed to be developed.

Prototype 3 was built in a mix of woods. I did not, as suggested by Alec Anness, move directly to hardwood, I considered that I was still experimenting with design, and I did not want to feel cost pressure in terms of the level of experimentation. But I did improve the quality of the softwoods that I was working with through different sourcing. The two finished top plates that you see on the damper bars and the keyboards are reclaimed from a broken guitar, acquired and de-constructed in order to better understand how the compound radius arching and simple curves of the top and bottom plate were respectively constructed (thinking ahead to prototype 6). In addition, I varnished the keyboard itself to a finish, in order to understand how this would affect its dimensions and friction.

The damping system integrates 15 bar autoharp spring mechanisms sourced from D'Aigle, which were then cut to 12-bar size, and reversed. The photograph below shows the integration of this mechanism, hinged on the bass side of the instrument such that damper bars can be removed and maintained without removing the upper action. The keyboard housing is removed in this photograph to show as much mechanism detail as possible.

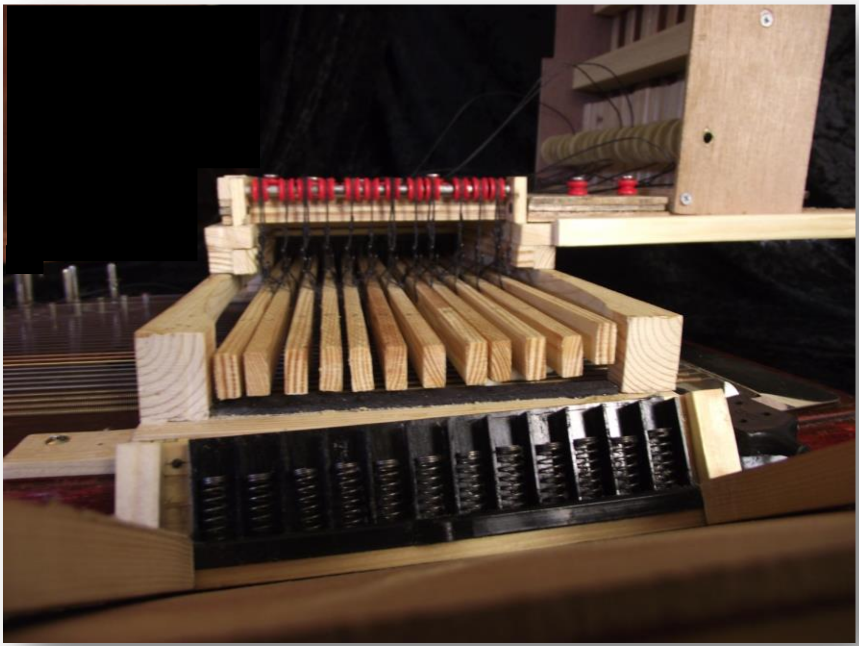


Figure 4.40. Prototype 3 stripped down to show pulley systems and lower action

Finalising the damper positions took about six hours over two sessions. There are 12! possible arrangements (479,001,600), which is a very large number, but otherwise uninteresting. In practice although each damper bar has 12 possible positions, many can be ruled out immediately. I proceeded by testing each damper bar in turn, recording unacceptable and acceptable positions for each, then overlaying each of the 12 diagrams in combinations and sorting through different possible solutions. Arriving at the final position remained time consuming, and there are still one or two minor harmonics remaining. Overall I felt that I had achieved comparable harmonic damping to Alec's harps, and I was pleased, when we met, that he agreed with this assessment.

The photograph right, shows the pulley system oriented from the bass side. The photograph below is from the treble side (now with the keyboard housing on). Note that the matrix pulley wheels do not now appear in a diagonal line, as they did in Prototype 2. Instead their positions are determined by the intersection of perpendicular lines from the keyboard pulley wheels and the new random damper bar order of: C, A, G, E, Bb, C♯, F♯, B G♯, D, F, Eb.

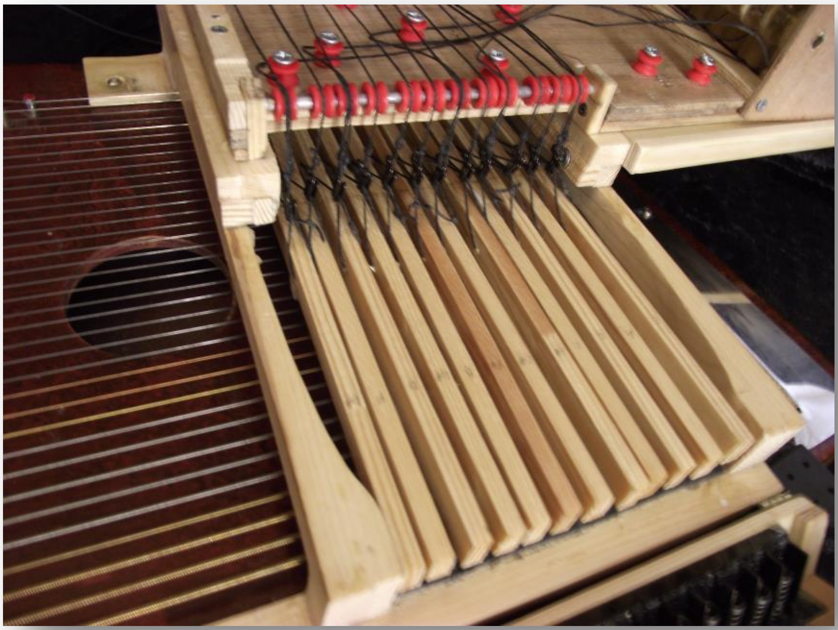


Figure 4.41. Photograph of the lower action (damper bar pulley system)

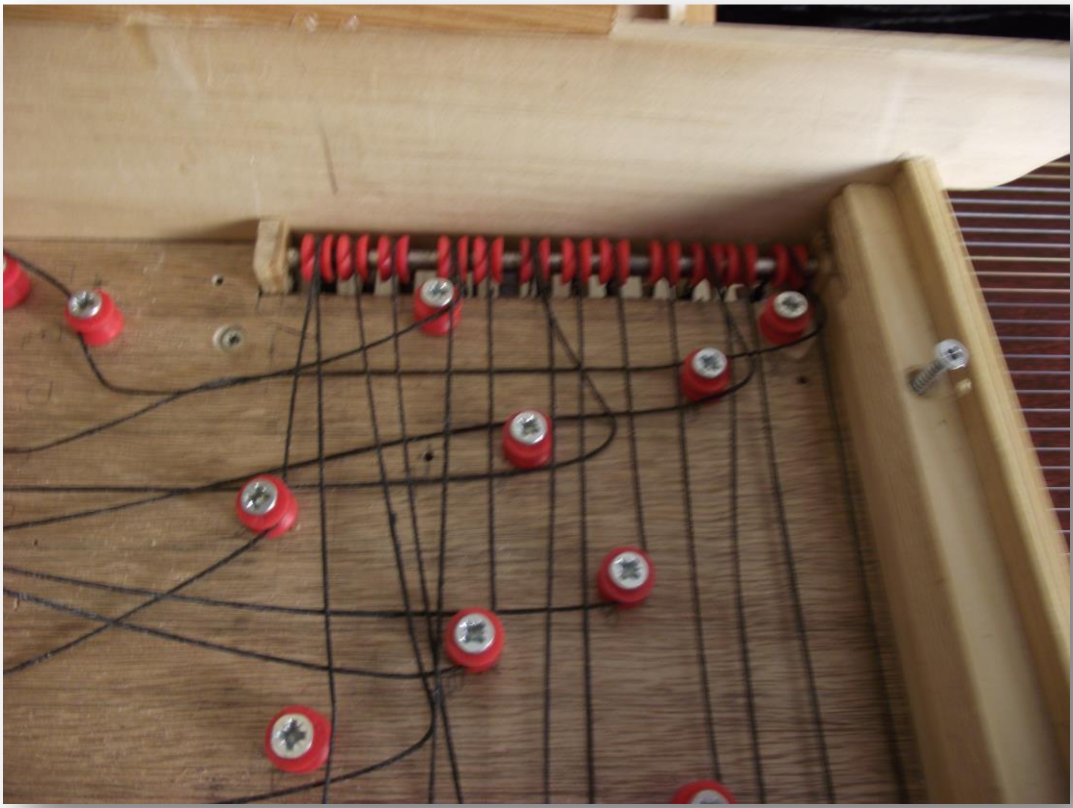


Figure 4.42. The Matrix & Damper Bar Pulley System

Below, the orientation is now from the toe end of the instrument looking towards the back of the keys. The keyboard pulley wheels were changed to sewing machine bobbins in this

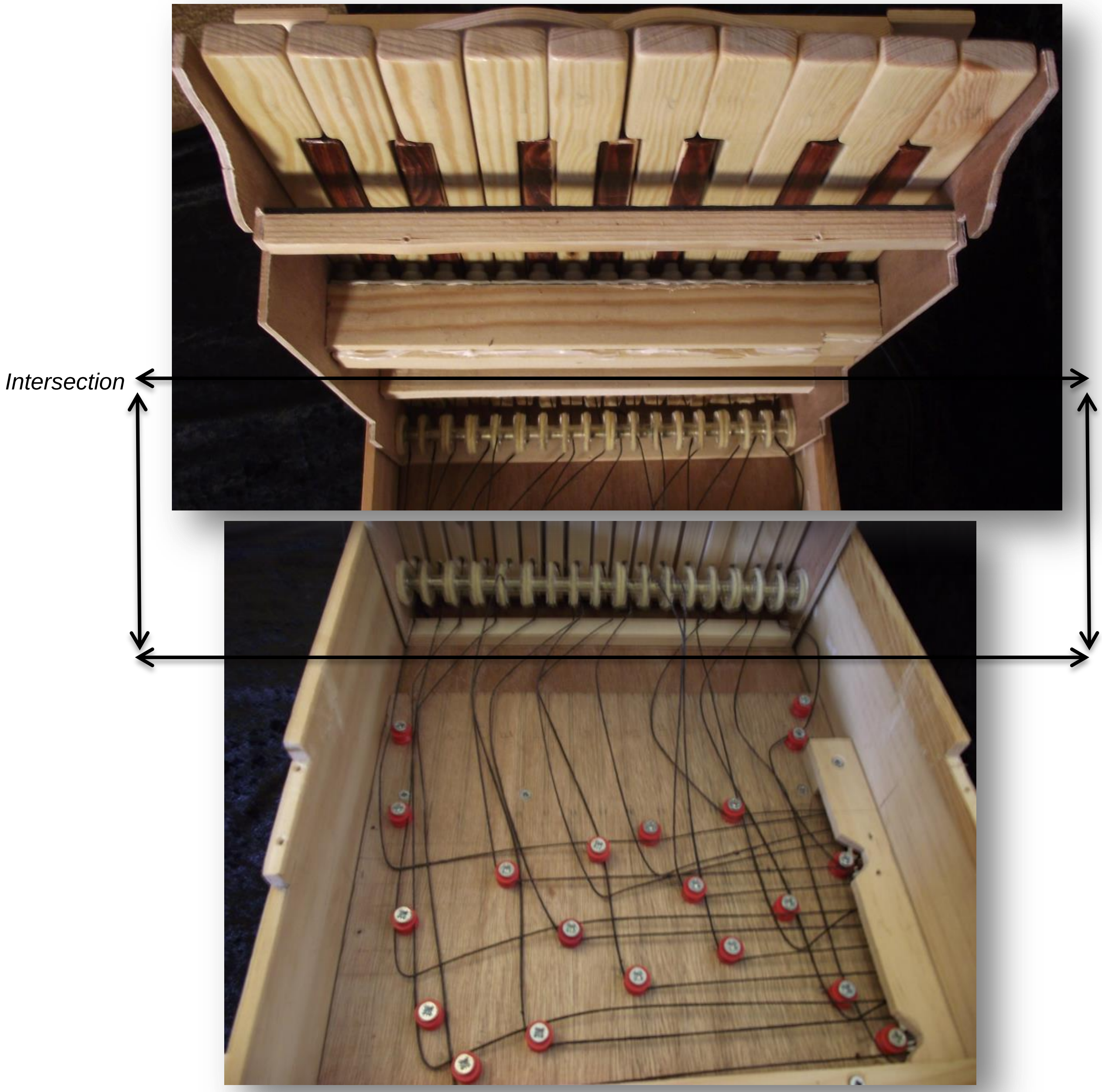


Figure 4.43. View from the Toe end of Prototype 3

prototype, which are a larger bore size (which results in a stronger bar), and a larger overall diameter. These are a good fit relative to the keyboard dimensions. The damper bar pulley system is now covered by its housing in this photograph. This series of photographs also shows how the action is dismantled for maintenance, giving complete access to all aspects of the action whilst minimising the effect on the outward appearance (very few visible screw points).

The dimensions for the keyboard build of this prototype were firstly considered in relation to ideal piano key size (octave span 164mm) and the size of the reclaimed keyboard that was first used to test the damping (similar to prototype 2), which is a little smaller. Given that this prototype added four keys to reach a total of 17 keys (discussed in chapter 3); thought had to be given to the added width to the rear of the keyboard which was now established within the playing position, as sitting between the legs of the player. The width of the reclaimed keyboard was acceptable, and its spacing as a playing interface, also acceptable; but I considered that there was now an added design pressure to constrain this measurement and not to allow it to expand to piano standard width (a similar pressure is exerted on the dimensions of the keyboard housing). This was the first design job undertaken in 3d rendering, a skill that developed throughout the subsequent period to the extent that I have included a section dedicated to virtual prototyping.

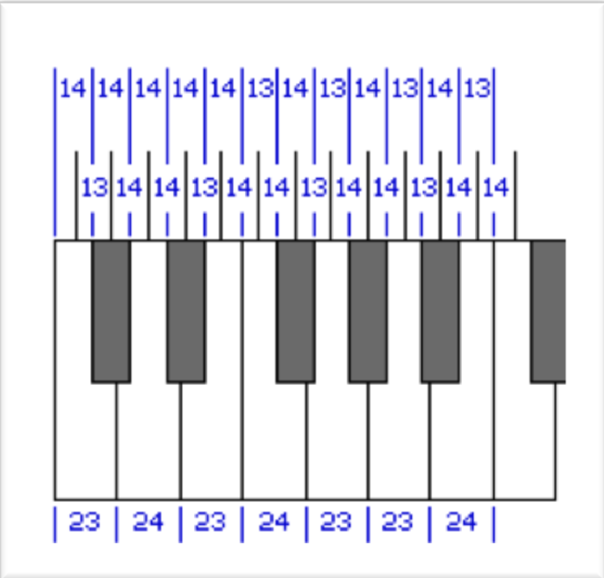


Figure 4.44. A Keyboard Simple Dimensions (Savard, 2007) Status: Permission Sought

For an excellent discussion on keyboard geometry and practical keyboard design John Savard's (Savard, 2007) discussion was invaluable. A practical solution arrived at in this document is shown left (measurements in millimetres). This solution achieves a standard piano octave span of 164mm. The design intent here is for individual key measurement to remain as whole number millimetre measurements (deemed the lowest possible for accurate hand cutting). It does not achieve complete uniformity across the white key surfaces. Instead, it preserves mirror symmetry between C and E centred on D, and between F and B centred on G♯, and allows a slight variance of 1mm between the presented white key surfaces. It does not take account of the spaces between the notes, and is slightly wider than required for prototype 3.

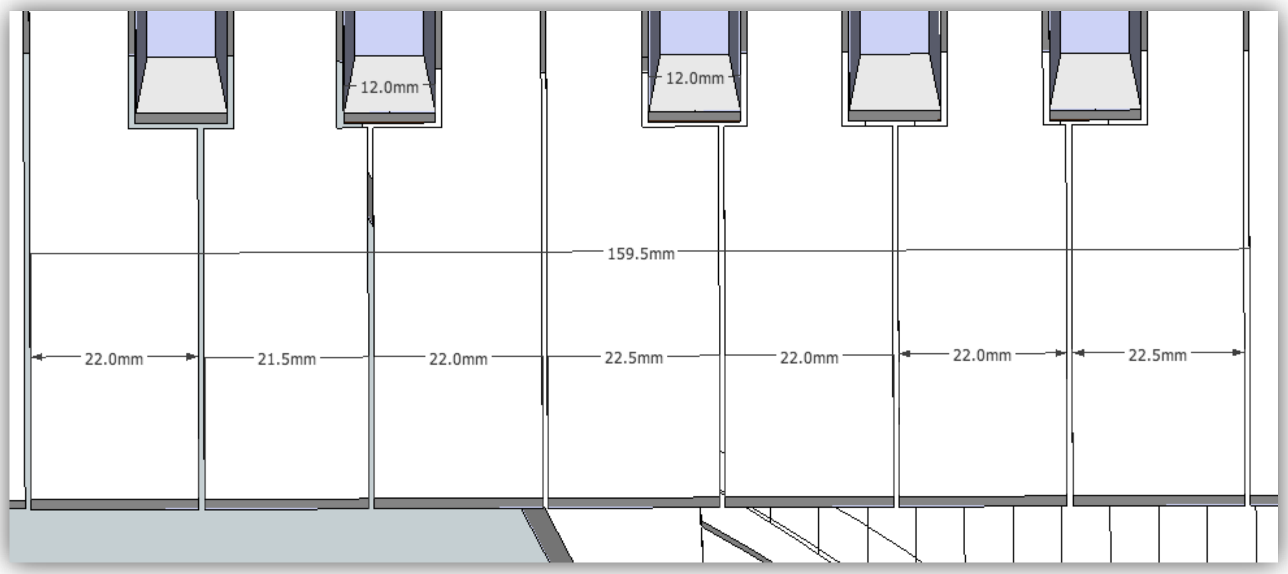


Figure 4.45. The Geometry of Prototype 3 Keyboard

The solution arrived at for prototype 3 (using 3d rendering) also preserves this mirror symmetry, and with the same variance of 1mm over the entire keyboard. However, in this keyboard no adjacent key varies by more than 0.5mm. The width of the black keys is 12mm. The lowest measurement allowed is 0.5mm

The sum of the white key surfaces in this projection is 154.5mm. Added to this figure are the spaces allowed between the keys, set at 0.7mm between white keys and 0.8mm black to white key. The final projected octave span is then 159.5mm — a shortening of nearly half a centimetre over standard width.

Whether or not this ideal was consistently achieved on prototype 3 is another matter, softwood is difficult to cut consistently at this level of accuracy, and the whole procedure needed to be undertaken, considered and refined. By the time the next keyboard was cut by hand (prototype 5), a series of improvements to the procedure led to a far more consistent result. Overall however, prototype 3 keyboard does fit the dimensions accurately and works extremely well.

The key springs used in this prototype are unusual silicone compression springs reclaimed from an evolution MK-149 MIDI keyboard. These can be seen in figure 4.43, integrated into the keyboard before the pivot point. Reclaiming parts from a variety of MIDI keyboards has been interesting, and a surprising aspect was that the key spring mechanisms were different in each. These compression springs were the easiest by far to integrate, and have the advantage of being silent.

Zither pins were again integrated as mechanisms to control the pulley tension. Whilst these (once again) worked very well and were better integrated in prototype 3, they did cause problems. Within prototype 2 the 5mm zither pins were hand pushed into a borehole of very slightly smaller dimensions. They didn't provide very much resistance, but in fact not much is needed for the pulley strings. After all, they don't need to tension a string to provide a pitch. However, I did think that they needed to be properly integrated; provide a reasonable level of resistance, such that they could be tensioned using a tuning hammer, rather than by hand and not be in danger of falling out. I had talked over this aspect with Alec Anness; the pin block for his harps is made from offcuts of Steinway piano pin block, too small for use in piano restoration, but perfect for the smaller autoharps. This super-pressurised material allows him to hammer 5mm zither pins into 4mm boreholes without fear of splitting. Alas, the same cannot be said for the zither pins on prototype 3, where there were numerous problems with splitting when I attempted to hammer pins into different materials for integration at the ends of the keys. The platform is simply too small when compared to the large surface area at the toe end of a harp. In the end, I solved this simply, by clamping and gluing around the pin in each case, and though none have given subsequent trouble, I did not consider this a reasonable method for future prototypes.

Another flaw was the possibility of sideways movement on the playing surface of the keys. The reclaimed keyboards invariably provide two points where individual keys are guided in their movement once at the pivot point, and a second mechanism underneath the playing surface, which prevents sideways movement. Pianos also integrate such a mechanism. The ReAPH keyboard however, pivots around a bar that significantly restricts this movement, and I had wondered whether a second point would be necessary. I also felt that such a mechanism needed to be drawn accurately before an attempt was made to construct it. The keyboard certainly functions well enough without it, but I considered that there was a reasonable margin for improvement here, and determined that this aspect too would be changed on the next prototype.

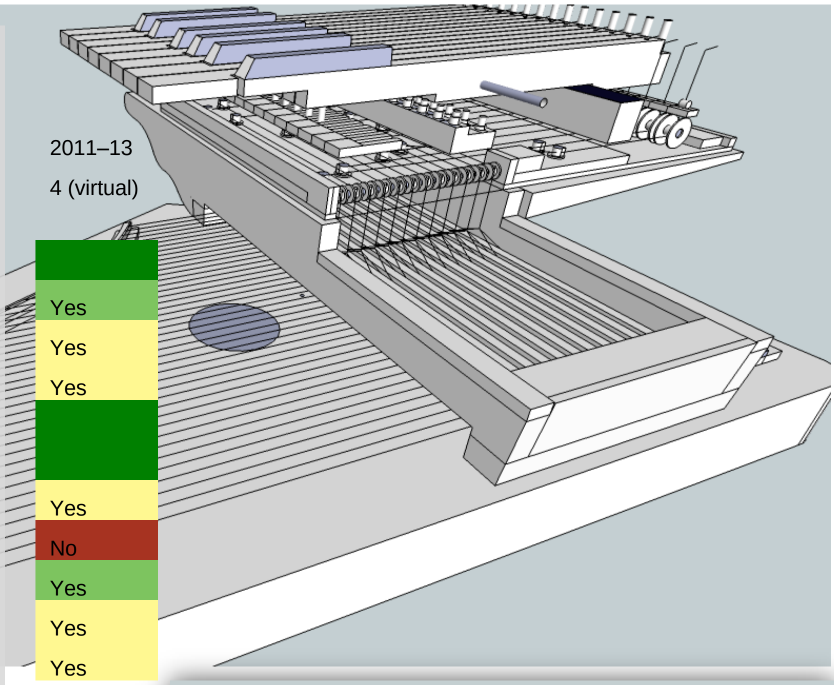
The principle benefit of the custom keyboard was that it allowed the pivot point of the keys to be re-set to 217mm (as in prototype one), now recognised as a key measurement in providing correct power, and also appropriate keyboard feel to a pianist. This distance remains a compromise when compared to the two separate pivot points of black and white keys found in a piano. In principle it would be possible to create separate pivot points on the ReAPH, and I do consider that there would be a gain from this. It would be complicated though, and I chose not to implement this in the virtual prototypes that were to follow, or in prototype 5.

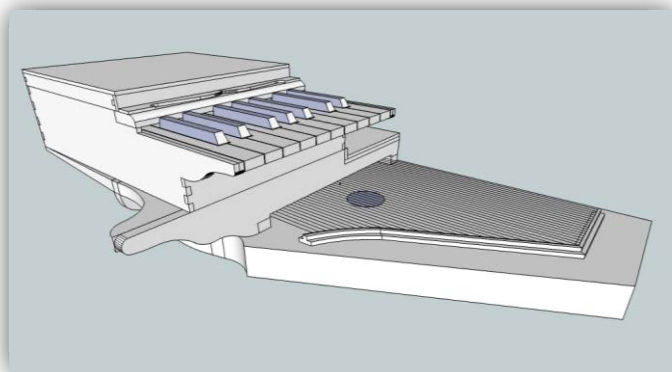
A last issue to highlight is that this prototype did consider the issue of string distinction. On the Schmidt harp the letter names of each of the strings are placed next to the zither pin. Since the pitch range (and some of the string gauges) were changed as discussed in chapter 3, a new system of distinction was called for. This was done using enamel paint on the top of each of the bridge pins such that adjacent octaves can be recognised by similarity of colour coding. I found this to be useful at times (and particularly for tuning), but that it didn't provide sufficiently clear visual distinction to be relied on, or even accessed during playing.

Overall, despite the flaws, this was the first ReAPH where the keyboard really felt right, looked reasonably good; where the harp was efficiently damped and was in itself a decent sounding instrument. For the first time I felt I could really develop some meaningful musical practice from it.

Prototype 4 (Virtual)

Year	2011–13
Considered in Prototype	4 (virtual)
Action	
1. Playing position	
2. Keyboard: appearance and feel	Yes
3. Pulley and string system	Yes
4. Key pivot point to damper coupling	Yes
5. Key range	
6. Harmonic damping	
7. Minimal noise	Yes
8. Integrated amplification	No
9. Playing space on the string surface	Yes
10. String tuning and range	Yes
11. Access for maintenance	Yes
Harp	
12. String distinction	No
13. Tuning mechanisms	No
14. Top plate	No
15. Depth and volume of the resonating chamber	No
16. Optimised coupling of bridge and top plate	No





No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

Figure 4.46. 3D Renderings of Prototype 4 and Assessment of the 16 Design Criteria

Though still relatively simple (when compared to, for example) a piano, I realised that the design had gained sufficient complexity by the stage of prototype 3 as to make the job of communicating the details of its construction to Alec Anness a significant problem. One option was to simply hand over prototype 3 to Alec, commissioning him to adapt it to the new harp. Alec still had prototype 2 in his workshop at this time, and I was aware that he had taken it apart and studied it, as we had been communicating regularly with reports of our respective progress.

This course of action would still present him a good deal of difficulties however; the Schmidt harp (prototype 3) and Alec's harp (for prototype 5) were different dimensions with different numbers of strings, and this would require completely new measurements for the lower action. In addition, there was no guarantee that the harmonic damping solution arrived at for prototype 3 would transfer effectively to the new harp; this job would have to be done again, and new positions on the matrix drilled for the pulley wheels. Further, though prototype 3 is a pretty tidy construction overall, it still relies on a good degree of trial and error, and layering of wood in order to arrive at the correct dimensions. This would not be satisfactory for Alec to work from — luthiers are used to working from specific plans where *all* of the parts are considered and dimensions are available. So despite the progress in prototype 3, significant obstacles to interfacing with Alec's harp remained.

Figure 4.47. The Lower Action of Prototype 3

The photographs of prototype 3, lower action (above and below), illustrate this last, and most significant aspect of the problems. Looking at the area facing the toe end of the instrument, for example (the area which will sit directly under the keyboard), a quick analysis reveals that five separate pieces can be reduced to one. In addition, end grain is visible from the comb backing from the toe end, whose shape also needs re-designing.

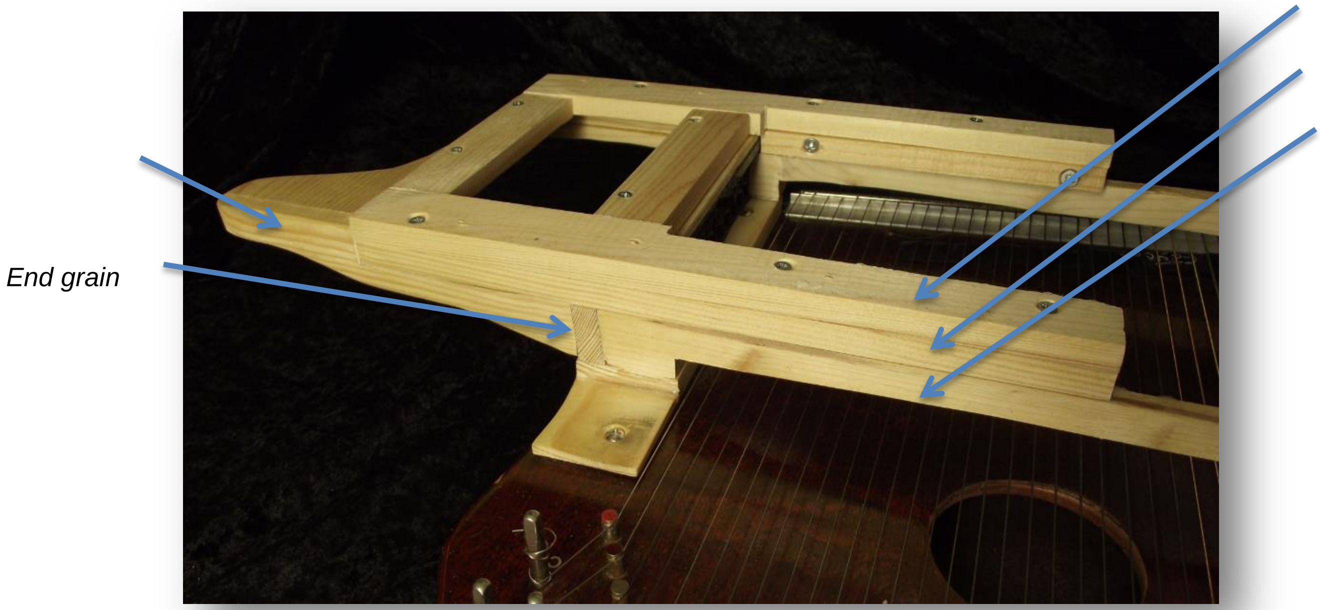


Figure 4.48. Analysis of parts for amalgamation

Three-dimensional rendering seemed to be a much better approach at this stage than returning to technical drawing. I had never used the technique, but I relished the prospect; I researched the options available, and spoke to various colleagues in the design workshop at University of Salford, regarding possible solutions. After some searching I settled on Google sketchup; as providing the necessary precision, the ability to print from screen at any angle, the ability to print 1:1 (or other) scale, and its ability to output to a file format called .dxf, which would enable me to communicate with computer navigated cutting 145echnology should this become necessary. In the terminology of manufacturing engineering this process is termed a Space Allocation Mockup; the drawing stage is termed maturity A, *as designed*. When the files are output to CNC or laser cutter and the prototype is built, the process has reached the *as built* maturity C (Brissenden I. H., 2011).

Learning 3d rendering gave a richness and freedom to the practice for this project that was not previously present. I have an ability to imagine well in 3 dimensions, and previously, would rather plan in this way — straight from the mind; measurements and method, than draw in 2 dimensions. 3d rendering suited this ability. The detail of the measurements and angles are the means of construction, once drawn the model can be turned and viewed from any angle, and magnified at will. This is completely unlike working on 2d drawings, where creating a sense of perspective is difficult, 3d rendering practice is uncannily similar to the reality of working with the materials. The 3d rendering files are included in the digital assets that accompany this written document and can be viewed using Google sketchup.

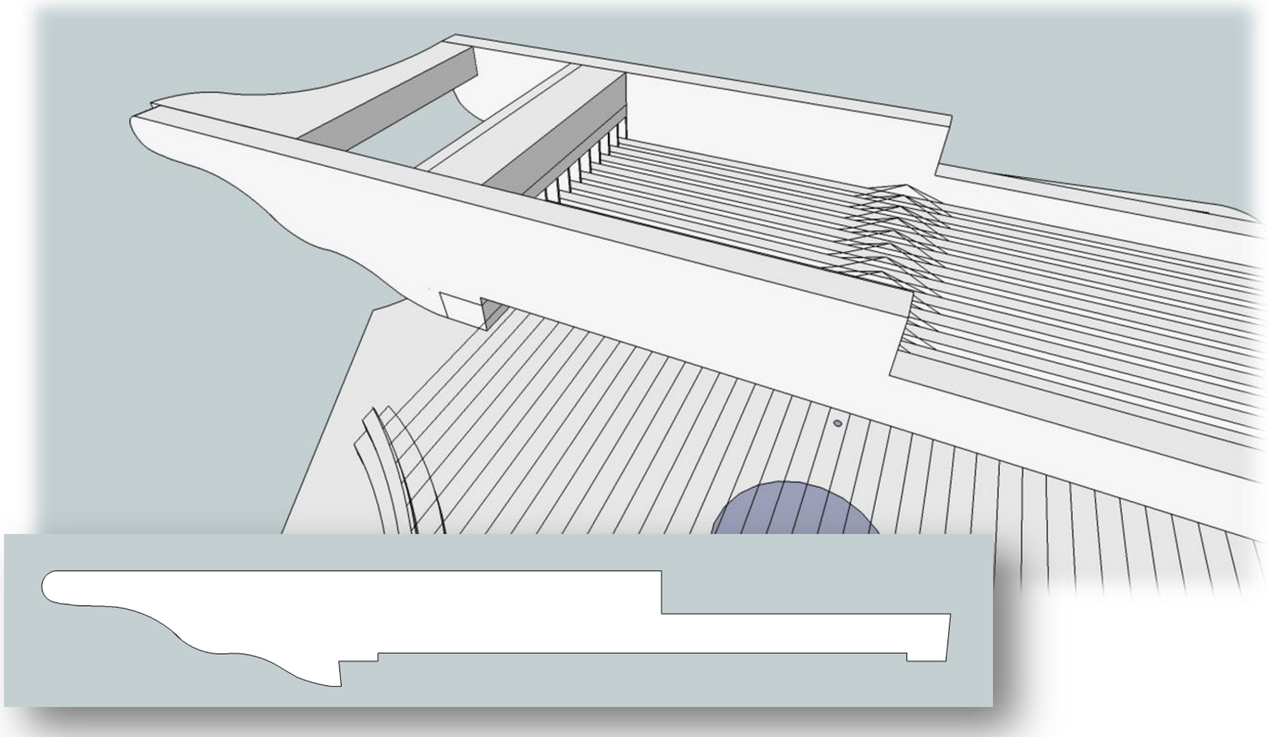


Figure 4.49. Five Parts reduced to one Toe Cross Spar

The rendering capture above shows a similar view as the previous photograph of prototype 3, where the five separate parts shown have been reduced to one continuous toe cross spar, with all of the different shapes and measurements that the various cuts required, captured and integrated. This single cross spar can then be printed at 1:1 (though this particular piece requires A3 to do so) or assembled as part of a .dxf file alongside all other 12mm depth profile cuts. Similar, very accurate simplification and tidying of multiple parts is present throughout the rendering process.

Having begun with keyboard design, I turned attention next, to accurate rendering of the harp bodies. I rendered the Schmidt harp first, and used this as a proving ground. The Schmidt harp proved to be quite difficult to measure. There are no sharp angles, very few right angles, no parallel lines and the strings are not parallel to any of the sides. Accuracy can be achieved though by reducing the complex curves to a series of triangles from a nominal centre point and then by changing the triangles considered. Measure – predict – compare – alter drawing, repeat; best describes the method used to achieve an accurate 3d rendering.

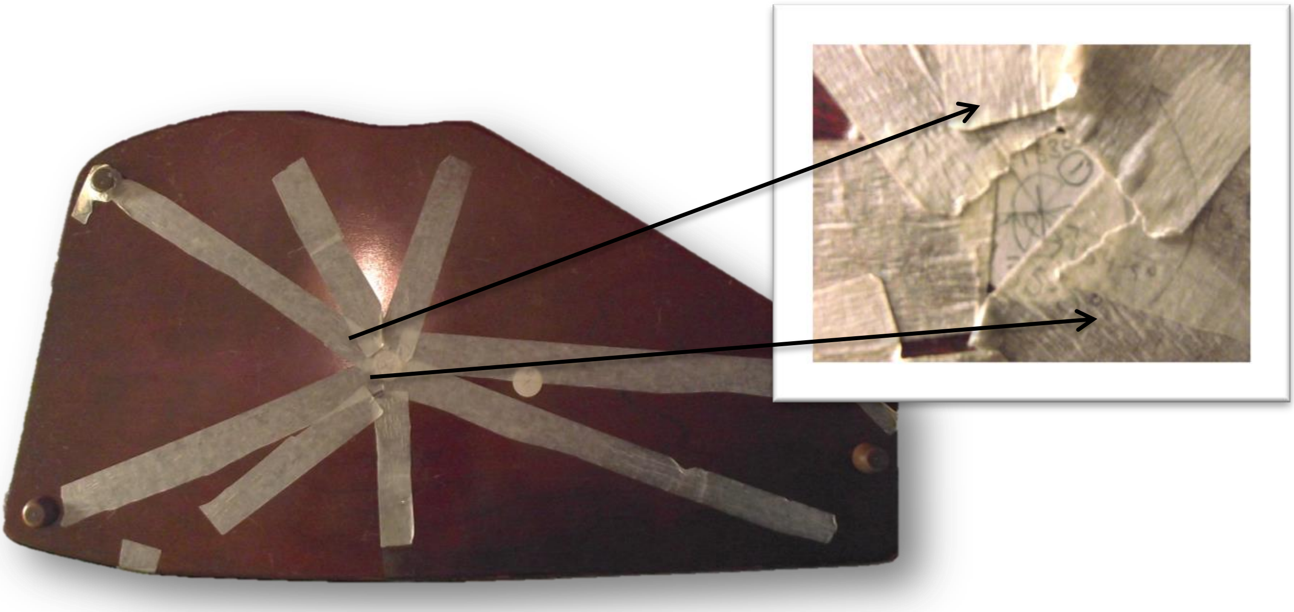


Figure 4.50. Illustrates the process of measuring the dimensions of the Schmidt Harp body

The capture below shows the final phase of this process, which is notable in my memory as the only time I have used trigonometry in a real life situation.

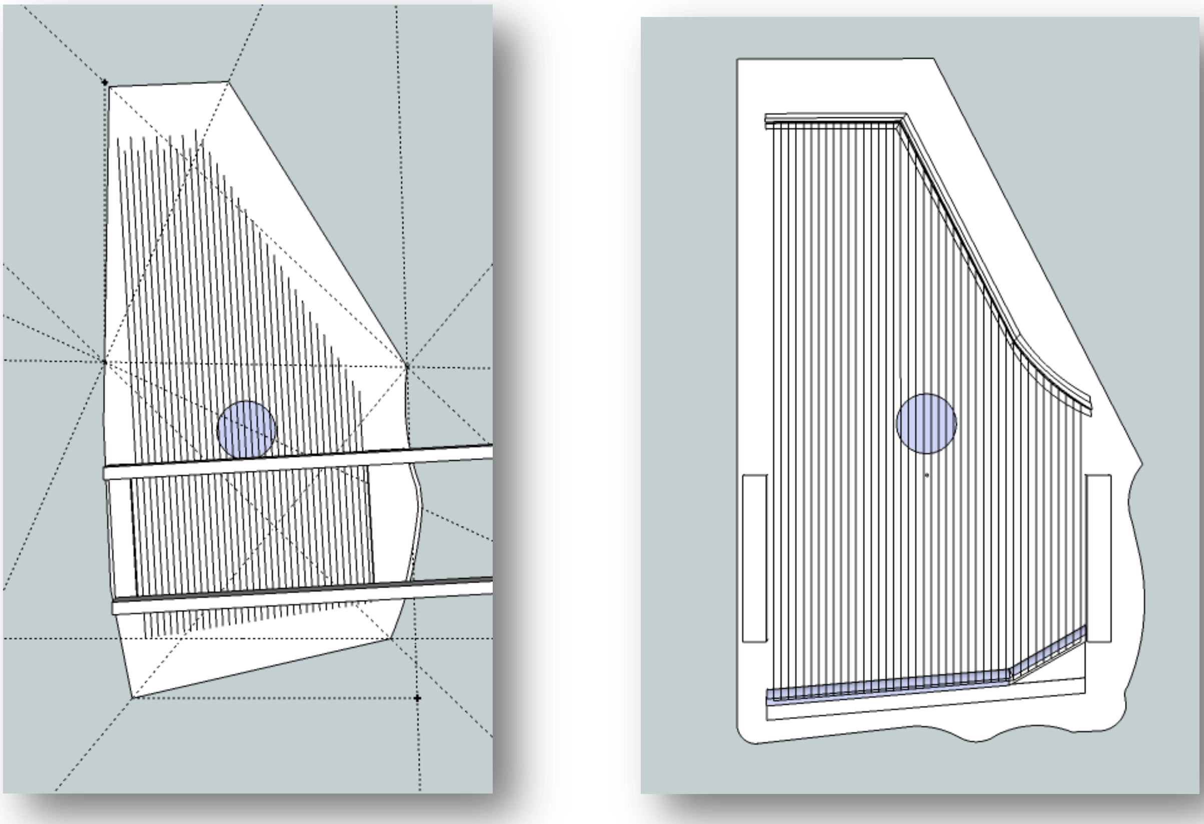


Figure 4.51. Final Renderings: Schmidt left (strings slightly off-axis), Annes right

A key finding of this exercise was to ensure that the strings were placed parallel to an axis within the 3d rendering software. Almost everything on the keyboard and damping action is then either parallel or perpendicular to this axis, which makes the drawing process considerably easier. Fortunately Alec's harp design was much easier to render precisely, as the strings are parallel to the bass side, which is a straight cut, and the top of the toe end is set at a 90° angle from the bass side.

There were three specific design aspects that were improved as part of the 3d rendering process. The first is that key guides were added at the front of the keys to stop sideways movement of keys (discussed in prototype 3).

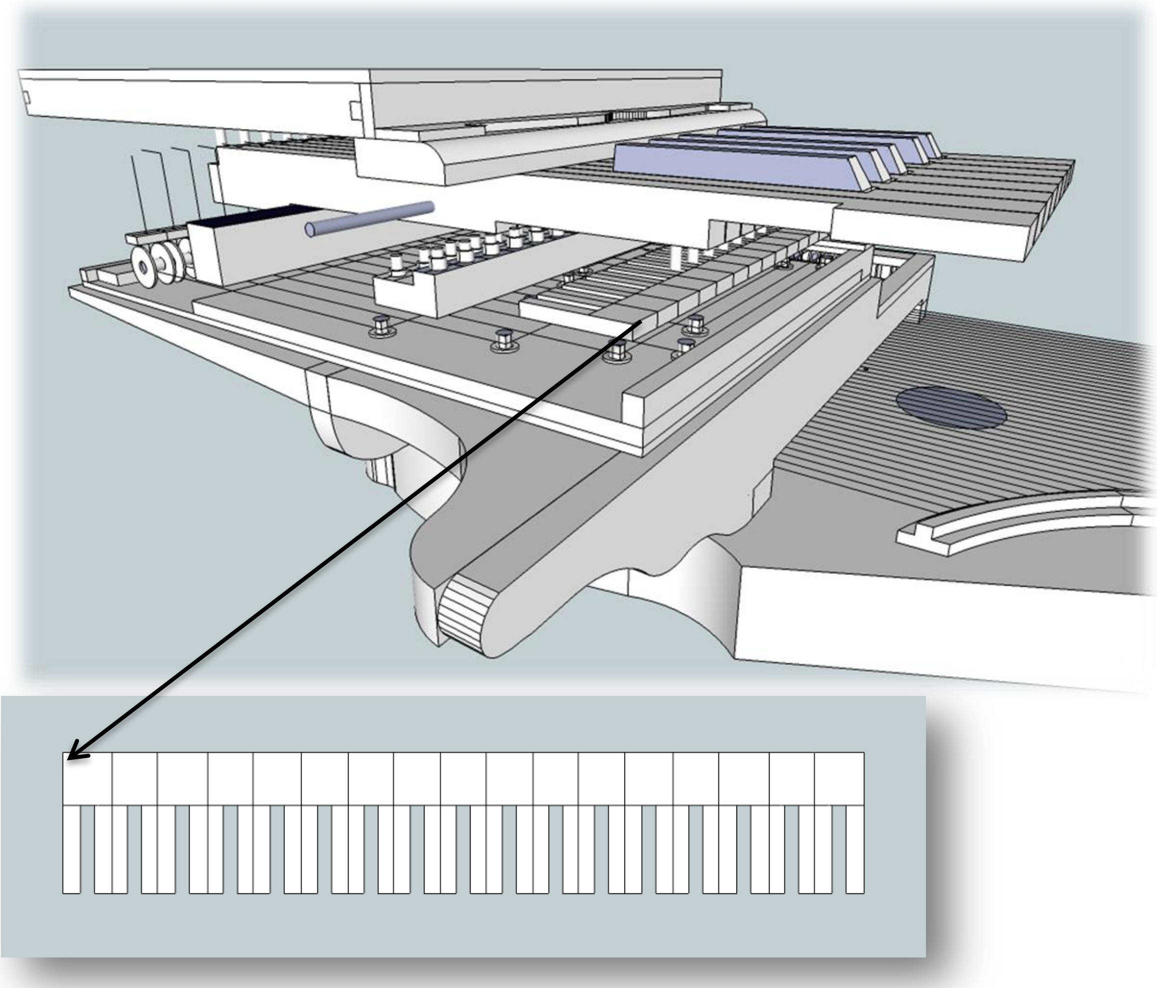


Figure 4.52. Cross-Section through the keyboard and key guard enlarged

This is set as close as reasonably possible to the toe end of the keyboard housing. The comb gaps are set to 4mm allowing the guides to be made from 3.6mm plywood and leave a 0.2mm margin on either side. The second change is to the keyboard pulley system. This has not been moved, but its point of attachment has been changed, such that it is glued to the bass plate permanently, and is not part of the keyboard box. The keyboard is then completely separated from the pulley system in terms of separation-for-maintenance (when the keyboard is lifted the entire pulley system is left intact). This enabled a third, further (suggested) weakness to be addressed. Free key travel, before the pulley system is engaged, led several people (including Alec) to question the stability of the pulley system given that this must result in a certain amount of slackness in the pulley strings. In practice I have never considered this a problem. Admittedly, prototype 2 did (very rarely) slip a pulley string from the smaller keyboard pulley wheels, though this more often happened in transit than in playing (these pulley wheels are left accessible on this prototype for this reason). Prototype 3 (where these smaller pulley wheels were changed to larger sewing machine bobbins) never slipped a pulley string, even after countless playing hours. Nonetheless, in order to satisfy the criticism, this problem was solved through the addition of the component shown below set directly above the keyboard pulley system. The bore diameter is 3mm, which allows free movement of the pulley strings on take up from the keys, but the pulley strings are knotted at neutral tension above the bar so that any slackness in the pulley strings is constrained between this bar and the keyboard. In this way no slackness can enter the pulley system.

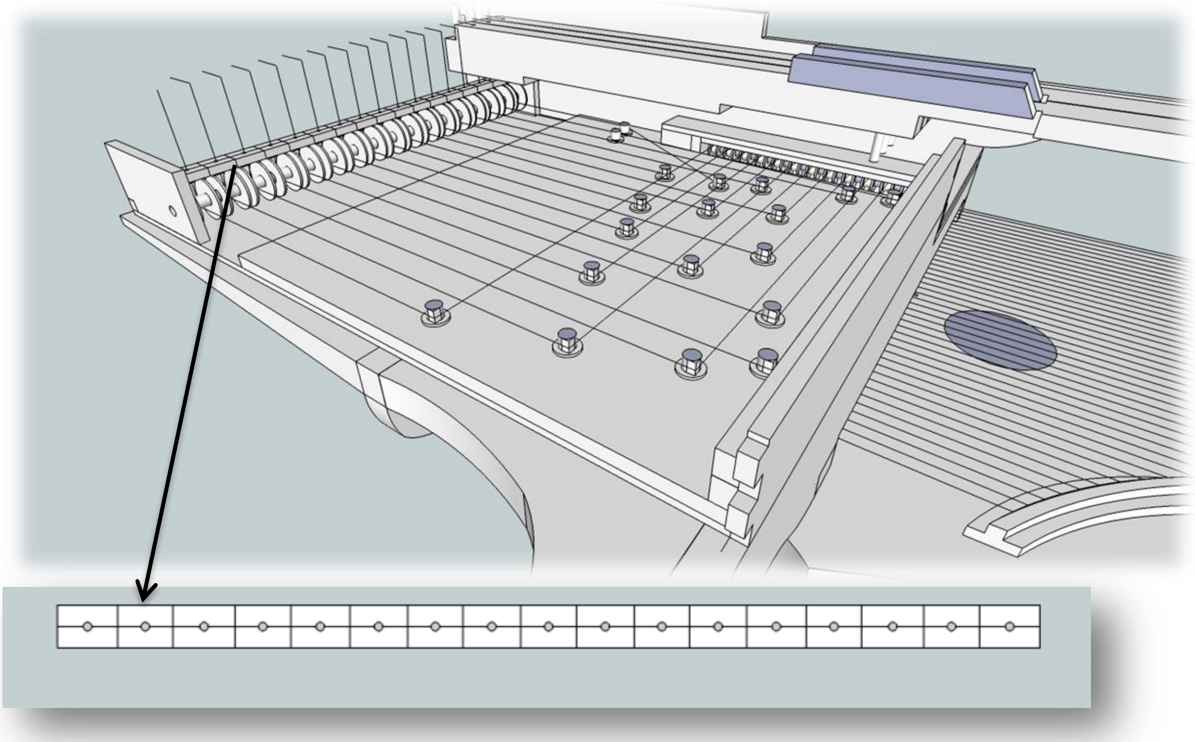


Figure 4.53. The Redesigned Keyboard Pulley System

Still, these three changes are relatively small compared to the changes through prototypes 1 – 3, and the majority of changes are to the precision of the overall form, reducing the number of overall parts and giving homogeneity to the overall surface and aesthetic appearance.

Considering the steady progress through the list of design principles expressed as selective pressures, it is natural that a different selective pressure emerged at this point; stasis. I felt it crucial that the gains made through previous prototypes be expressed in their most refined form for integration with Alec’s harp, and since I was essentially satisfied with the performance of prototype 3 I did not want random changes to cause unexpected problems. In the event several issues did emerge in this way; which will be discussed under prototype 5.

The completion of the 3 dimensional rendering enabled further possibilities. It formalised all of the parts that constituted the design in terms of dimensions such that templates for all could be formulated. This would enable much more effective communication of the ideas to Alec, should he wish to make the action after the completion of the harp body. Thinking ahead to wider distribution within the musical community — to reach a market (and assuming no mass production) two pathways struck me as realistic possibilities for development. Firstly, I could use this drawing to formulate and distribute a very accurate set of plans to enable a keyboard action to be built by anyone. Secondly, I could generate .dxf files to enable the same set of plans to be cut on a CNC. Both of these methods are accepted means of distribution for early adoption within innovation technology.

Substantive Search

Towards the end of May, I grew impatient with the lack of response from the UK patent office, and telephoned my original patent officer. Since the initial search, the patent had been published in the UK patents journal without comment, and no further contact had been received from the patent office. It was, after all, now nearly four years since the original application.

In the intervening time, I felt I had considerably improved the design, and solved, or at least mitigated to a good extent, all of the design pressures that I had identified. I had prepared rebuttal ground in anticipation of the substantive search results, and had considerable time to reflect on the patent process. I had (at least initially) taken heed of the repeated and somewhat ominous warnings published throughout the patent application guidance literature, to maintain secrecy during the process of patent application. But this was now becoming tiresome and creating unnecessary obstacles to attaining the overall outcomes of the project. Further, I felt that I had probably been correct in my original thinking; that patents, overall, obstruct musical instrument evolution and that if acceptance within the musical community was the target; clear communication and publication of the ideas was the real issue, *not* protection. Furthermore, the idea that anyone could "steal" the design, even should they wish to, from the drawings and description of prototype 1 which formed the basis of the original patent application was simply not credible.

Following the telephone call, I was contacted directly by the patent examiner with an undertaking to send the results of the substantive search by the end of June, and this duly arrived on 27th June. The substantive search contained no new information at all. It pointed out the faults with the claims, which I had known about since the first filing, having spoken to the same very helpful patent officer, who had advised me to simply allow the patent to be published rather than attempt to rewrite them at the point of filing. It then highlighted, as substantive search results, the same five previous patents found in the initial search. The following extract contains the crucial points:

> "5. However I will fully consider the wording and content of your claims and description at a later stage, if you are able to show that your invention is new and that it contains an inventive step. .. Claims drafting is a difficult art and if you want to continue with your application then you benefit from seeking the advice of a patent attorney…
> 6. Although your invention is not set out clearly, it is my opinion that the documents listed below show that the features of your invention (as listed in your claims) are already well known or do not include an inventive step. Please note that the documents listed below are merely examples selected from many similar documents that were found:

D1 – GB 22417 A (PAGE) See especially figure 6 and page 4 lines 36–40
D2 – US 559764 A (BACK) See especially figure 9 and page 2 lines 75–85
D3 – US 4506583 A (NEWTON) See especially figures 3 and 4 and columns 5 to 8
D4 – FR 2367328 A (HENNER) 09.06.01978 See the figures and the English language abstract
D5 – GB 9698 A (MILLINGTON et al). See the whole document especially figs 3 and 4.

7. These documents all disclose a "reverse action" damping arrangement for an autoharp type instrument. In each document, the damper is biased into contact with the string and is released only when a selected piano type key is depressed. Releasing the key allows the damper to regain contact with the string. Each document also discloses a plurality of group keys disposed on or adjacent to the strings that are plucked.

8. Any differences between your invention (as defined by your claims) and these documents appear to be design choices rather than inventive differences. For example, your invention uses a pulley system for operating the damper bars, whereas the documents above tend to use an arrangement of pivoting levers. However, it is my opinion that both pulley systems and pivoting levers are well known methods of manipulating moveable bars and so using a pulley system does not sufficiently distinguish your invention from the documents listed above.

What you need to do now

9. If you wish to pursue your patent application you will need to either redraft claim 1 to clearly bring out the difference between your invention and what is shown in the documents listed above, or present arguments in writing to refute the objections made above. The difference must constitute an "inventive step", in other words the difference must not be trivial or obvious.

Securing the Patent

The most confusing aspect of this was that only five patents had been listed, but presented as examples of "many similar documents". It was of course no surprise that there were more (these have already been discussed); but it *would* have been surprising if there were more than I had discovered by this point, and the vagueness of this statement did not seem to me to offer a fair platform for rebuttal. If I rebutted all five, did this constitute completeness or typicality? Or should I simply make the complete rebuttal that I had prepared. I sought clarification through email.

"Thank you for your report 27th June 2011.

Under section 6 of your report you state: "Please note that the documents listed below are merely examples selected from many similar documents that were found".

The implications of this for a response are not clear to me. Are the patents listed D1 - GB 22417 A (PAGE), D2 - US 559764 A, (BACK), D3 US (4506583 A (NEWTON), D4 FR 2367328A (HENNER), D5 - GB 9698 A (MILLINGTON et al) the most relevant examples? Or, are there other significant patents that I need to consider — most particularly instruments which are more similar?

In response to your examination report I have reconsidered and rewritten the claims from the original patent application. However, I have known since the initial search that this would be necessary. Bearing in mind that I followed all the guidance provided in order to search for similar and relevant patents before submitting the original, and that these searches did not turn up any of the above patents; I would be grateful to be made aware of other significant patents that require a response."

And received a prompt reply:

> "Dear Mr Brissenden,
>
> Thank you for your email. As you suggested, the patents listed in section 6 of my report are the most relevant examples that have been found from the searching that has been carried out so far. I apologise that this was not made clear in my report.
>
> In my report I could not list every potentially relevant patent document because the inventive concept of your invention was not clearly defined. For example, a very large number of documents were found which were relevant to your invention as it is defined in your first claim.
>
> Once I receive your rewritten claims I hope to have a clearer understanding of the features which distinguish your invention from other similar instruments. I will then carry out some additional searching and it is possible that new patent documents may come to light. Please also be aware that I may use any type of evidence to demonstrate that your invention is not new or is not inventive, including information published on websites for example.
>
> When you submit your rewritten claims you may wish to include a covering letter outlining the arguments as to why you believe your invention is patentable, which would be very helpful."

Following this response I decided to rebut only the inventions cited. The claims re-write had been prepared for some time, and I wrote the rebuttal statement in about 90 minutes of rather furious concentration. Since I did not quite trust my state of mind at this time, I resolved to seek objective opinion, seeking first the opinion of my wife; usually the harshest critic of my writing. She simply said, "yes, send that." So I dithered no further, and posted. Since the rebuttal statement is relatively short, it is included here:

> "The original claims have been re-written and are now expressed as the single claim at the end of this document. Additionally, I present the following arguments in response to the objections raised by the examiner.
>
> All of the technical elements expressed in the patents put forward by the examiner are adaptations from other instruments. Musical instruments evolve through such means. However, technical possibility does not automatically equate to musical possibility. Crucial to the success of a musical instrument development is the playing interface that it presents.
>
> Page 7 of the technical description stresses the importance of the playing position of both left and right hand.
> "One octave of full size piano keys is fixed in the position illustrated in figures 1 and 2. This playing position is carefully considered. Firstly comfortable access must be provided for the left hand to depress the keys, whilst the right hand is able to strum and pluck the strings. It is for this reason that the keyboard housing raises the keyboard 10.3 cm from the strings; this enables the right hand to move freely underneath the left hand. The piano keyboard is also placed slightly overhanging the top rail — on the right hand side of the instrument. The lever action overhangs the dead pin block by approximately 9 cm, thus lengthening the instrument by this amount. Again, this allows comfortable access for the strumming hand.
>
> The positioning of the keyboard interface as described above is critical to the success of the interface. The combination enables firstly: a strum/pluck position which is consistent with autoharp traditions: the instrument can be held at a variety of angles with the toe pin block oriented towards to the left of the body (assuming a right handed harp). A straight strum position (like a guitar) is perfectly possible, and the toe pin block can be raised

towards the left shoulder with the dead pin block pointing downwards enabling the steeper strum position of autoharp positions (also guitar positions). This position allows the string plane to be accessed with a relaxed shoulder, the right arm bent at the elbow with a relaxed wrist flex. The position is consistent with, and adaptive to autoharp strum positions. Secondly; it allows access to the keyboard such that the shoulder and forearm are relaxed, with a straight line through the wrist to the left hand resting upon the keys. The left hand position allows keyboard access, which is consistent with pianistic traditions. Rapid, relaxed limb movement is critical to the thinking behind this interface, and was the starting point in considering the mechanism necessary to achieve it. The interface will allow the development of virtuosic playing of a wide range of genres of music enabled through the greater range of pitch access provided through the keyboard, as described within the original patent application.

D2 – US 559764 A (BACK), D5 – GB 9698 A (MILLINGTON) and D4 – FR 2367328 A (HENNER), use a lever system in order to attach the piano keys to the reverse action dampers; a simpler mechanism, but the result is that the keyboard must be perpendicular to the strings. This arrangement is inconsistent with both traditions of playing: holding such an instrument – either horizontally (like a guitar), or steeply angled (like an autoharp) entails a significant contortion of the left arm in order to gain access to the piano keys, and will not allow freedom of movement. The alternative method of playing is to place the instrument upon a fixed table. This produces a poor strum/pluck interface and is not consistent with virtuosic autoharp playing.

D3 – US 4506583 A (NEWTON) is not a serious attempt to integrate a piano keyboard. The adaptation is an addition to the original chord bar mechanism, which adds dampers underneath. The keyboard “effect” is then added to the top of the chord bars. This does not produce the spacing of a piano keyboard, nor will it produce the familiar pivot point – this interface will not be adaptive to keyboard players. Additionally, this instrument presents the same problems as the previous three. The keyboard is perpendicular to the strings, and would require a significant contortion of the left wrist in order to play it like a keyboard.

D1 – GB 22417 A (PAGE): this is clearly a tabletop instrument, not designed to be held for an effective strum position. In order to strum/pluck the strings on this instrument the fore arm would need to be held in front and extended at the elbow, this is a similarly clumsy position, and will not allow virtuosic playing. Moreover, although this instrument incorporates a keyboard with an autoharp, this is clearly a very different musical instrument, presenting different possibility. The inventor defines this instrument as an orchestral instrument. A role producing a range of momentary effects within an orchestral texture is possible, but this is not a portable, solo instrument, nor does it seem an evolutionary step from either keyboard or autoharp traditions.

The key difference in approach in the design presented is that it begins with musical interface, defining a playing position for each hand, which is clear and consistent with each tradition of playing. Learning this interface is an adaptive step to musicians from either tradition. It provides an interface which allows most advantageous, relaxed limb positions in the first instance, and only then defines a mechanism which will enable this: a pulley system connecting keys to damper bars.

In addition to the differences in musical interface, a pulley system enables freedom of positioning of damper bars for harmonic damping. This is a heightened problem with reverse damped instruments. Harmonic damping is of consequence to all the instruments described above, and is critical to achieving a successful musical interface likely to gain acceptance amongst musicians.

In short, despite the application of dampers to strings harmonics will emerge if there is a proportional relationship between the point at which the damper is applied and the length of the damped string. This presents in the form of constant noticeable high harmonic content, or “plink” during even the most accurate playing of the instrument.

The problem is heightened on reverse damped instruments, firstly because of the reliance on a spring to provide the damping force, this is significantly less than that provided by pressing the damper bar against the strings, and secondly because each string is damped only once, from one position, as opposed to an autoharp where the chord bar structure will mean that each string is damped from many different positions on different chord bars. In the case of an autoharp system, ineffective harmonic damping for one string on one chord bar will only present as audible "plink" to the musician only when that particular chord bar is depressed. A reverse damped instrument however, will display these problems equally, throughout the instrument; resulting in a continuous "plink" that ruins the musical experience.

Two approaches may be taken for resolution, the first is much more effective than the second, particularly in the case of reverse damped instruments where the damping force is limited.

1. The damper bar is moved to a different position, thus changing the proportional relationship to the strings. In practice autoharp players are often attached to chord bar combinations and do not like to do this, and would rather put up with a persistent harmonic or use the second approach to try to solve it. Again, I stress that in the case of the autoharp, because the string is damped from a number of positions on different chord bars, the problem does not have the significance that it gains in a reverse damped instrument, where strings are damped only once, from one position using a spring rather than hand force. In this case all the un-damped harmonics have the potential to sound at any time.
2. The length of the damper may be extended slightly (a "fat" damper is added at the problem string). In practice this approach has limited effect in a reverse damped instrument, and is not nearly as powerful technique as changing the point of damping for the bar.

A significant flaw to all of the patents listed above is that they do not allow for repositioning of the damper bars, as the fixed mechanism connecting damper bars to keys would not allow for this. In practice I believe that this flaw would make these instruments extremely poor musical interfaces indeed, with a significant high harmonic content ("plink") present alongside the desired pitches.

Construction and refinement through three successive prototypes of pulley mechanism based instruments however, has proved that harmonic damping as successful as that of a very fine autoharp can be achieved, through repositioning of the chord bars with respect to the key placement. The number of possible combinations is 12!. The number of successful combinations is very small, and can be achieved by finding good positions for bars that damp four strings first, then three and then two.

A refinement of the pulley mechanism has been necessary to achieve this freedom of movement. In accordance with the instructions at the foot of page 1 of your report, I have not defined this improvement, further I did not think that this was necessary as the original within the patent offers similar potential for recombination in terms of positioning, and the single claim as it is now expressed encompasses the principle of a pulley system as an inventive step."

Certainly the statement simplifies the arguments and does not give a full historical perspective. Reflecting on it now, I feel some regret at the treatment of previous inventions and cite the fuller analysis within the chapter as providing a more balanced perspective. The simplification does serve to maintain focus continuously on the difference between the ReAPH and all of the other instruments however. A reply was received on 7th September (extract):

"..2. In light of the arguments presented in your letter I agree that the raised piano keys and pulley system features of your invention contain an inventive step, in comparison to the documents found during the search. The objections listed in paragraphs 6 to 8 of my previous examination report have therefore been overcome. .."

This was by no means the end of the matter; the claim had to be rewritten again, and various details had to be added to the description, the final text can be found at GB2449459 (Brissenden P. G., 2012). The patent was finally granted on 8th February 2012.

INTELLECTUAL
PROPERTY OFFICE

Certificate of Grant of Patent

Patent Number: GB2449459

Proprietor(s): Philip G Brissenden

Inventor(s): Philip G Brissenden

This is to Certify that, in accordance with the Patents Act 1977,

a Patent has been granted to the proprietor(s) for an invention entitled **"Reverse action piano harp"** disclosed in an application filed **23 May 2007**.

Dated 8 February 2012

John Alty
Comptroller-General of Patents, Designs and Trade Marks
Intellectual Property Office

The attention of the Proprietor(s) is drawn to the important notes overleaf.

Intellectual Property Office is an operating name of the Patent Office

Figure 4.54. Grant of Patent

Manuals and Flat Pack Harps

Despite the distraction of these patent exchanges, I continued to make progress on creating an accurate build manual. I planned to get as far as the lower action, and then to take a joint decision with Alec as to whether or not this was a reasonable way for the project to be progressed. Alec announced his completion of the harp body at the end of March 2012, and we arranged a meet for the end of June, by which time he had received a draft of the lower action manual. The manual is included within this document at Appendix 3 and consists of a method section with 3 dimensional views, and a complete parts schedule with measurements and 1:1 printing without annotation for template purposes. It is also included in the digital assets that accompany this written document in its original .pdf format.

I received feedback from Alec on the manual at this meeting, and had also received feedback from other colleagues and most helpfully from my brother Ian Brissenden who works in aircraft design. Ian's feedback particularly called for a tighter approach in terms of parts description, rendering, and method, feeling that this was part of the process he termed *manufacturing engineering* "a specific view where tooling is specified and built around the model [arrived at the *as built* — *maturity C stage*] , any jigs are designed here. They are not aircraft parts but still form part of the configuration as the final parts have to have traceability to the tools and jigs" (Brissenden I. H., 2011). I agreed with all the criticism, though I felt that there was some misunderstanding over the purpose of this particular version of the manual (it was after all, designed specifically for Alec, to be accompanied by prototype 4, and to serve as a starting point for discussion rather than a complete manual from scratch), but it helped me to pinpoint the differences in the approach that I had taken, and exactly what was needed for a "from scratch" approach. Overall, I felt that I had demonstrated that I had overcome the most significant technical problems involved and that such a manual could now be produced as part of a strategy of market distribution, should this be determined as a desirable option.

In the event, it was Alec's reaction to prototype 3 that decided the subsequent workflow. He quickly took in every aspect of it, turning the whole thing over and examining the build quality and finish from every angle. He appeared to be very pleased with it. Prototype 2 was set out ready for the meeting, in his workshop — I hadn't seen it myself for several months, and I had significant appreciation of the change he was seeing. I had been concentrating so much on the virtual prototype, engrossed in the improvements between this and prototype 3 that I had quite forgotten the really significant change from prototype 2 to 3, particularly in the issues that had most concerned Alec, which were to do with the quality of the build and the overall finish. By the time we had finished discussing all the changes, including dismantling prototype 3 to demonstrate the access for maintenance, and going through the manual and the 3d renderings, Alec was encouraging me to take control of the build of prototype 5 myself, saying that only the finishing (French polishing) should be left to him. Alec pressed me on two issues: firstly, to be sure that the dimensions of the new plans exactly matched the dimensions of the plans that he had sent me, and secondly, that I could print all of the parts that I was describing at 1:1, to provide templates. When I reassured him on both counts, we agreed that I would complete the action for prototype 5 and that he would finish it.

In the autumn of 2012 I explored the possibilities for interfacing the design with computer navigated cutting, and completed this process in an intensive period in January 2013. The workshop at University of Salford has a laser cutter, and two small router based CNCs. The laser cutter was suitable for profile cuts up to a depth of around 5mm, but had the disadvantage that it left burn marks on the wood. The CNCs were really too small for the number of profile cuts which were necessary for the project. After some research, I found another option, which was to use the Fab Lab situated within Manchester. Fab Labs are a worldwide movement initiated by the Massachusetts Institute of Technology in 2001 (Fablab, 2012), which aims to empower local communities by providing access to all kinds of physical rendering devices including 3 dimensional printing, laser cutting, computer programmable sewing machines and many more. There are currently 134 Fab Labs worldwide and one of these is situated in New Islington just ten minutes walk from Manchester Piccadilly train station. The Manchester Fab Lab houses a large flat bed CNC that was perfect for the harp project, and I signed up for and completed the initial training on this piece of equipment.

File preparation for cutting required classification of parts of similar depth, rendering each of these in simple profile with drill points and producing arrangements of the parts-of-similar-depth suitable to be cut from one continuous plywood sheet in separate .dxf files. The .dxf files are included in the digital assets that accompany this project, however the accompanying pdf part-indexes are included in Appendix 4, and can be viewed immediately. These illustrate how this process looks at the design stage. This file preparation was an extremely time-consuming process, but was necessary irrespective of whether or not the final hardwood cuts were to be rendered on a CNC or by hand, since it would allow me, for the first time, to order accurate hardwood pre-cuts with confidence.

A key issue in minimising cost is that of cutting margins (how much space to allow between parts on a wood sheet), and unfortunately the advice on this was rather inconclusive from all quarters. Between 2 and 3cm seemed to be the consensus — dependent on the depth and type of cut being attempted. The problem was that CNCs are not often deployed in either the Fab Lab or UoS settings to cut expensive hardwood. The issue of margins is not crucial when cutting plywood sheets (the most common material) and the simple advice is to err on the side of caution, and to allow larger margins in any doubtful case, in order to maintain the structural integrity of the material sheet as a whole during the cutting process. In order to gain an understanding of this issue, I tried very hard to minimise this cost at plywood level, which made the process more time consuming. A second issue, which complicates the final arrangement of parts further, is that of grain direction — again not crucial on plywood cuts, where concentric wood sheets are laminated at perpendicular angles. Because the grain direction was not crucial on this occasion, the arrangements that you see in appendix 4 are a compromise between optimising the area for maximum yield and achieving correct grain direction for outward facing parts. This was most confusing, and the issue had to be watched at every level of entry to the system, the initial drawings, rendering to .dxf, entry into the CNC computer and finally orientation of the wood in the CNC table — it was possible at each point to reverse the axes by mistake. I remember mid to late January of 2013 as almost continuous drawing, and redrawing together with days spent nursing plywood sheets at the cutting table. Unfortunately the grain direction on the 9mm cut was set erroneously at one stage of the process (I am unsure which) resulting in cross grain on the playing surface of the white keys. This was one of the last cuts of the final session, and unfortunately fatigue caused me to miss this fact at the time, and so I failed to repeat the cut. Subsequently a colleague in the workshop at UoS offered to recut this in slightly thinner plywood using the laser cutter, but made a similar mistake and the resulting keyboard surface was cross grained once again. This is a minor, non-crucial mistake in plywood but the consequences of such a mistake would be very different in hardwood.

Figure 4.55. Trimming and sanding the output from CNC and laser cutter (Brissenden P. G., 2012)

Time constraints at the end of January marked a halt to these processes because there simply wasn’t time to spend at Fab Lab during the teaching semester, and this gave me a chance to study the materials that had been produced and to take stock of the situation.

The photograph above shows me working on these materials, and set against the wall behind, you can see the raw output from laser cutter (left — defined by the characteristic burn on the wood) and right, from the CNC. Below shows close ups of the two different outputs within the original sheet (left) and after removal, trimming and sanding (right).

Figure 4.56. Outputs from CNC and laser cutter compared (Brissenden P. G., Reverse Action Piano Harp, 2013)

Neither process is the clean output that I had imagined, and both outputs take quite a lot of work in order to arrive at the precision of 0.2mm that is the stated accuracy of the machines; further there is the possibility of breakage in removal of delicate parts from the outer wood.

The spring of 2013 was taken up with preparation of recordings and the publishing of a website. The website contains aspects of both design and music, but I have considered it under the next chapter of musical engagement. I returned to the question of the prototype 5 build immediately after this, and decided not to return to Fab Lab immediately. The decision was an easy one to take after reflection.

1. As with the build manual, I considered that enough experience of the medium had been gained to enable wider distribution, should this be determined to be a desirable course of action
2. Further engagement was likely to remain prone to error; and this error, coupled with the issue of the large margins necessary to work with automated cutters, as opposed to a band saw was likely to prove frustrating and expensive
3. Many of the inside parts could be used directly on the project — only outward facing parts really needed to be rendered in hardwood
4. Where rendered parts were not to be directly utilised, they would provide concrete templates to work from by hand. I discovered that these were much more useful than 1:1 paper prints
5. Based on the experience, I was not sure that the automated processes saved time overall, given all the possibilities for error and the travel involved
6. Cutting of parts is but one process in completing the action as a whole and arguably, not even the most time-consuming.

Thus the virtual rendering segued seamlessly into the build of prototype 5, which began in earnest in the summer of 2013.

Prototype 5

Year	2014
Considered in Prototype	5
Action	
1. Playing position	
2. Keyboard: appearance and feel	Yes
3. Pulley and string system	Yes
4. Key pivot point to damper coupling	Yes
5. Key range	
6. Harmonic damping	
7. Minimal noise	Yes
8. Integrated amplification	Yes
9. Playing space on the string surface	Yes
10. String tuning and range	Yes
11. Access for maintenance	Yes
Harp	
12. String distinction	No
13. Tuning mechanisms	Yes
14. Top plate	Yes
15. Depth and volume of the resonating chamber	Yes
16. Optimised coupling of bridge and top plate	Yes

No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

Figure 4.57. Photographs of Prototype 5 and Assessment of the 16 Design Criteria

I began this build in earnest in July of 2013. It was quite unlike all the other builds in terms of the attention to detail, finish and fit that was achieved. Despite several intense periods of activity in quiet points in the teaching calendar, I was unable to make more than steady progress. In fact this build, more than any other, relied on continuous working late into the nights throughout the year, and even so I was unable to finally complete it until the end of September of 2014. A meeting then had to be arranged with Alec, which because of our various commitments, could not take place until the end of October. We then agreed a timescale for completion. We agreed that I would carry out the fitting and general tuning of the systems and that I would then detach the action and send it to Alec for finishing.

However, the two halves — keyboard and harp, waited a long time for completion. The Autumn of 2014 was particularly busy involving increased playing commitments that were now a part of the normal practice on the ReAPH. The next move in the workshop was to drill four bore holes to allow keyboard and harp to be joined at pre-drilled points in the lower action; a seemingly simple task, and at a non-crucial point, something which would require care and attention but would not exert undue pressure. However, this was not a normal situation, on the precision of these four bore holes the success of the entire project depended. There was no margin for error or replacement parts — catastrophic consequences would result from any inaccuracy. The situation was complicated by the fact that Alec's harp body would not fit satisfactorily into any jig that I could place under the drill press in the small confines of my workshop, and therefore the task would need to be completed on the larger surface area of the dining room table. This process had to wait until there was sufficient time, space and absence of children — and it was not until January that I finally prepared and executed this moment of high drama, which though nerve wracking, passed without incident.

For the majority of this build, a type of mahogany — *sapele* was used. This matches the wood used in the dead end of the commissioned harp. Since *sapele* is quite a dark wood, I used a lighter hardwood (that I was unable to discover the name of) to provide a visual relief for the "black" keys and the same wood was utilised for the relief carving on the lid. In addition to the hardwood pre-cuts in *sapele*, I lightened the pressure on the build by sourcing stock hardwood strips in *meranti* of different measurements. This was more expensive than working in softwood, but not nearly as expensive as the dedicated, depth-cut order in sapele. They were utilised within the keyboard box for a variety of small parts that are not outward facing.

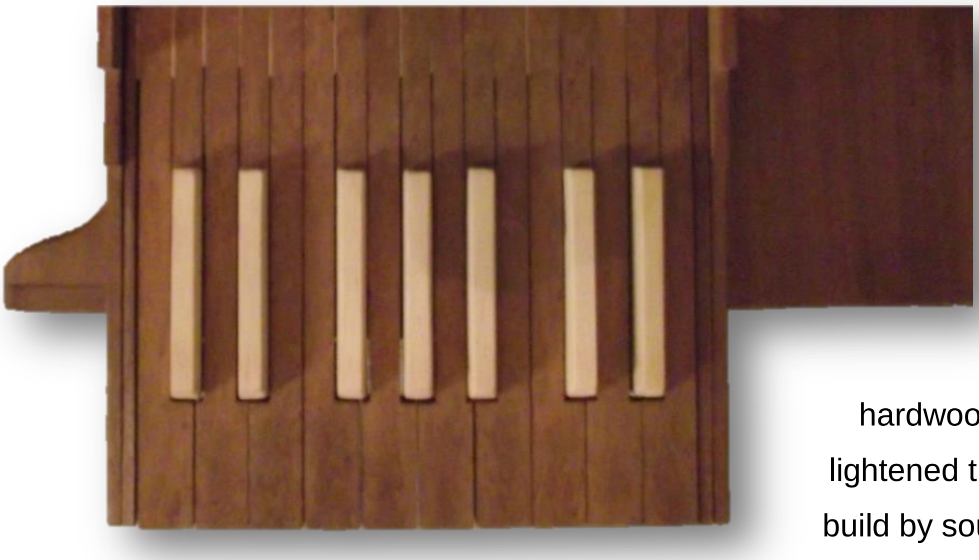


Figure 4.58. Prototype 5 keyboard viewed from above

Figure 4.59. Prototype 5.

The underside of the keyboard (September 14)

The keyboard was the first section to be cut, and this set the new standard of workmanship. I found the hardwood medium, with its dense and even grain, far more precise than softwood for sawing, carving and sanding, and in addition I had improved the method for arriving at a precise assembly. After cutting, the individual keys are clamped into a dedicated jig, which allows the front of the playing surfaces to be finished in line. The keyboard is then moved forward and clamped again, this time to allow the surfaces directly in front of the black keys to be finished in line. This ensures that any remaining inaccuracies are pushed to the back of the keys (which does not matter). The separation between the keys is achieved using marquetry strips glued to the side of the key at the pivot point. A set of digital measuring callipers rendered this process more accurate than the process used in prototype 3. The playing surfaces were levelled using similar techniques, by gluing different thickness materials from marquetry wood down to the finest paper, to the key rests — this is a similar process to prototype 3, but achieving a greater precision using the digital callipers.

The key guards are a new addition within this prototype, which added considerable time to the build. The keyguard comb, shown on the next page, was one of the parts that I was particularly pleased with from the CNC, and as it is not outward facing, I considered using the CNC output directly. The problem is that the part needs to be attached to the sides of the keyboard housing, but also needs to allow access for maintenance. Allowing release for the part as originally designed would necessitate screwing into plywood endgrain in order to secure it. Securing it was a problem, but nonetheless a laminate was the obvious material to provide the necessary strength for this part, as the layers of cross-grain added strength to the tines. The solution arrived at (shown below) allows each part of the comb assembly to be permanently fixed to the side of the keyboard box — and without screwing into endgrain. The assembly is then accessed for maintenance from the screw points shown in the centre, in order to allow the keyboard to come apart.

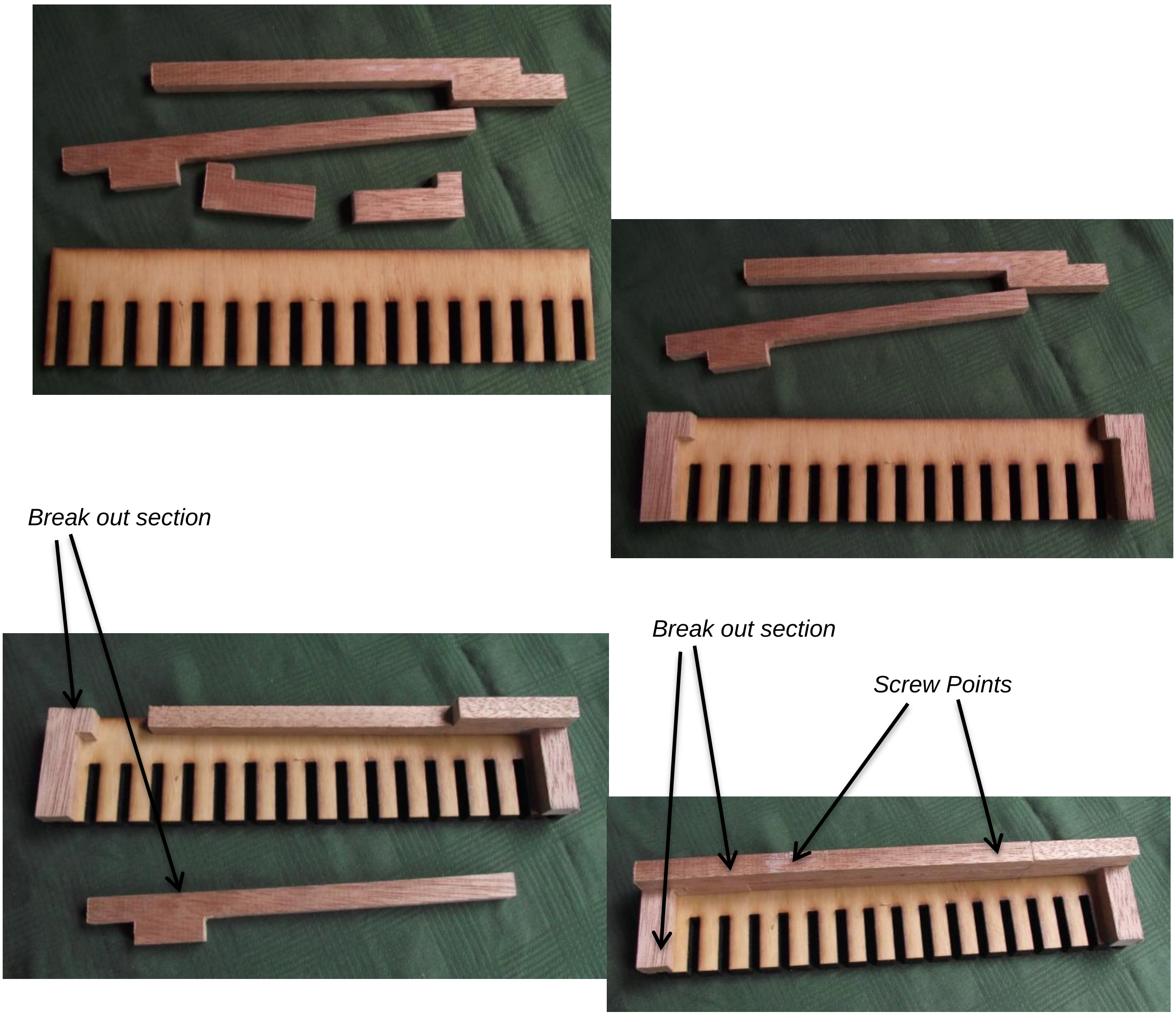


Figure 4.60. Keyguards, parts designed to provide easy breakout for maintenance at the middle of the mechanism

Figure 4.61. Finished key guard and guide system

Keyguard guides are then rendered using plywood mounted in a *meranti* base to provide an effective gluing surface. The keyguard guides are mounted individually and tested for movement whilst the assembly is still moveable, to ensure free key travel.

Further down the keyboard it can be seen that the key springs are not the silicone compression springs of the previous prototype. They are a set of extension springs from a Quickshot advanced MIDI controller keyboard, similar to the type of springs used in the Cheetah keyboard for prototype 2. A change to extension springs had the potential to render different pivot point lengths (between black and white keys) possible for subseqent builds that would be difficult using compression springs. I felt at the time that this was a minor change; the arrangement looks very simple but was in fact quite time consuming to arrive at with the correct tension and strength. In addition, it was noisy during the initial stages of completion; and this noise remains to an extent, despite the addition of felt to the spring retaining bar and other acoustic treatment.

Figure 4.62. Keyboard (extension) springs

The last variation is at the far end of the keys: where zither pins were replaced by adapted banjo friction pegs to tension the pulley strings. Resistance is achieved through the clamping action of the mechanism itself rather than through relative bore size of the drilled hole in the wood, so this solved the problem of the keys providing insufficient surface area for a drilling platform resulting in the wood splitting. At the initial fitting these seemed to be a considerable improvement. The disadvantages began to appear at the stage of stringing up the pulley strings. The banjo pegs have a separate turning head on one side and a tension end to which the string is attached which projects through the surface (photograph below).

Figure 4.63. Adapted banjo pegs to tension the pulley strings

Thus the pulley strings feed into the underside of the keyboard. This caused a great deal of difficulty as during initial stringing, crucial hand access is lost, which was needed to enable tension to be given to the pulley strings. Initial attempts at stringing up caused hopeless tangles. This was a pity, because all of the rest of the minor improvements in method and access to assist this process had worked, and the task had been swift compared to earlier builds.

Initially, I solved this by drilling twice through each key so that the pulley string appears on the key surface and then returns through a second hole to the tension mechanism. This enabled the string to be pulled under tension throughout the entire process and was a marginal improvement that at least allowed me to string the keyboard up and begin to play it.

Unfortunately this led to a critical problem. The first performance involving this harp took place on 20th February 2015 — the finale of the University of Salford Sonic Fusion Festival. Whilst regulating the keyboard before the performance, a pulley string became entangled with an adjacent winder. Because the string was not accessible from the keyboard surface, attempts to free it simply caused it to snap, and I had to complete the rehearsal and sound check in Peel Hall without the note D. Since no waxed linen thread pulley string had ever snapped on any other prototype through countless hours of playing, this was clearly a terminal fault of the mechanism that had to be rectified. Fortunately I had a reel of waxed linen thread with me, and was able to gain access to the recording studios workshop, in order to repair it for the performance.

Figure 4.64. Final version of the pulley string tensioners – returned to the top of the keyboard (April 2015)

Despite the flaw, I did not wish to return to zither pins (with the associated problems of wood splitting) so instead, the mechanism was reversed once more, and each round string attachment-point was filed square, to the dimensions of a zither pin, such that the same tuning hammer could be used to tune the instrument and regulate the keyboard (as for prototype 3). This was an extremely time consuming process, but solved the problem completely.

The pulley bars have been reinforced throughout the system, such that within this prototype there is no chance of different feel at the centre of the keyboard caused by either the keyboard or pulley wheel bar bending. The material has been changed to solid steel bar in each case, and the systems are formulated into cages such that support is provided at regular intervals along the length.

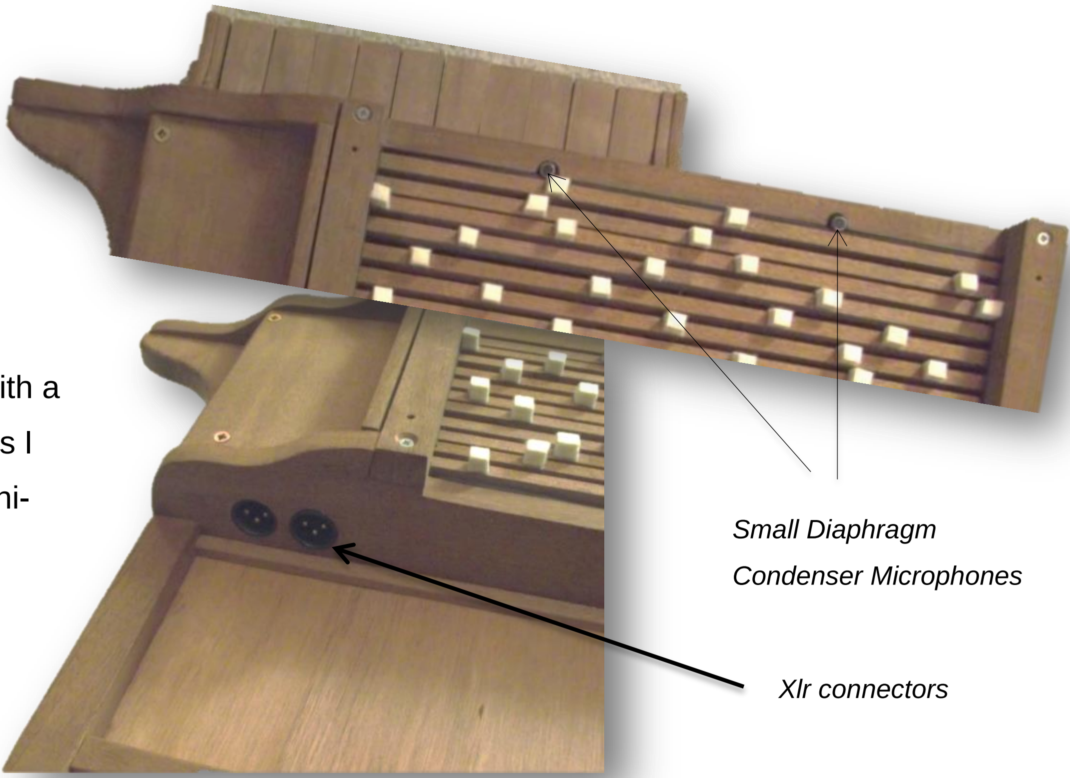


Figure 4.65. Integrated amplification in prototype 5

A late addition to the system was the integrated amplifaction. After experimentation with a number of methods I found that two omni-direction small diaphragm condenser microphones facing the strings was the best option. These are adapted from T-power to receive normal phantom power and pathed through the damper mechanism to a pair of neutrex xlr connectors.

Harmonic damping also caused considerable problems. I first adopted the combination of damper bars arrived at for prototype 3, which had achieved an excellent standard of harmonic damping. The arrangement also worked quite well on prototype 5, but there were some minor harmonics. However, I adopted it in the first instance because this meant that I could begin to play the instrument immediately, and it could take over the ensemble activity such as the ACMG that was currently reliant on prototype 3. The remaining harmonics were sufficiently irritating however as to warrant a dedicated session searching for a better solution. This was undertaken on 17th March 2015, the results are shown in the table below.

21	B	C	D	CS	A	E	AS	FS	DS	G	F	GS	GOOD	
22	B	AS	D	E	A	C	CS	FS	DS	G	F	GS		
23	B	AS	D	CS	A	E	DS	FS	C	G	F	GS		
24	D	AS	A	B	CS	E	DS	FS	C	G	F	GS		
25		A	B	AS										
26	D	DS	C	F	CS	E	AS	FS	B	G	A	GS		
27			F	C										
28	CS	E	D	GS	C	A	AS	FS	B	G	F	DS	VGOOD	CS MARG
29	D	AS	A	GS	CS	E	DS	FS	C	G	F	B		
30														
31														
32	C	C	C	C	C	C	C	C	C	C	C	C		
33	B	B	B	B	B	B	B	B	B	B	B	B		
34	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS	AS		
35	A	A	A	A	A	A	A	A	A	A	A	A		
36	GS	GS	GS	GS	GS	GS	GS	GS	GS	GS	GS	GS		
37	G	G	G	G	G	G	G	G	G	G	G	G		
38	FS	FS	F	FS	FS	FS	FS	FS	FS	FS	FS	FS		
39	F	F	F	F	F	F	F	F	F	F	F	F		
40	E	E	E	E	E	E	E	E	E	E	E	E		
41	DS	DS	DS	DS	DS	DS	DS	DS	DS	DS	DS	DS		
42	D	D	D	D	D	D	D	D	D	D	D	D		
43	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS		

Progress towards advantageous combination

Performance of individual damper bar in each position

Figure 4.66. Exploring and recording problems with harmonic damping in different arrangements

Rows 21–28 represent an excerpt of the trialling of different combinations. The colours are reports of the success of the damper bar in this particular position, where green indicates an absence of harmonics, yellow acceptable harmonic content, and amber and red represent unacceptable levels of harmonic content. The blue cells in row 24 represent the exposure of other "odd" artefacts in the combination at this point, possibly emerging because of the adjacent semitones. Rows 32 to 43 are a report of each bar in a particular position, such that a picture begins to emerge of which bars are acceptable in different positions. The diagram shows that at the trial of the 29th combination a problem has become clear; there is *no* suitable damper bar for the 4th position — all damper bars create harmonics. This was a situation that I had always feared might occur, it had taken a significant amount of time to arrive at a suitable combination for prototype 3, and in fact there were still one or two minor harmonics present in the final arrangement. The number and arrangement of strings differs considerably between the Schmidt harp and Alec Anness' harp, so the process was effectively started from scratch for this prototype.

Because of the special circumstances of the build (the action completed independently of the harp body) it might have been possible to test different combinations without securing the two together. This was tested to the extent that the optimum position was found for the prototype 3 combination, however the range of movement possible was only around 5mm because of the opposing selective pressure to maximise the playing space on the string surface. Further, I considered that there was enough pressure at this point of the build in drilling these bore holes accurately. The idea of dithering, while different combinations of damper bars were tried and secured using clamps, was simply not practical. At any rate, the bore-holes had long since been drilled, and the upper action secured to the harp. The build was thus committed to this position and a solution had to be found.
At the time, I settled for the best combination, which is that arrived at in row 29, and consoled myself with the knowledge that since I had been consciously paying attention to harmonics for around four hours continuously, they now sounded alarmingly loud.

By the time of the next ACMG rehearsal, my pitch-sense had returned to normal and I became aware that the new combination represented an improvement over the first. However, I still wasn't satisfied with it and, at this point that I wrote to Steve Brown (player of the Newton style reverse action keyboard autoharp) to ask how he had achieved the excellent harmonic damping found within his recordings. The detail of this exchange has already been documented within this chapter under *Harmonic Damping Compared,* and this provides methodology to effect a solution. The information within the spreadsheet even provides the correct orientation for the outrigger (towards position three).

Figure 4.67. The different build sequence allowed some unusual photography – this plate shows the keyboard from the underside. The damping felt is in contact with the strings when completed

Acoustic treatment, broad-spectrum absorbing foam was used to enclose lower and upper actions. The photograph below demonstrates that when closed, the damper bar system is isolated from the housing by a continuous layer of broad band absorption and this has served to minimize the noise generated by the movements within the action.

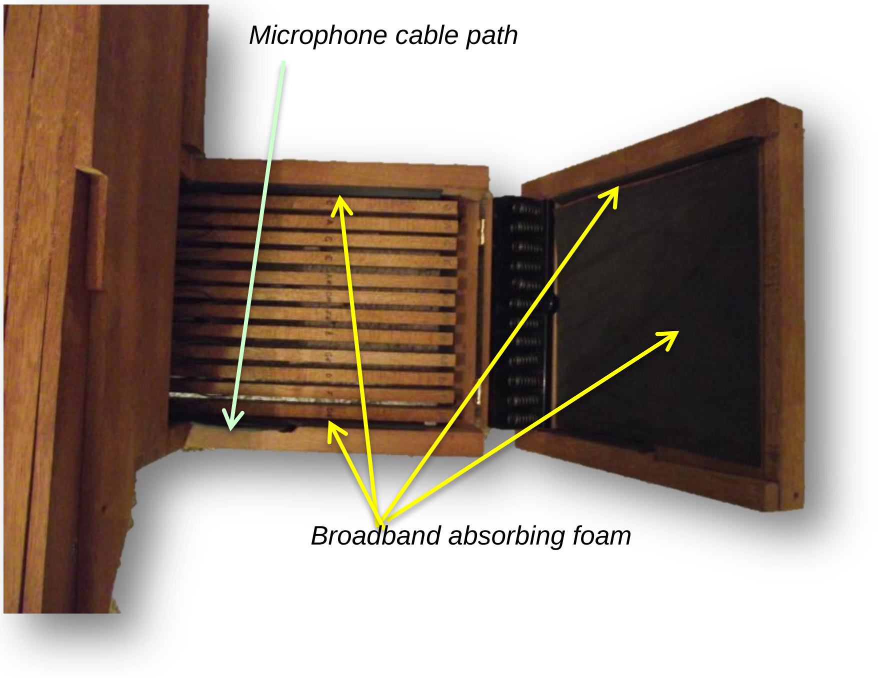


Figure 4.68. Acoustic treatment of the lower action chamber

In terms of the overall finish, I remain critical, but am looking forward to judging this once the action has been fully finished by Alec Anness.

Although not finished to the standard that I would like, each successive prototype unequivocally demonstrates a significantly improved standard.

Figure 4.69. Current finish of prototype 5 (July 15).

The keyboard action will subsequently be finished by Alec Anness

In terms of sound quality and response Alec's harp has lived up to expectations. The bass response is a truly significant improvement over a Schmidt harp, and the integrated amplification provided a further means to balance the instrument within ensemble settings. A significant difference was found to be in the extent of the dynamic response which is substantially improved, so as to enable a range of voicing effects with regard to melody and accompaniment separation to be rendered clear with relative ease. The overall projection of the instrument is also improved to the extent that after a short while, I decided to dispense with all finger picks except the thumb-pick, relying on nails only; a style which offers much increased freedom of technique and expression. This will be covered in more detail in the next chapter.

Conclusions — and Thoughts Towards Prototype 6

Year	
Considered in Prototype	6
Action	
1. Playing position	
2. Keyboard: appearance and feel	
3. Pulley and string system	Yes
4. Key pivot point to damper coupling	Yes
5. Key range	
6. Harmonic damping	
7. Minimal noise	Yes
8. Integrated amplification	Yes
9. Playing space on the string surface	Yes
10. String tuning and range	Yes
11. Access for maintenance	Yes
Harp	
12. String distinction	Yes
13. Tuning mechanisms	Yes
14. Top plate	Yes
15. Depth and volume of the resonating chamber	Yes
16. Optimised coupling of bridge and top plate	Yes

No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

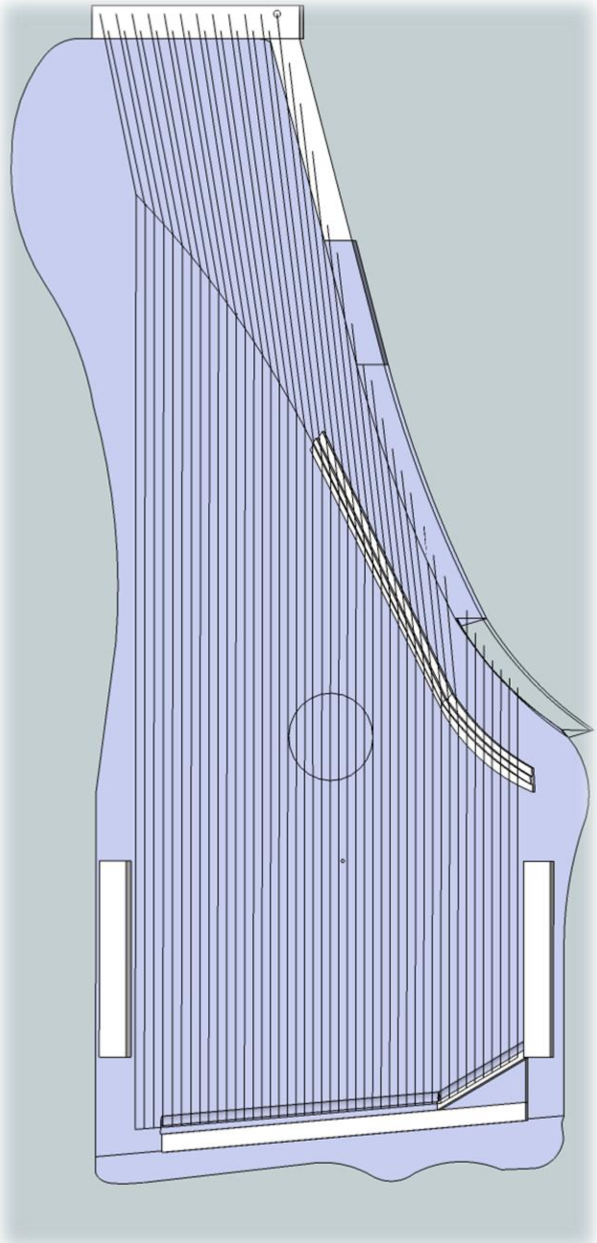


Figure 4.70. Projection of prototype 6 shape and assessment against design criteria

Prototype six remains purely at the planning stage, and this section serves to gather together thinking from various parts of this document, and summarise its current extent. The most significant change is that it is certain that this prototype will be based on a bespoke harp, and that this is likely to be somewhat different to a traditional autoharp shape.

In the spring of 2013 I arranged a meeting and consultation with another luthier; Tony Johnson. Tony specialises in making lutes including a very complicated 13-course swan-neck lute. Though a very different type of string array, this instrument is large enough that it encounters similar problems in some respects. There were two purposes to this consultation: firstly, I wanted some tuition in the hand tools that are part of the basic training of the craft. Whilst my self-taught skills had improved markedly, I still felt that I lacked some of the basic experience in chisel and carving techniques. In fact a good deal of this part of the session focussed on sharpening techniques (the importance of which I had previously missed), and this proved extremely helpful to the subsequent build of prototype 5. Secondly, with a view to the planning of prototype 6, I wanted another opinion on the acoustic design of the autoharp body and how it might be improved. Tony had not even heard of an autoharp when I spoke with him initially on the phone, but agreed to take a look at the instrument before our consultation.

I took along prototype 3 to the consultation, together with my 3d renderings, and asked Tony his opinion on the acoustic design of the harp. My understanding had deepened considerably in the time since the initial consultation with Alec Anness, but overall I still felt similarly about many of the issues.

I had, by now, through both practice and research, understood the principle of arched and radiused (crown) top plates. Many internet sources provided information, giving a better picture of the techniques involved in producing them, and these techniques (and results) display considerable variety even within individual instrument species. Resources such as the Bilhuber (Steinway soundboard) patent of 1937 (Bilhuber, 1936), taught me how radius principles can be applied to a large array of strings, and to the particular shape of top plate that results. I realised that Alec applied either a compound (crown) or an arched curve to his top plate in his harp designs, which contributes to the much richer quality that they produce over commercial harps, but in other ways Alec’s harps, quite deliberately, conform to the traditional autoharp design.

Guitar makers stress the importance of a large area behind the bridge in order to allow formation of a well-rounded bass. Even on smaller, travel guitars the bridge is almost invariably located on the soundboard itself, with a significant amount of space surrounding it (Howman, 2012). Talking to a trained luthier, who was clearly seeing the traditional autoharp instrument for the first time, was most refreshing. Tony first observed that the bridging on the Schmidt harp was to the frame at both toe and dead end, which would not transfer vibrations from bridge to top plate effectively[13]; there was no noticeable arching or crown shaping. In addition, he noted that the bass strings were too short, the cavity probably did not have enough volume (though this last could be deceptive, and should be calculated) and lastly, that he felt that the sound hole was in the wrong place. All of these excepting the placement of the sound hole (which was a surprise), were observations that confirmed my thinking and planning towards prototype 6.

Tony's initial thinking was that bridging over the soundboard could best be achieved at the dead end of the instrument — a proposal to which I was highly resistant because it would change the shape of the dead end completely and therefore the playing position. We talked around the issues for some time and the conclusion was that I should seek a design which incorporated all these ideas — but particularly that of allowing at least 2 inches on all sides of the bass bridging area. The design shown at the beginning of this section is the result. The string lengths are recalculated — slightly differently from the string distinction projection in chapter three, but still using guitar string gauges, to allow for a continuous tapering of the string surface down the length of the instrument. Bridging on the top plate is formulated at the toe end of the instrument where a new rounded lobe surrounding the bass area is created. This is similar in principle to the bridging found in the Millington/Young instrument, though extended. Separate radius points could be taken from the centre point of the new bass lobe, and the centre point of the main harp body, such that the top plate would have a double crown, or perhaps a crown around the bass area and a simple arch through the main body of the harp. Extra volume is created by offsetting the angle of the bass plate with respect to the top plate (a wedge shape), such that the cavity becomes deeper towards the toe end of the instrument.

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[13] Recall from the conclusion of chapter 3, according to the strictest definition this is not therefore, technically a bridge — the use of the term bridge applied to the toe end reflects variability of design in autoharps, and the design ambition of the project.

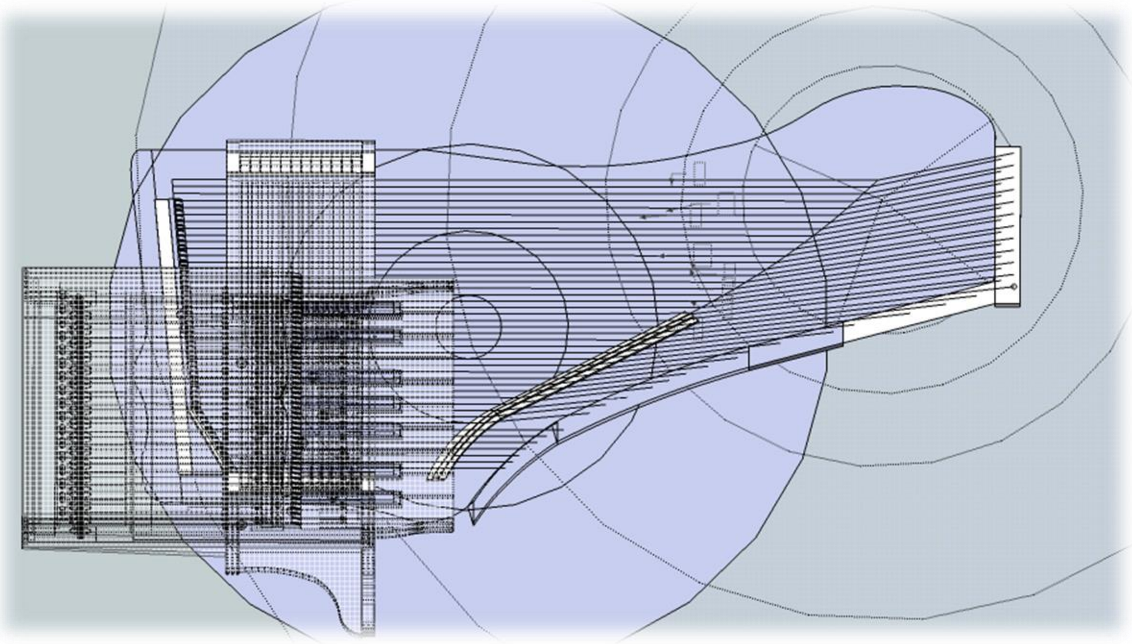


Figure 4.71. Possible radius points for prototype 6

All changes are designed from the perspective of improving the sound without altering the playing position. These two selective pressures result in an interesting aesthetic shape, very different to the autoharp. It is suited to the seated position of the ReAPH, but perhaps would not be suited to the slightly more upright autoharp position.

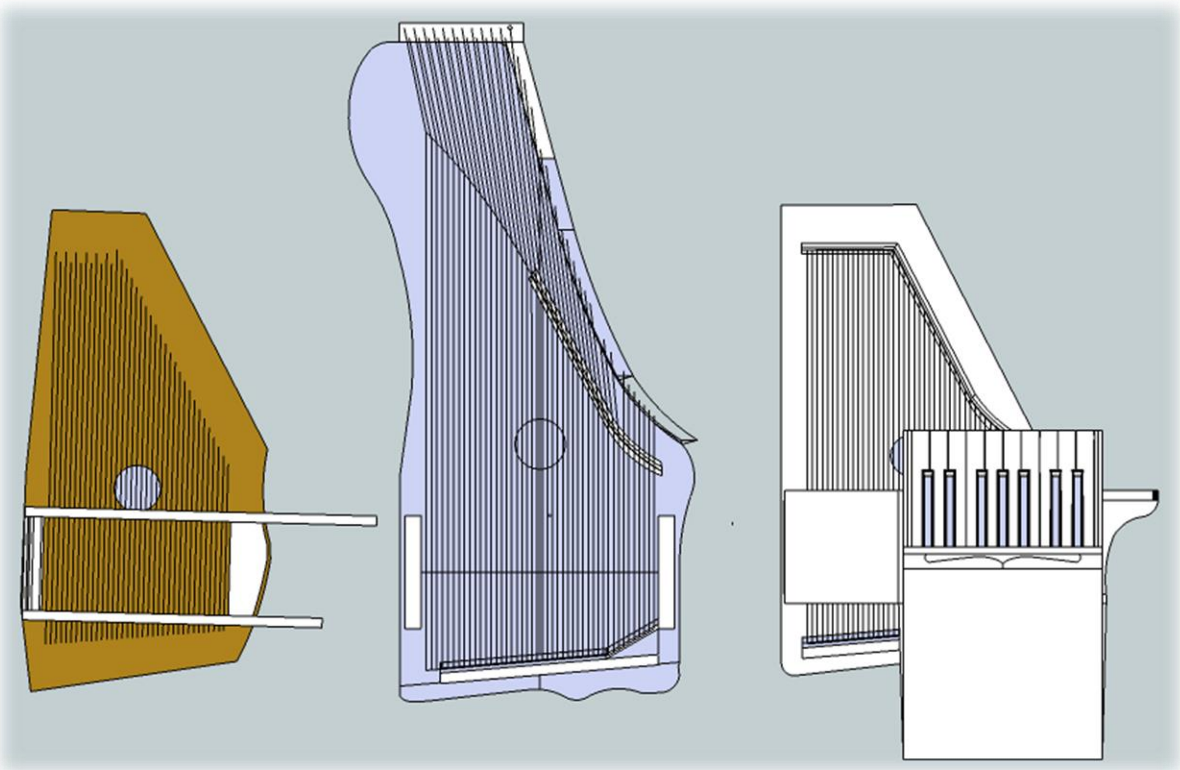


Figure 4.72. Overall size and shapes compared: left: Schmidt (prototype 3), middle: projection for prototype 6, right: prototype 5

An idea of the overall shape does not signal workshop readiness however. To illustrate the kind of unforeseen problem that might arise: at the meeting of October 14, I challenged Alec Anness about the issue of bridge connection to the top plate once again. Perhaps because I was clearly better informed and formulated my questions much more precisely Alec answered readily, and the answers were very helpful. It turns out that Alec's bridges do overhang the top plate — as far as possible, but that a limiting factor (and a serious consideration when formulating method for prototype 6) was that the bridge pins needed to be hammered into the frame in order to ensure that there was no subsequent movement of the bridge as a result of string tension from different directions (as the angle turns from bridge to zither pins). If the angle of each string is perfectly straight as it exits the bridge to the tensioning device, then there is no problem. In practice, this is quite difficult to achieve, particularly if an attempt is made to integrate geared machine heads as opposed to zither pins. It would also be possible to support the bridge from underneath the soundboard through a brace, which would place less pressure on this measurement.

The project requires a significant re-tooling before progress can be made. The radius template needs to be designed and rendered, and the means of producing the harp frame must be finalised. Using a radius for a large notional sphere (guitars commonly employ within a range of 25–40ft), a bespoke radius template may be rendered using routing techniques, or by using 2 MDF or plywood sheets at a thickness which is stable, but will bend under force. Separation distances are calculated between the two sheets and spacers are added. This technique also gives the ability to produce more complex non-circular shapes, which conform more closely to harp top-plate shape.

The means of rendering the new shaped frame itself requires careful planning. The new curvature, particularly on the bass side, probably calls for the application of a bending technique applied to the frame rather than a direct shaping to a single frame spar. Autoharp frames are rendered from four lengths of solid stock, and this provides a suitably rigid frame for the large number of strings, and also includes space for zither tuning pins. Since the shape is essentially rectangular, no bending techniques are necessary, and as far as I am aware have never been part of the fashioning process for autoharps. In contrast, guitar side plates are bent into shape through heat and steam, and are as little as 2mm thick (to around 4mm common for jumbo guitars). Such minimal depth would not be suitable for a harp, however, given the increased depth at the toe end (due to the wedge shape) there is potential for thinning, and also the application of bending techniques. Traditional guitar side plate bending techniques would probably be ineffective given the frame thickness required. However, I have been experimenting with a technique from furniture making where the spar to be bent is placed in a wood chamber and subjected to steam continuously for around three quarters of an hour, to the point where the wood is completely saturated. The spar is then highly pliable for around 30 seconds on removal and can easily be bent into shape and clamped. The clamping time is considerable — the furniture demonstrations suggest around 2 weeks. The wood suggested is beech — renowned for its bending properties. This would be a suitable material for the frame and is sometimes used in guitar side plates.

Once frame and top and bottom plates are rendered, a further jig is necessary to allow effective clamping for a permanent and airtight fix. There is considerable variation in the way that guitar makers achieve this; from multiple clamping to bespoke jigs where flexible rods can be placed at precise points under pressure from a ceiling plate.

Assuming that I have identified all the significant issues, I would estimate that the task of building a harp body is roughly comparable in complexity to that of the keyboard action — possibly marginally less so once the re-tooling is complete.

Overview of Design Criteria Within the Prototype Series

Year	2007	2008	2010	2011	2012	2014	
Considered in Prototype	1	2	3a	3b	4 (virtual)	5	6
Action							
1. Playing position	Yes	Yes	Yes	Yes			
2. Keyboard: appearance and feel	No	Yes	Yes	Yes	Yes	Yes	
3. Pulley and string system	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4. Key pivot point to damper coupling	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5. Key range	Yes	Yes	Yes	Yes			
6. Harmonic damping	No	No	Yes				
7. Minimal noise	No	No	No	No	Yes	Yes	Yes
8. Integrated amplification	No	No	No	No	No	Yes	Yes
9. Playing space on the string surface	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10. String tuning and range	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11. Access for maintenance	No	No	Yes	Yes	Yes	Yes	Yes
Harp							
12. String distinction	No	No	Yes	Yes	No	No	Yes
13. Tuning mechanisms	No	No	No	No	No	Yes	Yes
14. Top plate	No	No	No	No	No	Yes	Yes
15. Depth and volume of the resonating chamber	No	No	No	No	No	Yes	Yes
16. Optimised coupling of bridge and top plate	No	No	No	No	No	Yes	Yes

No	Not considered in this prototype
Yes	Actively considered
Yes	Working, but further optimisation possible
	Parameter considered optimised or range understood

Figure 4.73. Overview of design criteria assessments within the prototype series as a whole

The table above considers progress on each of the design principles expressed as selective pressures through the prototype series as a whole. It shows a gradual increase in engagement with the entirety of the principles that reflects the practice as I experienced it. For the most part, the transitions move smoothly from red through amber to green. Exceptions are found in the harp body itself. Points are marked green in Alec Anness' harp, but return to amber (actively considered) as I begin to take over all of these processes.

String distinction remains a thorny issue. It was considered to some extent within prototype 3, but the addition of visual indications of strings only helped with tuning — it did not seem to me to aid string recognition within the array. In principle, there is no reason why the variable-spaced projection at the end of chapter three could not be married with the straight-strung projection proposed for prototype 6; but I would like some way to demonstrate that the gain would be significant as, unlike all other changes described this particular “improvement” is very difficult to test. Probably the most direct and objective method it would be to obtain feedback from other players, and bearing in mind that there are other, simpler solutions, (such as the Millington/Young solution of simply drawing a keyboard oriented against the strings) I am more inclined to plan for a retrofit of this method on an earlier prototype for testing, rather than allowing the issue of acoustic design change to become complicated by the separate issue of string distinction within prototype 6.

Returning to the keyboard action, another marginal issue is that of the sustain pedal. Many of the early patents studied within this chapter implement a means of lifting all the dampers simultaneously. I am attracted to this device, but remain hesitant as to its actual musical value. In the autumn of 2014 I began playing prototype 3 in the Adelphi Contemporary Music Group at the University of Salford, and it was this experience that finally persuaded me that it might be worth trying to implement this system. I remain unsure as to whether it will prove useful during engagement with tonal repertoire, but it would certainly be useful in achieving a freedom of engagement across the harp as a whole and would suit a particular brand of contemporary classical engagement within this ensemble. Again, the best way to implement this might be initially through a retrofit to either prototype 2 or 3, in order to test it, because the device will be quite imposing, and will certainly change the look of the instrument somewhat, and its overall musical value is yet to be demonstrated.

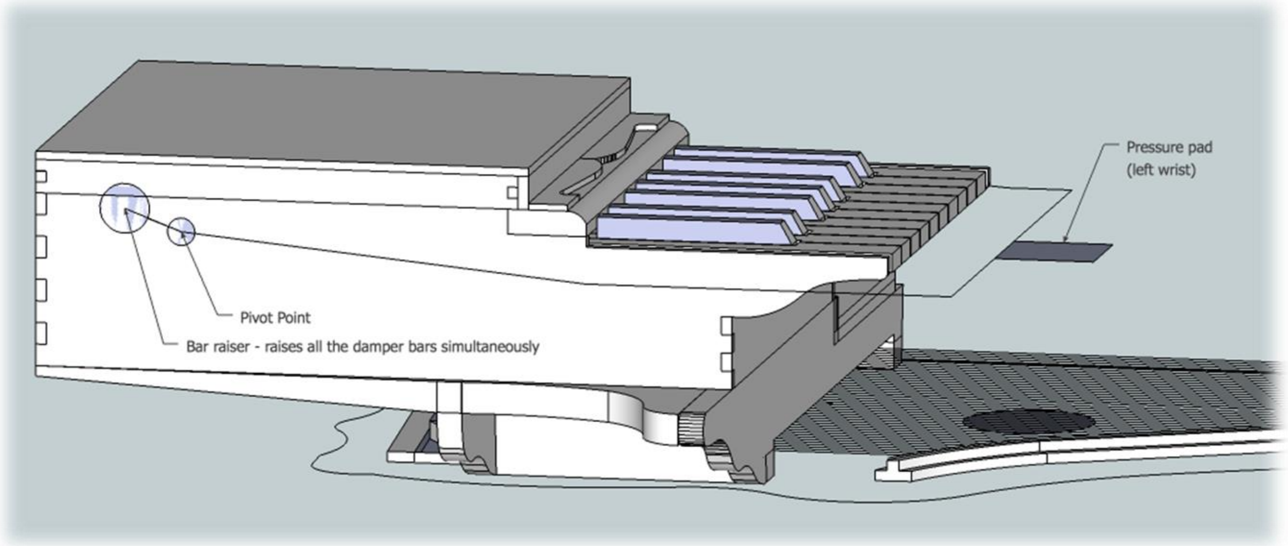


Figure 4.74. The principle of the sustain pedal – operated by the left wrist resulting in a bar which pushes all the dampers up simultaneously

Irrespective of whether or not adapted banjo friction pegs are determined to be the best mechanism for tensioning the pulley strings, a redesign of the keyboard box (and the way in which the keyboard system breaks down for maintenance) is to be explored in 3 dimensional rendering for prototype 6.

Summary of Next Steps towards Prototype 6

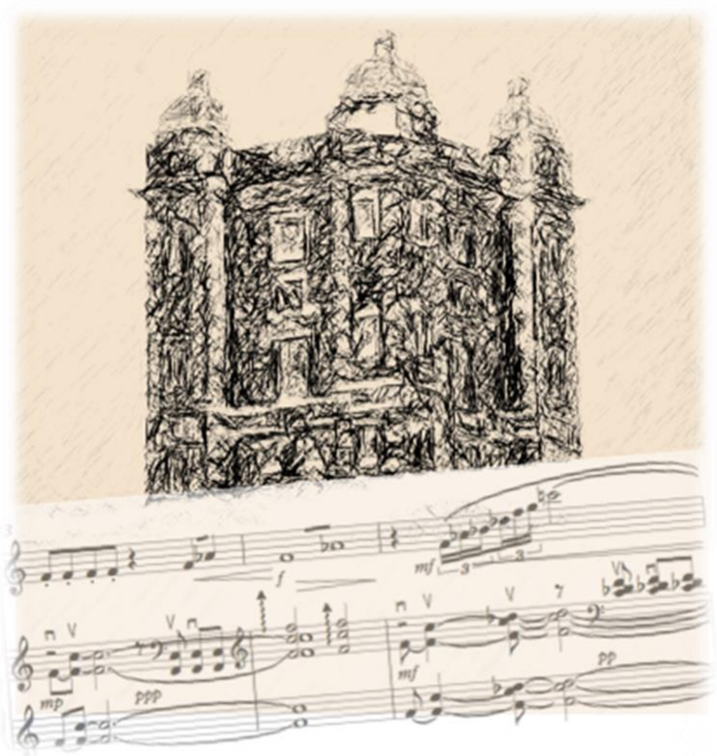
Harp body

1. Finalise top plate design
2. Finalise arch and radius points
3. Design and finalise bracing across top plate (render radius template)
4. Design and finalise string tension devices (decision; geared machine heads or zither pins)
5. Design and finalise harp frame, and harp frame method (render frame templates and clamping jig)
6. Render harp — tune and observe stability over time
7. Retro fit string distinction mechanisms to prototype 2 and test

Keyboard action

1. Retro fit sustain pedal to prototype 2 and test
2. Consider alternative redesigns of keyboard housing. Assess for comparable or better maintenance access, and more efficient build time.

5. Musical Engagement



Context

One of the fundamental all-encompassing questions at the conclusion of chapter one was to ask whether or not the ReAPH could be established within a musical community. Success with regard to this aspiration can be measured by considering the development of activity within the project, to establish the extent to which the activity is able to demonstrate:

- Greater variety
- Increased extraversive activity
- Increase in initiatives from others upon aspects of the project

This change inspires a creative momentum and a critical mass should enable:

1. Activity upon the project becoming increasingly independent of the inventor's involvement
2. Increasing musical acceptance and stable (and innovative) propagation of memes.

Activity certainly demonstrates increased variety and increased outward perspective over time; experience within ensembles has broadened to encompass genres from gypsy-jazz to contemporary experimental music and within these (and other ensemble settings) composers have written and arranged for the instrument, and other players have played it in performance. In addition, I note with some pride that I am already not the only serious student of the ReAPH; my daughter Lucy expressed an immediate interest in it, claimed prototype 2 and then prototype 3 when each, respectively, became available and she has successfully performed on the ReAPH publicly, in school concerts and various drama presentations. I published my website (reverseactionpianoharp.com) in early 2013, which discussed the design progress and showcased recordings. Traffic through this web-site has increased significantly as a result of engagements such as the 2012 UKautoharps Mickleover meet. This in turn led to contact with other inventors and players (Ben Devoy and Steve Brown), an invitation to present the instrument at the Newport Folk Festival in June 2015, and has recently even resulted in direct purchase requests.

This activity demonstrates an increasing awareness, presence, and from one perspective, indicates direct acceptance within the musical community, but it is not the purpose of this chapter to simply critically evaluate this experience. Analysis within this chapter must also progress towards pedagogy.

The design-led discussion of previous chapters has already presented significant musical analysis because design is, of course, guided by musical experience; the method of *action research* dictates that analysis within each domain influences decision making upon the other in turn. In order to progress towards pedagogy this intertwined process needs to be untangled and presented from a musical perspective. In so doing this chapter aspires to reach a comparable progress-stage to that of the potential design distribution of the instrument discussed in chapter four.

Chapter four, in addition to documenting progress on the prototype series, noted progress towards the various means of bringing the ReAPH design to the wider musical community, such that in each case the most significant technical obstacles have been addressed to varying extents. These are summarised as:

1. Production of a self-build manual from scratch
2. Production of a self-build package that includes digital means to commission the majority of parts (CNC and laser cutting) and to self-assemble
3. Production of a kit-based package for adapting a commercial autoharp (probably an Oscar Schmidt) — similar in principle to available harpsichord kits
4. Sale of finished instruments
5. Approaches to manufacturers to provide finished instruments.

In each case, the project is now poised to move from a prototyping stage to a development stage, working on distribution and propagation. However, this is not sufficient in itself to establish a musical community. The term *musical community* is used specifically as opposed to *market*. The subject specific differences lie in the support structures, which must accompany the product (and the extent to which the interface is adaptive to pre-existing skills and repertoire). We can say firmly that creating fully developed learning method cannot precede instrument design and given the design stage achieved, production of comprehensive method remains out of the scope of this study. However we can make significant progress towards this end. We can analyse the adaptive aspects of the interface from an *as built* maturity C (Brissenden I. H., 2011) perspective and produce resources: exercises, arrangements, compositions and recordings.

The overwhelming majority of learners of musical instruments expect pre-existing learning structures: method, exercises and repertoire. In addition, they would normally expect other players, teachers and ensembles where the genre specific role of the instrument is well defined. It is to these ends that analysis of subjective experience of the instrument must proceed. It must aspire to develop and present a vision of its accessibility and capability resulting in significant learning resources (perhaps with the potential to attract early adopters) and a critical outline of a proposed learning method.

At the end of chapter two we concluded that an optimised ReAPH should:

4. Provide a significant capability to produce polyphony; this will be more limited than a piano (because one hand is sacrificed from this task, in order to allow it to be in contact with the strings), but should demonstrate comparable flexibility to that of a guitar (because the physical compromises are similar); ideally this flexibility would be increased
5. Provide a similar range of the timbral capacity to the guitar when engaged in polyphony
6. Provide a similar capacity for individual melody as a guitar, this is expected to differ as it will lack some timbral capacity such as vibrato and string-bend (because the stopping hand is not in contact with the strings). However, access to sequences of individual notes may actually be improved in certain circumstances.

To what extent were these aspirations achieved in musical experience of the prototypes?

Playing the Prototypes — Design Meets Musical Practice

Certainly the ambition and sophistication of musical engagement developed through the prototype series, and many perceptions (regarding playing technique and possibility) developed as the prototype series progressed.

Prototype 2 (completed summer 2008) provided the first stable platform to explore its potential, and to finally get a chance to fully understand the extent of the adaptive elements of pianistic technique. I had imagined, at the outset of the project, that a good pianist, particularly those with any experience of the guitar, would be able to pick up the instrument and at once be able to play it to the extent that their left hand keyboard technique and right hand strumming technique allowed. It was a pleasing first finding that this did indeed prove to be the case. A good knowledge of chords, combined with a reasonable strumming technique adapted from guitar, opened a wealth of folk based repertoire and songs. The new chromatic capability, combined with knowledge of four note substitutions opened a wider jazz repertoire, and from this perspective the instrument was entirely successful from the outset. In terms of the first criteria, prototype 2 succeeded; the ReAPH proved itself to be an excellent accompanying instrument, superior to the guitar in some respects (for example register changes that demand significant technique and fret-board geography are trivial on a large string array) and highly adaptive to pianistic technique.

First experiments with precise melody reading began in the folk domain — again based on lead sheet arrangements. At first I did not seek to arrange music or to develop notation specific to the instrument; I simply read melody with chordal accompaniment in simple folk-based repertoire and tried to understand the problems that arose. I also played scale based exercises and improvised. The issue of “wrap around” described in chapter two proved a significant obstacle to fluent sight-reading but was certainly not insurmountable; and my sight-reading of lead sheets became more fluent over time.

Slightly later, but still on prototype 2, I began experimenting with violin, flute and other solo line classical repertoire, and also certain types of suitable piano pieces. This exploration led quickly to dissatisfaction with prototype 2 — it was possible to endure the poor harmonic damping when strumming chords, but not when bringing out the detail of (particularly solo) melody. I continued to experiment with this repertoire however, and began to explore methods of more precise notation, which helped to alleviate the problem of wrap around, and this in turn allowed the right hand on the string surface to become more precise.

Prototype 3 (completed summer 2010 in its first form) provided a much better platform for musical exploration. Not only was the issue of harmonic damping vastly improved, it also had a completely chromatic melody range that could be trusted to fully engage with melodic repertoire. At this time I began to study seriously the performance techniques of good autoharpists. There certainly seemed to be a wide variety of methods, but there are commonalities between all of the best players. The lynchpin of technique at the instrument to render chords, chords and melody in combination and occasionally independent melodic lines, is a technique called “pinch”. The technique deploys the opposed thumb in an up-strum from bass to treble whilst simultaneously providing a down strum using (usually) the 3rd finger (using piano fingering nomenclature, where thumb=1), although this does differ from player to player and is dependent on technical situation.

Autoharp Notation

Although autoharp notation is not suitable for ReAPH, elements of it certainly need to be integrated into a developing ReAPH notation system and it is worth understanding its salient features at this point.

Figure 5.1. Typical Autoharp Notation (Carolan & King, 1991) Status Public Domain

Autoharp notation uses a two-stave system. The upper stave denotes melody (similar to a normal lead sheet). Below this, between the two staves, chords are indicated, although these are not necessarily a representation of the harmony to be played — some chord bar changes indicate passing notes rather than chords and this is clarified by the lower line notation. Below this is a line of mixed symbols and note heads. The inward facing vertical arrows, on the strong beat of each group of 3 quavers in this arrangement, denote a pinch. The arrow heads indicate the starting notes for each finger, increased width does not necessarily indicate a full width of stroke (Mueller, 1999, p. 7); note the double chord bar at the first beat at bar 8, which allows the octave Cs to be isolated. On the second quaver beat, where there is no melody note (for example bar 1), an accompanying thumb strum from the lower or middle octave is indicated (lower to higher strings). Also possible as accompaniment (but not used in this arrangement) is a downward arrow, denoting a third finger brush from higher to lower strings. Single notes, which are rather confusingly notated as semibreves, but in fact, follow the melodic line, signal that individual strings should be sounded rather than chords (the change of chord bar is necessary as the passing or auxiliary note is not found within the sounding harmonic chord bar).

This exposes the melodic weakness of the instrument: firstly because the sounding harmonic strings will be silenced at this point; secondly because this accuracy is difficult to achieve, and notes from the passing chord bar are likely (this piece is most commonly and sympathetically rendered with a chord change every three quaver beats and the increased harmonic turnover is not desirable). Note that within section B, the melody is simplified from its most common form (where F rises to G on beat 2 of bar 9 and G rises to A on beat 2 of bar 10) presumably in order that the accompanying strings are able to sound throughout the bar. The lower brackets denote the groupings of three quavers within the time signature, and the tie at bar nine denotes the dotted rhythm in the melody.

This notation achieves a reasonable degree of precision, but is extremely limited given the new possibilities offered by the ReAPH formulation. However, the technical elements such as pinch and strum combinations do need to be reflected as the notation develops.

Developing ReAPH Notation and Method

The most obvious means of providing accurate notation on the ReAPH will again call for two staves, the upper to denote the right hand upon the strings and the lower to denote the left hand on the keyboard. This typical scale-based exercise in G major illustrates this effectively, and the notation can be understood at a glance because it follows piano notation closely in providing precise guidance for each hand.

Figure 5.2. Scale based exercise in G major

The right hand on the string surface has three alternative sets of fingerings, all of which were practiced on prototype 3. The left hand, at the keyboard, follows instruction similar in all aspects to piano notation. The “wrap around” point, which seems to place the two hands in opposing directions, is set at C in this particular exercise. Note that the left hand is notated with treble clef. Piano left hand notation does appear in treble clef quite often (dependent on register), but an arrangement of combined treble and bass clef is by far the most common notation for a pianist to encounter. A reasonable assumption, this being the case, and given at least 40 years of piano experience, is that it would prove most advantageous for ReAPH arranging, but successive tests proved that, at least for my own reading, the arrangement above was always a notch faster than the bass-treble alternative. Based on this well-tested but admittedly subjective finding, and the fact that the left hand notation sits better within the treble staff (only one ledger line at middle C is required) I decided to adopt this arrangement. This scale-based exercise is put forward as typical, and would be expanded in developing a complete method to encompass full chromaticism, and also to provide further motor pattern learning and flexibility by adapting from such as Hanon. Within the Jazz idiom, similar exercises may be developed by adapting from Abersold.

The excerpt from the arrangement of Bach's *Fantasie* (Partita No. 3 in A minor BWV: 827) below shows how tortured the issue of wrap-around can become within melodic situation; it proved a particular tongue twister. A good deal of the time the two hands are similarly engaged in melodic direction, but the level of octave displacement within the melody itself, combined with the complication of rendering one of the hands within a range of a tenth, means that this piece requires independent thinking between the hands and is in fact more like learning a piano piece.

There are two (sometimes conflicting) selective pressures in arranging for the left hand. Firstly, where possible (and practical) the left hand does mimic the movement of the right hand melody. Note: for bars 25–29 this movement is exact, even though slightly easier arrangements of the left hand might be rendered through octave displacement. A second selective pressure is expressed in bars 1–3 where octave displacements must at least be used for the low A (opening) and B (end of bar 2). Aside from the low A, the first bar and first beat of bar 2 mimic the right hand movement, followed by an octave displacement which allows the downward stepwise movement to be common to both hands for the remainder of the bar. Opposing movement direction in bar 3 (where the music moves only in quavers) allows the left hand to be placed in the correct position to engage in the subsequent quicker semiquaver movement at bar 5, where the movement is similar. An example of a marginal decision is the octave displaced C at the beginning of bar 19; this renders the figuration easier under the left hand, but takes a little more learning altogether, because of the opposing movement. In general an attempt is made to follow the step-wise semi-quaver melodic direction, and to allow the jumps in melodic pitch to displace at the

Figure 5.3. Bach's Fantasie (Partita No. 3 in A minor BWV: 827) Arr: Brissenden

keyboard, and orient the octave such that subsequent step-wise movement can be similar (bars 11–13 illustrate this).

The difference between this level of arranging and the initial reading that I undertook is that this formal notation definitely requires learning and a willingness to accept the arranging decisions. Reading the melody line alone is entirely possible, but because of its nature, is prone to stumbles at wrap-around points. Decision-making does improve on successive readings, but in order to completely stabilise it, precise notation is necessary. Reading this notation can be quite frustrating, and initially at least, I found that most favoured decisions at the instrument did not quite match most favoured decisions when arranging away from the instrument.

This example was adapted from a mandolin arrangement of this piece. Compositions and arrangements for this instrument provide a fairly rich melodic repertoire which is highly suitable for adaptation to ReAPH. Violin repertoire is also adaptive in terms of melodic range, and the baroque style is particularly suitable.

Pinch is incorporated into the exercise below. The two note combinations allow a greater precision of pinch to be given by the left hand at the keyboard than using chord bars on an autoharp. “Pinch” here is issued as a score direction, and is denoted by the combination of fingering called for in the right hand (4–1).

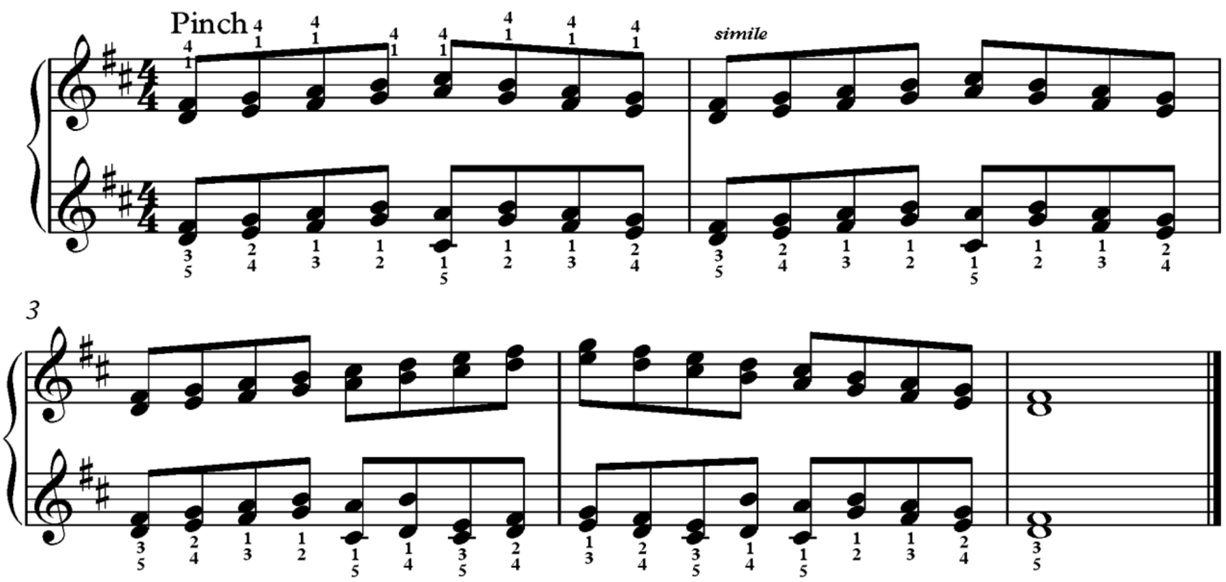


Figure 5.4. Scale exercise in 3rds in D major

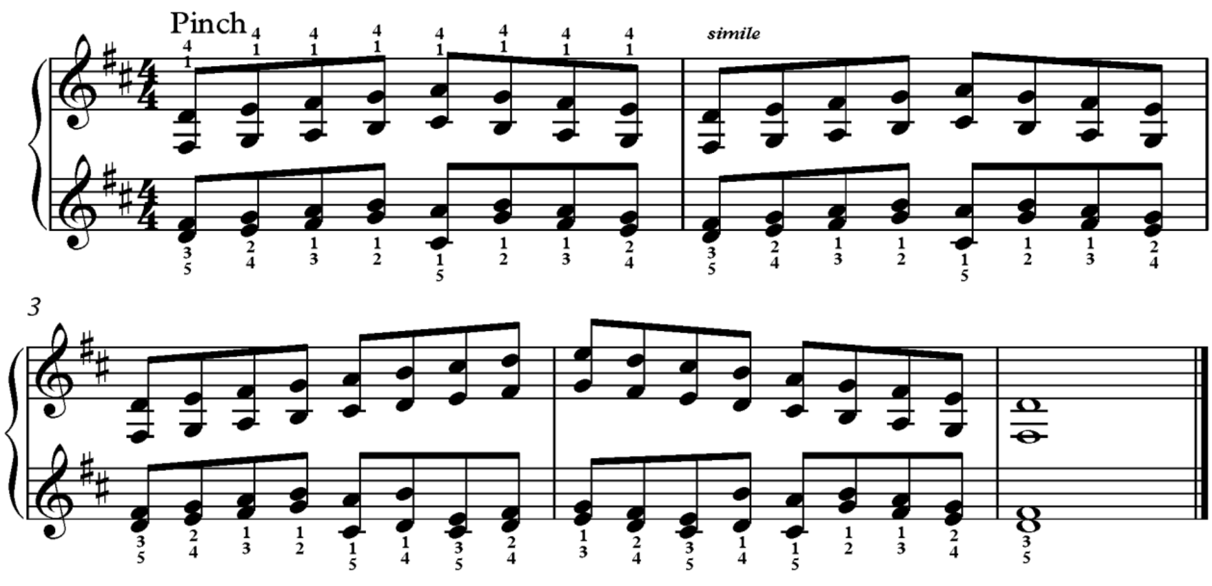


Figure 5.5. Scale exercise in 6ths in D major (left hand patterns are the same for both)

The notation stands up to the test of this exercise, illuminating the fact that the same left hand patterns can be used for scales in 3rds and 6ths, and that legato at the wrap-around points can be enhanced by changing between 3rds and 6ths in the left hand at appropriate points.

Techniques, Finger-Picks, Thumb-Picks and Nails

“Pinch” as a term, evokes a mental image of the hand motion effectively, but is perhaps an unfortunate descriptor overall because it suggests quite a forceful engagement with the strings. Strum effects across a range of instruments appear to the listener as bright and highly percussive, which belies the small, precise, and above all relaxed movements which actually achieve attractive sound. The best tone for pinch technique is rendered through a smooth attack concentrating on relaxed hand, which absorbs the shock of string engagement easily, and an oblique angle of finger pick engagement.

Autoharp players adopt varying numbers of finger-picks, from picks-on-all-fingers, to just thumb and first finger, or no picks at all. This last was initially the most attractive to me (since an ambition of the instrument was that the hand should be in direct contact with the strings). During initial engagement with purely chordal accompaniment, it proved sufficient to simply strum the instrument similarly to guitar strumming. However, my first attempt at copying the technique of Bryan Bowers, using only fingers, left them shredded and bleeding, and it was clear that a rethink, and emergency visit to the music shop was necessary. I thus began to experiment with finger-picks, first adopting metal finger-picks on all fingers — these being the easiest to alter in size for a reasonable fit-to-finger, and a plastic thumb-pick (which I did not like and began alter immediately). The photograph below shows a typical autoharp arrangement.

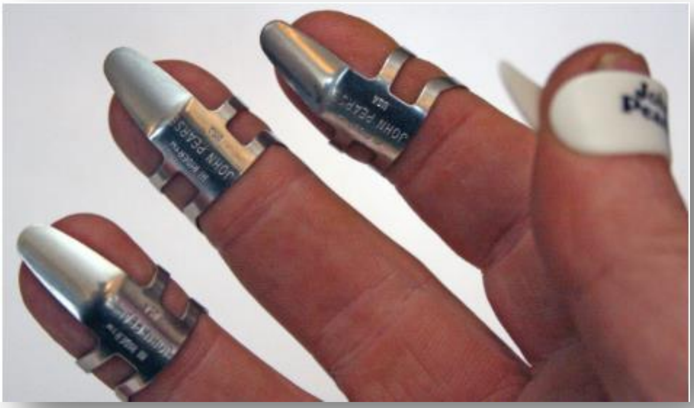


Figure 5.6. Typical Autoharp Finger-Pick Arrangement

A limiting factor of finger-picks (when compared to finger engagement) is that they are designed to engage in only one direction. The orientation of the finger-picks in the photograph right, are for downward engagement (treble to bass) and the thumb for upward engagement (bass-treble). I found this arrangement very limiting, because the up strums from the thumb do not easily cover the range of the string surface. I sought a more balanced arrangement by reversing the pick on the third finger such that it provided an alternative up-strum to the thumb, and this arrangement felt immediately more comfortable.

I then began to arrange pieces based on a mixture of pinch, strum and pluck techniques, without formalising them within the score. Below is an excerpt of the Vivaldi Violin Concerto Op. 3 No. 6 movement 1, arranged for ReAPH and mandolin. An accompanying live rehearsal excerpt, recorded using a zoom H4 field recorder (November 2011), demonstrates the very bright sound of the metal finger-picks. This is a fair representation of my skills at the time, in both arranging and playing.

Figure 5.7. Excerpt from Vivaldi Violin Concerto Op. 3 No. 6 arranged (Brissenden) for Mandolin and ReAPH

This is just a stereo recording, but there is some detail to draw out; the continuous clicking that you can hear is the result of each pinch finishing in a clicking together of the thumb and fingers — a feature which can often be heard on autoharp recordings, and a habit which was difficult to control. There is also a second type of click, caused by the little finger occasionally tapping against the keyboard housing (I eventually abandoned the pick on the fifth finger). Some off-beat chords, particularly rising chords are often rendered using an up-strum (bass to treble) from the third finger rather than a pinch, and semiquavers are always played using a pinch followed by an up-strum.

Another demonstration recording dating from this time is the folk tune *The Rambling Pitchfork,* made in order to demonstrate the ReAPH assuming a melodic/harmonic role within an ensemble. This is an overdub recording where I have (in addition to ReAPH) provided piano, bass (rendered) and penny whistle recordings. The mandolin and fiddle were played by Rachel Brissenden. The sound of the ReAPH is rather better here, partly due to the detailed editing which overdub technique allows, the pick technique remains rudimentary when compared to subsequent development, and the microphone choice was limited. A third live recording of the jazz standard "Every Time" was also made at this time. The slow swing patterns are rendered in this recording using combinations of pinch — 3 and 4 – 3, placing pinch (and 4) on the strong down-beat and 3 on the weaker swung up-beat. This appeared to me to be logical at the time, because it enabled chords to be pinched on the strong beats.

Together, these recordings represent the first attempt to render recordings of sufficient quality for publishing within a website on the internet[14], following the securing of the patent. However, *The Rambling Pitchfork* was the only recording that was eventually included within the website presentation and this was because it presented the instrument in an ensemble situation.

I reconsidered the approach to swing strum patterns, following involvement with the gypsy jazz band *Toe Rag,* at the performance at the UoS Media City building in December 2011, which was part of the celebratory events which marked the opening of the UoS presence at Media City. I was approached by Paul Dennis after a presentation of the ReAPH to MA students and invited to sit in with the rhythm section of his gypsy jazz band. Paul and I both agreed that the sound of the ReAPH really suited gypsy jazz — the bright sound combined with the unique ability of the ReAPH configuration allowed for a precise control of sustain. We both wanted only rhythm from the harp for this event, and for its sound to sit roughly an octave above the rhythm guitar and to provide a very similar feel, continuously brightening its sound.

Gypsy jazz requires a very strong straight down-beat, and minimal off-beat input from the rhythm guitar. Standards are often presented in keys which favour open strings (which is unusual within the context of jazz as a whole) and tempi are very fast. I found that a much better match for the rhythm guitar was given by an up-strum (1 or 3, from bass to treble), immediately damped at the keyboard, and the occasional down-strum (4 from treble to bass, on off-beats), pinch was not used at all. This pattern really suited the music and the instrument, and influenced all my subsequent strumming patterns, such that the first consideration when approaching strum/pick patterns would be whether to render 1 and 3 (up-strums) on strong beats or to pinch. The two can be mixed, but sufficient thought is required for a comfortable change.

I received further feedback on these recordings at the meeting with Alec Anness in 2012. Alec was strongly against metal finger-picks and said in no uncertain terms that they gave a poor sound and were potentially damaging to the harp strings (and also might easily damage the harp body). I did not mind abandoning them — the main attraction had been

[14] This followed the reply from the UK Patent Office of 7th September 2011 which accepted that the ReAPH represented an inventive step. Though the patent was not secured until February 8th 2012, it became highly likely at this point that it would be, and I began preparing materials to showcase the instrument.

the fact that because the metal was easily bent it was easy to alter them to a good finger fit. Alec recommended the full finger picks (shown right). These were an improvement in some respects as they were a secure fit when compared to the metal finger-picks and did allow movement in both directions on the string surface. However, they are made of quite thick plastic, and because they fit around the entire finger, enlarge its diameter noticeably — it was even more difficult to avoid clicking because of this.

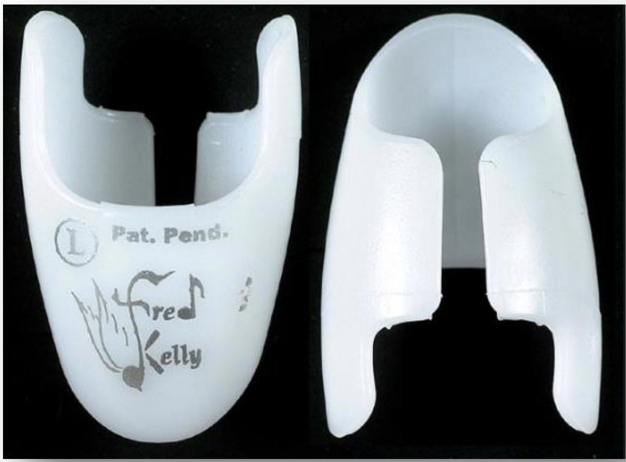


Figure 5.8. Fred Kelly full finger picks

At the UKautoharps meet in Mickleover in September 2012, Mike Fenton, an accomplished autoharpist and winner of various US competitions on the instrument introduced me to the Fred Kelly speed-pick (for thumb), which I found to be a revelation. The minimal, and highly flexible surface area presented to the strings by this pick allows Mike to formulate a tremolo effect using thumb and third finger tucked in line with the thumb, using lateral movement of the hand, similar in technique to the way in which a tremolo chord is achieved on the piano, and similar in sound to mandolin tremolo.


Figure 5.9. Fred Kelly speed thumb-pick

I was unable to directly copy this technique because of the pick arrangement that I had arrived at (reversed on the third finger). However, with practice I was able replicate Mike’s tremolo effect using 1 and 4.

I discussed the reversed pick variation with Mike in some detail; in keeping with the autoharp community ethos, he was not judgemental in any way, instead he discussed the detail of his own strategies saying that he would be likely to change the number of finger picks that he used depending on the particular piece, from as little as thumb and third only to picks on all fingers. However, he did comment that it was an unusual arrangement.

The Fred Kelly thumb pick delivered a different sound and feel to any finger pick that I had so far encountered. The narrow width means that the pick has a pleasing bounce as it engages the strings; the effect is a reduction in the noise generated, and a clearer sound. It also gave a greater precision than I had previously been able to achieve with the thumb. Thus inspired, I began a further round of experimentation with different shapes, materials and thicknesses of finger pick.

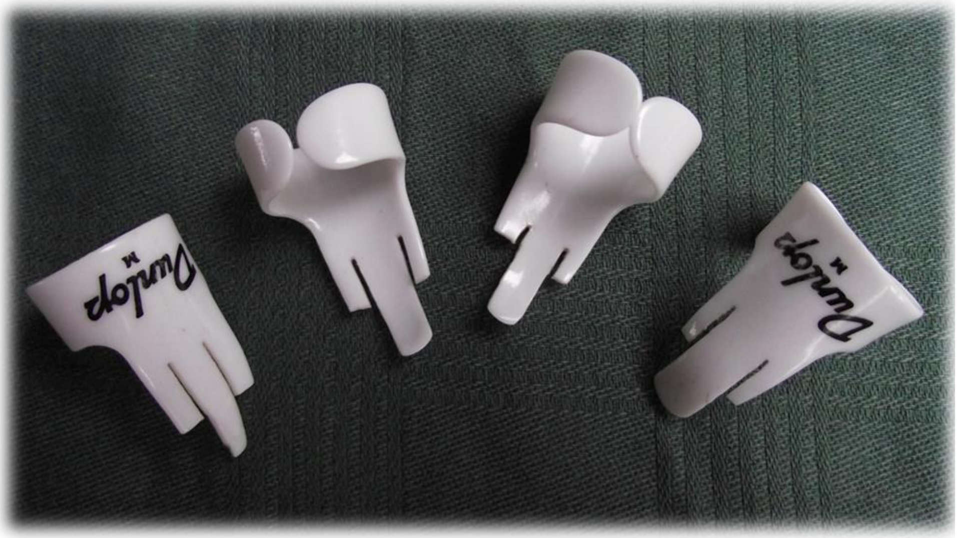


Figure 5.10.

Various Dunlop finger-picks adapted along the lines of a Fred Kelly speed pick.

More precise sound, and less plectrum noise result from these adaptations

However, eventually in 2015 (now playing the much louder prototype 5) I travelled almost full-circle with this journey and returned to playing with nails save only for the thumb-pick, which remains. By this point my technique was sufficiently accurate that I was able to adapt to a fingernail style without further finger damage, beyond a couple of initial blisters. This is certainly the combination that offers the most freedom, but how can this be reflected in terms of pedagogy? The twists and turns taken in this journey give pause for consideration, because some combinations of finger-picks allow for different potential and require slightly different training and orientation of the supporting technical exercise material. Moreover, based on my own experience, it takes a long time to arrive at sufficient accuracy and finger durability to adopt a fingers + thumb-pick style of playing. The experience of my daughter confirms this — she is currently attempting to change to this style, but is finding the experience painful, and that she has to change back to finger picks after short periods of playing.

Summary of Common Technical Principles Established and Implications for Method Development

To a certain extent variation is to be expected; it certainly exists within guitar styles, where plectrum, finger picks and nails co-exist; it even exists within the more narrow confines of classical piano fingering, where it is by no means certain that individual players will follow composer (or editor's) directions. There are three key points to consider from this exploration with respect to pedagogy and we can summarise these;

1. There are core aspects of technique (**pinch, thumb up-strum, brush down-strum, pluck**) that are common to all pick and finger arrangements and are the foundation of both autoharp and ReAPH technique
2. A variance from autoharp technique, which has remained constant throughout my own learning (and irrespective of finger-pick arrangement) is to allow a **further possibility of up-strum (apart from the thumb) from the third finge**r. When using finger-picks, strum/pluck is limited to one direction only (an attempt to strum or pluck in the opposing direction is likely to make the finger pick fly off)
3. Upon changing to fingers + thumb-pick (removing the finger picks) all possibilities become open to all fingers

I concluded that method should be created assuming that the player is using a thumb-pick (1) and finger-picks on index (2), middle (reversed for up-strum) (3), and ring (4) fingers but not on the 5th finger, and that notation should follow piano fingering (labelled in brackets). Fifth finger is not strictly necessary to provide all the necessary combinations and can easily cause unwanted noise, this also corresponds to other harp techniques where the little finger is not used. I deliberated over the reversed third finger for some time, trying to decide whether it was simply a quirk of my own technical development that varied from autoharp technique or whether it should become a part of the critical outline of a ReAPH method. Though subjective, the discovery of the new arrangement was quite a powerful experience. I arrived at it after struggling with finger-picks, supposedly placed in the correct direction, for months. The idea came to me late one night in a practice session, I changed the finger-pick on the third finger round, and it provided an immediate and rewarding freedom. After a brief flurry of experimentation it never returned to the original position.

It was logical to turn to the only other learner of the instrument for an opinion: as a student of my teaching the reversed third finger-pick is naturally also a lynchpin of my daughter's technique and when asked if she would consider changing to a more normal autoharp arrangement, she replied that her second and fourth fingers were perfectly capable of pinch and brush — why would she want to limit the third finger to a similar technique? Of course, the restatement and confirmation of my own logic constitutes only evidence of acceptance — not proof of advantage. However, it does confirm my own experience.

Another piece of evidence is given by the different design of the autoharp as compared to the ReAPH. The high keyboard housing on the ReAPH obstructs the thumb up-strum from easily gaining access to the higher strings, the autoharp may offer different possibility, but on the ReAPH the frustration of being only able to perform down-strums in the high treble demands a technical solution.

Assuming a reversed third finger-pick, other minor differences in pick arrangement do not significantly affect method development with regard to early-learner pieces and exercises, and these can be discussed within the presentation of method material. More difficult pieces (intermediate to advanced level) are likely to be subject to player modification with regard to specific technique anyway. At this level, players establish an independent and adaptive technique unique to their own needs.

We have therefore, established some principles of notation, technical engagement and progression and explored to an extent, areas of existing repertoire that will yield suitable pieces for ReAPH. A fuller exploration of the possible breadth and depth of the instrument is detailed in the next section. This material also has implications for pedagogy that will be evaluated at its conclusion.

Showcase Recordings

In January of 2013 I spent five days solidly recording on prototype 3. I worked within my own studio, but using higher quality location equipment (from the University of Salford) than for previous recordings (including a pair of large diaphragm condenser AKG 414s and a pair of small diaphragm Octava 012s). During this time, I recorded a great deal of music of which the solo ReAPH pieces Debussy's *Clair de Lune*, Bach *Marche* BWV 122 (from Anna Magdalena), and the standard *I Wish I Knew (how it would feel to be free)* (Billy Taylor and Dick Dallas) were selected for immediate publishing. Editing and producing was undertaken through January and web design during February; the website was finally fully published in early March. The ReAPH parts for a further three duet arrangements, Chopin *Valse* Op. 64 No.2 for ReAPH and violin and arrangements of folk tunes *Off She Goes* and *Rosin the Beau* for ReAPH and Mandolin were recorded at this time, edited in 2014 and finally completed in June 2015.

The solo material is designed to showcase the ReAPH in three different settings, *I Wish I* *knew* was recorded from a lead-sheet and improvised. This piece was selected because it leant itself to the quality of rhythmic solo construction using mixed chords and blues/gospel type riffs that the left hand at the piano naturally constructs. It is possible (though more difficult) to construct a more scale-based solo but this is better suited to an ensemble situation. In addition this piece shows off the self-damping properties of the ReAPH as opposed to the continuous sound of the autoharp — it would be difficult to imagine the autoharp playing this piece as successfully, even granted that it was adapted to produce the harmonic freedom. The sound of this recording is therefore unique — it evokes a heavy 12-string guitar sound, but played from a pianistic perspective.

Bach *Marche* BWV 122 (from Anna Magdalena) is a simple piece at the piano or harpsichord, but still surprisingly difficult for the ReAPH. The recording was extemporised from a mandolin arrangement of the piece. The written mandolin arrangement does not attempt counterpoint but does take advantage of the polyphonic capability of the instrument.

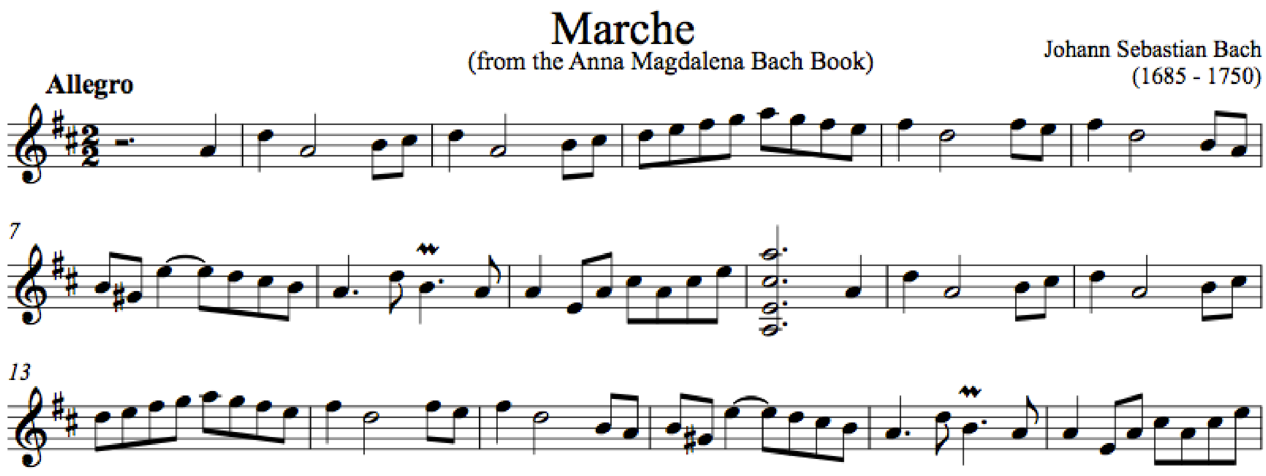


Figure 5.11. Bach Marche *BWV 122 (from Anna Magdalena) (excerpt) arranged for mandolin*

The ReAPH has the capacity to produce a harpsichord-like sound, but brings a further capability to shape the phrasing dynamically, the combination of these two elements is unusual and the instrument produces interesting recordings of baroque repertoire, to which the instrument is suited.

Clair de Lune shows off the ability of the ReAPH to render performances of some pianistic repertoire. Not all is suitable, and there are no set criteria for establishing that which is, and that which is not, however a guiding principle is that instrument lends itself more towards piano writing that is oriented towards left hand accompaniment and right hand melody[15] — it is difficult to imagine it rendering dense Mozart passagework, for example. *Clair de Lune* was formally notated for the purpose of the recording. A first version of this score was completed as early 2011 in preparation for a master-class presentation at University of Salford, at which excerpts were performed.

[15] For example; Chopin *Valse* Op. 18 No. 1 was also considered for showcase inclusion, and a practice score is included within the digital assets that accompany this written document.

Figure 5.12. Clair de Lune (excerpt) (version 1 November 2011)

Figure 5.13. Clair de Lune (excerpt) (version 2 April 2015)

Figure 5.12 shows that the novel aspects right hand technique upon the string face, with techniques adapted from autoharp technique was very much the focus of attention at the time of producing this version of the score. The left hand at the keyboard is provided with a reduced version of this arrangement limited to one octave, but no further thought was given to illuminating the precision needed in order to render an effective performance at this time.

A similar passage re-worked as late as April 2015 is shown below this (figure 5.13). Here the left hand has been considered and edited to a similar standard to the right, with precise indication as to which notes are required to be held and released at a given time. Where no change is needed, subsequent notes are hidden using the notation software, and precise use of ties (often illegal in the strictest sense) illuminate notes that are required to be held. The effect appears more like Schenkerian analysis than score based cues, however it does result in much more precise performance. The right hand is further annotated with precise strum/pluck directions, capturing the essence of autoharp right-hand technique, and developing it. These directions also enhance the precision of the performance. The technique to accomplish these score directions quickly and accurately developed in the intervening period and benefitted considerably from collaborative practice and ensemble engagement with the Adelphi Contemporary Music Group.

Key to Score Directions

P – Denotes a pinch (assumed with 3^{rd} finger as a default)

$\overset{2}{\mathrm{P}}$ – Denotes a pinch with 2^{nd} finger

⊓ – Denotes an up-strum (from bass to treble) with the 3^{rd} finger

V – Denotes a brush down (from treble to bass) with the 3^{rd} or 4^{th} finger

$\overset{1}{+}$ – Denotes a thumb only up-strum (from bass to treble)

Up-strum has been described throughout this text in relation to pitch (bass to treble). Generally this falls on the strong beats, and it is therefore logical to use a down-bow symbol to denote this despite the description of up-strum.

Two further passages illuminate the simplification that this score-design provides for the left hand in faster semi-quaver passages — the left hand changes are placed at the equivalent point that the sustain pedal would be changed at the piano.

Figure 5.14. Clair de Lune (excerpt) (version 1 November 2011)

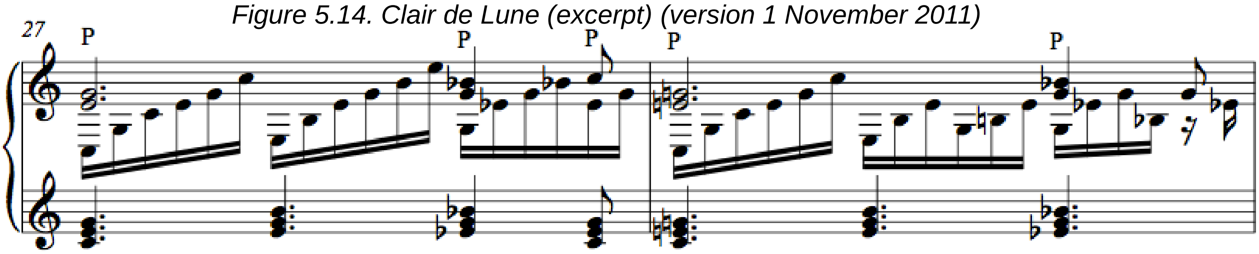


Figure 5.15. Clair de Lune (excerpt) (version 2 April 2015)

Figure 5.16. Clair de Lune (excerpt) (version 1 November 2011)

Figure 5.17. Clair de Lune (excerpt) (version 2 April 2015)

As in the original piece, three staves were needed to render the musical intent clear at times during this piece.

Further Collaboration and Ensemble Work

Tom Miller – Singer/Songwriter – Spiderman (recorded May 2013)

Tom Miller is a talented singer/song-writer. He was heavily influenced by the semi-improvised, mixed spoken and sung delivery of early Tom Waits. At the time of this interaction he was an undergraduate student specialising in his third year electives within composition. He was most interested in the ReAPH and asked if he could sit in on the 2012 presentation to MA students. Tom was attracted to the potential of the ReAPH to improvise blues and requested that I record parts on two of his songs.

In both cases, preparation was undertaken from a demonstration recording and a lead sheet. Only one formal recording session took place, the ReAPH parts were overdubbed in Adelphi Basement Studio 1 in May of 2013. The initial guitar and vocal recordings were not performed to a click or tempo map and no thought was given to how to cue overdubs to the continuously varying tempi within these performances. They certainly showcase the potential of the ReAPH to engage with this repertoire, but they do exhibit some timing problems at times. The two recordings are included within the digital assets that accompany this written document.

Chris Lawry – Composer/Pianist – Be Still My Soul (recorded January 2014)

Chris Lawry is an accomplished composer and pianist. He was a Master's student at the University of Salford from 2013–14, and attended the ReAPH master-class, which was timetabled early during that particular academic year (October 4th). Chris was immediately interested, and full of detailed questions regarding notation. He was particularly concerned about issues of sustain. He played the instrument for some time after the presentation, and later in the semester we had a further one-to-one session where Chris played some of the textures that he was imagining for his piece, and we discussed elements of notation and blend with the piano. We also agreed on a timetable and technical approach to the completion of the project.

The piece is a setting of A. E. Housman poetry from *A Shropshire Lad* for voice (soprano/tenor range), piano and ReAPH; the style, evocative of Vaughan Williams and other examples of early twentieth century English song. The ReAPH part is designed to provide a timbral counterpoint to the piano accompaniment, sometimes through contour, but often sitting directly over the piano part and providing timbres that the piano cannot. Chris described the sound of the ReAPH as "Hollow and resonant like a harp, but with much greater flexibility as to how chords can be selected and played" (Lawry, Be Still My Soul, 2013); his focus was certainly on its harp-like properties, which had not been such a focus in my own arranging to this point. He also seemed to grasp the essence of notating for it immediately, and created a clear part, which could be immediately sight read and comfortably practiced against the recording.

Figure 5.18. Excerpt from Be Still My Soul (Lawry, Be Still My Soul, 2013)

Status: Permission Granted

This notation (from an independent composer) represents a considerable step forward in terms of engagement with the musical community. It is entirely consistent with, and develops my own ideas on notation — it looks and feels like a ReAPH part. Moreover, the ensemble role is different to anything that I had written to this point. The harp-like textures and glissandi had not featured to a significant extent in my presentations of the instrument.

Not everything was quite as Chris initially imagined it to be in performance, and during rehearsal we agreed some changes. Subsequently, I overdubbed the ReAPH part in my studio and Chris re-notated the score to reflect the changes, the same excerpt is shown below in re-notated form.

Figure 5.19. Excerpt from Be Still My Soul (Lawry, Be Still My Soul, 2013) – final version

Status: Permission Granted

There is some detail to draw out from the score; slower harmonic turnover in the second line (one chord per bar) is reflected in the left hand, which is sustained through the bar. In the excerpt below, for the first time, bowing marks are adopted to ensure that strum patterns are precisely indicated and rendered similarly each time.

Figure 5.20. Excerpt from Be Still My Soul (Lawry, Be Still My Soul, 2013) – final version

Status: Permission Granted

These details, which make a considerable difference to the precision and simplicity of the notation, emerged from the detailed discussion with Chris.

The overall technical standard required to perform the piece, which I would assess as intermediate, represents a slightly less ambitious level of playing than I had been attempting in other notated repertoire. It is similar in principle to playing songs from lead sheets, but brings precision of performance direction and sophistication. It occurred to me that there was a good deal of similarly approachable *Leider* and 20th Century English repertoire that might be adapted to ReAPH.

Both versions of the score and the recording of this piece are included within the digital assets that accompany this written document.

The Adelphi Contemporary Music Group (September 2014 –)

In September 2014 I began to play the ReAPH in the Adelphi Contemporary Music Group. This is a university-based ensemble. It is heavily reliant on contributions from postgraduate students and also includes undergraduates, ex-students and members of the wider community; the sole pre-requisite for membership is an interest in experimental music making. The instrument combination of this ensemble is always unusual and differs from year to year. In 2014–15 it consisted of three pianos (with two of these playing electronic instruments, providing other voice-timbres), flute doubling piccolo, alto and bass flute and clarinet, Soprano and alto Saxophone doubling piano accordion, ReAPH, viola, guitar, bass guitar, tuned and untuned percussion (usually two players) and a singer.

Compositions and arrangements are invited from players and composers within the ensemble and wider composition community. There is a good deal of structured improvisation during rehearsals, especially during the early stages of the academic year, in order to explore textures and timbres and to discover the capabilities of the group.

Within this unusual ensemble, the presence of the ReAPH barely raised an eyebrow, and it provided invaluable broadening experience for me as a player, as I encountered parts adapted from various instruments, and different ideas of how the ReAPH might sound in various contexts. The ensemble has performed regularly across the academic year beginning with a performance at the finale of the Sonic Fusion Festival in February of 2015, in May, a collaboration with the Oldham Contemporary Music Group and in June it performed within the *Salford* Create Festival.

Four pieces from the Sonic Fusion repertoire are discussed here as representative of this practice engagement as a whole, with particular points of interest to the ReAPH within each.

Postcard from Budapest – Vilmossy Edvárd Elemér (Alan Williams)

Postcard from Budapest was presented as the final pieces of a suite of Bartok arrangements and was composed for the ensemble by Alan Williams. An excerpt from the opening is presented below.

Figure 5.21. Excerpt from Postcard from Budapest (Williams A. , 2015)

Status: Permission Granted

In order to achieve the difference in attack between the *ff* and *p* sections I rendered the *ff* with pinch and the *p* with a 3rd finger up-strum. Once again, the precision that this simple score direction gives led to a noticeable improvement in performance consistency. The contrast between the two sections however, provided a further problem — the slower attack of the up-strum rendered a feeling that I was playing the section late, when compared to the rest of the ensemble. Eventually, I discussed this with the group, and the percussion players advised that I simply came in early when relying on slower attack, the effect being that the latter part of the up-strum, which appears to be the sounding part to the listener, would seem in time. I experimented with this, and my ensemble sense of timing in relation to attack is gradually improving.

The section change at bar 16 presented a different problem. The lower B (beat 1) and upper F♯ (beat 5) in these figurations are out of range of the left hand. The subsequent re-arrangement below also specifies a different pattern of thumb up-strum, followed by 3rd up-strum.

Figure 5.22. Excerpt from Postcard from Budapest – final version (Williams A. , 2015)

Status: Permission Granted

A subsequent re-appearance of this section B material called for notes out of range of the string surface:

Figure 5.23. Excerpt from Postcard from Budapest (Williams A. , 2015)

Status: Permission Granted

The F at 62 falls right in the break between bass and melody range for both prototype 3 and 5, but was replaced with this richer bass texture:

Figure 5.24. Excerpt from Postcard from Budapest – final version (Williams A. , 2015)

Status: Permission Granted

The piece was recorded in Peel Hall at the end of semester 2 of 2015 and this recording, together with two of the Bartok pieces which also feature the ReAPH are included in the digital assets which accompany this written document.

Is that a Threat?

Is that a Threat? Is a piece put forward by Joe Beedles, a talented undergraduate composer, and this piece was also included in the finale of the Sonic Fusion Festival. It contained a particular tongue twister (shown below). This figure is confusing from several standpoints: the high G is out of range of the keyboard, the bass G (which *is* playable on the ReAPH drops to the lower stave, and the (unspecified) strum/pluck patterns tended to vary and this variation caused stumbles and lack of precision. These factors combined to render it unplayable at sight and during successive rehearsal this seemingly simple figure required several minutes of practice before it began to be accurate.

Figure 5.25. Excerpt from "Is that a Threat" (Beedles, 2015)

Status: Permission Granted

The re-written passage, shown below produces a more accurate performance:

Figure 5.26. Excerpt from "Is that a Threat" (Beedles, 2015)

Status: Permission Granted

The Buxton Line (Brissenden)

The Buxton Line is an experimental piece that mixes spoken word with accompanying pitch/timbre based elements. In the foreground of the piece a group of speakers improvise a reconstruction of a previously prepared individual life situation (detailed instruction is provided within the score and the group spent some time establishing this material); dynamics are achieved by changing the context of the narration.

Pitch-based elements from the digital domain open the piece, where material recorded during rehearsals is signal processed using various techniques, but with the main focus on reverberation. Initially obscured, the live speakers begin whispering as if engaged in unnoticed internal monologue; after a minute, the pre-recorded material vanishes, leaving only the speakers. Reverberation is used to evoke notions of alternate spaces and past times, and therefore the effect of this transition is to bring the performance into the moment. Dynamic contrast within the speakers is achieved by changing the context of the narration from whispered internal monologue, to conspiratorial narration (as if to a sympathetic friend), and finally to a full reconstruction of the crux of the original event. Pitch-based material is re-introduced within this development through just a few live instruments accompanying the speakers; ReAPH, piano and flute provide the backbone of this material, based on a whole tone figuration, and tuned percussion provide improvised “interventions” based on speech patterns.

Clearly the focus of this piece was not on the ReAPH — yet it is a significant milestone because it called, for the first time, for another player from the ensemble; Deimante Pranckeviciute, to play the ReAPH, as I was conducting. Deimante was initially hesitant with the instrument, but by the time of the performance was contributing effectively to the textures that the ensemble created.

Showcase Score – Snow all the Way to the Cage – for Flute and ReAPH (Brissenden)

Figure 5.27. Photograph by Rachel Brissenden January 2015

Status; Permission Granted

The Cage is a folly found in Lyme Park in East Cheshire. This imposing building stands at the summit of a hill, which provides views to Kinder Scout and the hills around Edale to the East, and an inspiring view of Stockport and Manchester to the West. On a clear day the Beetham tower can easily be picked out from the summit. Similarly, the Cage imposes itself as a landmark that can be seen from all of the surrounding hills. The inspiration for this piece was provided by a memorable walk in January 2015. This walk did not take place on a clear day, and the Cage, impressively glazed in snow, was often the only visible landmark from various viewpoints on the walk, as swirling mist alternately cleared and descended around it.

Aside from this extra-musical inspiration, there were several technical aspects of the instrument that I wanted to demonstrate within this piece. The first is illustrated in the excerpt below.

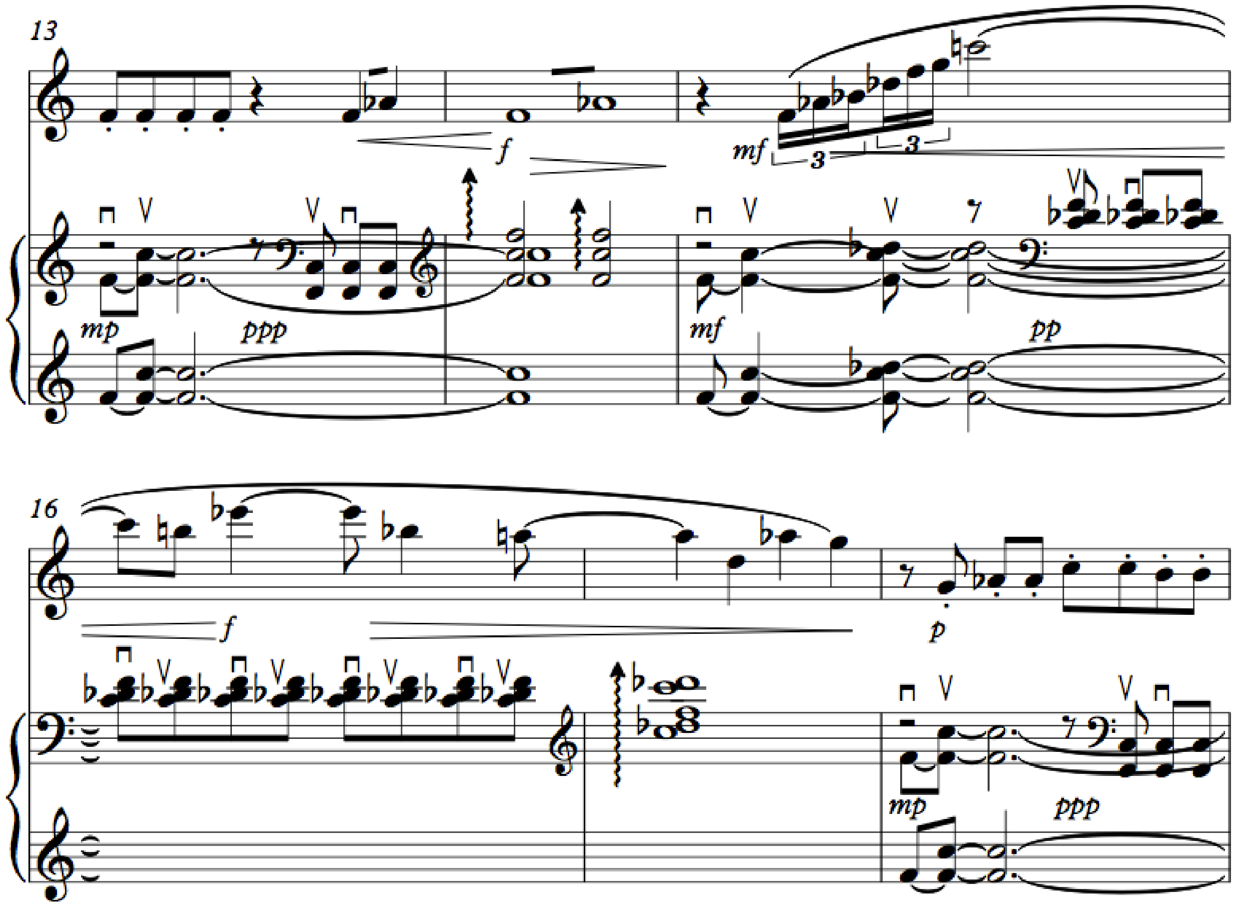


Figure 5.28. Excerpt from Snow all the way to the Cage (Brissenden P. G., 2015)

The full range of the ReAPH is used within this passage, but presented through small and precise combinations of strings with varying timbres. The second is a repeated accompanying chromatic figure that gives a feeling of simple contrapuntal movement within the figuration itself; the upper line moves alternately in quavers and crotchets, a slower, underpinning movement in minims (given by the movement between F and E) gives an impression of contrary motion. The flute part swirls around this ostinato and provides the foreground of the piece.

Figure 5.29. Excerpt from Snow all the way to the Cage (Brissenden P. G., 2015)

A third texture that I wanted in this piece was heavily influenced by Chris Lawry's harp-like textures within *Be Still My Soul*. To this point, I had tended to avoid obvious glissandi structures in ReAPH arranging and composition; these are relatively easy to achieve, and are very often over-used in amateur autoharp performance, to the point that they become tiresome. Better autoharp players do not use these techniques very much at all, and instead value more highly the ability to isolate groups of pitches effectively. Perhaps I had, during my now significant contact with the community, unwittingly picked up some of this prejudice. I now realised that the ability of the instrument to produce these effects remains a strength, and a unique property, which when well used, is one of its most impressive features. Therefore, at bar 62, the ReAPH is finally allowed to occupy the foreground of the piece with its own swirling textures, based on *glissandi* and *tremolo* effects.

Figure 5.30. Excerpt from Snow all the way to the Cage (Brissenden P. G., 2015)

The piece was performed at the finale of the Sonic Fusion Festival in February of 2015. Danny Thompson, a highly versatile woodwind player, played the flute part, and requested further collaboration — a further two pieces are planned as a result. A first movement will place Danny on the bass flute, and a third, more folk-oriented movement will see him change between alto flute and Celtic flute. A video of the live performance at Sonic Fusion was captured, the sound quality is poor, but it captures the atmosphere of the performance. This is included with the digital assets that accompany this written document. The full score is also included in Appendix 6.

The scores for all four of these ACMG collaborations are included within the digital assets which accompany this written document.

Summary and Findings From Engagement and Collaboration

The sample discussed above is representative rather than exhaustive. It demonstrates that successive presentations of the prototype since 2011 always led to collaboration from interested parties, and that each of the collaborators heard different genre possibilities from the instrument, which has led to development in many directions and to the broadness presented here. It has also led to a considerable improvement in the precision of notation, which in turn will assist in the development of method.

Innovators and Early Adopters — Empirical Observations

There was always a good deal of post-presentation experimentation upon the instrument by interested players; some of whom even expressed an interest in acquiring a ReAPH. The instrument attracted immediate interest from two types of player, in broad terms: multi-instrumentalists, studio composer/producers saw the ReAPH as an interface that could be added to their current instrument array, and produce unique timbres and different sound with relative ease; and pianists (and other keyboard players) saw it as an instrument that demanded more serious study. Contrary to my expectation (and perhaps desire), the first group were considerably more numerous than the second. I also realised that I had a specific expectation of the kind of player that I really wanted to attract. From the engagement described in the previous sections, Chris Lawry most closely fits this mould, perhaps because his experience most closely corresponds to my own. Chris is a broad musician, but he is very definitely a pianist.

Theoretical Frameworks

A closer reflection is necessary on the potential of the instrument to attract early adopters, and the likely skill base that they will bring. We will consider this with respect to a more theoretical framework for marketing and analysis; within the context of this chapter this will inform the development of method, but it also has implications throughout the project for subsequent innovation activity, marketing and the type of distribution.

The dominant theoretical framework used to analyse adoption of innovation within society is *Diffusion,* first proposed by Everett Rogers in 1962.

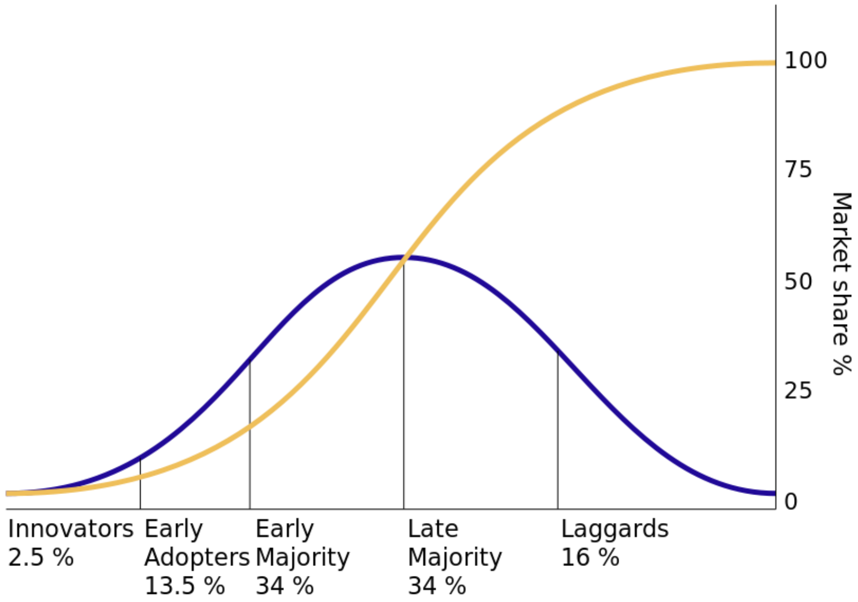


Figure 5.31. Diffusion Innovation from Rogers (Hvassing, 2012)

Status: Public Domain

Rogers posits the diagram (left) as a model of diffusion of innovations. He defines the term diffusion as the process by which "(1) an *innovation*, (2) is *communicated* through certain *channels*, (3) over *time* (4) among the members of a *social system"* (Rogers, 2003, p. 11). The Bell curve is divided into 5 bands, which constitute the market for the innovation, the yellow line defines progress towards complete market saturation. *Innovators* are characterised as venturesome individuals, able to imagine the possibilities of an innovation and not deterred by the risk. *Early adopters* are described as trend-setters who will quickly adopt as benefits of an innovation become apparent. The *early majority* are described as pragmatic individuals not interested in risk or troubleshooting, the *late majority* and *laggards* are characterized as increasingly risk-averse, conservative, sceptical and resistant to innovation. (Rogers, 2003, pp. 252-280).

These categorisations do not easily map the elements of risk to our analysis of adaptive elements that render the acquisition of expert performance easier, or more difficult dependent on prior skills, nor do they neatly fit our conceptions of the musical community. However the aspect of risk and risk-benefit can be considered. We can observe, for example, that multi-instrumentalists/studio-composers are potentially risking less, in investing in the ReAPH interface, than a pianist adopting the instrument; and that the relative advantage of owning and learning a ReAPH would be greater, for this type of musician, for less investment. To the multi-instrumentalist/studio-composer the ReAPH is likely to remain one of a number of potential instrumental interfaces utilised to create novel sounding musical textures. The investment of practice time required to accomplish competence to this level is relatively small — particularly given significant keyboard experience, which is expected.

From a subjective standpoint of inventor-seeking-next-steps, the analytical framework is useful; it next provides a series of testable criteria that can be considered with respect to the potential market. These are summarized as; *Relative Advantage* as compared to existing technology, *Compatibility* which takes account of evolutionary as opposed to revolutionary change, *Complexity,* which takes account of the performance of the innovation within authentic settings, *Trialability* which questions the extent to which an innovation can be tested prior to adoption and *Observability*: the extent to which the innovation is demonstrable, and adoption can be observed. (Rogers, 2003, pp. 15–16).

The first of these categories, *Relative Advantage,* is overtly Darwinian in character, and the other categories also maintain a sense that the attributes under scrutiny amount to an assessment of the adaptive potential of an innovation at any given moment. However, the explanation of this theoretical framework to this point, already posits a number of assumptions based on empirical reduction, which might seem incompatible with the Darwinian analysis framework of this study. For example, it pre-supposes that behaviour of individuals with respect to innovation falls neatly into the described categories, an approach criticised by Myers from an evolutionary perspective (Myers, 2006, p. 121):

> "While these frameworks exhibit differences with respect to broad research parameters, such as problem definition(s) and level(s) of analysis, there is similarity in that a number of the same underlying theoretical assumptions are widely used. In particular, they emphasis the market-place as economically efficient, decision-making as a rational 'means-end' process, the behaviour of system members as a homophilious pattern, information as a perfect good, and progression as an ordered linear sequence".

Situational analysis certainly demonstrates that the extent to which real-life innovation diffusion patterns conform to the bell curve model of innovation diffusion is at best, extremely limited. However within Rogers' narrative (and other commentators' from this discipline) the underlying assumption is that the model is aspirational (a fact admittedly forgotten within less critical commentary), that the discipline standpoint is narrow and that the perspective subjective (marketing perspective). This does not necessarily render it incompatible with a Darwinian framework, it is in fact a restatement of the principle established within Chapter 2; that invention [and marketing] is clearly not random from the perspective of the inventor and as innovators [and subsequently as marketers] we seek to influence the market as a change-agent. The narrow analytical framework seeks to maximize the potential of the change-agent to effect change. When viewed from a more objective systemic perspective, all innovation can be viewed as change which is adapted to local condition, the 'random' change given by the innovator providing an altered (innovated) copy of a pre-existing meme, its advantage (with respect to local conditions) proven through establishment within a community (which is an open dissipative system).

Myers approach is consistent with this view seeking the *contextualization* of such explanatory frameworks as that proposed by Rogers, rather than simply opposing them from an evolutionary standpoint (Myers, 2006, pp. 8–9):

> The dominance of empirically-based conceptualisations and/or methodological practices, and the elevation of such to omnipotent status due to a lack of critical analysis, highlights the broad need for mainstream marketing to adopt a more pluralistic research orientation. More specifically, such ideological dominance, in concert with the narrow and limiting range of explanatory frameworks ascribed to the phenomenon of technological innovation, demands the consideration of a plausible alternative explanation … .. most, if not all processes that incorporate human experience and activity, requirers strong links to aspects of evolutionary theory.

His exploration of *evolution* is itself interdisciplinary, and in keeping with the aspiration of Gould within *The Panda's Thumb of Technology* — he seeks a consensus of meaning (common, deeper principles of organisation (Gould, 1991)) across a number of disciplines. His conclusion is that "there is no single meaning (and inherent conceptualisation) of evolution that is accepted as proof positive of an underlying set of generalisations and/or predictive laws.. ..What does hold true however, is that any explanation of evolution must incorporate the principles of 'variation', 'selection' and 'preservation'" (Myers, 2006, p. 161). Both the contextual framework of this study, and the methodology is consistent with this conclusion.

We have discussed the issues of *relative advantage*, *compatibility* and *complexit*y quite exhaustively from a design standpoint, *Trialability* and *observability* however, are new and useful classifications. Numbers accessing and listening to the showcase recordings of the ReAPH on Soundcloud over time, demonstrate punctuated equilibrium. The extraversive activity undertaken during the numerous presentations of the instrument from 2012 onwards resulted in increased listening that corresponds closely to the dates of public engagement and performance. These statistics demonstrate that listening, and other activity, is taking place independent of direct action of the inventor. However, the most significant spikes in interest are due to random events (at least from my perspective). An early post across the University of Salford by Alan Williams, shortly after the website was first published resulted in at least 200 listens (all in one day). The previously described post from Bob Ebdon of UKautoharps resulted in around 1000 listens (also mostly in one day) all from American autoharpers. It also resulted in the approaches from Katherine Rhoda and Steve Brown, and in three direct approaches to buy instruments (this one is typical):

> Dear Mr. Brissenden
> I stumbled upon your web page in search of an instrument that is acoustic and portable and is played with piano keys. After coming across the Indian banjo, the claviola and the hurdy gurdy, I found your page and viewed your impressive demonstration. Your creation is precisely what I'm searching for.
> That being said, do you have the piano harp on the market for sale, and how would I go about purchasing one.
> Thank you for your time and effort

Whilst *trialability* by potential customers remains out of scope at the moment, the efforts to demonstrate potential within showcasing are clearly effective enough for potential customers to evaluate its musical merits against other potential interfaces.

Technical Interest

Technical interest in the project comes from two distinct musical communities (in fact *so* distinct it might seem they have little else in common); autoharpers and those interested in experimental instrument design (where there is significant crossover with the multi-instrumentalist, studio-composer profile).

Autoharp Community

During the initial stages of prototyping and patent application, I worried at the possibility that the isolation caused by the esoteric nature of the autoharp interface at its most extreme, would lead to rejection by the autoharp community (i.e. that it would be viewed as revolutionary rather than evolutionary from an autoharp). These fears proved to be completely unfounded and in fact I have received a warm welcome, a great deal of support and continued interest from the autoharp community. I would summarise their reaction as relaxed curiosity, and a feeling (similar to the accordion community) that the increased interface variation *should* be present within the instrument range.

A considerable strength of the autoharp community is their technical security in experimentation, they *do* like to tinker with their instruments, and in this respect, contrary to my fears, I fitted right in to the ethos of the community. This is a valuable ability indeed — especially when compared to pianists, who are generally not even capable of tuning their instruments, because it demonstrates a community well equipped to maintain and further innovate on the instrument from a technical perspective. Discussion with Steve Brown reveals that he feels similarly:

> "Yet as Pete [D'Aigle] and others have observed, the autoharp since its inception has become and still is the ultimate "tinkerer's instrument". And there continues to be a market, although a somewhat limited one, for creative autoharp innovations and improvements. Part of the challenge is to identify and promote that market."

The potential of the instrument to attract players from this community is undoubtedly far more limited though. The table below is an assessment of the difficulty level of approach for a pianist and auto-harpist learning the ReAPH interface, formulated in late 2012. It is idealised of course; a musician's skill bases are rarely completely polarised in this way. However, it does serve to give an effective impression of the level of difficulty of approach to individual aspects of technique, which when developed formulate an accomplished technique.

	Pianist	**Auto-harpist**
Keyboard (left hand)		
Harmonic/Textural	Adaptive	Novel – easy
Melodic/Linear	Partially adaptive	Novel – difficult
Damping	Adaptive	Adaptive
String surface (right hand)		
Strum (whole hand)	Novel – easy	Adaptive
Detailed Harmonic/textural strum/pick techniques	Novel – difficult	Adaptive
Detailed melodic/linear picking techniques	Novel – difficult	Partially adaptive
Reading at speed	**Adaptive**	**Adaptive**

Figure 5.32. Table assessing the difficulty of approach to individual aspects of technique for an autoharpist and a pianist

The reverse damping is completely logical for a pianist, for it corresponds very closely to the behaviour of a piano. It is much more difficult for me to assess the skills and adaptive potential for an autoharpist, as my subjective experience is biased to pianist perspective. However, after some thought, I assessed the reverse damping as adaptive to autoharpists also. Damping falls within the domain of the right hand on an autoharp and is an aspect of practice that must be continuously and consciously borne in mind by the player. Adapting to the environment of a self-damping instrument therefore, should be easy.

The remaining areas of right-hand technique — the right hand upon the string surface are novel to a pianist, but highly adaptive to an autoharpist. Precise right hand pick and strum is crucial to autoharp technique, and something that they spend many years developing. Because chord choice and note combination are limited, the player is reliant on right hand technique to provide the detail of texture or melodic aspects to the playing.

Harmonic playing is assessed as novel for an autoharpist, although in fact it is highly likely that a capable autoharpist will also have keyboard experience of some sort, which thus renders it more adaptive (this dual experience is likely for an autoharpist; it is not so likely for a pianist). However, novel or not, I still assess this aspect of technique as easy for an autoharpist for two reasons. First, many fine autoharpists are expert performers within a narrow domain of genre engagement. They generally have extremely good right hand technique, and rely upon only a few chord bars. Bob Ellis (cited in chapter 1) is an example of this type of player. To such a player, the ReAPH would be either a logical step providing access to a different range of genre engagement, or an unnecessary step as the diatonic autoharp is a comparably good interface (better in some ways) for the chosen range of genre engagement. Second, learning more ambitious harmonic playing is a task certainly no more complex on a 24 bar autoharp than on a keyboard.

Overall the balance of skills and the difficulty of adaptation are surprisingly similar, and the problems for extending technique and possibility into new areas are also remarkably similar for expert performers adapting from both domains. However, even a technical assessment must take account of the relative musical conservatism of the community (concluding that for many, the ReAPH would be an un-desired step), and that there are a number of extended harmony innovations which are based on chord-bars that might well prove more attractive than the ReAPH to an autoharp player.

The chromatic workshop led by Steve Brown at the Newport festival will discuss 16 different chord-bar based extensions of the original interface before finally turning to the two reverse action keyboard based harps, and in discussion Steve warned continuously against excessive expectations:

> “the vast majority of autoharp players, even though many want access to more color chords and improved string schedules, are reluctant even to try ‘harps which require pushing more than one button or chord bar at a time. My hope in offering the upcoming workshop at Mountain Laurel is to at least expose more people to the potentials of these various “super duper chromatic” instruments.”

We might conclude that we can expect continued technical interest and support from the autoharp community, which is extremely valuable in its own right and might further assist in developing and harnessing *observability*, but perhaps only small numbers of early adopters.

Experimental Instrument Design — A Potential Community

A short discussion of this subject is included within this chapter for completeness, however, since this is an area that has only developed a significant community and momentum from February 2015, fuller discussion of its potential direction more properly belongs within the final critical evaluation chapter of this written document.

In February of 2015 we were visited at the University of Salford by Dutch experimental instrument designer Yuri Landman who gave an open masterclass; this was well-attended by the student body, with students from every year group of the programmes represented. After this event I had a long meeting with Yuri in order to discuss possible future collaborations. Yuri's experience as an instrument maker is similar to my own, in that it begins with frustration with the limitations of the traditional array of western musical instruments, but also very different because he has developed quite a number of instruments as a response. None of these seek the mainstream, genre and ensemble integration that became my obsession with respect to the ReAPH. They are all, quite definitely, experimental instruments, with niche purpose. Recently, Yuri has been travelling in Europe creating ensemble collections of these instruments. He has also integrated his practice with community engagement, and a part of his visit at Salford consisted of open workshops, which had quite large groups of people building roughly-finished versions of his instruments. A groundswell of support from across the musical community at Salford has led to us seeking funding, through an Arts Council bid, to allow him to return to Salford and help us to found an ensemble of made, modified and found instruments. Discussion has seemed naturally to coalesce around me to lead the enterprise, and indeed I find that I have significant transferable skills, which complement the immediacy of Yuri's approach, with which to do so. The ensemble will not only consist of Yuri's instruments — a number of other proposals have been tabled as well and I have practical skills, from workshop to 3d rendering, and developed interface with the Art and Design workshop, to bring these projects forward.

Discussion with a number of interested parties has led me to a different understanding of the multi-instrumentalist/studio-composer profile; there is, and has been considerable technical interest in the ReAPH during and post-presentation — and the aspiration of a number of people is to join in from a design and build context. This will provide an entirely new context for the ReAPH, within an ensemble where its presence needs no justification whatsoever.

Early Adopter: Case Study – Lucy Brissenden

Lucy's formal adoption of the ReAPH dates from March 2012, when I returned from meeting Alec Anness with both prototype 2 and prototype 3. Lucy would have been 12 years old at the time and in her second year of high school. However, her interest in the instrument certainly dates from before this time, and with hindsight I wish that I had paid more attention to her early engagement, which must have begun as prototype 3 was brought to a playable stage in January 2011. March 2012 marked a watershed moment however, as she demonstrated her commitment to the instrument by claiming prototype 2 as her own, practicing it regularly, and demanding tuition.

Perhaps one of the reasons that I had not paid much attention to Lucy's early expressions of interest was that her musicianship was clearly *not* oriented towards the piano. Lucy is a talented violinist, currently working towards grade VI (though this grade standard perhaps reflects a conservative teaching strategy, in my opinion her overall standard is higher), she has become one of the founding members of the *Crescent Orchestra* at the University of Salford this year, and she is quite obsessive about her practice regimes on this instrument. She likes to sing, and the voice is even throughout its range, in tune; the delivery is expressive, with a good sense of line and legato. Her attraction to the piano is not nearly as strong, but she does play it, at a lower level (and much less often) — her skills might be assessed as around grade III – IV. However Lucy's most significant passion and career ambition is not musical at all: it is to write, and at the age of 15 she has already e-published her first novel, and typically when discussing the various formats that we might use for interview, Lucy elected to communicate through writing only, and to provide formal written responses to questions, of which we decided that there should only be three. The following gives significant insight into the reasons for Lucy's attraction to, and adoption of the ReAPH and gives an indication of how a first method book might look.

Interview with Lucy Brissenden April 25th 2015

What first attracted you to the ReAPH?

“There are quite a few reasons why I first liked the reverse action piano harp. I was of course excited by the project and wanted to be a part of it — but I also liked the style of interface that it provided. I have always liked the sound of the guitar but the over-complex changes of chord, and the difficulty in getting a good sound from strumming, always annoyed me. I do like the piano, but I have never felt that I could deliver to a reasonable degree, the ambidexterity it requires to be a good standard (the most I can do is slam down chords or play very simple parts in the left hand). I found a chordal instrument with a keyboard a much easier interface to learn because of the slick changes of chord (and the fact that you don’t have to go through the whole blisters-on-your-fingers-bit was an added bonus — although you have changed this mistake now that you have decided a better sound is produced without picks!). The strumming techniques, once mastered, can be used for a whole range of music. It’s not like learning a guitar where each chord has to be painfully memorised and rehearsed — as long as you know three and four note chords on the piano (and these are far easier to learn than guitar chords) and are prepared to spend a few weeks getting to grips with the picks and strings — there is suddenly a whole world of music out there that you can play. You can very quickly sound very good on a ReAPH and I enjoyed the novelty of this very much, after spending 6 or 7 years trying to get rid of my squeaks and scratches on the violin, and being embarrassed to play it in front of anyone who didn’t understand what I was going through!”

What kind of music do you like to play on the ReAPH?
“Using the ReAPH as an accompanying instrument has always been my favourite way of playing it — I think the smaller keyboard makes it very easy to learn all the notes so you don’t have to keep looking at your hands while you’re singing — which is a massive advantage over a piano with its gigantic playing surface or a guitar with its four finger chords and again a new thing for me because it’s impossible to sing with a violin jammed under your chin. I love the tone of the instrument — while it’s less resonant than a guitar, and more crowded than a piano, it’s very rich and has a depth to it that’s very difficult to achieve on other instruments. Its range has also been one of my favourite qualities. The fact that I can skip up about six octaves without much effort was a quantum leap, as doing this on a violin usually results in a terrible noise! It also meant I could change my volume very easily, going from a huge racket in the bass to a delicate plucking of the very top strings. The fact that I can vary the instrument so much more than my voice makes any music sound very complex when playing and singing together, and the fact that it’s both a melodic and a harmonic instrument means that with enough practice, I can string several

accompaniment parts together at once”.

I want to prepare method material in order to teach the instrument – what do you think should go into a method book?

“If you were to write a method book for it I think I’d want strumming technique to be in there first because I found that the hardest to grasp – the specific up-down, up-down strum with different fingers, in three-time and four-time, and the fact that unlike violin you don’t lead with your right wrist, it’s more the forearm. I’d like something about pinches (simultaneous strum with thumb and index finger). There are little things like keeping the left hand wrist parallel to the keyboard which are also very important. I liked the scales you set me on and I think the rhythm of up and down a major fifth twice and then up to the octave supertonic and back fits with the instrument and helps me get to know the keyboard a bit better *[this refers to the scale exercise in figure 5.2 extended to all keys]*; it’d be nice to see those written out for other learners. Some other exercises like that, devised specifically for the keyboard and learning where all of the strings are e.g. some playing around with arpeggios, would be good as well.

I never really had any easy music to play which was specifically set out for the ReAPH and I would like to be able to get used to the two treble clefs you’ve suggested to play music for the ReAPH. I think it’s also important that you show the distinction between melodic and accompaniment music on the interface and teach the chords on the keyboard so that you can also use guitar chord letters e.g. A, G, C as a form of notation for the instrument. You could have some simple songs and lyrics then like Hallelujah. In that way I think it really comes into its own.”

Lucy’s profile is slightly different to any of the target (market) group assessed within this chapter and she is also at a different stage of learning. The materials that Lucy requests to be included in the method book have significant resonance with my own vision but perhaps aimed at a slightly lower level of engagement than I had originally imagined.

A striking aspect in the description of her attraction to the instrument is the similarity to the reasons why children often want to take up guitar as a second instrument at a developmental stage where the limitations of a solo melody instrument become apparent to them. Lucy certainly had plenty of access to guitars in her environment, but she very definitely gravitated to the ReAPH as an accompanying medium for her singing, and this has naturally led to a desire to improve her ReAPH technique independently of her pianistic skills.

I have a sense that Lucy is able to perceive the relationship between the keyboard and the strings more directly than I am, and is not easily distracted by the issue of octave displacement and wrap-around. To illustrate this: one of the skills that Lucy has focussed on developing through my demonstration in lesson interaction is her blues technique. Again, this is a common aspiration for young developing guitarists in order to enhance the sophistication of their accompaniment of vocal delivery. There is a definite divergence in Lucy's acquisition of this material. In order to play blues on the ReAPH I must first adapt right hand riff-based material to left hand, and then focus on how this should be reflected through the right hand on the string face. In contrast, Lucy's attention when absorbing this pre-developed material never waivers significantly from the right hand on the string face, and the learning is most certainly curtailed as a result.

An obvious conclusion is that the level of keyboard-based skills necessary to provide strong attraction to, and stimulus for sustained engagement with the ReAPH as an interface might be much lower than I had imagined, and that in fact limited engagement with multi-octave keyboards assists the mind to construct a mental model of the instrument as right hand focussed from the start. Lucy has contributed two recordings and one arrangement to the digital assets which accompany this written document. The first is an arrangement of a piano piece *Metamorphosis One* (Glass) which appears in the 2006–2007 remake of *Battlestar Galactica,* Lucy identified this as suitable for the ReAPH and independently sourced this material and arranged it for the ReAPH following the currently developed principles of ReAPH notation*.* The second is a cover of Bastille's *Oblvion* — Lucy is singing and playing prototype 5 in this live recording.

Conclusions

The difficulty of accounting for musical engagement undertaken on the ReAPH is that it cannot demonstrate the linear process of Action Research as applied to the design process. Some work aspires to raise the profile of the instrument, some to develop and explore aspects of technique, some is simply opportunistic experimentation and collaboration. Throughout the chapter I have endeavoured to provide a sense of the aspiration of each documented case and balance subject distinction with the need to provide a reasonable sense of chronology, which gives a sense of the development activity over time. Despite the complexity, we can draw some conclusions from this narrative with respect to the original research questions.

With respect to pedagogy, a progress-stage similar to that of design distribution has been achieved. This can be summarised:

1. A logical sequence of technical progression has been established which takes account of the intended variety of genre engagement of the instrument, such that more exhaustive generation of material can now be undertaken
2. This sequence has been assessed against the divergence in finger-pick technique between ReAPH and autoharp and conclusions have been drawn to allow consistent technical advice to be developed for learners
3. Notation has been developed which is evolutionary from piano and autoharp notation, which allows for development of repertoire at all levels. Problems of consistency of approach may remain for advanced scores — particularly with respect to left hand notation, but for lower grade material (to around Grade VI) this notation will likely be completely consistent and can now be developed
4. The balance of skills and likely level of aspiring ReAPH players has been critically examined from a number of different standpoints, such that a logical sequence can be now developed
5. Exploration of the ReAPH within a variety of genre settings, and adaptation of repertoire from suitable instruments has provided a vision of the genre range of repertoire to be developed for inclusion.

In terms of the research questions put forward at the conclusion of Chapter 1, the narrative, unequivocally demonstrates *increased variety* of engagement, and the depth and variety of genre engagement increased as prototypes of higher quality were produced, and in conjunction with development of technique. *Extraversive activity* also increases over time, leading to a raised profile both in terms of raw numbers of people aware of and listening to, the ReAPH and the range of profile of the people listening. *Increased initiatives from others upon aspects of the project* is less obvious, but nonetheless has a presence. There is significant collaborative work with others, and the collaboration with Chris Lawry in particular developed the finer aspects of ReAPH notation. The development of the listening base has in large part been due to the actions of others. I would further highlight aspects not detailed in the narrative such as Lucy’s singing performances in school concerts to large and appreciative audiences, and the appearance of the ReAPH within a full Victorian presentation of Dickens *A Christmas Carol* in which she took part in 2013, where it accompanied choruses singing carols. It appeared completely natural within its Victorian surroundings and in keeping with its aesthetic and heritage.

Depending on the perspective taken, the ReAPH has also achieved a good measure of *acceptance within the musical community* although I consider that this can only be truly measured after channels for sale and distribution of the instrument are established. However, overall, and across the multiple disciplines which constitute this project, I feel that the progress towards this aspiration is balanced.

6. Conclusions and Critical Evaluation

Measures of Success — Key Findings

The conclusion of the first chapter set out five overarching questions which, when fully addressed, serve to record the key findings and to measure the success of the project.

Can a working musical instrument be created?
Can we analyse its strengths and suggest further change/development?
Is there an appropriate range of variation?
Can the instrument be integrated into the musical community?
Can the instrument be made available to the wider musical community?

Summary conclusions and key findings addressing each of the overarching questions in turn are provided here, and this serves to draw together the disparate strands of the project, and to arrive at an overall picture of what has been achieved. This is followed by a discussion of future directions for the research, and overall conclusions.

Can a Working Musical Instrument be Created?

A fully working instrument was a practical reality from prototype 2 and since this point, successive prototypes have refined the vision, delivering increased quality and refinement to the action and ergonomics of the instrument, such that the quality of the musical practice undertaken upon them demonstrates a corresponding increase in quality and variety. Theory and practice have contributed to the improvement in equal measure.

Originally, design intent was expressed in four statements:

1. Comfortable keyboard playing position for left hand whilst simultaneously providing;
2. Comfortable strum/pluck position for the right hand.

Design considerations

3. Maximizing the playable string surface
4. Providing and effective reverse damping mechanism

This was expanded to sixteen design criteria as a result of the theoretical analysis undertaken within chapter three:

Action

1. Playing position

2. Keyboard: appearance and feel
3. Pulley and string system
4. Key pivot point to damper coupling
5. Key range
6. Harmonic damping
7. Minimal noise
8. Integrated amplification
9. Playing space on the string surface
10. String tuning and range
11. Access for maintenance

Harp

12. String distinction
13. Tuning mechanisms (winders)
14. Top plate
15. Depth and volume of the resonating chamber
16. Optimised coupling of bridge and top plate

This list defined the effective criteria, whilst allowing for the fact that the selective pressures that they exert are often competing. The method of action research provided a platform for practical analysis, and defined next steps towards improvement. Detours (sometimes extended) for technical acquisition have been a practical necessity as a result of this, and skills have been assimilated in automated design technique and hand-crafting in equal measure through prototypes 3 to 5; all have resulted in significant improvement to the finished instruments. The conclusion of chapter four analyses the success of the prototype series as a whole with respect to these sixteen design criteria, and this demonstrates all have been brought to a fully working standard, although in some cases further optimisation is possible.

One context remains — to evaluate the prototype series from a resource perspective. Successful prototyping should demonstrate that the most resource-intensive prototypes lead to the highest quality outcomes and that resources are deployed as efficiently as possible across the series as a whole.

Costs

The table below shows the most significant costs attributed to each of the prototypes in the series. This table demonstrates a successful outcome with respect to this resource; if we exclude the costs associated with securing the patent we see that the material costs have risen in line with the aspirations for the quality of each of the prototypes. There is a significant jump to prototype 5. The overall material cost for prototyping the project (to date) is £3,900.00 and prototype 5 accounts for 66% of the total prototyping costs.

Costs	Prototype 1	Prototype 2	Prototype 3	Prototype 4	Prototype 5	Prototype 6
Harp	30	50	60	0	1,500	
Wood	30	50	50	70	285	
Pulley wheels	0	20	20	0	20	
Damper felt	0	0	20	0	20	
Keyboard	0	0	0	0	0	10
Consultation						80
Damper springs		20	20		20	
Zither pins			20			
Finishing			5		500	
Metal bar	10	0	10	0	10	
Waxed linen thread	15	15	15		15	
Friction pins					30	
Patent		130	350			
Travel				70	70	
Tools		30	30	100	100	
Fablab				0		
Sketchup				0		
Other			60		10	
TOTAL	85	315	600	240	2,570	90
(Excluding patent)		185	250			
3,900						

Figure 6.1. Overall costs of prototypes

Minor changes in prototype planning have far-reaching consequences in terms of cost. A clear example is the cost of wood, which remains stable throughout the prototype series until the change to hardwood at prototype five. This increase is significant, however I consider it to be successfully minimized; there was considerable pressure to move to hardwood at prototype 3 from different parties, but the danger was that the different methodology at this point (working directly with the materials as opposed to working from finished plans) might well have caused this cost to spiral considerably higher than that achieved for prototype 5. Repeat cuts and experimentation is a relatively minor cost in softwood, but is significant in hardwood. By the time of prototype 5, a complete list of pre-cuts for the hardwood order could be generated straight from the 3d renderings and was commissioned from Tomlinson's sawmill in High Lane, Derbyshire. This order accounted for failure margins, which in many cases were necessary, but no additional costs were added after the first order costing £285.

	Order Width	Order Depth	Order Length
Damper bars	12	6	4000
White keys	22.5	7	4500
Black keys	12	7	2500
Black tops	12	10	1500
Action platform	20	13	600
Spitfire wing	130	15	250
Cross spars	65	12	2000
Boxing 6mm	250	6	3500
Allternative box	250	6	1500
	85	6	4000

All measurements in mm

Figure 6.2. Hardwood order for prototype 5

Grain ---

Time

Analysis of time spent on practice associated with each of the prototypes represents a more complex picture. The figure for workmanship on each prototype increases much more steeply for each prototype (roughly doubling at each). There are different reasons for this; during the construction of prototype 3 for example, a good deal of time was spent in practical experimentation with aspects of the design, in conjunction with achieving a reasonable level of finish. Whereas prototype 5 represents a change; the majority of the time here was spent improving method and finish, but not innovating (a good deal of this time actually went on improving my own skill base in terms of working with hand tools, and another significant portion was spent on the unforeseen problems caused by minor changes such as the pulley system, the keyboard springs and the harmonic damping).

(2007) Preparation/Viability	Hours	2008	Hours
Prototype 1 (1 month intensive)	80	Prototype 2 (1 month intensive)	120
Patent Application	30		
2010–11		2011–13	
Prototype 3 (2 months intensive)	250	Prototype 4 (continuous)	400
Commissioning of Prototype 5	20	3d Design	50
Patent secured	20	Luthier Development	50
Recordings	32		
Editing & Mixing	50		
2013–15			
Prototype 5 (continuous)	600	Prototype 6	
ACMG	35		
Composition	20		

Figure 6.3. Time spent on respective prototypes and significant accompanying activity

It is fair to say that I was slightly unprepared for the increases in time commitment necessary to complete these later prototypes and also that the outcomes, in musical terms, were slightly different to those expected. The Oscar Schmidt based prototype 3 turned out much better than I expected musically, both from the perspective of the base instrument (which was much better than the Chromaharp) and from the build quality achieved; as a result it has undertaken significantly more musical practice than initially expected. Prototype 5 on the other hand, has proved extremely troublesome to bring to a finished standard, and significant jobs remain outstanding on it even at the time of submission of this study. In terms of musical practice prototype 5 has only been available for the Adelphi Contemporary Music Group practice undertaken in 2015, and the problems with this have been documented.

Can We Analyse its Strengths and Suggest Further Change/Development?

A demonstrated strength of the instrument is the adaptive nature of the keyboard interface: a pianist, with no prior experience will certainly understand the instrument, and will be able to implement prior learning immediately. However, acquisition of an advanced technique is dependent on adaptive features of autoharp technique and it is this technical learning which gives voice to the rich timbral variety of which the instrument is capable.

With regard to the balance of melodic/harmonic playing, the instrument demonstrates obvious strength in harmony, in keeping with the design intent. Melody and melodic/harmonic combination is possible and this is evidenced in the recordings that accompany this written submission. This is dependent on the skill of the arranger/composer, but is comparable to the problem on guitar, where a reasonable knowledge of the interface is necessary for the ability to express melodic/harmonic combination effectively to develop. It is notable that composers, arrangers and other collaborators tend to conceive a harmonic/timbral role for the instrument. To an extent the given strength in harmonic playing results from the adaptive design which places the left hand on the keyboard. The recording of *Stormy Weather* within the accompanying digital assets, where melodica is overdubbed to a ReAPH accompaniment demonstrates this separation; the melodica allows full expression of the right hand learning with a similar immediacy to that of the left hand on the ReAPH, and demonstrates the difference between the two effectively. On the other hand Lucy Brissenden attempts melodic/harmonic combination in both her arrangements and resulting recordings. Overall the balance of melodic and harmonic capacity demonstrates a close correlation to the design predictions.

The increased timbral capacity has given a wide platform for genre exploration with some surprising results; the instrument has an interesting adaptive potential to baroque music, providing an expressive harpsichord equivalence. The self-damping mechanism renders the instrument highly adaptive to jazz and blues and it was particularly effective within gypsy-jazz.

Potential further change to and development of the instrument, resulting from theoretical and practical analysis is suggested at the conclusion of chapter four which outlines a path to implementation within future prototypes. These are: string distinction, tuning mechanism, sustain pedal (interface) and further improvement to the acoustic properties of the fretless zither itself.

Is There an Appropriate Range of Variation?

The potential range of variation, and the nature of change within technology were the subject of analysis within chapters two and three. These chapters considered variation within the spectrum of fretless zithers, and related forms, and the selective pressures which enable or limit possibility. Analysis concluded that the instrument should exhibit variety in its design ambition and proceeded to explore and define the potential range of variation on all aspects of the instrumental interface. Future design planning allows for this expected range of variation.

With regard to the keyboard, custom design can accommodate key size that deviates from standard piano dimensions, allowing comfortable access to the compass, regardless of hand size. In conjunction with this, different compasses of keyboard (which deviate from the established major 10th, or start from different points on the keyboard) may also be accommodated. With respect to alternative keyboard layouts, which might prove attractive to the accordion community, design equivalence and compatibility has been established with the Janko design, but other isomorphic keyboards are not suitable for adapting to the pulley and string mechanism.

With respect to the zither interface we can expect changes to the string spacing, compass, to the number of strings and to the tuning of individual strings, to provide distinct variety dependent on genre ambition.

A consideration with respect to pedagogy is the different strategy for implementation of chromaticism (where a range break is introduced between the bass and treble as distinct from the autoharp strategy of gradually removing more notes from each octave); deviation might render custom interfaces incompatible with established pedagogic structures. It is possible that these might exert a lock-in pressure.

Design Analysis and Practice and the Evolutionary Framework of Reference

Analysis and practice that led to the findings for these first three questions relied heavily upon the evolutionary framework of reference, which has been a crucial analytical tool throughout this project. Chapter one noted that the challenge for *this* study is balance and set out specific criteria to measure success:

1. *Has the terminology and analytical framework been defined sufficiently?*
   In each case key terminology is defined through returning to source rather than using contemporary literature, hence Darwin is used for the principle of *descent with modification over generations*, Dawkins provides the original definition of a *meme* — the cultural unit of propagation.

However, as noted in chapter 1, a fundamental aspect of its power to illuminate, lies in the differences in interpretation of individual studies. Commentators can agree on the principles but may well disagree on the significance of individual detail. A central tenet of Patel's *Music Language and the Brain* (a *tour de force* in terms of integrating research data from across related disciplines) for example, is that it is necessary to demonstrate that music and musicianship have had a direct influence on our physiology. Patel is able to demonstrate this conclusively for language, but is ultimately unable to sufficiently disentangle the musical data to demonstrate conclusively, an independent effect from music. Such a conclusive demonstration would be valuable — perhaps a final rebuttal of Pinker's views, but it is not in my opinion a necessity in order to demonstrate individual aspects of heritability, in terms of music and musicianship.

Similarly, Myers' *Evolutionary theory: a 'good' explanatory framework for research into technological innovation?* provided an invaluable evolutionary study that seeks to integrate the various forms of analysis of technological change within an evolutionary framework. It also asserts that researchers across disciplines do not agree on an overall definition of evolution and it contains a fascinating and very persuasive argument that evolutionary change is *not* random. The flow of the argument takes into account Lorentz's chaos theory "What is theoretically and/or empirically treated as a 'random variation' is in reality an unforeseen consequence of multiple cause and effect relationships, in essence, Lorenz's 'butterfly effect'" (Myers, 2006, p. 139) and concludes from Gould's *Life's Grandeur* — a fundamental source for all who seek to understand the workings of evolution; "As such 'selection' is not a random process per se, but rather one of default, the result of 'uncaused' (ie. indirectly produced), unintended *sequelae* or side consequences (Gould, 1996)" (Myers, 2006, p. 147). Despite the differences, I see no conflict with the tenets of my own framework arising from this, the thesis critically examines similar issues as those discussed here within chapter two and in fact reaches similar conclusions.

Random is an abstract term defined by the Oxford dictionary as "Made, done, or happening without method or conscious decision" or "equal chance". The two meanings might appear to have similar outcomes, but as definitions are neither connected nor similar. We might control a range of randomness with great precision from a determinist perspective, as is done every week in the UK national lottery for example; where a random array of numbers from within a very small possible range is, *truly,* randomly selected (but the degree to which randomness occurs has been strictly limited within a closed system by the range and method). We equally might assert that a frustrated pianist, who longs for direct contact with the strings, is a random variation from the range of all pianists (an open system). Randomness is present within each of these systems, as is conscious control, and is *observed* dependent on perspective. This use of perspective also follows the conclusions of Gould (Gould S. J., 1997, pp. 169–176).

2. *Have all obvious arguments against the application of such a framework been identified and rebutted convincingly?*
   The most common objections are then identified as the *means of transmission*, *conscious direction*, and the *nature of technological systems*. The exposition of chapter two identifies each of these, and rebuts them from a number of perspectives. The subsequent development using the QWERTY technology-based example also takes the approach of returning to source material — David's paper is seminal in this field. A subsequent direct response by Steven Jay Gould adds the richness of evolutionary commentary from an authority, whilst maintaining focus on matters technological. The 2010 paper by the Yasuokas adds further richness, providing insight into the detail of the invention not uncovered by David or Gould. Further, Myers observes at the outset of his thesis; ".. accepting the premise that theory construction and dissemination is an innovative act, the present thesis adopts the proposition that explaining most, if not all processes that incorporate human experience and activity, requires strong links to aspects of evolutionary theory." (Myers, 2006, p. 9). The Yasuoka's conclusion that David and Gould are jointly responsible for the propagation of a meme-set which misrecords the facts surrounding the design strategy for QWERTY provides an immediate practical example of this.

3. *Has the terminology and analytical framework been consistently applied within the remainder of the study and has it added value to the study?*
   Implementation of terminology is consistent throughout, and it conforms to the principles expressed by Myers (with which I thoroughly agree); "What does hold true however, is that any explanation of evolution must incorporate the principles of 'variation', 'selection' and 'preservation'... As previously discussed, principles are

‘illuminating metaphors’, conditions if you will, that have to be included so as to provide not only a direction for inquiry, but also to help establish the explanatory ‘facts’ of the phenomenon under investigation.“ (Myers, 2006, p. 161) The framework has enabled the development of analysis in chapters 2 and 3 and was an integral facet of the formulation of the sixteen design principles used to analyse and evaluate the prototype series.

4. *Has the footprint of the framework of evolutionary theory been minimised within the study as a whole?*
   It is undoubtedly the case that of all the chapters in this document, chapter two has been subject to the most drafting. I consider that its footprint has been minimised as far as is reasonably possible whilst allowing the necessary space to discuss the complexity of the ideas. The subject matter of this commentary is deliberately selected from a number of similar papers because of its resonance with keyboard technology — the commonalities of the QWERTY/DSK and traditional/isomorphic keyboard narratives allows the development of the framework to remain within similar subject matter.
   Within the remainder of the text, where matters of evolutionary theory have threatened to take over the discussion at the expense of the central subject matter (namely; classification methods of musical instruments), the material has been moved to an appendix for a more complete discussion. The criticism and contextualisation of diffusion theory from an evolutionary standpoint within the final chapter provides a useful reminder of context, whilst simultaneously maintaining focus on matters technological.

   Significantly, integration of this unusual analytical framework assisted with progress with, and integration of, all the different disciplines that formulate this study; it is the overall governing framework that provides perspective.

Can the Instrument be Integrated into the Musical Community?

A considerable body of musical practice, evidenced in chapter five and within the digital assets which accompany this written document, demonstrates that this is possible across a wide range of genre engagement.

An aspect to highlight here is the extent to which technical improvements (from all perspectives) have correlated with increased depth and confidence of engagement and integration within the musical community. January 2013 represented a watershed moment, the recording and publishing of the first showcase recordings of the instrument. This was made possible through the improvements to instrument and technique in equal measure. However, the most ambitious recording Debussy's *Clair de Lune* was only possible at this stage as a result of detailed editing of the recording — the depth of which I have never before attempted (and would not wish to repeat), and I remain highly critical of the finished product from a technical and interpretive standpoint; whilst I wished to showcase the instrument to its best ability at this point, I did have doubts as to whether this standard could actually be achieved in performance.

However, subsequent detailed thinking with regard to developing the notation system (developing the notation for the right hand on the string face in conjunction with the left hand on the keyboard) together with further acquisition of technique have proved that accurate rendering can be given within performance. *Snow all the way to the Cage* is a work of equal technical difficulty, but the precision of the score, enabled an accuracy not previously achieved within performance.

Forward planning of pedagogy has also resulted from this development; progression over a range of difficulty has been mapped. At submission point technical and musical development stand at comparable points such that pedagogic structures will accompany the wider availability of the instrument, increasing the player base.

Can the Instrument be Made Available to the Wider Musical Community?

In terms of reaching market, clear long term planning has been established and technical obstacles in both design and musical domains have been largely overcome. Subsequent forward planning has been formalised; current prototypes and musical practice undertaken, together with the plans for design automation will form the basis of a pitch to major manufacturers. In commercial terms an autoharp manufacturer contract probably represents the best hope for rapid, wide adoption within the musical community because the manufacturing process would reduce costs to minimum, and therefore the instrument would reach the market at the lowest possible price.

Market research has not been a formal part of this project, however, the overall activity has generated a good deal of information, which suggests evidence of interest in the instrument. The experience gained in successive presentations and through the early adoption and technique acquisition by Lucy Brissenden suggests that the player base might have a wider profile than I had initially imagined, and planning for pedagogy has allowed for this.

How much should the instrument cost? The only sales-based evidence that is available comes from the ebay price achieved by the Millington Young *Gondolin* instrument recently sold which achieved a price of around £600 at auction in the USA. For comparison; a basic commercial autoharp costs in a range of £300–500, a luthier-built autoharp is rather more expensive; beginning at around £1000 and extending upwards to very high priced instruments. This range is broadly comparable to that of guitars, though guitar pricing within the UK also exhibits a lower tier, with playable quality instruments at entry level imported from the China (and other areas of low cost manufacturing base) available at astonishingly low cost — as little as £100-200 (assured high demand is clearly a significant factor here). Because the ReAPH is designed to attract comparable musical engagement to the guitar this comparison offers a guide to possible viable pricing. The entry-level price is significant because it offers the best chance to engage younger players. Whilst I do not believe that a commercial ReAPH could match the very low prices of entry-level guitars, I do believe a figure in the region of £300–£500 (similar to the pricing base for autoharps) is realistic and achievable, particularly if a major manufacturing contract could be developed.

A successful pitch to major manufacturers could result in manufacturing costs broadly comparable to autoharp. Though the keyboard action is more complicated than the over-damped chord bars much of the manufacturing of parts could now be achieved through automated process, and the most significant technical obstacles to achieving this have already been addressed. The keyboard itself would be rendered in plastic through laser cutting (since there would no longer be a selective pressure to match high cost hardwood, and plastic would be an acceptable and expected material for a keyboard). Other small internal parts can be rendered using 3d printing with CNC cutting of wood for the overall housing. Assembly of the overall action (complicated in prototyping because problems such as harmonic damping must be solved in relation to the individual instrument), could be fixed in relation to a particular model and rendered to a production line approach with no overall loss in quality.

If the approach to major manufacturers fails, then there is enough evidence of interest to warrant a cottage-industry initiative. Three different product types are possible and all would be undertaken (though not necessarily sustained in the long term) in order to generate interest and publicity. Firstly, a very limited number of finished ReAPH instruments can be built and sold at auction on the open market, with associated musical publicity. During the prototyping process I kept the cost of autoharp instruments to a minimum by importing from America; an area where second-hand autoharps are cheap and plentiful; in both cases the cost of the autoharps themselves were so cheap as to be roughly equal to the import costs (shown as a single figure within figure 6.1). This low cost was assisted by seeking instruments with damaged damping actions where the harp itself was in reasonable condition. This can be repeated, but the type of autoharp would have to be strictly limited to models of sufficient quality (this probably rules out any other than Oscar Schmidt models), and similarity, to ensure that time-consuming processes such as harmonic damping, can be standardised.

A simpler alternative might be to ask for a price reduction on a small number of similar new instruments (between three and five), and negotiate the price as low as possible. Since there would no longer be pressure to work in expensive hardwood throughout the prototype, the keyboard, damping mechanism and other small parts will be rendered in plastic (in co-operation with the Art and Design workshop at University of Salford) and the housing in hardwood. The finished product would thus be very similar to the imagined major manufactured product.

A second product would be formed from finished reverse-action keyboard mechanisms designed for specific autoharp bodies sold as specific conversion kits for the buyer to attach to the harp; these have the advantage that they could be produced on commission and dependent on demand. A third product would take the form of sets of plans and instruction manuals for self-build, which can be disseminated through purely digital means.

Overall, I consider this to be a realistic and achievable plan which maximizes the potential for wide adoption of the instrument, with regard to the timing of the pitch to industry, and also puts forward a highly realistic prospect for breaking even, at least in terms of recouping costs, for a cottage-industry approach. In the medium term, if cottage-industry proves the most successful means of propagating the design I will almost certainly drop the patent, and encourage innovation and further collaborative development activity on the design.

Obstacles, Adaptation and Evaluation of Change

Obstacles

Paul Von Janko's ability and early promise cannot be doubted; after preparatory studies he gained a joint scholarship to study music and mathematics — at both the Conservatory of Music in Vienna and at the Polytechnicum and left both with the highest prizes that they had to offer, he then continued at Berlin University. Amongst the notable people he studied with were Anton Bruckner and Herman von Helmoltz (Doge, 1911, p. 83). Janko clearly possessed an unshakeable belief in the advantages of his invention, such that he was certain of its eventual acceptance. Unfortunately the musical community demonstrated an equally unshakeable indifference to it, and this led to a tragic final chapter for the inventor; trapped in debt accrued from the costs of prototyping, consigned to obscurity, and unable to contribute further to the musical community. His association with Helmoltz, Bruckner and the long list of endorsements for his invention from various musical celebrities appeared to have counted for nothing.

I first encountered this story and the salutary lesson that it embodies sometime in 2010. I had completed prototype 2 at this time, and this prototype represented the height of my dissatisfaction both with the standard of my own workmanship, and in the musical quality of commercially available autoharps. Based on the experience of the Chromaharp-based-prototype 2 I felt that commercially available autoharps were simply not good enough to fully explore the potential of the new formulation of the instrument. Serious autoharpists attest to the quality of luthier-built instruments, and are relatively scathing regarding the merits of commercially available instruments. My own, (at this time) limited experience of commercial autoharps and the astonishing difference demonstrated in Alec Anness' harps had confirmed this view and in order to engage interest and to create an eventual market outside the autoharp world, I felt that a high quality instrument was a necessity. It was during this period that I commissioned Alec Anness to build the harp instrument for prototype 5, committing myself to the most significant single cost of the entire project, a figure of £1500.00. This is perhaps a reasonable price for an instrument for a professional musician, but it is nonetheless a considerable sum and represented a risk — especially bearing in mind that the means for completing the reverse action keyboard was not at all clear at the time. I constantly questioned and worried over the wisdom of this decision, for it committed me to significantly more cost than I had originally planned, and a much longer prototype series before finally arriving at market readiness. Moreover, I could see that the prototyping costs were likely to escalate significantly, and that great care would needed in order to minimize them.

Adaptation

Several events converged to change my perspective and to bring a different balance to the project, and my perspective on future planning. The first was a conversation with my wife Rachel: sensing that something had changed subsequent to the commissioning of prototype 5, she persuaded me to abandon the workshop late one night in the Autumn of 2010 to talk. My obsession with the project had reached new heights at this time, but clearly some of the joy had left it, replaced with the pressure to bring the prototype series to a successful conclusion in terms of reaching market, in order to justify the significant expense to which I had committed.

During this transforming conversation I was encouraged to consider the true context of this project, and the significant progress that had already been made. Together we considered the progress that prototype 3 represented from a standing start, and the forward planning that now emanated from it. Its existence, and the musical practice that could now be undertaken on it, represented the fulfilment of a long-held dream. We agreed that given the forward planning that now existed for the prototype series, commercial success was probably now out of scope, but this had arisen as a result of my own analysis from musical, design and theoretical standpoints, in which I should have faith and pursue to conclusion. In so doing, the planning showed that I would, at least, solve all of the most significant obstacles that stood in the way of reaching market. Finally, that commercial success would be a bonus in the overall context of the study, and would not be the sole arbiter of success.

This was a watershed moment in the prototyping process. Subsequently I surrendered to it completely, learning new skills, forming new relationships with industry partners and giving significantly more attention to developing musical practice, and to recording and documenting it. Ultimately, I judge the success of the prototype series and its market readiness as a balanced output across all the disciplines. Though forward planning exists from prototype five, I do not feel that further prototyping is necessary at this time. This further work represents a far more personal journey in search of perfecting the instrument.

Change

A welcome change was that the urge to compose gradually returned to me after a long absence during the subsequent period and two unusual works that I encountered whilst researching related instruments particularly inspired me. These are Pringles *Katric Ark* for theremin and Vulcan Harp (Pringle, 2011) and Tarnow's *Sonata for Theremin and Piano* (Tarnow, 2013). These chamber works are not highly experimental in purely compositional terms, rather they seek exploration of a new range of timbre and texture through placing the "experimental" instruments in relatively conservative and traditional chamber roles, which demonstrate their respective strengths and range with sensitivity to their heritage.

In fact both instruments now have quite a long history: the theremin approaches its first century of existence (the first concert given by Leon Theremin in 1920). Theremin demonstrated clear ambition for his instrument to engage in traditional repertoire and exponents such as Clara Rockmore (with technique adapted from violin) rose to the challenge, performing arrangements from the classical repertoire throughout her career (Lester, 2007). The Vulcan harp, created by Wah Chang, at half a century old is rather younger, and originates from the original Gene Rodenberry *Star Trek* (first appearance around 1964) (Williams S. L., 2010). Various working instruments have been designed and realised since then, the most recent in the form of a digital application for ipad. Both instruments have a significant history of association with cinema and particularly with science fiction, and the lyrical content of both works seems to affirm and to build on this heritage with sensitivity and imagination.

I sought a similar affirmation of history; affirming the link with the autoharp tradition and the overall Victorian heritage of the ReAPH. The involvement within the Adelphi Contemporary Music Group and particularly the association with the multi-instrumentalist Danny Thompson offered the chance to fulfil this ambition. The composition of *Snow all the Way to the Cage,* the rehearsal, performance and subsequent forward planning of works to form a suite has been a rewarding re-engagement.

Finally, meeting and corresponding with Yuri Landman from February of 2015 provided a unique perspective and opportunity for collaboration with a kindred spirit. Though there are many differences in the skillsets that we have acquired and the approaches that we have taken there are significant commonalities. We are both driven by a desire to re-affirm the bond between instrument player and fashioner of musical instruments that seems to have been lost from western music, an urge to bring experimentation out of its current digital ghetto and into the purely acoustic instrument domain, and to provide a different context for experimentation in terms of genre.

At the point of submission, these values define my identity, and future planning, as clearly as the urge to compose and to play the piano once did and these older desires and skills have re-emerged one by one over the last year, confident in their new context.

Postscript – A Pianist and a Reverse Action Piano Harp

In the first week of May 2015 I am asked by a colleague if I can provide a session on the ReAPH to the second year studio composers — an extra, context-based session to the main lecture series. I reply that I could probably talk about the ReAPH for four days in a row without stopping, and the event is fixed for the 7th May.

The event does not begin well. Earlier events have conspired to make me ten minutes late, and I enter the lecture theatre flustered, carrying prototype 5 and place it on the grand piano. Curious eyes fix upon it, and my colleague laughingly jokes that no-one will now listen to him, and why have I arrived 50 minutes early?

Realising my mistake I withdraw, and return shortly before the correct time, and listen to the end of my colleague's session. I see that prototype 5 is, as my colleague predicted, drawing continuous attention and I see with the audience's eyes what it has become; it sits with its larger cousin, a thing of beauty, full of musical promise.

My technical presentation is short, I talk too fast, in too much technical detail, and I see that eyes remain fixed, not on me, but on the instrument, so fairly quickly I give up: "does anyone want to come an try it?" I say, and at once a "Yes!" comes from the back of the room, a second year pianist. He picks up the instrument, he plays it and immediately exclaims with delight. The remaining Q&A is comically punctuated with his experimentation and approving expressions, interspaced with technical pointers from me; a pity, because the group finally really warms up to some more demanding questions. The session closes and I ask for final questions, of which there is just one, from my friend the pianist:
"Yes, where can I get one?"

Appendix 1:

A Musical Instrument Classification System Suited to a Darwinian Analytical Framework

We have classified musical instruments variously from the perspective of *groups of players* (pianists, organists and harpsichord players), the *sound producer* upon which the instrument is based and from such esoteric aspects as *the mode of engagement of the secondary damping* interface. We are, of course, entitled to classify as we wish; exploring the design *ideolect* necessitates that we allow wide cultural influence, and unusual relationships are a natural consequence. But having done so, it also natural now to consider the issue of classification of musical instruments in more detail, and that this discussions should centre around the issue of consistency.

If all we seek is a name, then the most-used classification system, Hornbostel-Sachs suffices; in many cases it also illuminates design and musical relationships. However, as we have seen, it has many inconsistencies, and seems to obscure relationship as often as it illuminates.

Hornbostel-Sachs has many comparable qualities to the early Linnaean system of classification within biology. Linnaeus could only base his taxonomy on structural similarities between organisms, and the evidence for this came from empirical observation. This naturally led to a great number of correctly identified relationships, and also some mis-classification. The most obvious examples are from convergent evolution, where unrelated organisms evolve to fill similar niches in separated ecosystems — their features appearing similar from an empirical standpoint. Other types also exist; for example, Stephen Jay Gould has famously asserted that the term ”fish” is meaningless as a biological classification unit, because teleosts are, in genealogical terms, more closely related to *us* than to cartilaginous “fish”. This does not alter the fact that the term “fish” remains useful within everyday language usage — a natural unit of sea creature classification.

The most significant modifier to the Linnaean scheme has been the flow of information from different discipline standpoints, which converge to give ever more precise definition of genealogical relationship. The most striking changes to the Linnaean system have taken place at the first divisions, where greater understanding of relationship have led to additional kingdoms.

Hornbostel-Sachs, like the early Linnaean system, identifies obvious structural features of musical instruments based on empirical observation, and this leads, as with the Linnaean system, to a great many correctly identified relationships. Unfortunately, it also leaves some flaws that appear as afterthoughts and add-ons[16].

The system divides instruments at the top level into four: Idiophones (sound produced by the body of the instrument), Membranophones (sound produced by a stretched membrane), Chordophones (vibrating string or strings) and Aerophones (sound produced by a vibrating column of air). This appears to be consistent and the categories seem similar, but as we have seen in practice; an immediate problem is that the category of aerophone contains a great many subdivisions which perhaps more naturally belong at the top level of classification. Subdivision attempts no consistency at all across the system as a whole. Instead the subdivisions focus on the most obvious structural features which provide distinction, and these are then deployed as classification strategies with varying degrees of success; most often this leads to a division based on *acoustic* and *morphological* properties (for example: Chordophones; composite chordophones; lutes; necked lutes; **necked bowl lutes** or **necked <u>box</u> lutes)**, with rather less regularity on *performance technique* (for example: Idiophone; Struck idiophone; **directly struck** or **indirectly struck)**. Sometimes there is a division based on a more *musically esoteric capability*, for example: Chordophones; composite chordophones, frame harps; without tuning mechanism; **diatonic frame harps** or **chromatic frame harps —** here the most obvious distinguishing feature is the selective pressure exerted to provide chromaticism, and the difference in the structure of the instrument that this pressure has produced. The classification system now ventures into the arena of *culture and genre*.

Of course we cannot expect that a musical instrument classification system will lead to similar refinement with respect to descent and relationship in the way that Linnaean taxonomy has evolved in light of growing sophistication of genetics and other disciplines;

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[16] Recent modifications to the original Hornbostel Sachs, such as that undertaken by MIMO (http://www.mimo-international.com/documents/Hornbostel%20Sachs.pdf) have improved the consistency of the system.

and in any case the issue of relationship is very different. How do we define the relationship between the Chinese *sheng* and a *melodica* (both free reed instruments but presented through culturally different secondary damping interfaces)? Despite the differently evolved secondary damping interface, each is reliant on the same meme for its sound producer — it may even be that the idea for arrays of free reeds originates from the same inventor, or there might be independent points of origin; we just cannot tell, and we are unlikely to ever answer such questions with certainty. Equally, how do we define the relationship between provable independence of meme origin? The Wicki-Hayden keyboard layout is a nice example. Michael Hayden proposed and patented this system in 1986, and only later discovered the completely independent patent filing of the same system from the Swiss Caspar Wicki in 1896 through the research of Göran Rahm. In terms of descent there *is* no relationship between the two — and yet they are the same.

Yet the instruments central to the analysis of chapters 2 and 3, despite their structural differences, have similar design intent in terms of their musical engagement. Although the issue of classification is not central to this study, and in most cases all that we seek *is* a name for an instrument, for the sake of consistency we would seek a system that illuminates the design properties, that draws out the design intent and musical capacity of an instrument irrespective of cultural background, such that relationships are consistently

	Group of Instruments	With tones that die away	With continuous tones
Instruments used for single-voiced music making	not changeable	drum gong musical bow	musical bow pipe trumpet/horn
	freely changeable	percussion pot rod zither	singing saw siren
	changeable by fixed intervals	jew's harp bar zither	various wind instruments
Instruments used for multi-voiced music making	not changeable	dulcimer harp piano	panpipe glass harmonica organ
	freely changeable	lute	stringed intrument
	changeable by fixed intervals	guitar zither	double oboe bagpipe

Figure A1.1. Kurt Reinhard's diagram illustrating his 1960 proposal for a classification system for musical instruments. (Kartomi, 19990, p. 180) illuminated. A suitable system was proposed by Kurt Reinhard in 1960.

This diagram is taken from Kartomi’s *On Concepts and Classifications of Musical Instruments* and originates from a translation of an outline of part of Reinhard's table (Kartomi, 19990, p. 180). This is not a system of hierarchical classification as is the case for the Hornbostel-Sachs system; the categories expressed within the table are of equal weighting (the table could be redrawn with these three categories in other positions without effecting the overall categorisations and relationships between them). A moment's contemplation of Reinhard's table above reveals that the primary classification categories are the most significant analytical criteria of chapters 2 and 3.

Placed in the far right hand column we see the categorisation stringed instruments under continuous tone/ freely changeable (I have assumed from the diagram that the term “stringed instrument” refers to violins, violas and 'cellos; continuous tone reflects the fact that these are bowed. As we have seen in analysis this leads to a richness of melodic timbral potential)

The percussion pot referred to must be (or be similar to) an *udu*, which is capable of continuous pitch change as the hand covers holes in the pot to varying extent. A more common contemporary example of a freely changeable continuous tone instrument would be a swanee whistle. The Jew's harp seems mis-classified within the definitions of the table to me, as changeable by fixed intervals — fixed intervals can be achieved in-as-much as harmonics can be defined through shaping the mouth, but these are referenced to the fundamental provided by the instrument, and are more likely perceived as timbre. Within the multi-voiced category, not changeable fading tone instruments are listed as dulcimer, harp and piano — the majority of the instruments that we examine fall into this category. Below this, the most common configuration of freely changeable multi-voiced instruments will be multi-stringed with finger-boards (but not fret boards). The repertoire of these instruments is likely to remain predominantly in the melodic domain, whether fading tone (plucked or struck) or continuous (bowed), but with some polyphonic capability. This will be problematic because continuous variation is difficult to control with respect to polyphony (example: violin, violin double stopping). Below this, instruments are changeable by fixed intervals, likely candidates will have a greater plurality of strings and a fretboard.

Voices	Fading	Continuous
Single Voiced		Erhu
Intersection*		Violin
		Chromatic Harmonica
		Harmonica
		Melodica
		Nyckellharpa
		KABI
		Hurdy Gurdy
Multi-Voiced	Chorded Zither	Sheng
	Autoharp	Concertina
	ReAPH	Accordion
	Venezuelan Harp	Organ
	Concert Harp	
	Celtic Harp	
	Cross Strung Harp	
	Triple Harp	
	Lute	
	Harpsichord	
	Piano	
	Guitar	
	Koto	
	Guzheng	

Not Changeable
Changeable by fixed intervals
Freely Changeable

*** Intersection**: Primarily concerned with melody and melodic inflection, but capable of some polyphony

Figure A1.2. Reinhard's classification system applied to the range of instruments compared in chapter 3

The table above shows various instruments considered within chapters 2 and 3 classified within Reinhard's system. The vast majority of these are multi-voiced, fading and not changeable. There are a few exceptions, koto achieves freely changeable pitch through its bridge and string structure, and the potential of the unusual system to achieve freely changeable pitch is the aspect considered in chapter 3. It is polyphonic, however it is not capable of functional harmony. Hurdy Gurdy can best be described as a mechanised violin. I have placed this in the intersection; it is primarily melodic, but examples of this instrument have drone strings, and are thus, to an extent capable of polyphony. The table immediately illuminates similarity and difference of design intent.

1. Instruments with comparable design properties similarly categorised
2. Where instruments are similar but design intent is modified, relationship can be seen in adjacent categorisation
3. Where instruments are similar in design intent but based on different principles of sound production relationship can be identified from adjacent categorisation.

Subsequent layers of classification that Reinhard suggested include variable or fixed dynamic (for example a piano would be variable, but a harpsichord would be fixed, terraced dynamics), absolute loudness, timbral spectra, whether instruments are tunable and the type of music played on multiple-voiced instruments. Each has the potential to further illuminate design aspects, but it is really the top layer of classification that is most novel, applicable and consistent with a Darwinian mode of analysis.

Appendix 2

Further Development – Working Title; Keyboard Adapted Bowed Interface (KABI)

For me, the melodica provided a spur to think about another instrument: and this specifically related to the immediacy of the adaptive environment for the right hand piano technique. The ReAPH, despite its great flexibility, can be frustrating from a melodic perspective particularly for improvising solo material; the left hand at the keyboard is at a disadvantage, because the vast majority of the motor training for melodic control is effected upon the right hand.

In fact playing the melodica provided such an effective counterpoint to the ReAPH interface as to give an immediate feeling of a "unit" of classification to the two instruments.

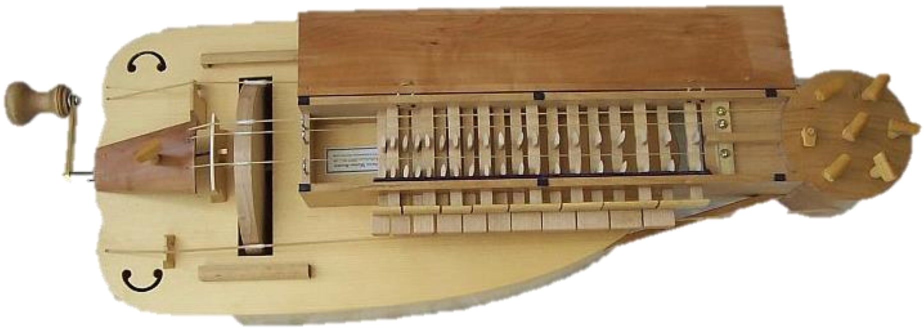

Figure A2.1 The workings of a Renaissance Hurdy Gurdy dating from c1515 made by Owen Morse Brown (Brown, 2015)

Status: Permission Granted

An overdub recording of the two instruments together is included within the digital assets that accompany this written document. Listening to this recording is an odd experience for me because it ties together two key components of pianistic technique; individually it sounds like each of my hands playing, but together, the enriched timbral environment renders the performance a true ensemble. The experience of combining the two left me a good deal more comfortable in my mind with the set of compromises which enable the specific possibilities of the ReAPH, feeling that the compromises it makes might ultimately be counterbalanced, not just by obsessively improving the ReAPH and ReAPH playing technique, but by producing a family of such adaptive instruments. This provided a more urgent impetus to bring, at least to a design proposal stage, another interface that I had been considering; a bowed/pluck interface keyboard enabled interface.

There are two existing instruments that influence the design. The hurdy gurdy (right) stops its single melody string using a keyboard like interface.

There is no bow for this instrument; instead the player turns a rosined wheel (usually) with the right hand whilst the left hand plays the quasi-keyboard interface.

Figure A2.2. One of a number of different possible playing positions for the Hurdy Gurdy (Grosso, 2015)

Status: Permission Granted

There are various playing positions; the most common is depicted in the photograph (left). The arm engages the keyboard with relative comfort, but is clearly having to play the keyboard backwards, and with uneven key spacing which reflects the stopping positions on the strings.

This position is necessitated by the simple pivot fretting mechanism; the depressed key pushes the fret (after the pivot point) up, against the string. The hurdy gurdy is capable of playing very fast with relative ease, but the bow-wheel mechanism limits the number of melody strings to one, and severely limits the possible polyphonic combinations. A second, related instrument is the Swedish Nyckelharpa (below). This instrument displays the wide range of timbres that bowing draws from an instrument. Bow speed, pressure, orientation

Figure A2.3. A Swedish Nyckelharpa (Johansson, 2005)

Status: Creative Commons

and proximity to bridge all continuously vary the timbre and dynamic of a melodic stream.

The instrument, like the hurdy gurdy is capable of considerable speed of articulation that combines effectively with the timbral versatility. An interesting demonstration of this instrument is to be found at http://www.youtube.com/watch?v=Zs3aUCM8BX8 (Torbjorn, 2007). This rendering of the Bach 'cello suite has a curiously different feel to 'cello performance; the mechanical fretting gives a feeling of continuous open strings and because of this there is an unfamiliar feeling of quick attack time to the bowing and ease of articulation.

Unlike the hurdy gurdy, the left hand fretting mechanism has no relationship to a keyboard beyond that it is a series of keyed levers. The orientation for the left hand operating this mechanism reveals adaptive design thinking from violin positions. The bowing position is more natural, but nonetheless looks restricted; the very short bows which are characteristic of the instrument provide evidence in support of this view. A steeper angle (neck oriented down to the floor) would give more space for forearm movement, but this is constrained on the nyckelharpa by the left hand access, which must come right around the instrument.

Figure A2.4. Marco Ambrosini playing the Nyckellharpa (Evers, 2005)

Status: Creative Commons

The key mechanism places fretting force in a different direction to the hurdy gurdy. This can be seen from the keyed fourth finger (using violin fingering) in the photograph below, resulting in fret movement parallel to the soundboard, rather than upwards like the hurdy gurdy mechanism. Both nyckelharpa and hurdy gurdy are interesting instruments, showing different selective pressures and adaptive qualities. Hurdy gurdy has properties that are adaptive to keyboard players, but the range and timbral capability are too restrictive. Nyckelharpa provides sufficient range and timbral variation, but is not designed to be keyboard adaptive. Taken together, however these instruments solve many of the technical problems necessary to produce such an instrument.

The key mechanism that can enable a re-orientation of the interface is the pulley and string mechanism. This technology is now well tested in the ReAPH, and we have established that key movement, with comfortable weighting from a pianistic perspective can provided movement at an independent position on the instrument. This is crucial; because utilising this mechanism means that we are not tied to lever positions directly relating to calculated scale length with respect to the strings.

We can therefore, proceed as we did for the initial design stages for the ReAPH. Design should begin from establishing optimum playing positions; both for bow access, and keyboard position. Keyboard position has already been much discussed; and is reliant on a supported forearm with a straight-wrist with access for left hand. Bowing relies on supported forearm movement describing an arc, with a flexible wrist.

Prototyping requires a lot of imagination, and, as with the ReAPH; in the first instance playing a lot of "air" instrument is a good idea, thinking carefully about arm movements, and the plausibility of achieving effective mechanisms, the resulting position from this process is unusual, but comfortable for both bow and keyboard.

Adapting from the Nyckelharpa position above. The restricted bow movement arises because the forearm angle is simply too tight. Orienting the neck towards floor, and providing a steeper angle leaves an open bowing movement.

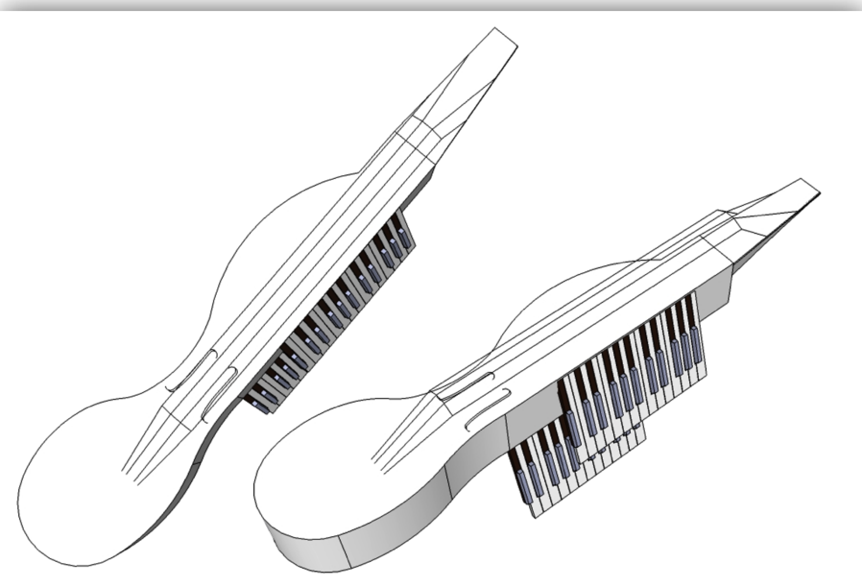

Figure A2.5. Projections of the KABI

The left hand keyboard access must be re-oriented with respect to the nyckelharpa position; moving back around the instrument, and accessing the keyboard from the opposite side. This produces a conflicting pressure — full size keys are desirable for adaptive playing, but require a great deal of space on the instrument; a flat orientation of keys with respect to the string surface renders effective bowing angles for the strings impossible. One solution, in order to accommodate full size keys and maintain comfortable bowing position, is to turn the instrument around the right hand side of the body, the drawing renders this with an angle of 80 degrees.

Through 3d rendering we can give a reasonable impression of the playing position. Since everything in 3d rendering is drawn to an accurate scale, this can be quite informative. The downloaded person is an average 5ft 8” in height, giving a reasonable sense of the size of the instrument. The bowing position is shifted towards a side orientation with respect to the trunk of the body, rather than across the front of the trunk, as with the 'cello; an unusual looking position, but is a natural and comfortable movement for the bowing arm.

Figure A2.6. The KABI playing position

A curious fact of violin versus 'cello design is that from a bowing perspective the bass-treble orientation is reversed. The two instruments appear to be similarly strung when placed alongside each other from a front facing orientation. But the violin, right hand – bowing arm effectively wraps around the instrument when it is held against the chin, whereas the ‘cello bowing position is open. The simplest way to understand this is to take a (real or imagined) violin under the chin, and ready left and right hand to play a down bow from the G string. The instrument is angled away from the body. The violin bow perspective, therefore, is that the low G string is on the left side of the instrument, and a backhand down-bow is angled with the heel angled upwards. Now take the violin away from the chin and place it front of the body like a ‘cello. The low G string is now on the right, and a down-bow begins with the heel of the bow oriented downwards. Repeating the exercise, considering the left hand experience, reveals that although it too experiences a left-right re-orientation, the difference with respect to the instrument is not pronounced; the hand to interface orientation has not changed significantly at all; the violin position requires the left hand to reach across three strings in order to stop the G string, changing to the ‘cello position re-orients the hand right to left — but does not change its interaction with the interface.

This leaves an interesting minor dilemma, because the proposed interface could be strung to either orientation; the bowing position seems to fall in between and depending on player experience might give a more natural feel from either orientation. The LH keyboard position is similar in both cases. The string scale length is designed on 'cello proportions, and the key choice shown in the photograph above assumes 'cello fundamental pitches and string gauges. In principle there is room for variation within a reasonable range of a perfect 5th.

Figure A2.7. The playing position for the guzheng (Hill, 2012)

Status: Creative Commons

String Bend, Tremolo and Vibrato

A last technique to mention is an unusual technique of melodic ornamentation deployed on zither type instruments such as the *guzheng* and *koto*. The player produces vibrato, melodic ornamentation and other pitch effects through direct pressure on the string behind the bridge (thus increasing string tension between the bridge and nut). A good demonstration of the technique is to be found at www.youtube.com/watch?v=ujzMHLac404 (Guzheng, 2009).

The scales utilised by the guzheng are not designed to be oriented towards western harmony, although it can be adapted for this purpose. We should note that although that the design intent of the Guzheng is both melodic and harmonic, and it is capable of achieving quite complex combinations, it is not chromatically strung with respect to either western music, or its own various musical systems; and the string bend technique described provides “accidentals” through momentary retuning of strings as often as it is used for pitch bend and vibrato effects. The capability is approximately comparable to the lever and pedal systems of non-chromatic harps within the west, which similarly do not seek a complete chromatic string set, but allow quick modification, not dependent on retuning.

Clearly, the keyboard produces a chromatic interface for ReAPH and KABI, so the focus for adaptation here is the bend and vibrato possibility illustrated by the technique rather than momentary retuning. For adaptation to the ReAPH, a first observation is that there is no hand free for simultaneous performance. Bend/tremolo/vibrato effects could be achieved by the right hand *after* playing the string, but implementation would be difficult.

In contrast to the ReAPH, The KABI player has no hand at all free to provide string bend effects; each hand continuously engaged either in bowing, or at the keyboard. A better way of implementing the effect on the KABI might be to produce force directly on the keyed fret. Whammy bar interfaces native to electric guitar provide a design precedent. This is technically possible, requiring that the key to fret sprung mechanism is closed, and that a second, stronger set of springs are engaged by a stepped increase in pressure which rock the entire key and bridge mechanisms together without changing the respective pressures for achieving effective fretting. The technique itself is more suited to the primarily melodic environment imagined on the KABI.

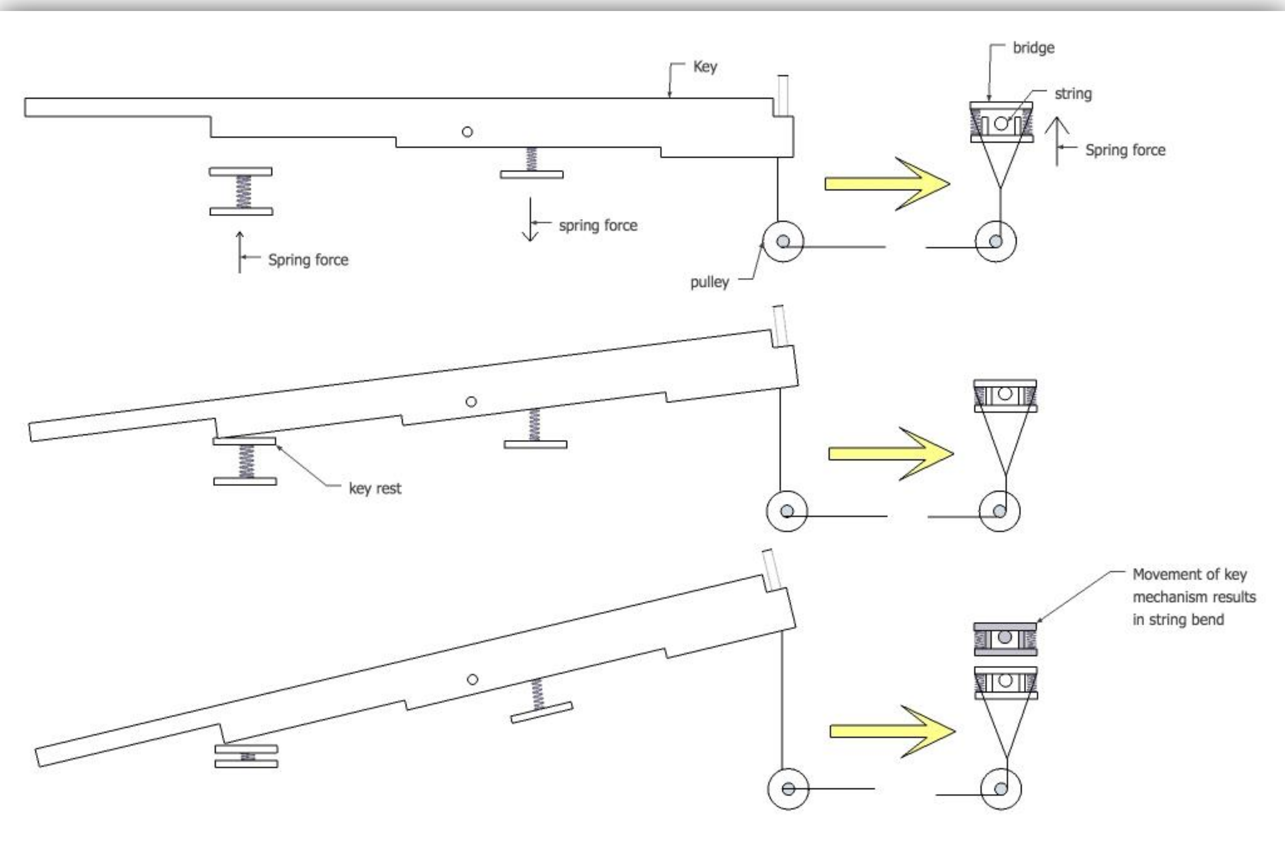

Figure A2.8. Proposals for independent spring mechanisms for fretting and string bend effects

The drawings above describe the independent spring mechanisms for stopping and string bend. The key is open in the top picture, depressed for fretting only in the middle; in the final picture greater pressure is placed on the key, engaging the second spring and producing a resultant increased downward force on the string. This diagram is drawn using ReAPH keys; but after some reflection I re-considered the key pulley system.

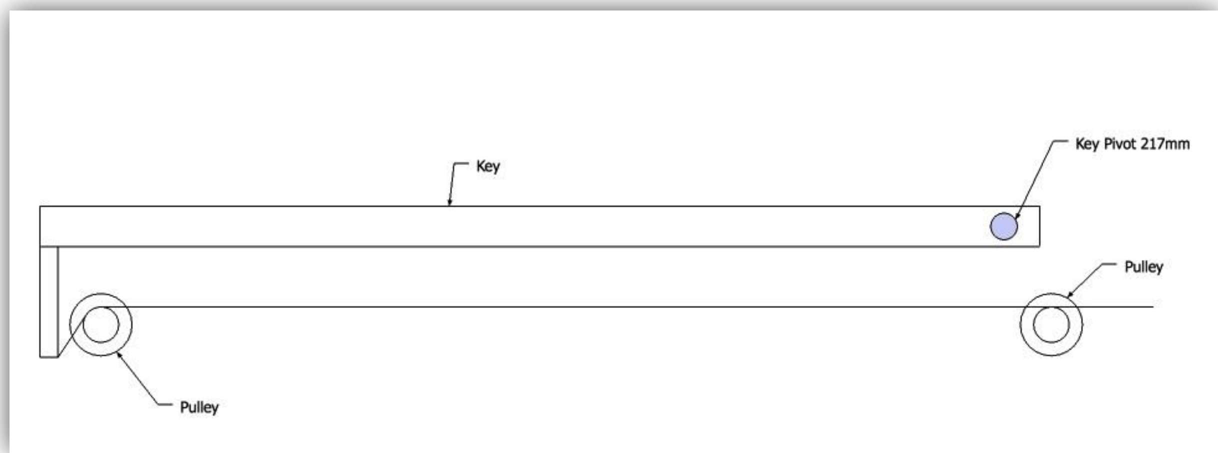

Figure A2.9. Key pulley system re-design

This mechanism has the advantage of halving the effective length of the key, pivoting around the pulley from the front of the key, whilst retaining the piano pivot length. This is possible on the KABI because access under the front of the keyboard is not required (as mentioned, this was a crucial measurement on the ReAPH).

A last aspect that favours implementation on the KABI rather than the ReAPH is the string properties. Guzheng and Koto string designers seek flexibility to the strings utilising materials such as silk, nylon and gut, and this is adaptive to string design considerations for bowed string instruments, whose string properties are similar.

Appendix 3

Original Patent Application –

Describing Prototype 1

Abstract

The Reverse Action Piano Harp (ReAPH)

The following proposes a replacement damping action for an autoharp, a type of fretless zither. An autoharp damping action is a spring mounted chord bar across a zither, strung in a linear fashion: thicker, steel wound bass strings to the left, and thinner, shorter treble strings to the right. Chord bars are placed on springs above the strings. When the chord bar is pressed and held in contact with the strings, felts spaced along the length of the damper bar damp strings extraneous to the desired chord; thus the only strings that are allowed to resonate are the members of the chord. The instrument is then plucked or strummed. The autoharp is a popular instrument. It is easy to learn, but is severely limited in many respects.

The development I propose is to replace the autoharp sprung chord bar action, with a reverse action damper bar arrangement that is controlled through a pulley system from one octave of a full sized piano keyboard. The position of the keyboard has been considered to produce a comfortable playing position for both hands.

The term “reverse action” refers to the fact that the dampers are in contact with the strings when the instrument is at rest, as opposed to the over-sprung action of an autoharp. The autoharp at rest places the damper bars above the strings. Conversely the ReAPH at rest places all of the damper bars in contact with the strings. The force of the springs is reversed — keeping the damper bar in continuous contact with the strings, and the piano key in the upright position. However, the springs are not fully compressed until a piano key is depressed, pulling the damper bar 0.5cm above the strings. Thus pressing a piano key does not in itself make a sound. The key is not attached to a hammer system, it simply raises the damper bar, enabling the strings to be strummed or plucked. The felts on the damper bars are not spaced to damp chords. Instead each damper bar aligns the felts with each octave occurrence of a single pitch. Each damper is then attached to the corresponding keyboard key through means of a pulley system. In order to play a D pitch, the D key is depressed, raising the D damper from all octave occurrences of the D strings. Strumming the instrument across its range then sounds all of the D pitches. More accurate strumming or plucking sounds individual pitches, yet the damping of the surrounding pitches is maintained. Lifting the finger from the key damps the D strings at once, and the instrument returns to silence, as lifting the finger on a piano returns the instrument to silence. The force of the spring also returns the piano key to the upright position.

As a playing interface, this renders the instrument far more intuitive to a trained musician, and also more versatile. It induces an intuitive connection between the activities of the left hand — playing the keyboard, and the right hand — strumming/plucking the instrument.

Description

Background Discussion

Fretless Zithers, and Related Instruments

A fretless zither is a harp type instrument (many strings). The body is usually quite flat when compared to a guitar, and smaller in size. It is usually strung with steel strings of varying gauges and lengths to produce different pitches. Fretless zithers are designed to be played either with the instrument sitting on a flat surface, or held on the lap. All harps and zithers have problems as playing interfaces for musicians. Because of this, tinkering with the interface is an integral part of the history.

Examples of fretless zithers are most commonly strung in a linear fashion, with longer and thicker gauge (usually steel wound) bass strings at the left, and shorter thinner gauge strings to the right. As the instrument is designed to be portable, it is quite small and therefore the strings are quite close together. Playing melodically on such an instrument is difficult, even with a simple diatonic tuning, when compared to a keyboard type interface or a fretboard, such as is found on a guitar. Harmonic playing is also difficult with a linear stringing. Individual string combinations must be plucked together to form chords. To easily play in this way the instrument must be much bigger, like a harp, with wider spacing between the strings. The upright position, and wider string spacing of a harp enable chord combinations to be picked accurately. Even so, smaller folk harps are commonly tuned diatonically, or in an extended diatonic tuning. The concert harp deploys a moveable bridge, such that by means of a pedal each string can be crooked [linked] to three different tunings. Thus it is a fully chromatic instrument, but essentially diatonic in its immediate playing interface. Because of this, once again, the instrument lacks versatility in some ways.

There are examples of various stringing configurations throughout zither history. The concert zither, for example integrates a fretboard section for melodic playing, with wide spacing on these strings, and strings groups of different gauge strings designed for chord work across the main body of instrument; these are closely strung as they do not need to be individually picked out. The unusual string groupings enable the instrument to be picked and strummed in combination. This is a versatile instrument, but is notoriously difficult to master. It also requires constant retuning of the chord groupings in order to achieve its full potential

Another approach is to hammer the strings individually, by hand. This is the approach used by dulcimer and cimbalom type instruments. This produces good accuracy for melodic playing, but limits the available polyphony.

Autoharps

The most common damping mechanism is deployed in all autoharp type instruments. This is spring mounted chord bar across a zither strung in a linear fashion. Simpler models are diatonic, or slightly extended diatonic, designed to play in two or three keys. Chord bars are placed on springs above the strings. When the chord bar is pressed and held in contact with the strings, felts spaced along the length of the damper bar, damp strings extraneous to the desired chord, thus the only strings that are allowed to resonate are the members of the chord. The damping mechanism means that this instrument can be rhythmically strummed as well as plucked. A smooth change of chord is accomplished by allowing the first chord bar to rise, whilst pressing the next chord bar against the strings.

The autoharp has always been a popular instrument. It is easy to learn, but is severely limited in many respects. Since the technology of the ReAPH damping action is designed to replace the autoharp chord bar damping action, the limitations of the original system are now discussed in detail.

Perhaps the most disappointing aspect of the autoharp action is that it remains a very limited instrument even in the area of its supposed main strength, rhythmic harmonic playing, designed for accompaniment. The reason for this is obvious, a 12 bar autoharp will cover the most significant triads in three different keys, it will also provide some dominant sevenths. This limits the instrument very strictly to certain genres of music. It is good for simple song based material, or some forms of folk. There are a significant number of attempts to extend the chord range of this instrument. Commonly 21 or 24 bar chromatic autoharps are available. This certainly extends the modulatory capacity of the instrument. Yet the range of chord available remains strictly limited. Generally chords are triadic in nature, and these are by no means complete. The instrument remains incapable of supporting modal thinking — integral to many Western folk music traditions. It is also incapable of easily integrating into Jazz traditions, and totally incapable of integrating into Western classical traditions. It is true that many attempts have been made to extend the chord range of the instrument, in order to accomplish this. All of these take the approach of further complicating the chord bar systems, including complex combinations of chord bars. All of these systems are possible to learn, but the interface presented to a musician becomes very complicated indeed and quite difficult to play. This goes against the original ethos of the instrument. Furthermore, the interface remains musically un-intuitive. Learning a guitar or a piano necessarily requires that the player acquire some music theory skills — whichever genre of music is attempted. Generally speaking, intuitive grasp of functional harmony and melodic structure improve as the player improves. This is true at both an intellectual, and instinctive level. This is not however, true of the autoharp where the actual playing of the instrument remains quite disconnected from aspects of reading or understanding of what is being played. The equivalent activity is to continuously redesign the interface — changing around chord bar arrangements and designing specific chord bars for different musical situations. This develops a cerebral sense of music theory, but not an instinctive sense of theory in practice. It also renders the instrument difficult to bring to ensemble situations. An instrument that needs to be continuously rebuilt in order for the musician to contribute effectively is by no means ideal.

If the instrument remains harmonically basic, then melodically it is even more unsatisfactory. Here a method for achieving clean melody playing is described. [17]

> (Beginning with the editor's note)
> "As you know the autoharp is based entirely on chords and all melody notes are derived by using different chords for each note. In contrast a piano allows one to play a continuous chord with one hand while playing a melody "over" that chord with the other hand. Up until now, it hasn't been possible to achieve the

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[17] The Autoharp Owner's Manual p.66. Ed Orthey. (article by Carey Dubbert) Pub. Mel Bay 2000

same effect on the autoharp — that is, not until Carey Dubbert and his special bars. ...

(Dubbert)
The two special chord bars explained here provide a compromise between changing chords whenever needed to provide a given melody note and using open chording so as not to have to change the chord to provide a given melody note. With the first method, the chord structure of the piece is altered, and the chords usually progress much faster than would be called for by the piece. This can tend to sound choppy and fatigue the ear. The second method allows keeping the chord progression that may be called for by the piece and still have the ability to play melody notes outside the current chord. The two special bars are best placed at the top and bottom of the harp where the thumb ... and little finger can most easily press the bars. ...

The following illustration is my D autoharp. ... The special bars target one specific key and work as a pair in that key. My thumb presses the number 1 bar, and my little finger presses the number 2 bar. In the adjacent keys [subdominant and dominant], one of the special bars will be applicable and the other occasionally. The bars are cut such that one bar accounts for every other note in the key selected, and the other bar allows for the other (also every other) notes in the selected key. Pressed at the same time, all the notes would be damped in the upper couple of octaves. ...

The bottom octave has all the felt cut out on bars, allowing the bass strings to vibrate and sustain. ... A chord is strummed or picked with a standard chord bar, which includes notes in the lower octave of the harp (although other notes may well be sustained). Then, after letting up on the original bar, melody notes can be picked cleanly going back and forth on the two special bars without altering the basic sustaining chord."

All of this is to achieve the correct damping to play a simple melody. The instrumental interface is effectively compared in the quoted editor's note to the ease with which this is accomplished on a piano.

All of this illustrates that whilst both advanced harmonic and melodic playing can be accomplished on this instrument, the interface for advanced players remains highly esoteric, and ungainly in practice. One effect of this is that skills developed in learning the autoharp are not readily transferable to other musical instruments, and conversely, the instrument is unattractive to accomplished musicians generally, as its limitations are immediately apparent. In general the instrument has never made an impact in the mainstream of Western musicianship, and its evolution is rather isolated and specialized.

Conceptualising the Reverse Action Piano Harp (ReAPH)

The development I propose is to replace the autoharp sprung chord bar action, with a reversed action damper bar arrangement that is controlled through a pulley system from one octave of a full sized piano keyboard. The integration of a keyboard with this instrument is not in itself a new idea. I have been able to identify several historical examples of instruments that attempt this[18]. All of them are fundamentally different from

[18] www.fretlesszithers.com: for example The Celestophone, patent 1912, The Marxophone, The Supertone Phonoharp, The Piano Mandolette, Menze's Piano Zither, patent 1898, The Dolceola.

the ReAPH in conception and construction. The keys on these instruments have nothing to do with the action of the damper bars. Instead, each piano key operates a hammer of some sort. The conception is, as with other keyboard instruments — one key depressed will sound one string on the instrument.

Similarly, a reverse action is not in itself a new idea, a similar system is integral part of piano design. I have not been able to find a single example of a fretless zither conceived in this way during its evolution, however.

The term reverse action refers to the fact that the dampers are in contact with the strings when the instrument is at rest, as opposed to the over-sprung action of an autoharp. This is a fundamentally different conception of the instrument. In the autoharp at rest, all of the damper bars are raised by the springs, above the instrument. Conversely the ReAPH at rest places all of the damper bars in contact with the strings. The damper felts do not damp chords. Instead each damper bar aligns the felts with each octave occurrence of a single pitch. Each damper is then attached to the corresponding keyboard key through means of a pulley system. The original autoharp springs are utilized, but reversed — keeping the damper bar in continuous contact with the strings, until a key is depressed. Thus pressing a piano key does not in itself make a sound. The key is not attached to a hammer system, it simply raises the damper bar, enabling the strings to be strummed or plucked. Thus, even though the instrument is differently conceived, the effect is that the interface has some similarities to the original autoharp interface. In order to play a D pitch, the D key is depressed, raising the D damper from all octave occurrences of the D strings. Strumming the instrument across its range then sounds all of the D pitches. More accurate strumming or plucking sounds individual pitches, yet the damping of the surrounding pitches is maintained. Lifting the finger from the key damps the D at once, and the instrument returns to silence, as lifting the finger on a piano returns the instrument to silence.

As a playing interface, this renders the instrument far more intuitive to a trained musician, and also more versatile. It induces an intuitive connection between the activities of the left hand — playing the keyboard, and the right hand — strumming/plucking the instrument. Let us consider the change produced from the points of view of harmonic and melodic playing.

Harmonic playing is greatly enhanced by this system. In fact it is possible to play any chord, and to change simply between them as on a keyboard. Chord change is more fluid, because common notes can be held down over the change. Moreover individual notes can be added and subtracted to a chord during rhythm playing producing far more subtle shading. Suspensions are easy to create, and the resolutions are fluid. The instrument is capable of playing supporting rhythmic harmony, found in all folk traditions easily. Additionally, and importantly for these traditions, it is possible to take a modal approach to accompaniment, generating drone notes, and secundal and quartal chords. Fluid pentatonic or whole tone scales can be generated. This instrument is also capable of performing a rhythmic/harmonic function within a jazz ensemble. A good knowledge of four and five note substitutions and their inversions on a keyboard is immediately transferable to a versatile strumming/picking environment; this is limited only by the knowledge and skill of the player. Thus 9ths, 11ths and 13ths are easily created. 5ths can be raised or flattened — the full chromatic array is available.

Melodically the instrument is also considerably enhanced. The ability to produce a single line of melody develops intuitively with practice. Depressing one key with the left hand enables the right hand to strum every octave occurrence of the desired pitch. Strumming becomes isolated to single pitches through practice, and this process is highly intuitive in development.

One difficulty with melodic playing is that because the keyboard is only one octave, the left hand must continuously transpose the melody to remain within this range. In practice I have found that an ability to accomplish this at sight develops quite quickly. However a simple notation system can help a less skilled musician to overcome this. Two staffs of Western notation are presented to the musician to read at sight. The top line notates the melody; the lower line, which can be in bass or treble clef, renders the pitches of the melody to a single octave. This mimics piano notation rather precisely, and is easy for a pianist/keyboard player to read.

Combinations of melodic and harmonic playing can be accomplished. A skilled improviser at the piano can very quickly transfer to this instrument.

Melodically, the instrument still has limitations when compared to a guitar, or any continuous tone instrument. It is difficult to produce ornamentation — turns and trills are not easy. However, neither are these easy on a harp. All musical instruments are a compromise in one way or another.

Technical Description

Piano Keyboard Mechanism

One octave of full size piano keys is fixed in the position illustrated in figures 1 and 2. This playing position is carefully considered. Firstly comfortable access must be provided for the left hand to depress the keys, whilst the right hand is able to strum and pluck the strings. It is for this reason that the keyboard housing raises the keyboard 10.3 cm from the strings; this enables the right hand to move freely underneath the left hand. The piano keyboard is also placed slightly overhanging the top rail — on the right hand side of the instrument. The lever action overhangs the dead pin block by approximately 9 cm, thus lengthening the instrument by this amount. Again, this allows comfortable access for the strumming hand. The instrument is played on its side, the strum position more resembling a guitar than the traditional upright position of an autoharp.

From a mechanical point of view the placement of the left side of the keyboard housing slightly to the left of centre of the instrument, enables a series of eyes (described below within the pulley system) to be attached directly to the inside lower left side of the keyboard housing, such that they are centred, and in line with the final set of damper bar pulley-wheels. The entire pulley system is covered by the keyboard housing.

The prototype has utilized one octave of a keyboard, cannibalised from a four octave MIDI keyboard. Each key in the octave is attached to a wooden rod; the wooden key rods extend beyond the axis point. Depressed keys therefore produce a lever action. The ends of the pulley strings are attached to the ends of each of the wooden key rods by means of pegs. Piano key travel is restricted to 13mm by a wooden block placed across the front of the keyboard housing, covered in craft foam.

Key Crooks

(For Diatonic, and Extended Diatonic Instruments Only)

Diatonic, and extended diatonically tuned autoharps will have fewer damper bars. An extended diatonic autoharp, such as the one used in the prototype, tunes its strings to the following pitches.

C, C#, D, E, F, F#, G, A, B.

Thus, this harp will require only nine reversed damper bars, with pulley strings attached to the appropriate keys. The remaining piano keys can be crooked to the keys either side, by means of a moveable crook placed on the underside of the wooden key rod beyond the pulley string peg. This is shown in figure 6. The extended diatonic tuning allows the instrument to play in C, G and D majors. To play in A major, for example, all G strings are tuned to G#, and the G# piano key is crooked to the G piano key. The G# key will then operate the G pulley string system. As all the G strings have now been tuned to G# this is the pitch that will sound. This crooking system enables the maximum flexibility possible within the system, as the instrument can be tuned relatively quickly to play in any key.

Fully chromatic harps will have twelve damper bars, and will therefore not require key crooks.

Pulley Mechanism

The pulley mechanism is illustrated in cross section in figures 3.1 and 3.2. The two illustrations show the mechanism at rest with the damper in contact with the strings (3.1) and the key depressed, lifting the damper from the strings, acting against the force of the springs (3.2). When the key is released, the force of the springs returns the damper to its rest position in contact with the strings. It also returns the piano key to its rest position. The series of turns taken by the pulley strings allows the keyboard to be placed in a comfortable playing position with the left hand, whilst at the same time maintaining reasonable clearance for the right hand to move under the left hand and strum/pluck the entire width of the instrument just above the midpoint of the strings.

The number of pulley strings will depend on the tuning of the instrument. Fully chromatic harps will require twelve pulley strings, attached to all twelve wooden key rods. The harp used in the prototype, and drawn in the diagrams, is an extended diatonic harp. It produces nine individual pitches and therefore has nine pulley strings, attached to nine of the wooden key rods, and nine damper bars at each end. Other keys are utilized by means of the key crook system described above.

In all, each pulley string is constrained through four turns in the working prototype.

Firstly a tendency to pull the key mechanism to the left is constrained by placement of a series of pulley-wheels in line with each wooden key rod, beneath the peg hole. Subsequently a lateral series of pulley-wheels, placed on a lateral bar across the instrument, turns the pulley strings through 90 degrees translating the upward motion of the lever into a force pulling along the length of the instrument. A further series of pulley-wheels is positioned after the back lateral bar to ensure parallel movement to the keys. The pulley strings then travel at varying angles to a series of eyes located on the inside left of the underside of the piano keyboard housing. Eyes are used at this point, rather than free running pulley-wheels for several reasons. Firstly there is very little space to add a further series of pulley-wheels on the inside of the keyboard housing, and I have not been able with my current level of skills and knowledge of materials to think of a way of miniaturizing this sufficiently. Secondly, the angle shifts are all obtuse angles (a correction rather than a full turn through 90 degrees) therefore the resulting friction caused by use of eyes rather than pulley-wheels has proved minimal. Thirdly, the angle shift of the pulley string here is not only a correction from the diagonal such that all pulley-strings now travel in a line, down the length of the instrument, it also shifts each of the pulley-strings to travel at a slight downward angle (to the final lateral set of damper bar pulley-wheels). In practice the use of eyes at this point has proved robust, and may be retained in the second prototype. The angles are shown in figures 3.1 and 3.2 and in figure 4. Figure 4 shows that the nine pulley strings enter the series of eight eyes at different points, and from different angles (twelve pulley strings and eleven eyes for a chromatic harp). Not shown is the fact that the pulley strings exit this system at corresponding intervals in the series of eyes, ensuring maximum separation between the threading of the pulley strings, as they travel in line to the final series of pulley-wheels above the damper bars, and also optimal exit angles to the damper bar pulley wheels. The damper bar pulley-wheels turns the pulley strings through an angle of just over 90 degrees downwards (towards the instrument), translating the motion along the length of the instrument into an upward force.

The end of the pulley string is attached to the middle of the damper bar. This is shown in figure 5.1. An improvement to this mechanism is also illustrated (figure 5.2), to be implemented in the second prototype. Force exerted on the middle of the damper bar only, on the first prototype, results in slightly uneven lifting at the edges of the damper bars. It is planned to attach the end of each pulley string directly to the damper bar pulley-wheel at the centre point, such that as the key is depressed, a sufficient length of pulley-string is free to unroll from the pulley-wheel. The damper bar pulley-wheel is lengthened and pulley strings similarly attached to the damper bar at two points equidistant from the midpoint of the damper bar. This will prevent one end of the damper bar lifting before the other. It will also have another benefit, allowing the entire mechanism to be disassembled more quickly and easily. It is envisaged that the diameter of the damper bar pulley wheel will have to be increased.

Pulley-Wheels

The pulley-wheels are made using two diameters of cylindrical metal bar, the outer running freely over the inner bar, which is lubricated. These can then be cut to very short lengths, or to a long length, such as with the back lateral bar, which provides space for twelve pulley-wheels to run over it.

Tension on the Pulley Strings

Tension on the pulley strings must be equalized, such that each of the piano keys feels even to the player. The player is able to adjust these individually using the pegs at the ends of the wooden key rods over the dead pin block. This has proved robust on the first prototype. It is planned that hook and eye attachments, just before the damper bar pulley-wheels, will enable easier disassembly, and independent disassembly of the keyboard and damper mechanisms.

Pulley String Material

Waxed linen thread is used on the prototype. This material is stretch resistant, and has properties of retaining shape through the turns. It has proved a robust material through several months of use on the first prototype.

Damper Bar Mechanism

The damper bar is reverse sprung. Two springs are placed on the damper bar, dividing the length of the damper bar into three. The springs fit flush over cylindrical metal bars mounted on the damper bar at these points. The top ends of the metal bars protrude into a drilled hole in a fixed wooden block mounted immediately above these points. Washers are mounted on the underside of the wooden block, whose diameters are greater than the cylindrical metal bar, but less than the diameter of the springs. The distance between the top of the damper bar and the block is 1cm. This distance places the springs under partial compression. The resulting force pushes the damper bar downwards, such that at rest, all the felts on the dampers are in contact with the strings. When a piano key is depressed the force acts against the springs, lifting the dampers 0.5cm from the strings, and compressing the springs completely. The cylindrical metal bar moves freely through the washer, protruding further up into the drilled hole, whilst the surrounding spring is compressed against the washer. The felts on the damper bar are spaced such that each occurrence of a single pitch is damped, at each octave, on a single damper bar. Therefore, for example, playing D on the piano keyboard with the left hand, lifts the damper bar 0.5 cm from the strings. The spacing of the felts enables any D string to be sounded through a strum or pluck, but all other notes will remain damped, irrespective of the accuracy of the strum. Playing D F# A with the left hand lifts the dampers from all octave occurrences of a D major chord. Strumming the instrument then produces a D major chord. When the piano keys are released the force of the springs simultaneously pushes the damper bars downwards, damping the strings, and returns the piano keys to the upright position.

Felts

I have used the term “felts” because this is the common technical term used in autoharp manuals. In fact the material that I have used on the prototype is craft foam. I used this because it was readily available, cheap, and easy to cut accurately for purposes of continuous experimentation upon the prototype. Felt has been used on autoharps since their inception. I had confidence that foam had the right damping properties, but thought that it might quickly wear out, and that I would eventually have to replace the foam-felts on finished damper bars with approved autoharp material. In fact the foam has proved extremely robust through hours of playing, and recording the prototype instrument, and I don’t see a reason to change it. I therefore include it in the patent application.

Listing of Drawings and Descriptions

Key to Drawings

(a) Toe pin block
(b) Dead pin block
(c) Bass rail
(d) Top rail
(e) Keyboard
(f) Wooden key rod
(g) Damper bar
(h) Spring mounting
(i) Peg
(j) Pulley string
(k) Keyboard housing
(l) Back lateral bar (pulley-wheel)
(m) Damper bar pulley-wheel
(n) Pulley-wheel
(o) Eye
(p) Pivot point
(q) Spring
(r) Washer
(s) Damper bar felt
(t) string
(u) Key crook
(v) Key depressed
(w) Damper bar raised

Figure 1

Drawing 1/3 of actual size from above the instrument.
This shows:

1. keyboard placement and orientation.
2. Wooden key rods extending over the dead pin block.
3. Maximization of the strumming surface when compared to an autoharp.
4. Pulley system enclosed within keyboard housing.

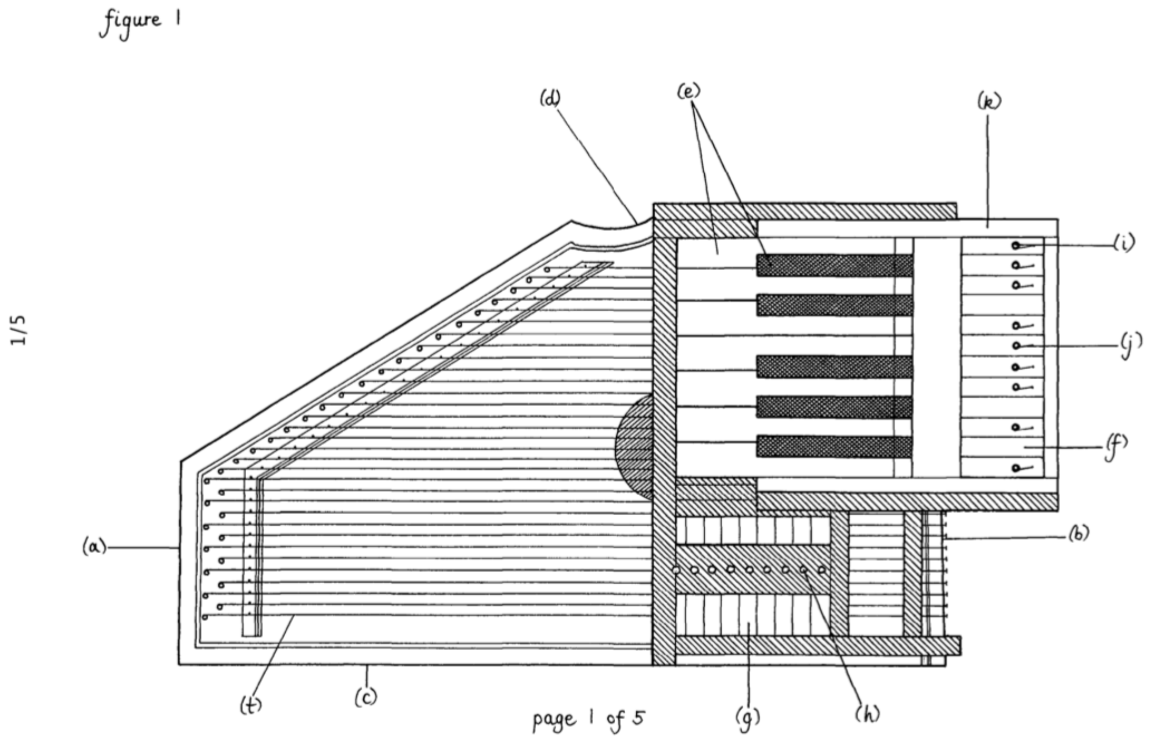


Figure 2

Drawing 1/3 of actual size side view of the instrument.
This shows:

1. Keyboard height of 10.3cm from the strings, allowing the left hand to play the keyboard and the right hand to strum underneath.
2. Wooden key rods extending over the dead pin block.
3. Maximization of the strumming surface when compared to an autoharp.
4. Pulley system enclosed within keyboard housing.

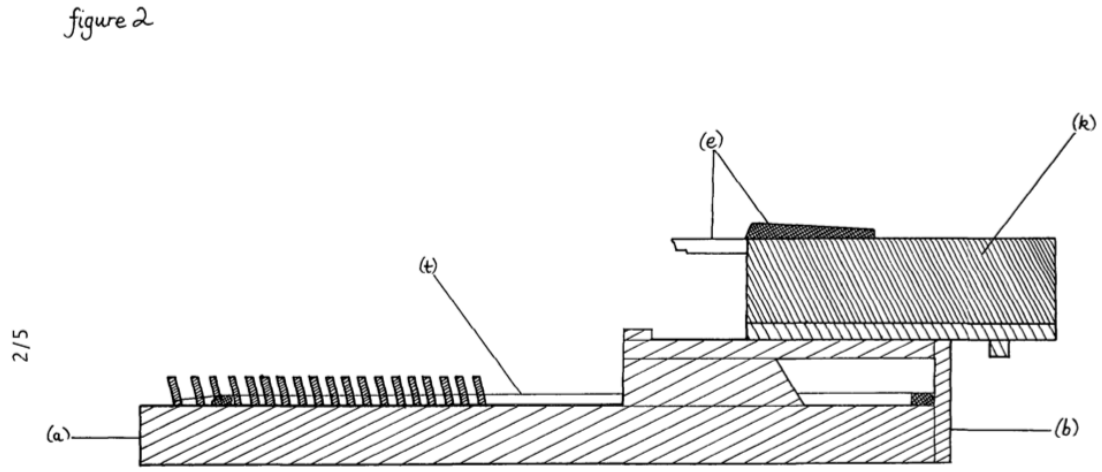


Figure 3.1

Drawing 1/3 of actual size, cross section.
Side view of the pulley system, piano key at rest.
This shows:

1. White piano key attached to wooden key rod. A black piano key is shown as background, to orient the observer.
2. Peg and hole system at the far end of the wooden key rod.
3. Pulley string, wound round the peg, and descending through the pulley string hole.
4. Pulley string constrained through three free running pulley-wheels at differing orientations.
5. Pulley string passing through eye system, altering angle to damper bar pulley-wheel.
6. Damper bar pulley-wheel and damper bar at rest. Partially compressed spring (not shown) maintains contact with the string.

figure 3.1

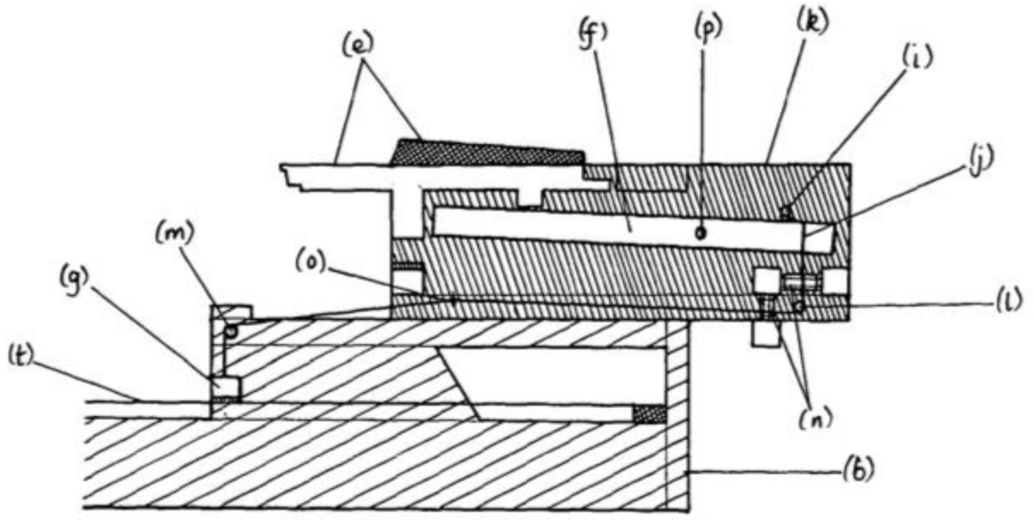


Figure 3.2

Drawing 1/3 of actual size, cross section.
Side view of the pulley system, piano key depressed.
This shows:

1. White piano key attached to wooden key rod (depressed). A black piano key is shown as background, to orient the observer.
2. Peg and hole system at the far end of the wooden key rod.
3. Pulley string, wound round the peg, and descending through the pulley string hole.
4. Pulley string constrained through three free running pulley-wheels at differing orientations.
5. Pulley string passing through eye system, altering angle to damper bar pulley-wheel.
6. Damper bar pulley-wheel and damper bar raised from the string. Spring (not shown) is at full compression.

figure 3.2

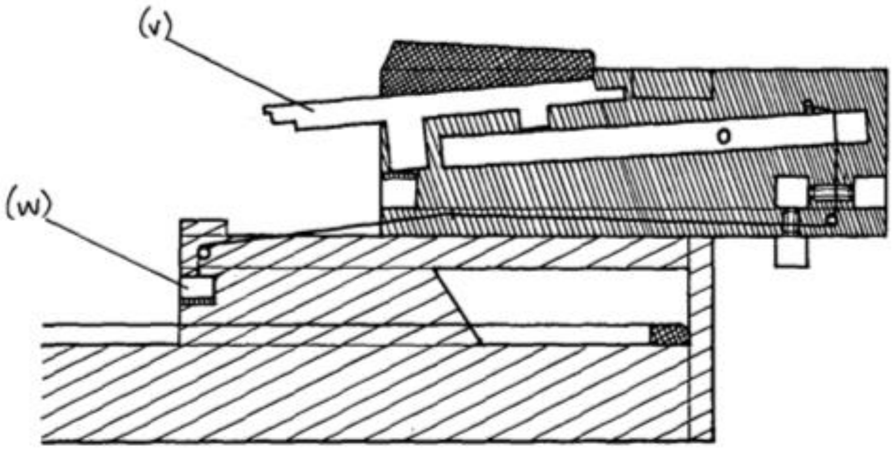


Figure 4

Drawing 1/3 of actual size, cross section
Pulley system from above. This shows the angles corrected by the series of eyes, such that pulley strings travel in line to the damper bar pulley-wheel.

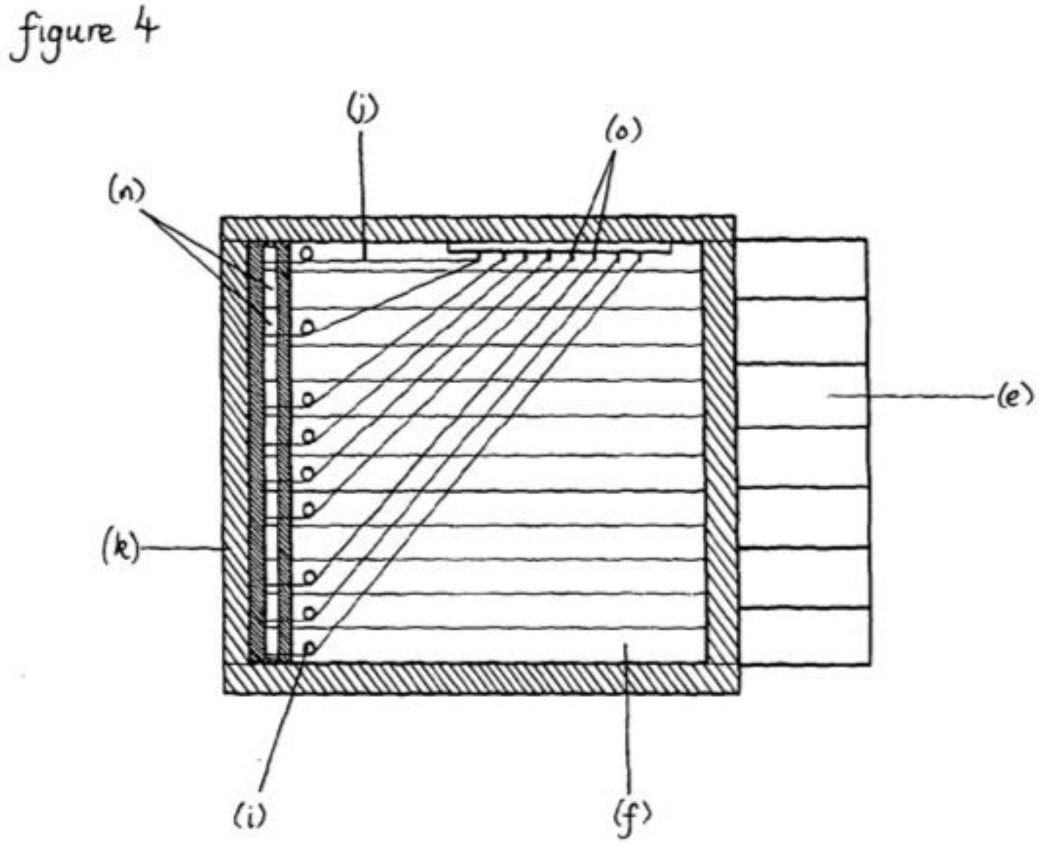


Figure 5.1

Drawing 1/2 of actual size showing damper bar spring mechanism and damper bar pulley-wheel and pulley string.

figure 5.1

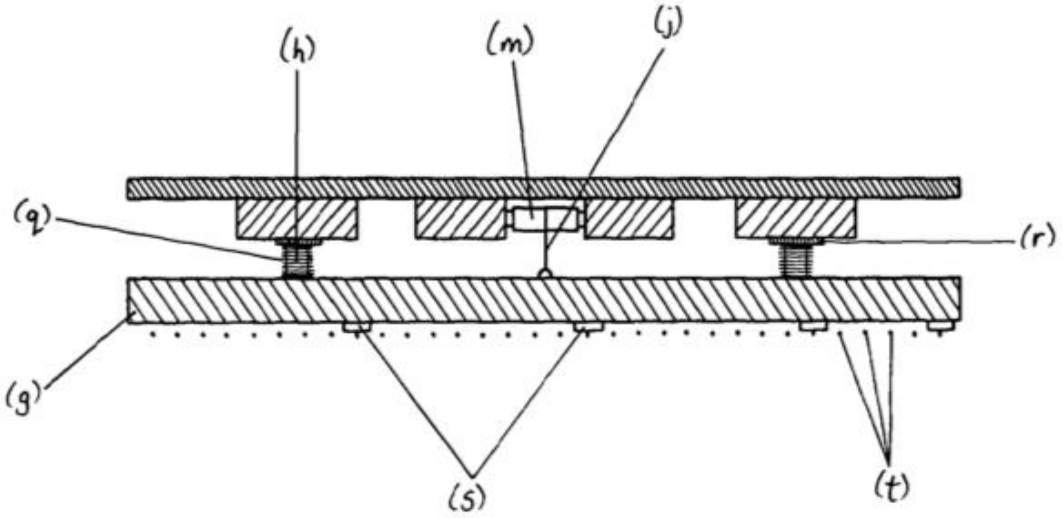


Figure 5.2

Drawing 1/2 of actual size showing damper bar spring mechanism and proposed damper bar pulley-wheel improvement. This should prevent uneven lifting at the ends of the damper bar, caused by lifting from the centre point only. It is envisaged that the diameter of the pulley-wheel will have to be increased.

figure 5.2

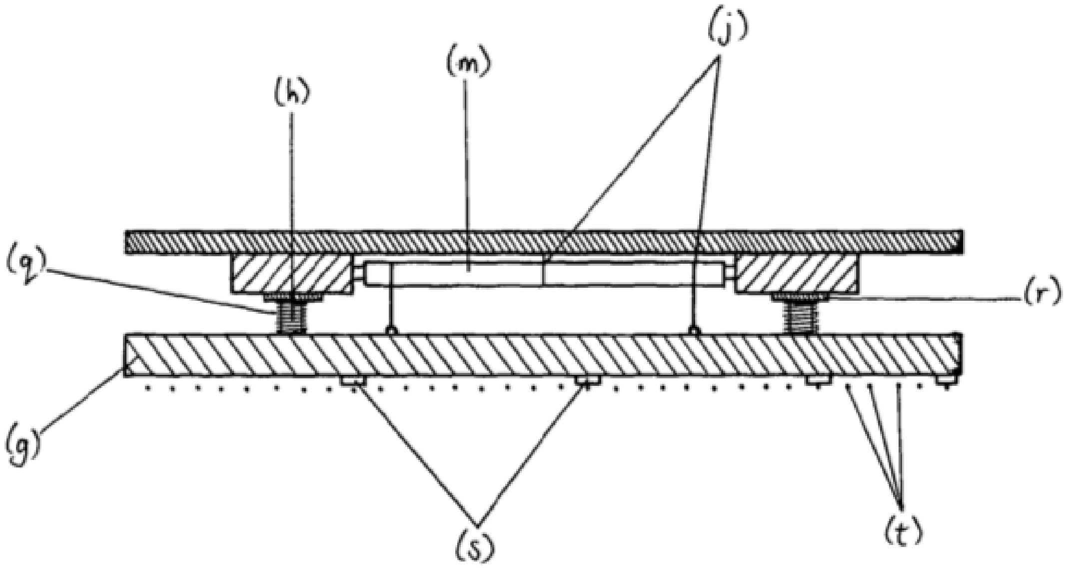
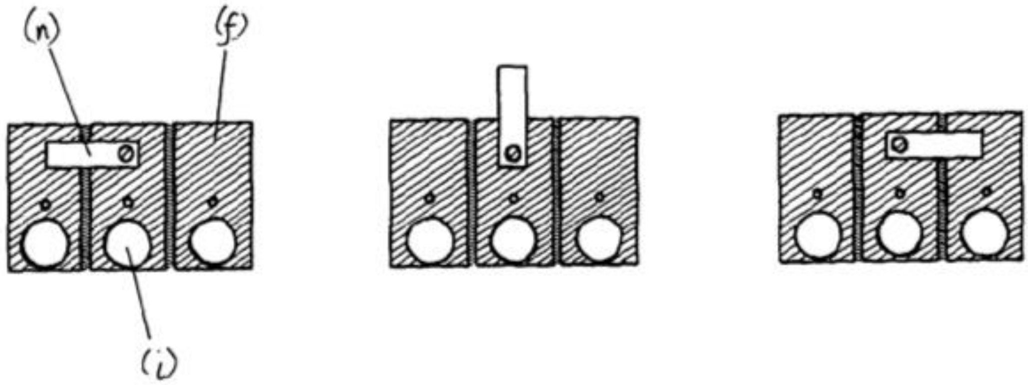


Figure 6

Actual size drawing, showing the key crooking mechanism, allowing one piano key to be crooked to either of the adjacent keys. (Diatonic and extended diatonic harps only).

figure 6



Appendix 4

Manual

1. Lower Action

1.1 Chord Bar Comb

1.2 Action Platform

1.3 Bass Chord Bar Assembly

1.4 Toe Cross-Spar

1.5 Dead Cross-Spar

1.6 Treble Chord Bar Assembly

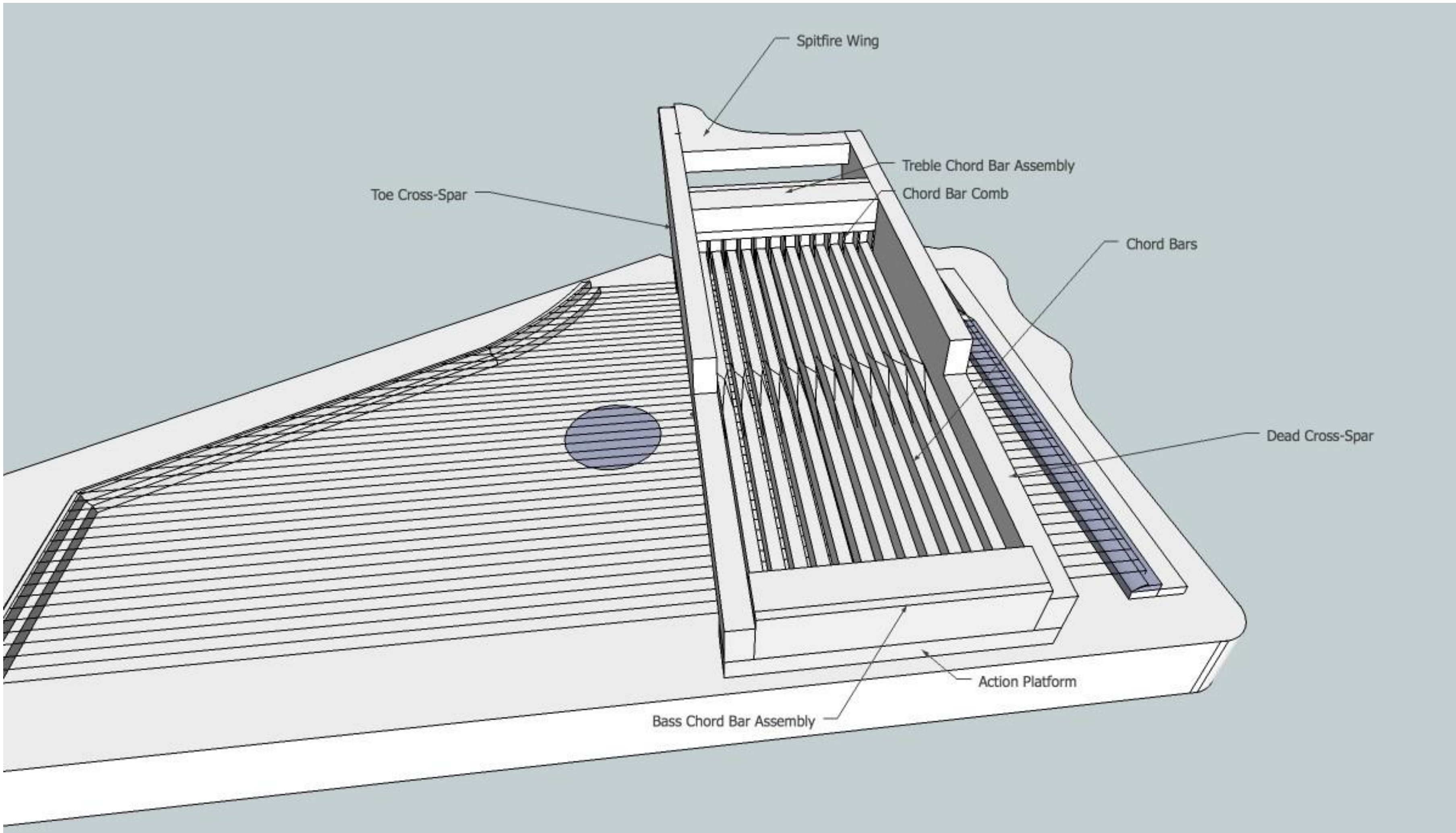
1.7 Spitfire Wing

1.8 Attach to Harp

1.9 Chord Bars

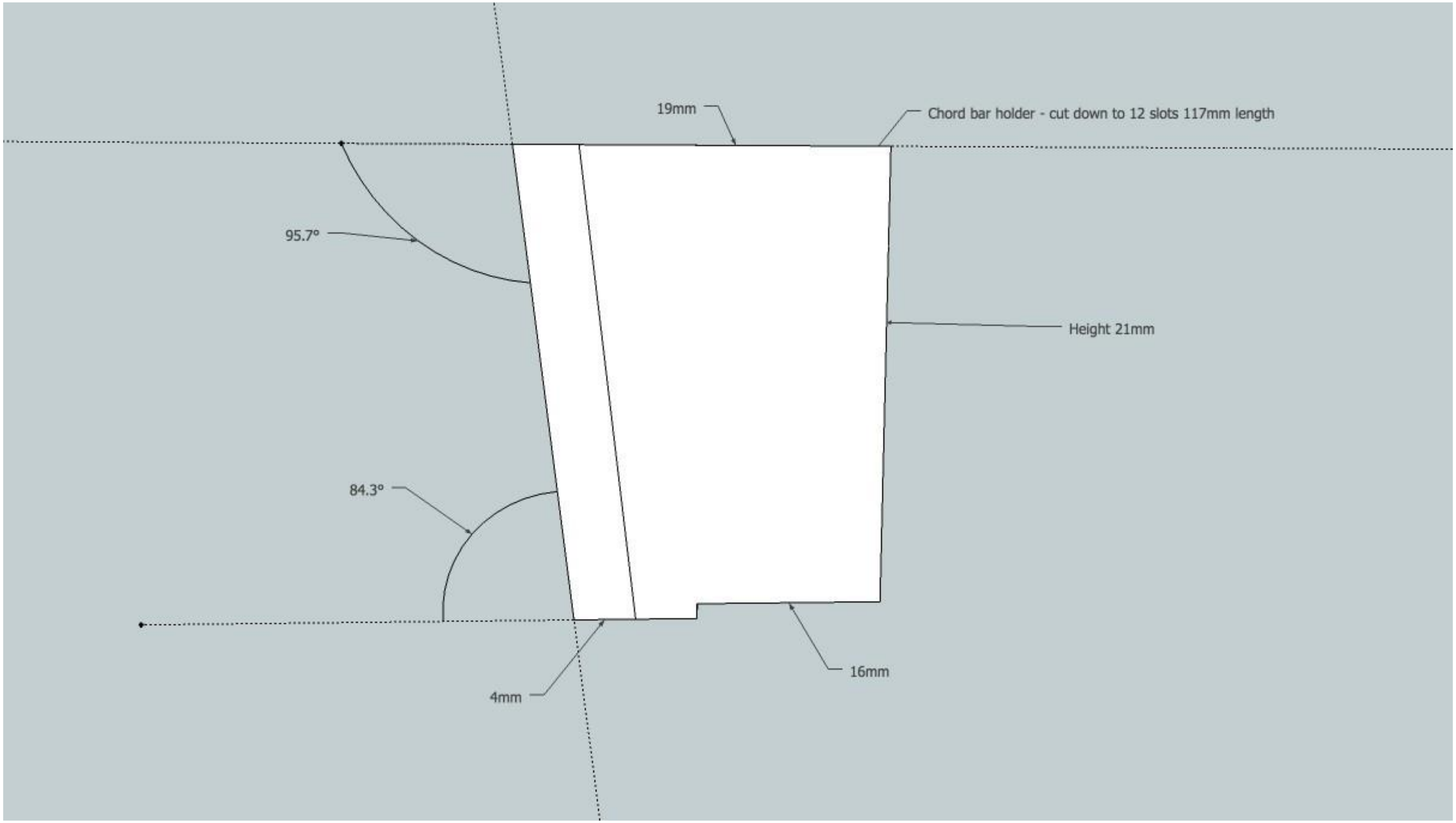
Photographs of previous prototype and discussion of difference

1. Lower Action

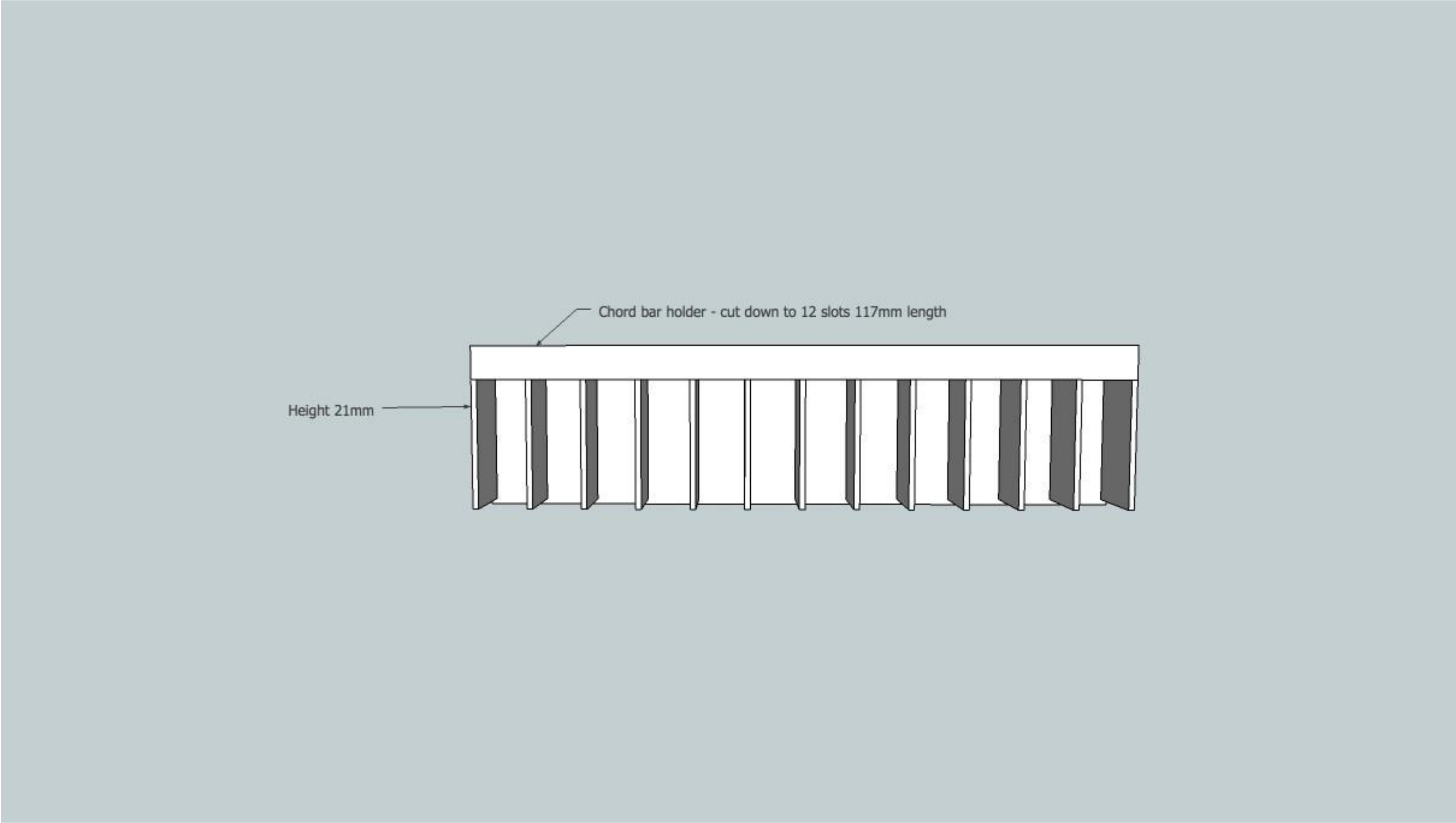


1.1 Chord Bar Comb

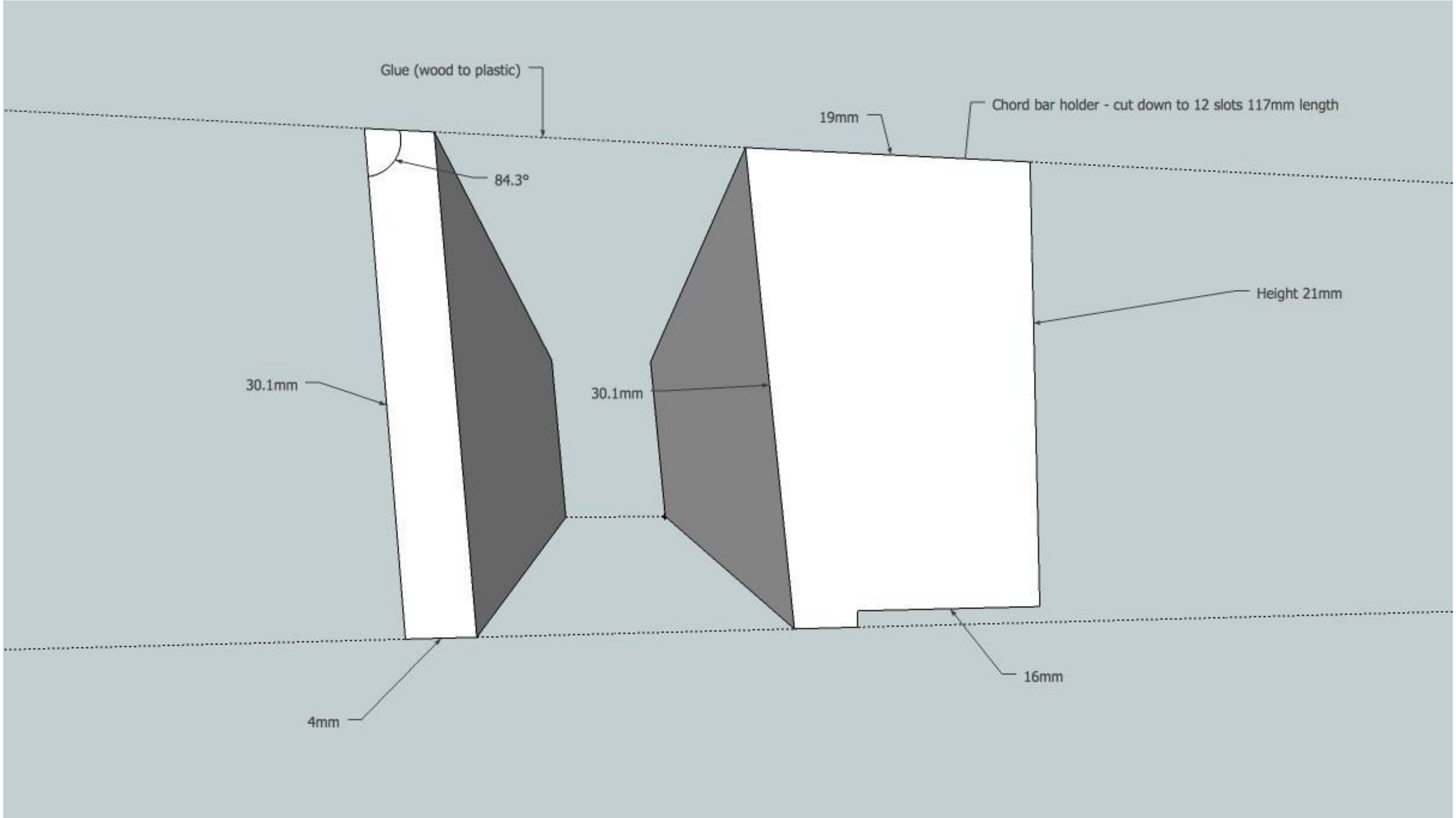
Chord Bar Comb – Side



Chord Bar Comb – Front

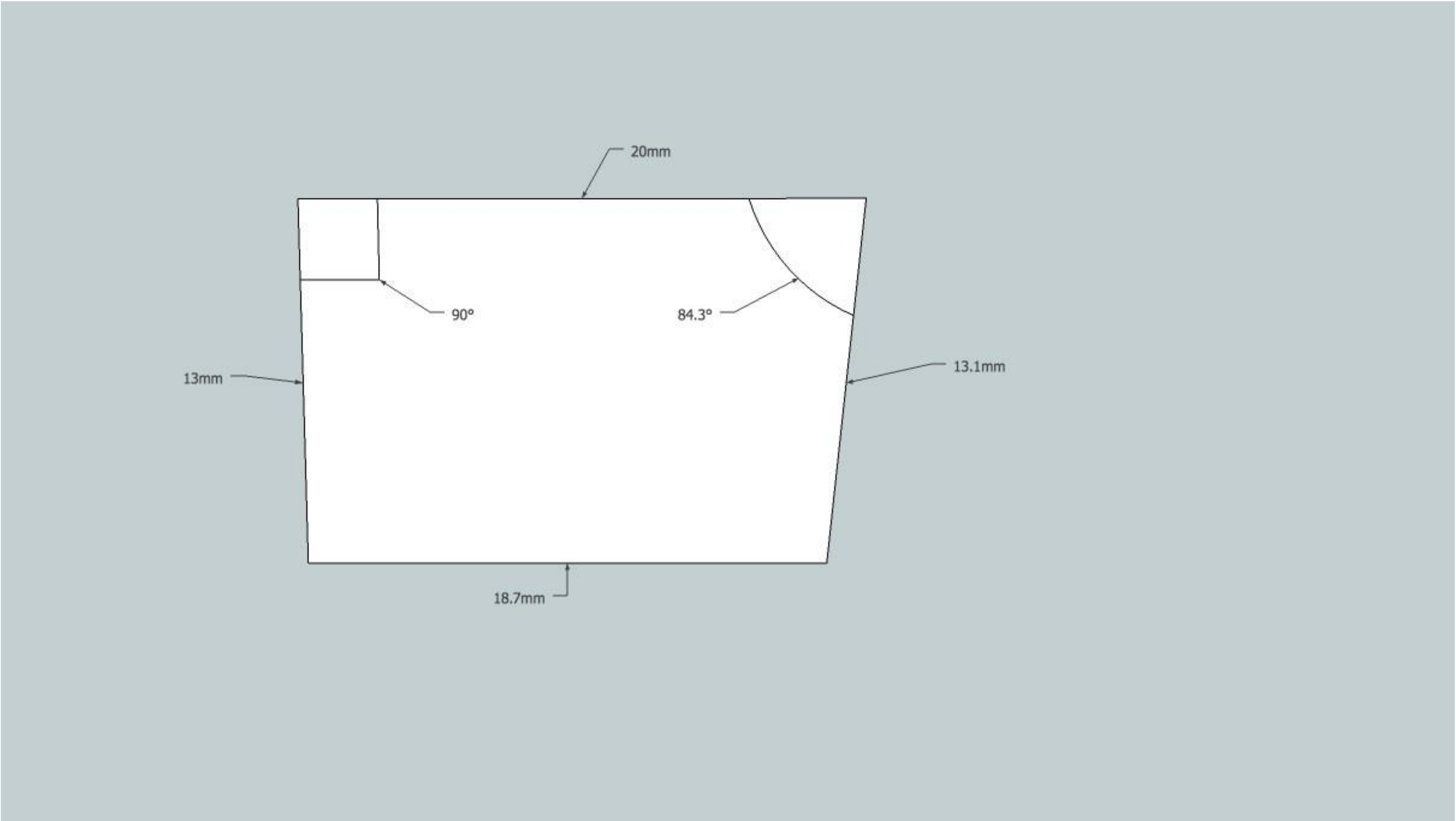


Chord Bar Comb – Separated

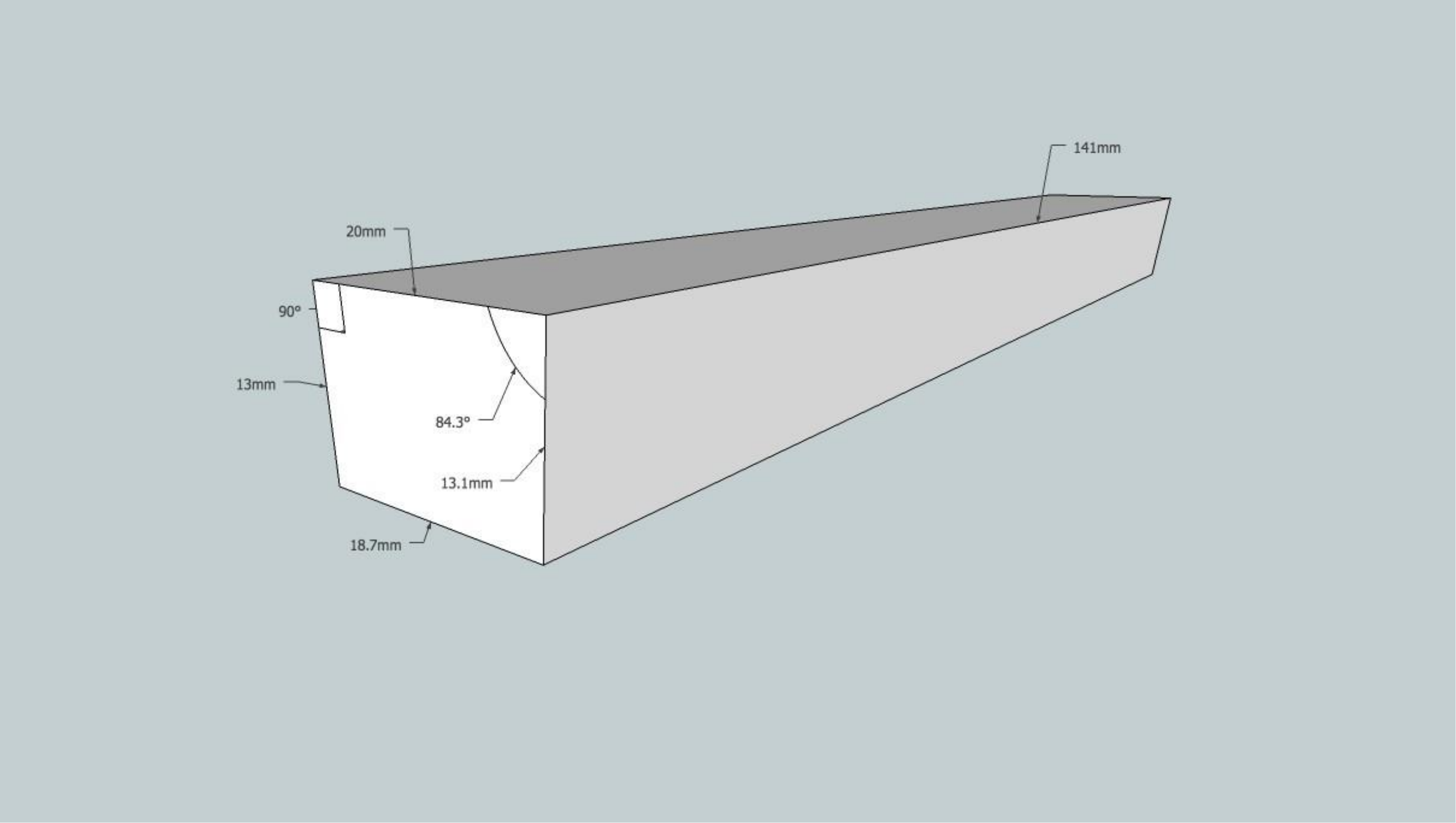


1.2 Action Platform

Action Platform – Side

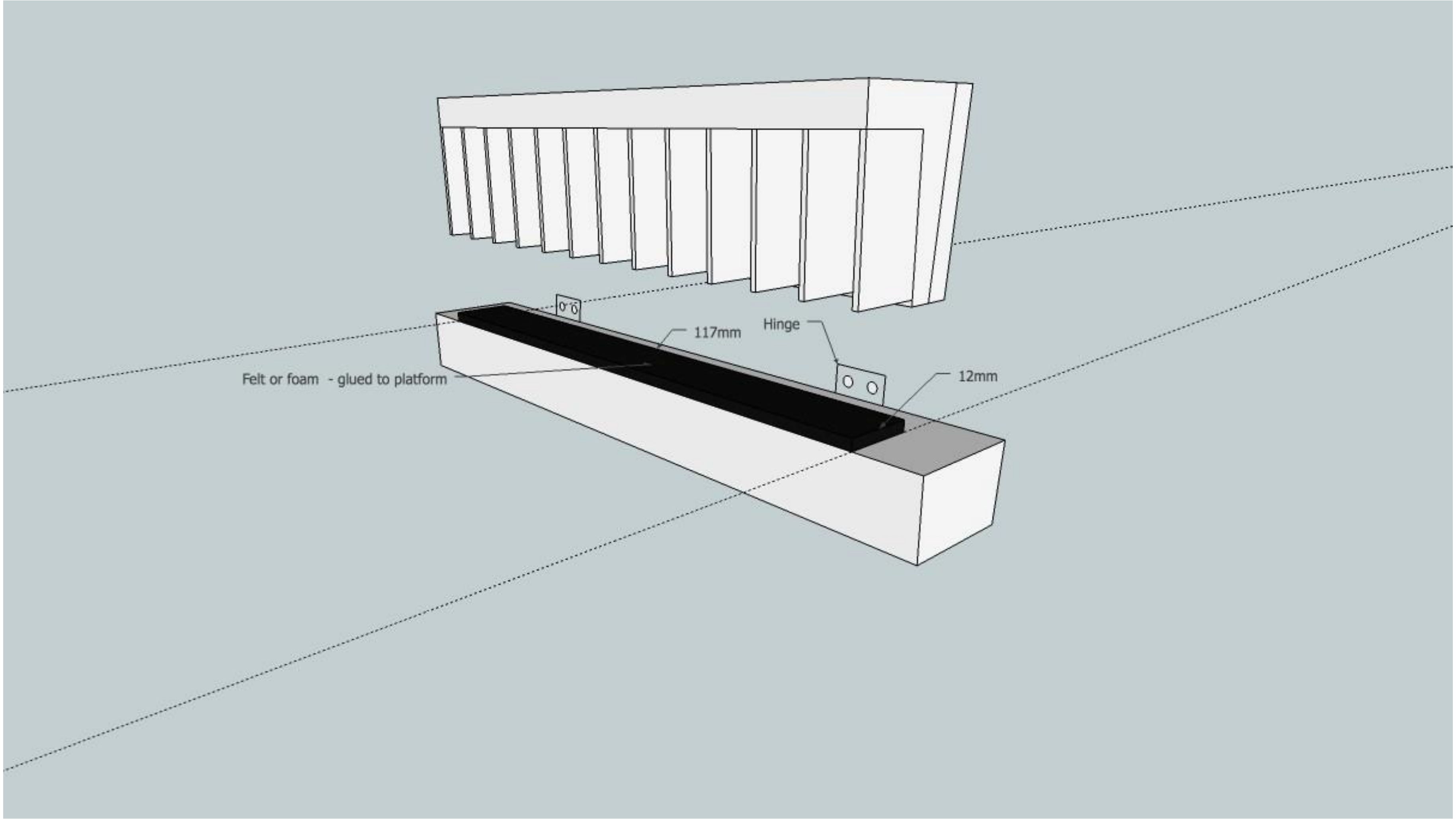


<u>Action Platform – Length</u>

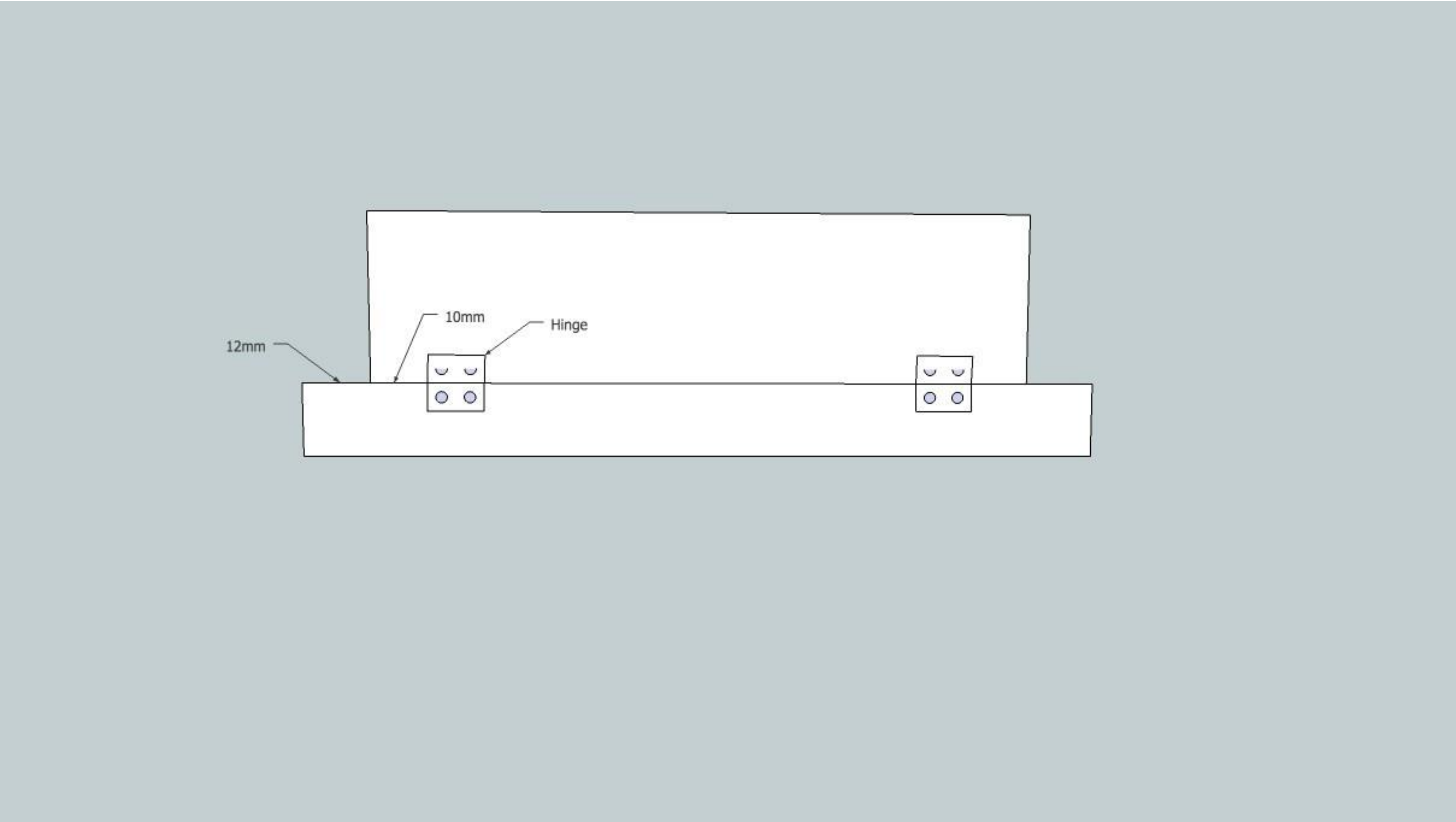


1.3 Bass Chord Bar Assembly

<u>Bass Chord Bar Assembly – Front</u>



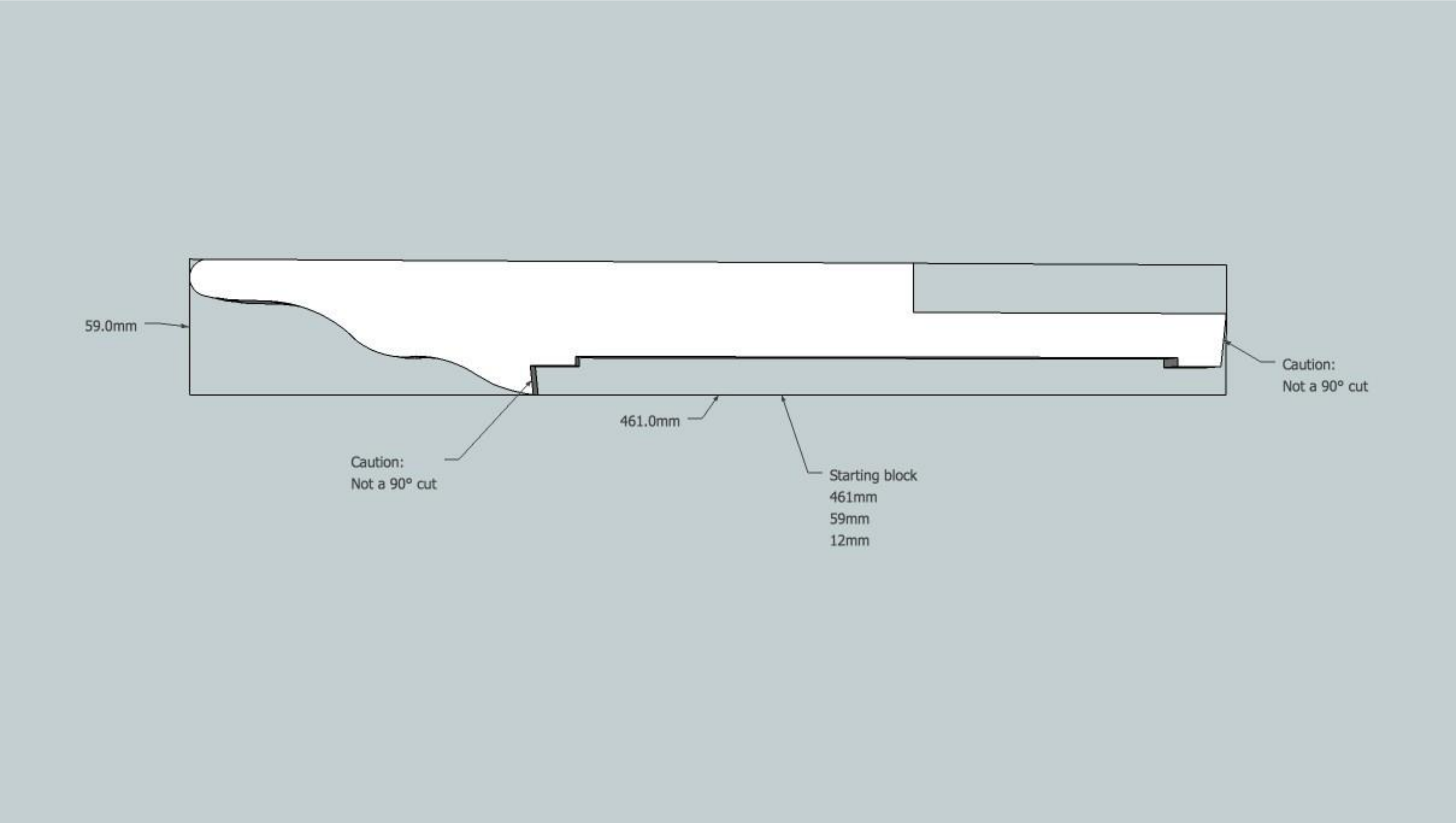
<u>Bass Chord Bar Assembly – Back</u>



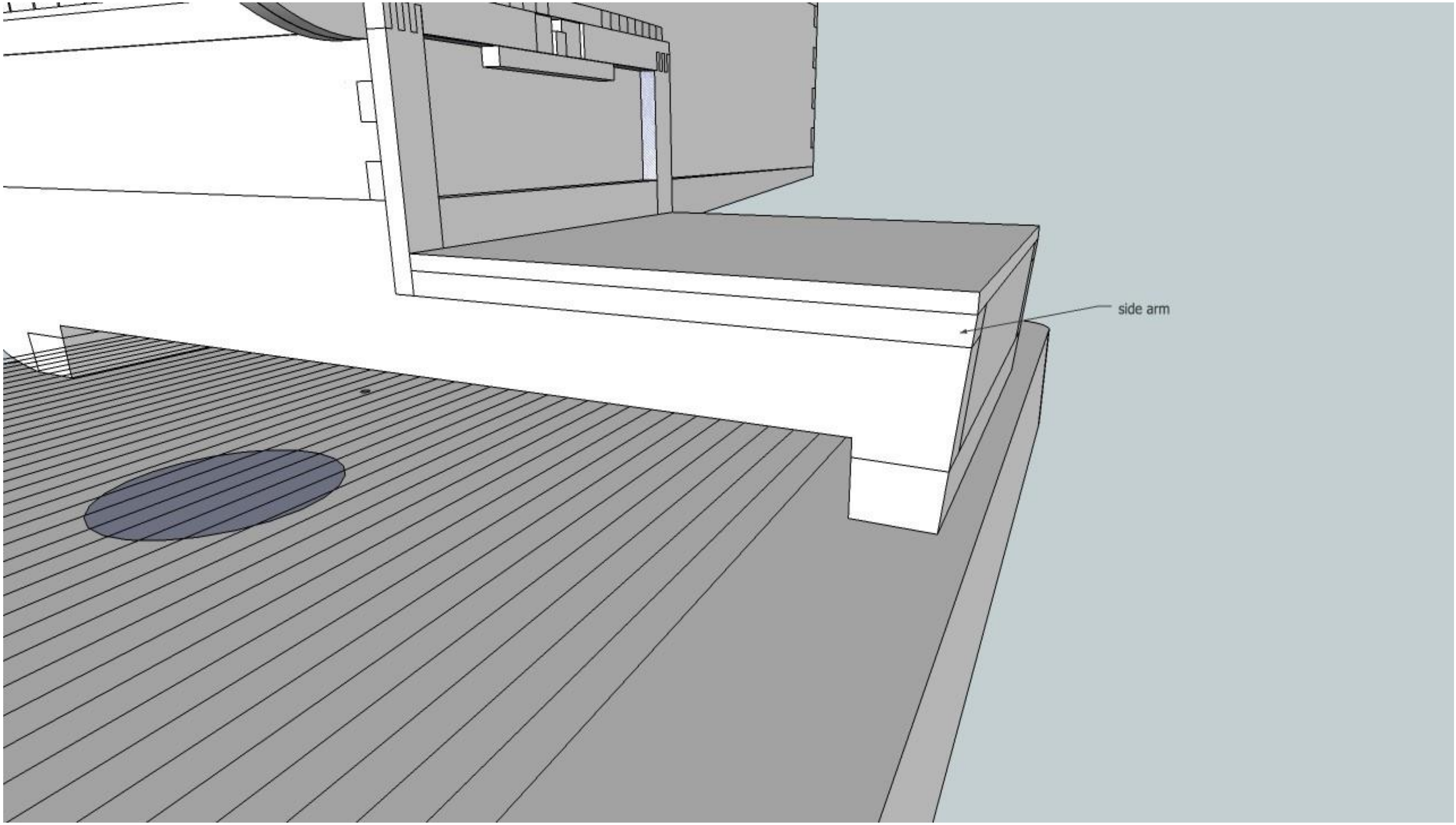
1.4 Toe Cross-Spar

Toe Cross Spar – Overview

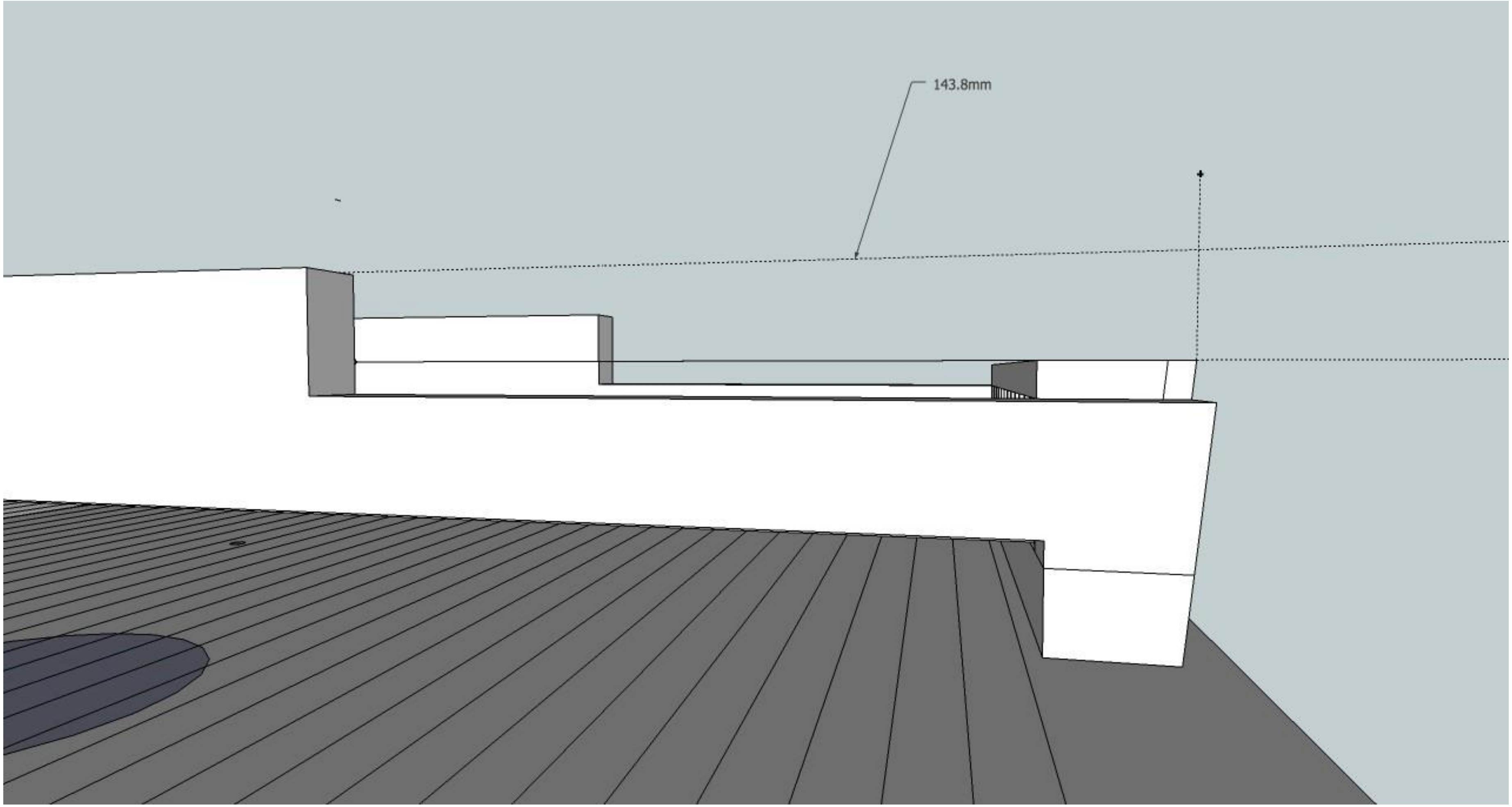
Cross spar dimensions



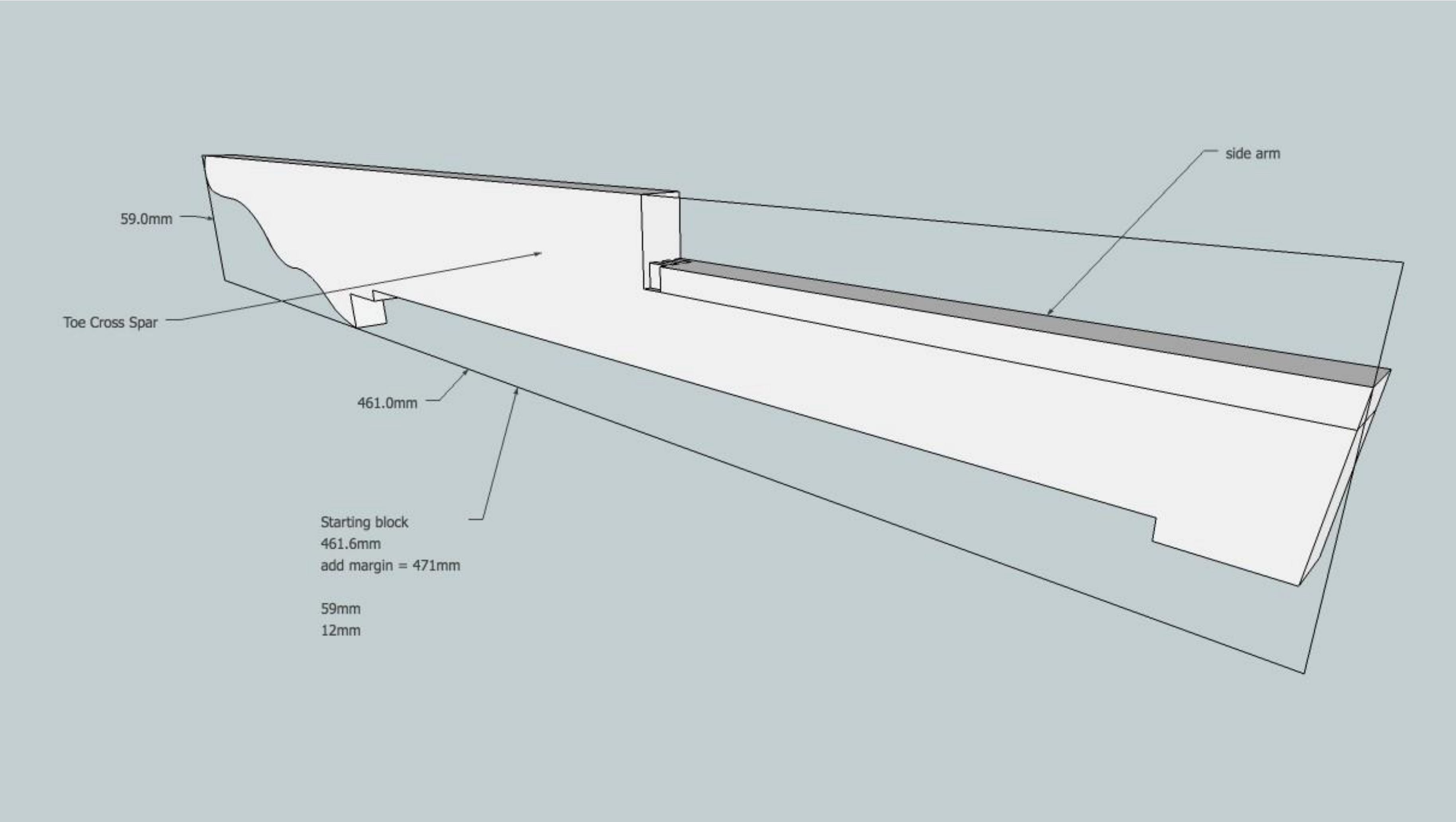
This cut could also generate the side arm and match grain given sufficient margin.



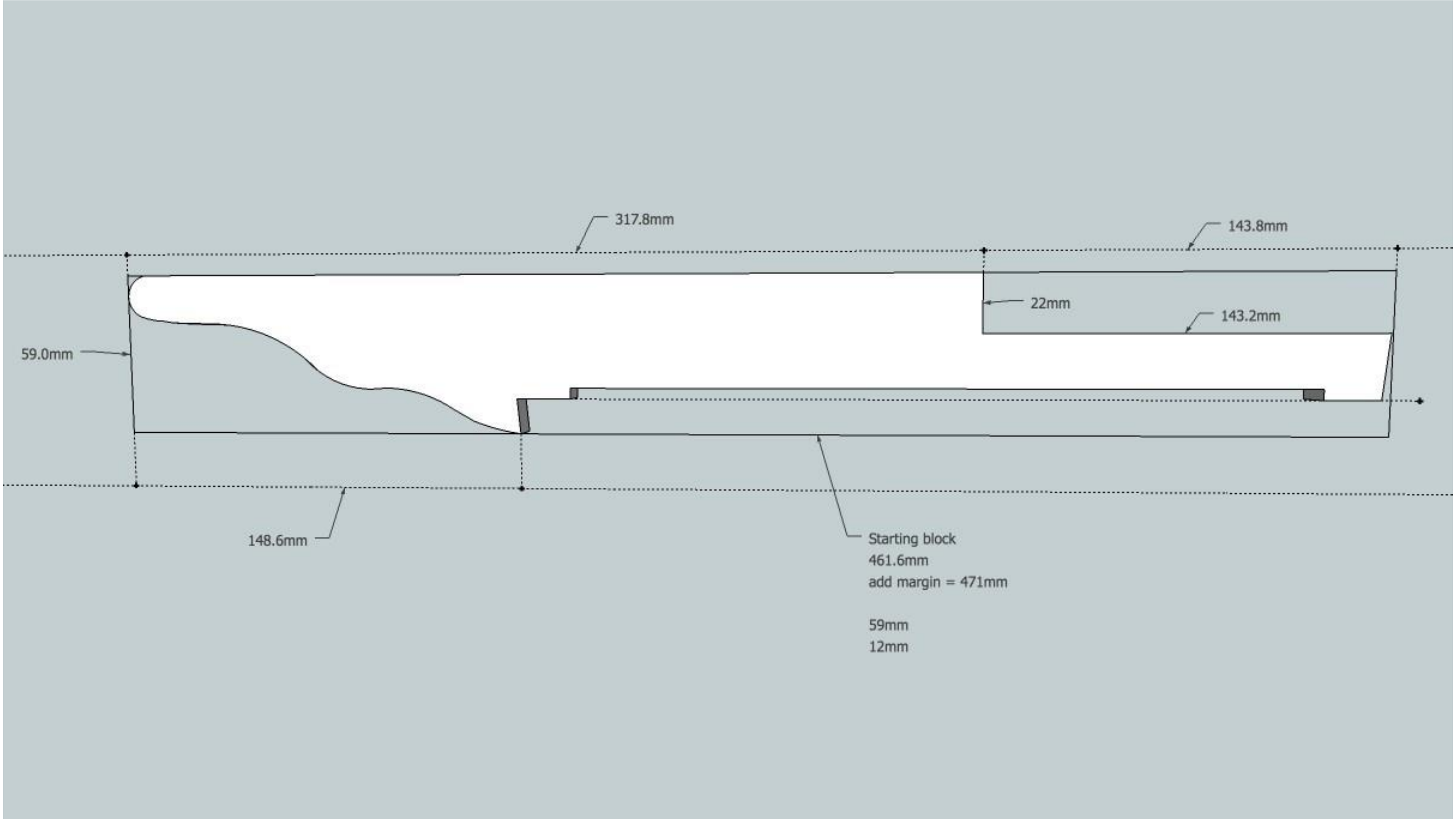
Extension must also allow a margin for the centre vertical cut



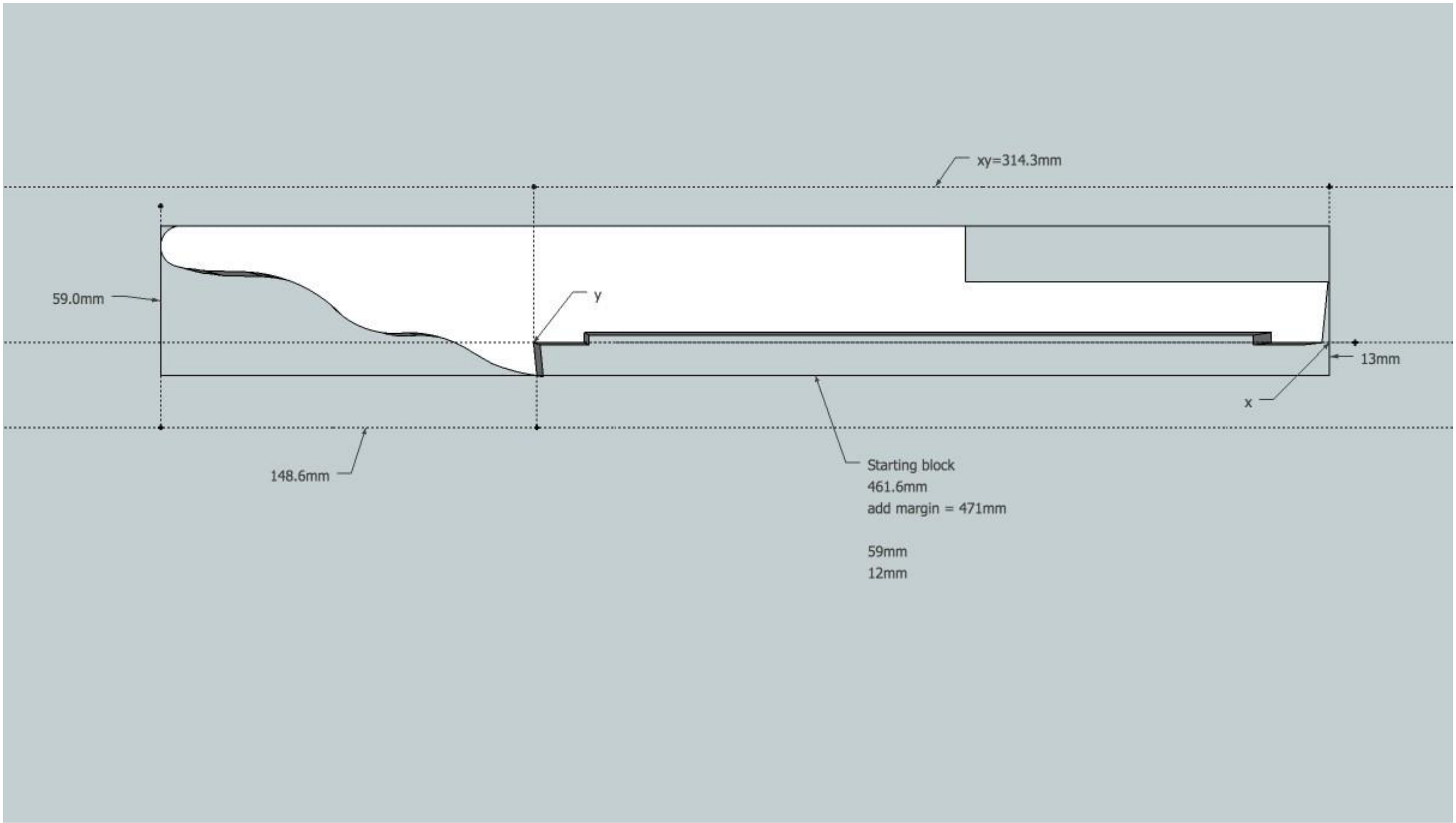
Extension must also allow a margin for the centre vertical cut



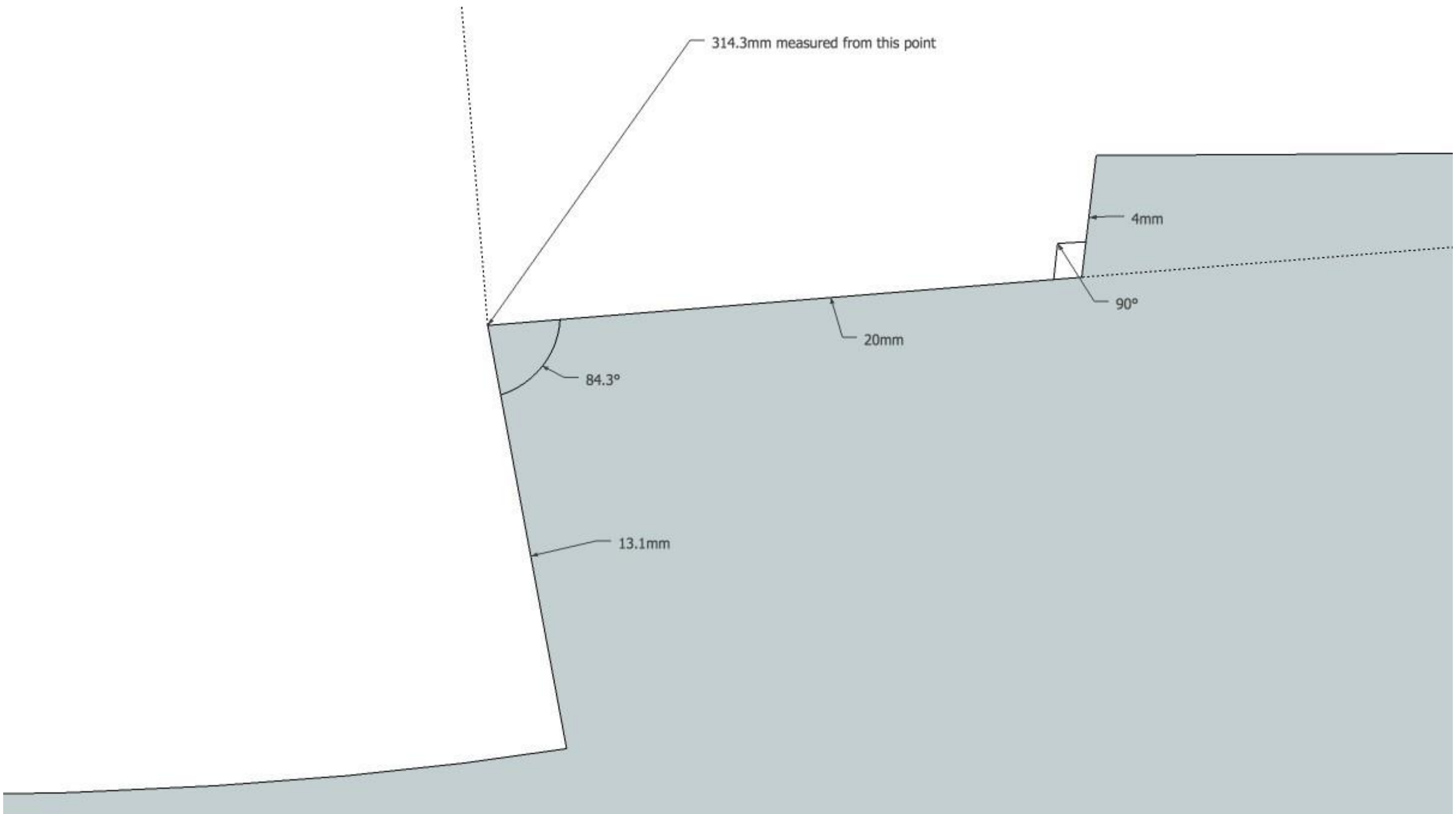
Cut top right corner



Lower cut – to 314.3mm, beginning 13mm measured up vertical right hand side

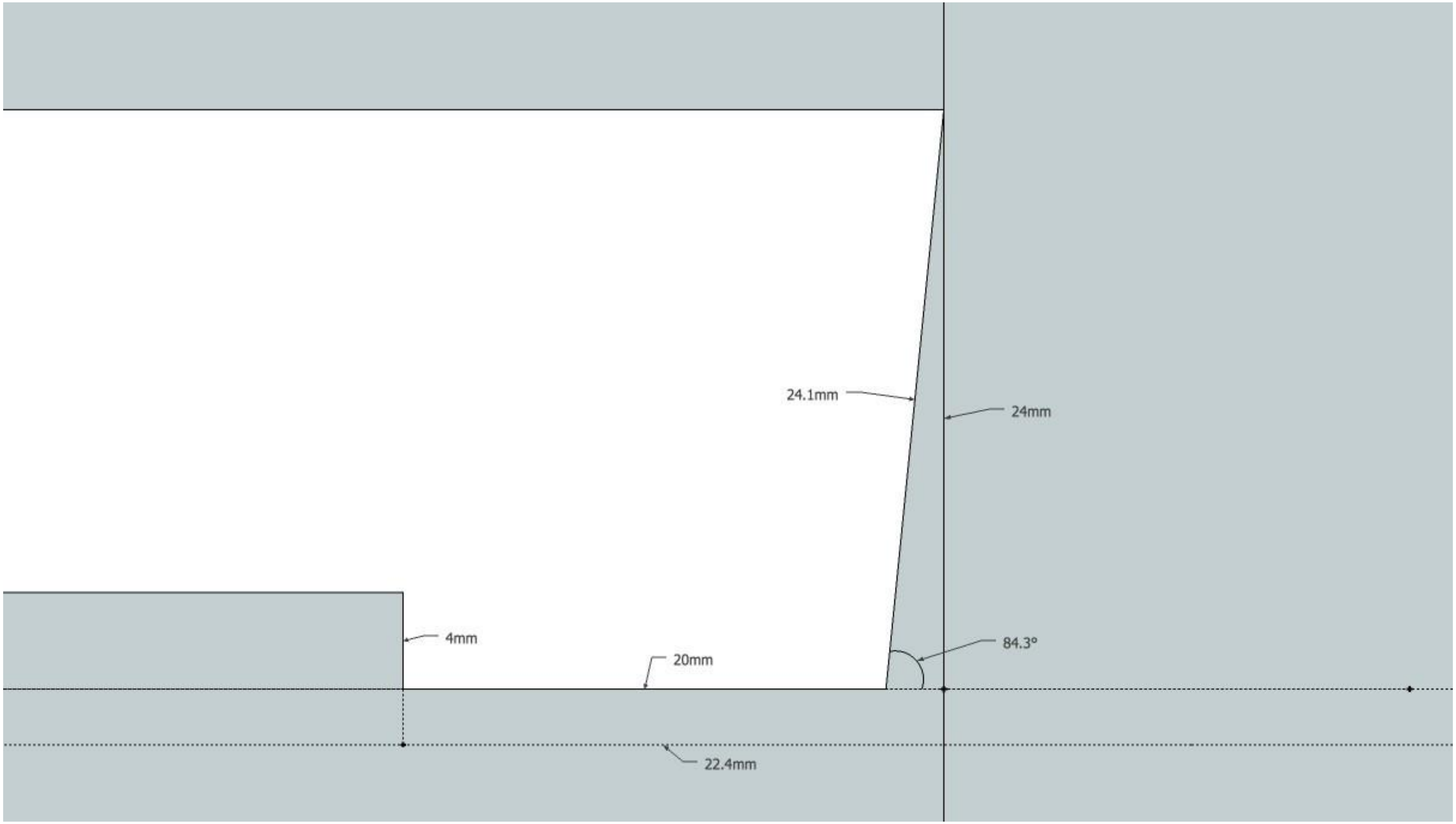


Angled cut using measurements 148.6mm (from left), 314.3mm (from right) Angle follows the back of the Action platform

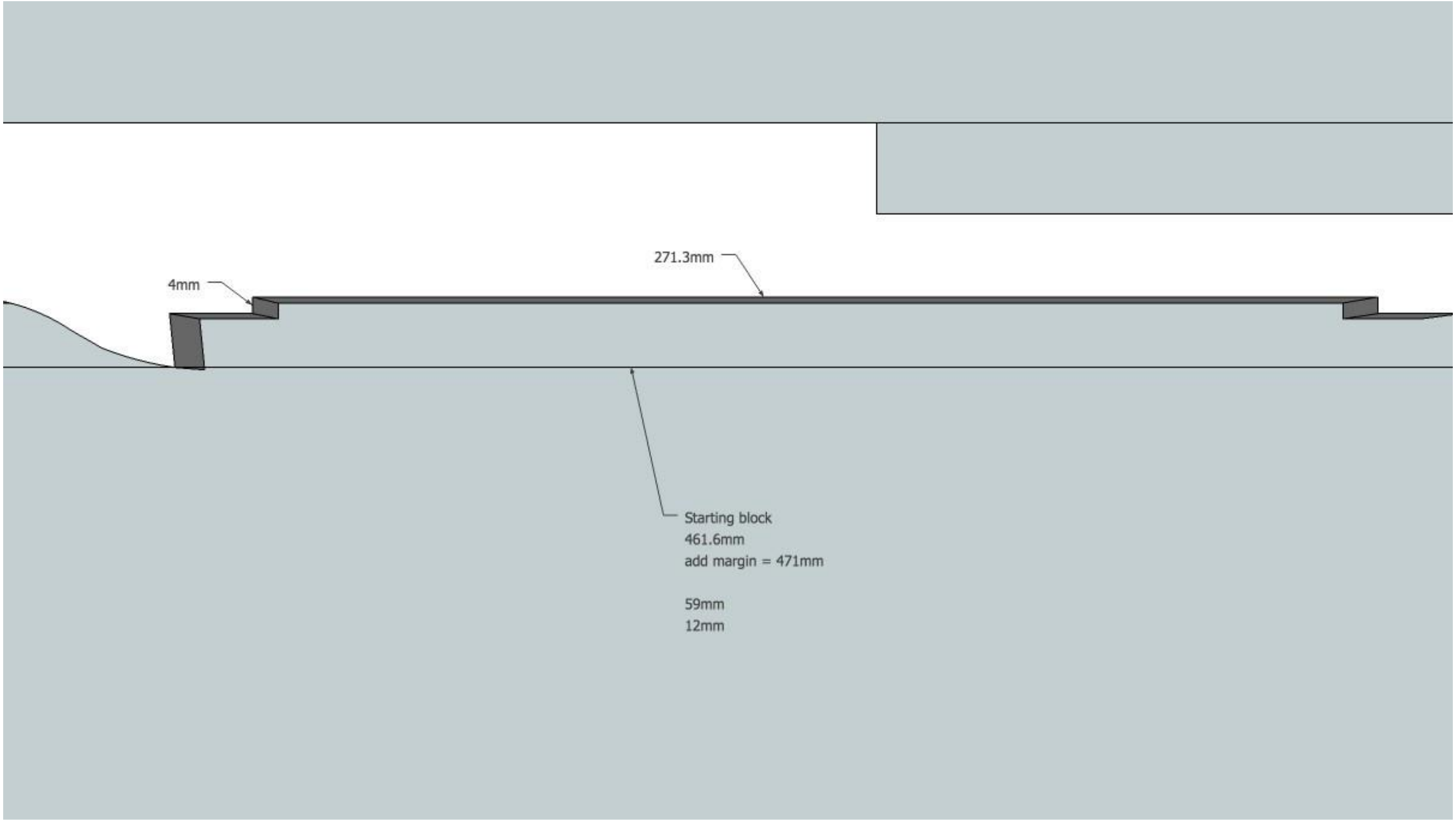


Angled cut on right

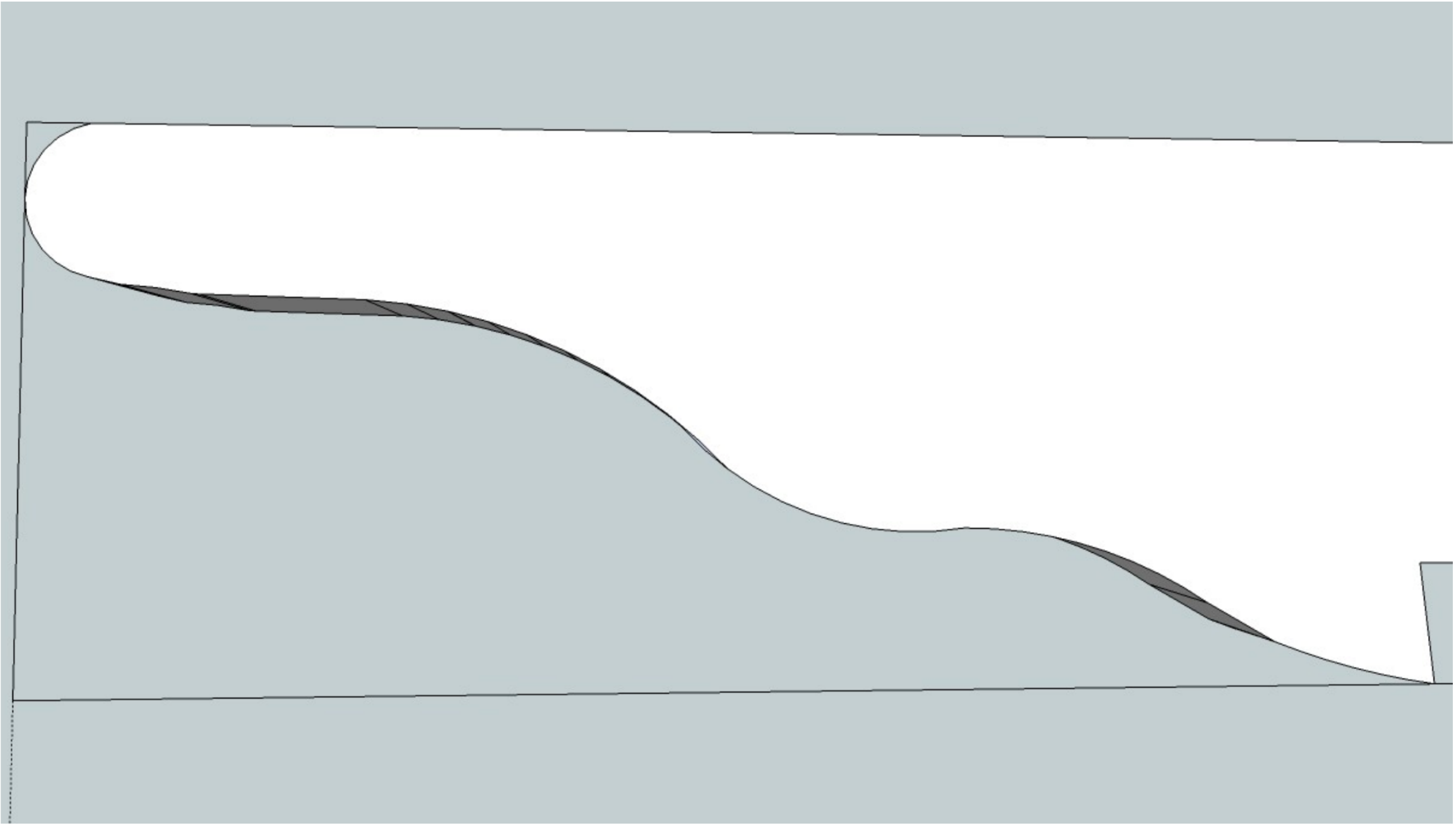
Angle follows the back of the Action platform



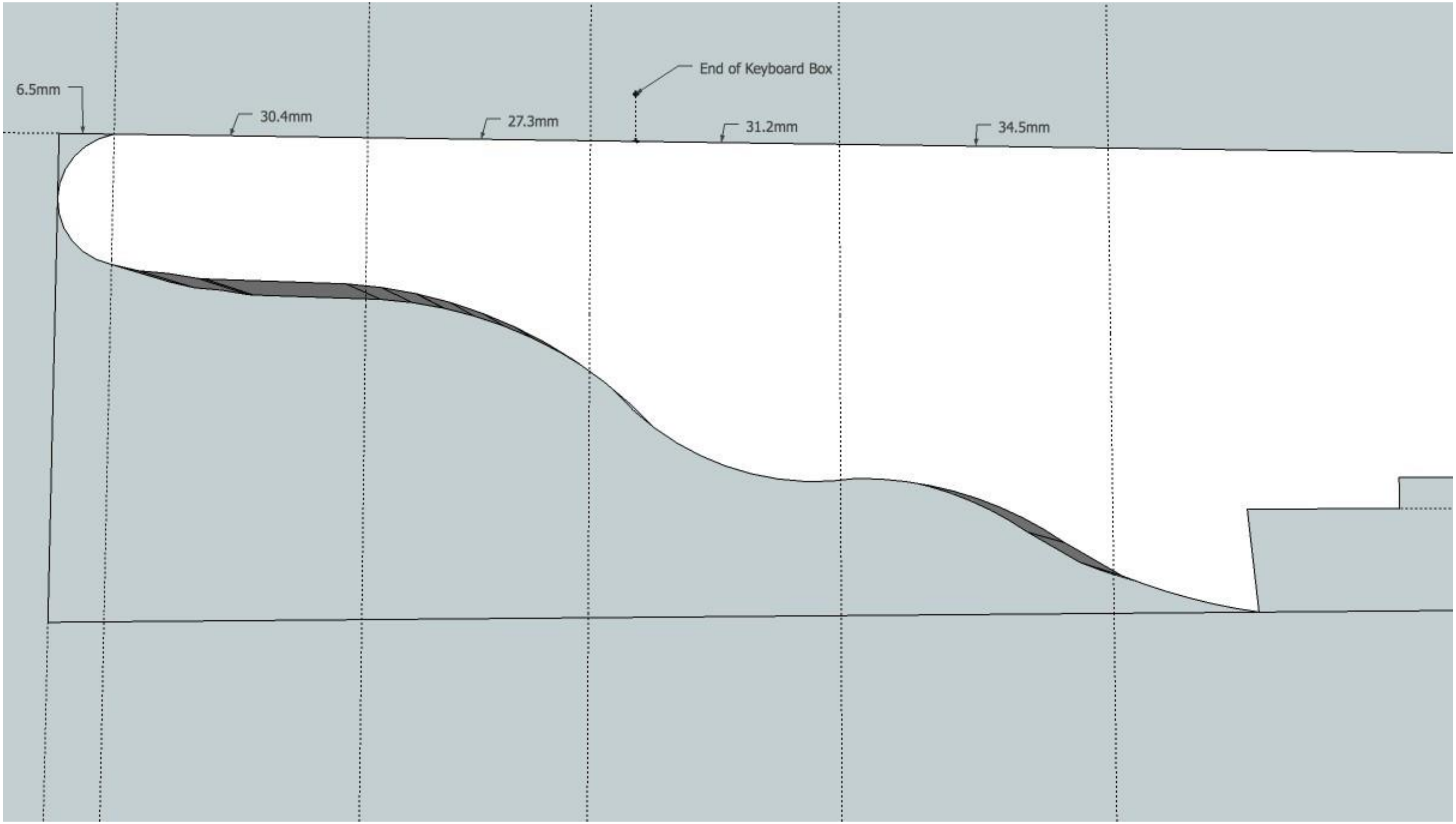
Centre cut – to give clearance from strings



Curves

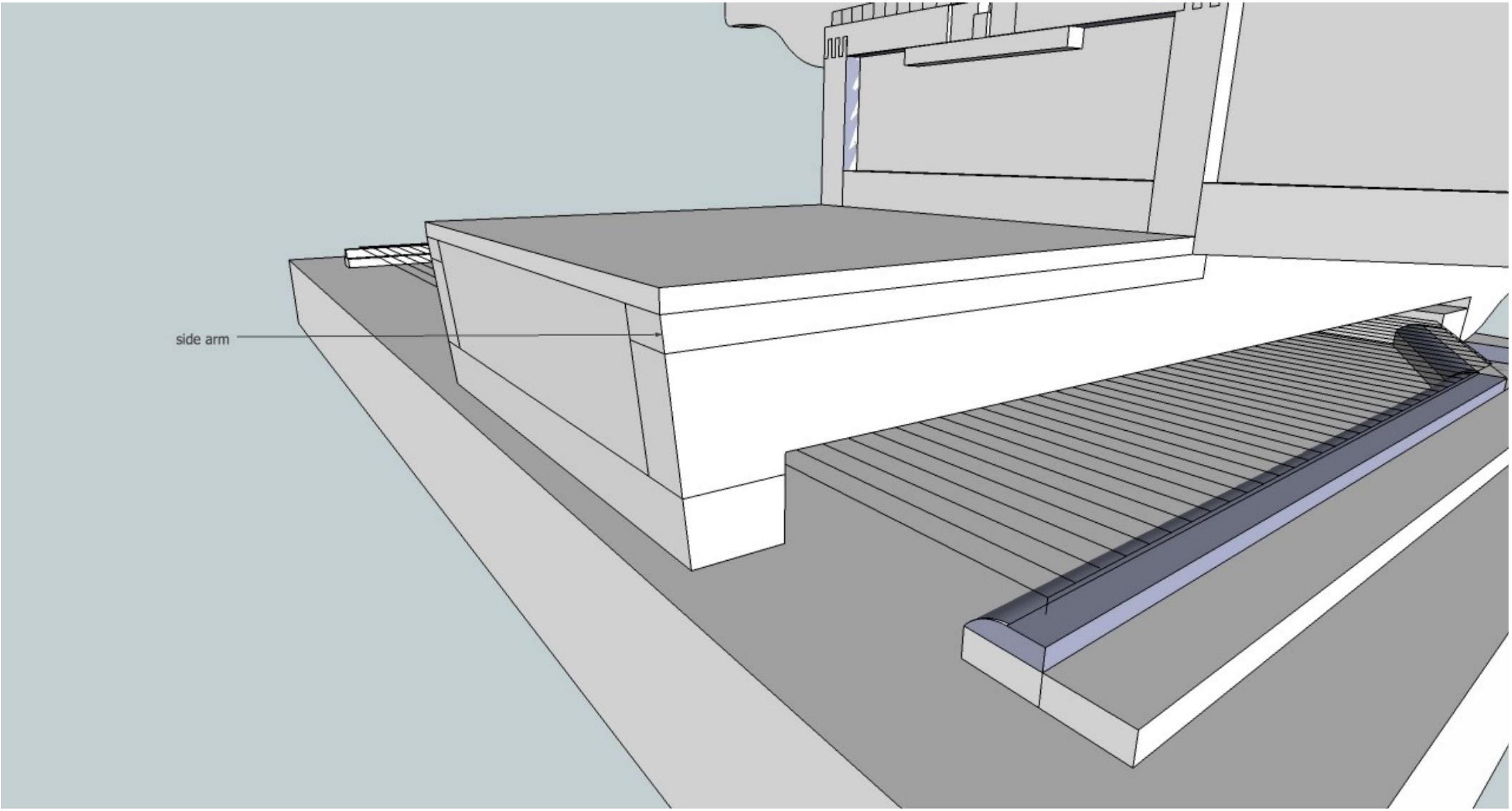


Curves – section to show the areas framed by change of direction



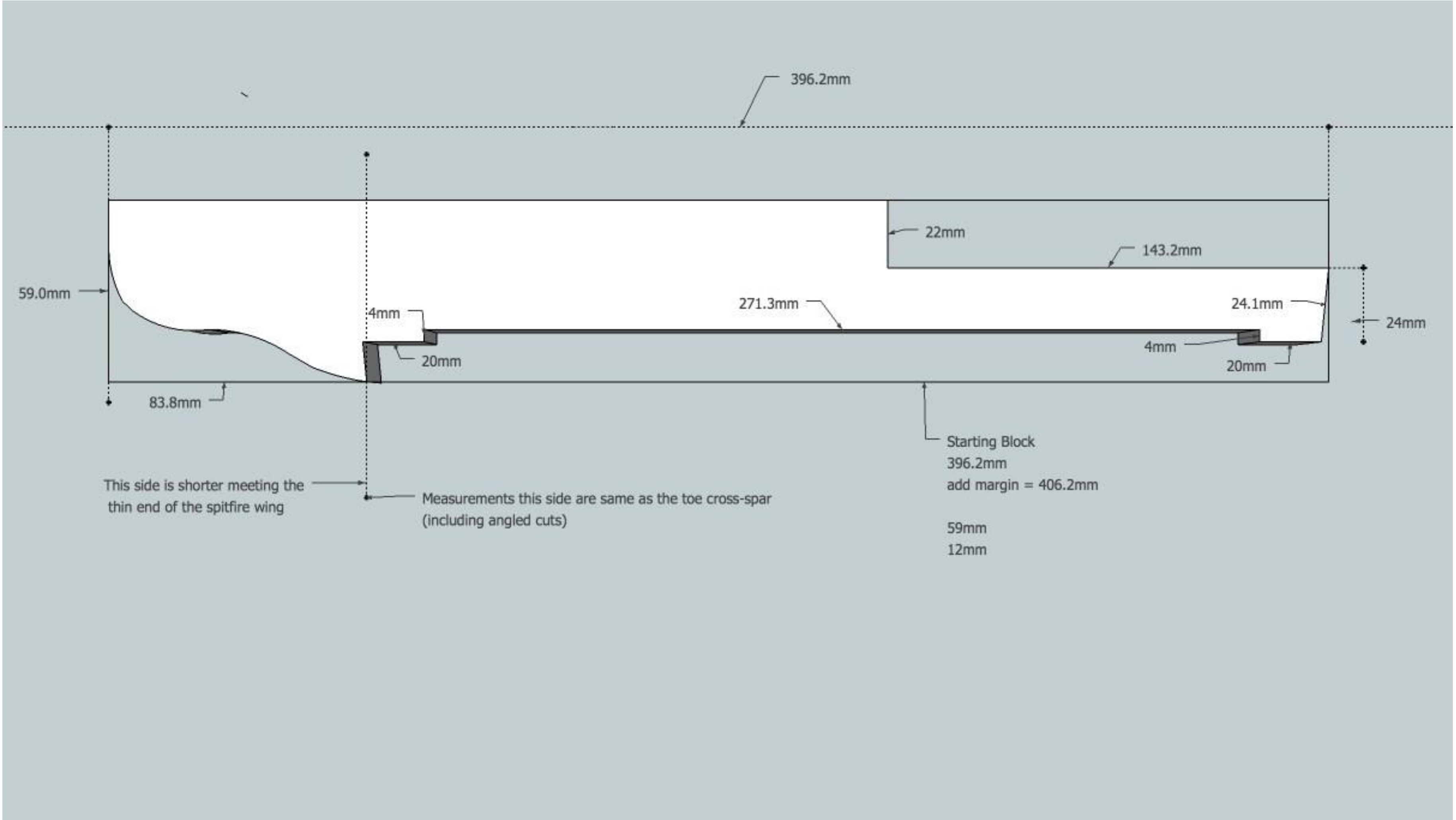
1.5 Dead Cross-Spar

Will also generate a side arm

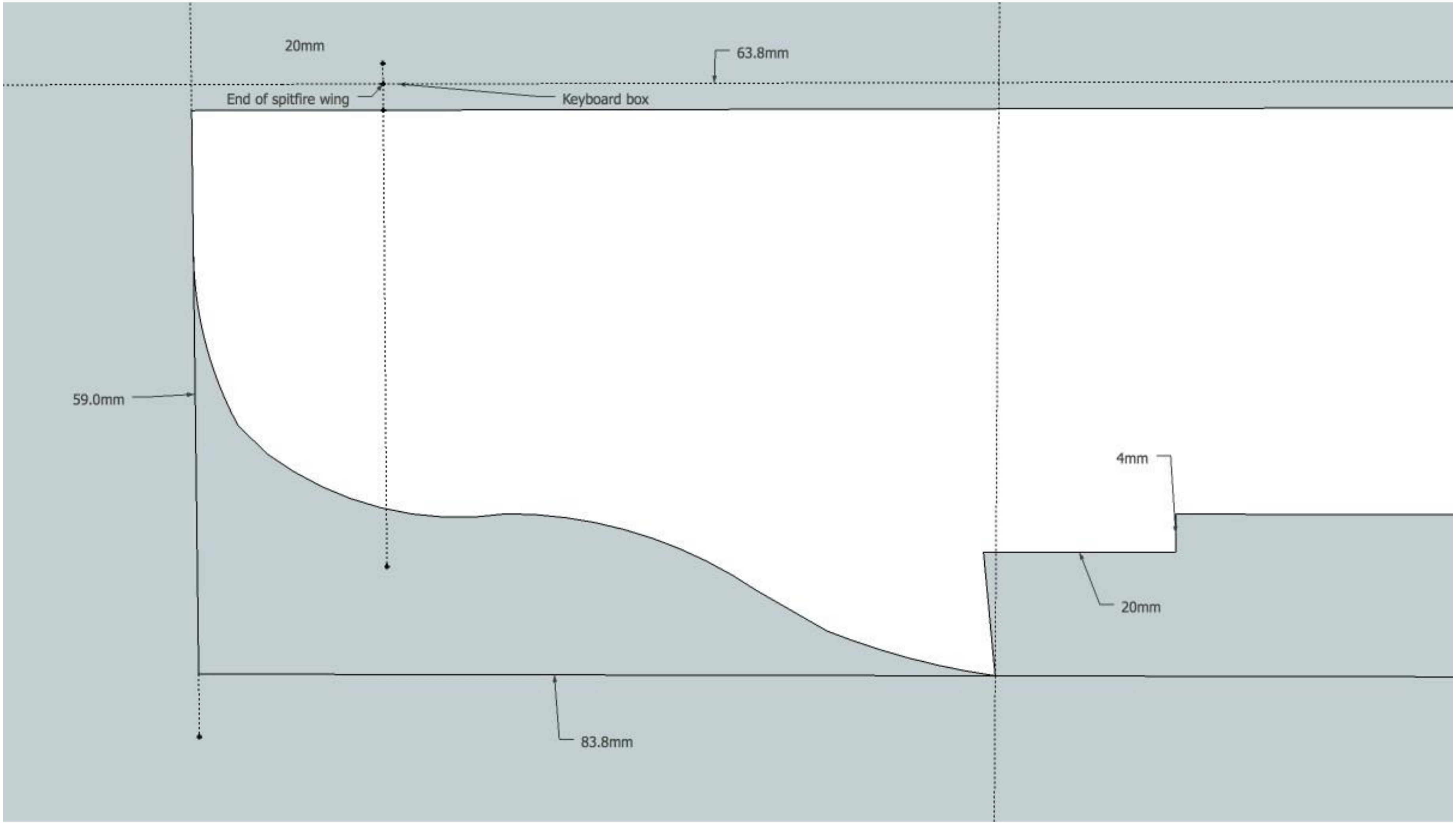


Dead Cross-Spar

Curve is different – shorter to meet dead end of spitfire wing. To the right of the curve is as for Toe Cross-Spar



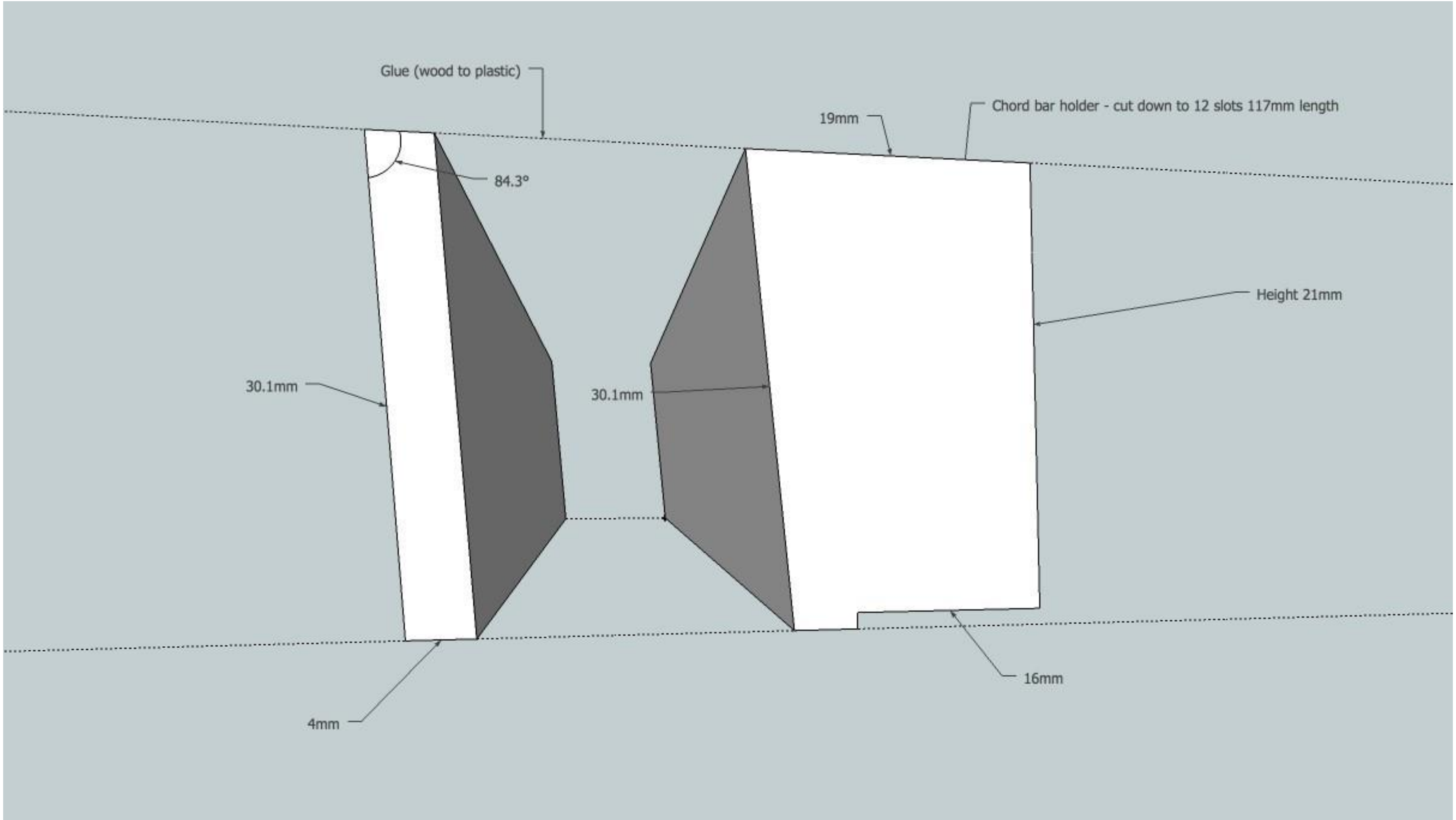
Curve sectioned to indicate framing



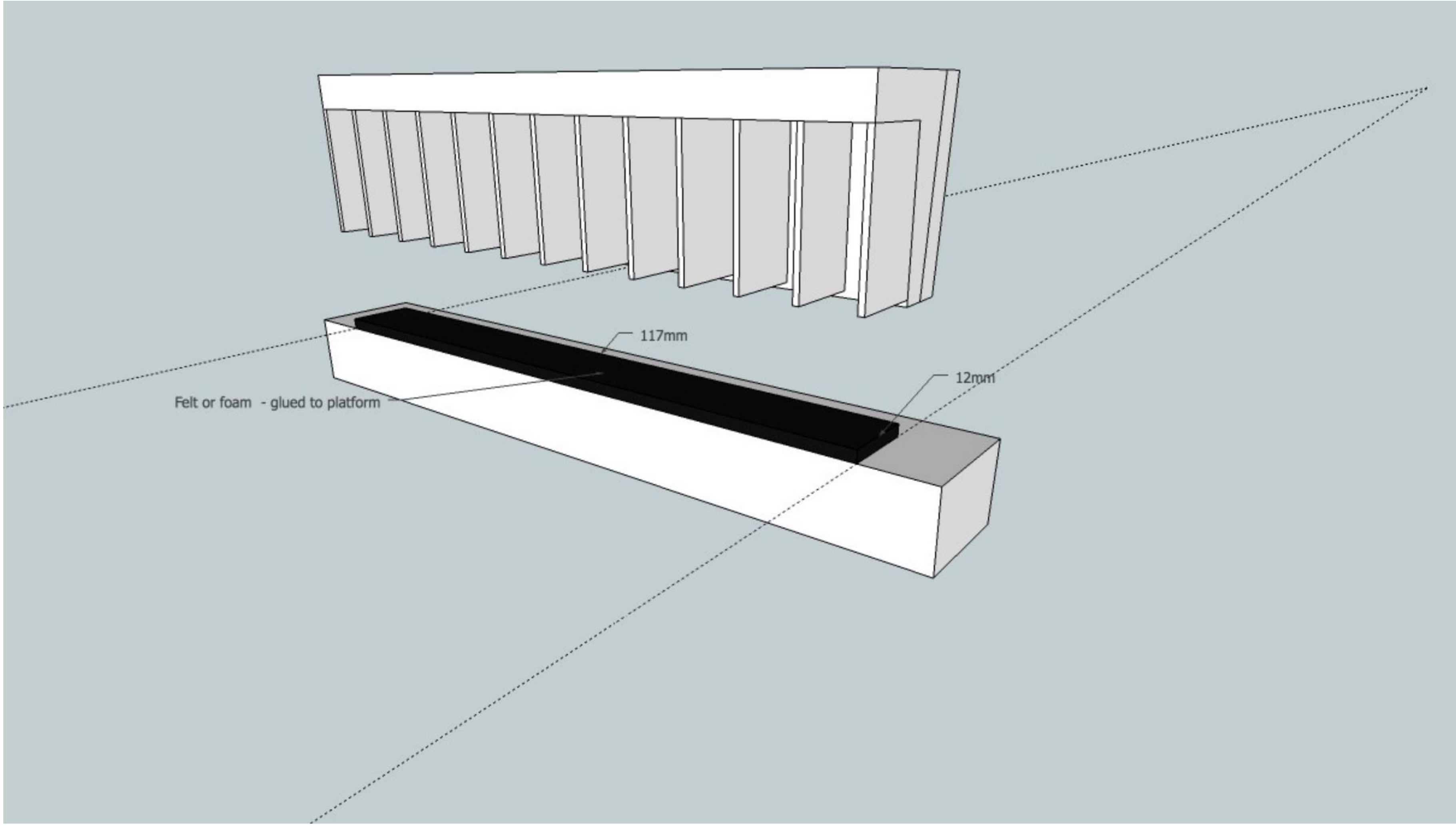
1.6 Treble Chord Bar Assembly

Treble Chord Bar Assembly

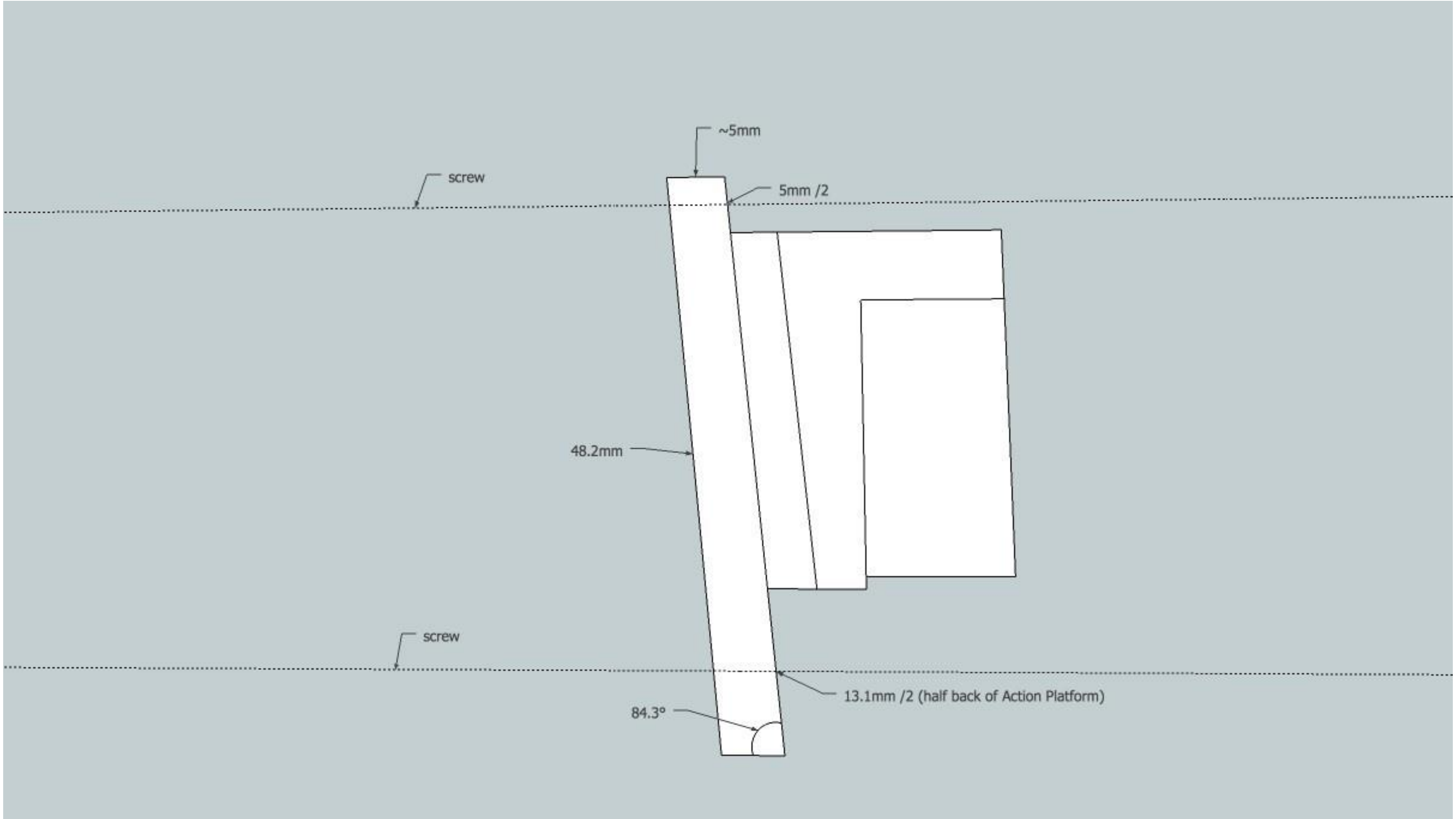
Chord Bar Comb as before



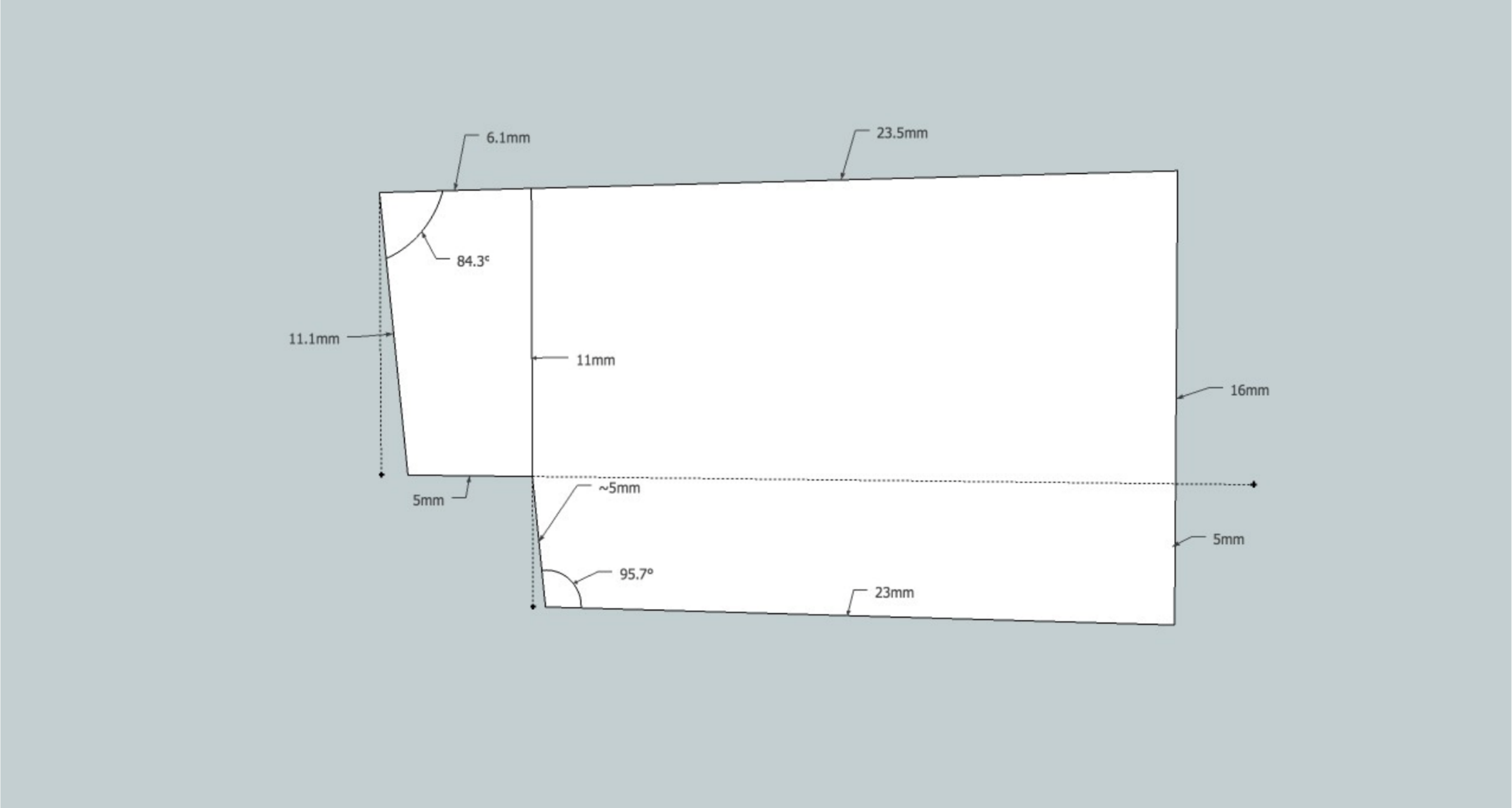
Chord Bar Comb – same measurements as for bass — **not hinged**



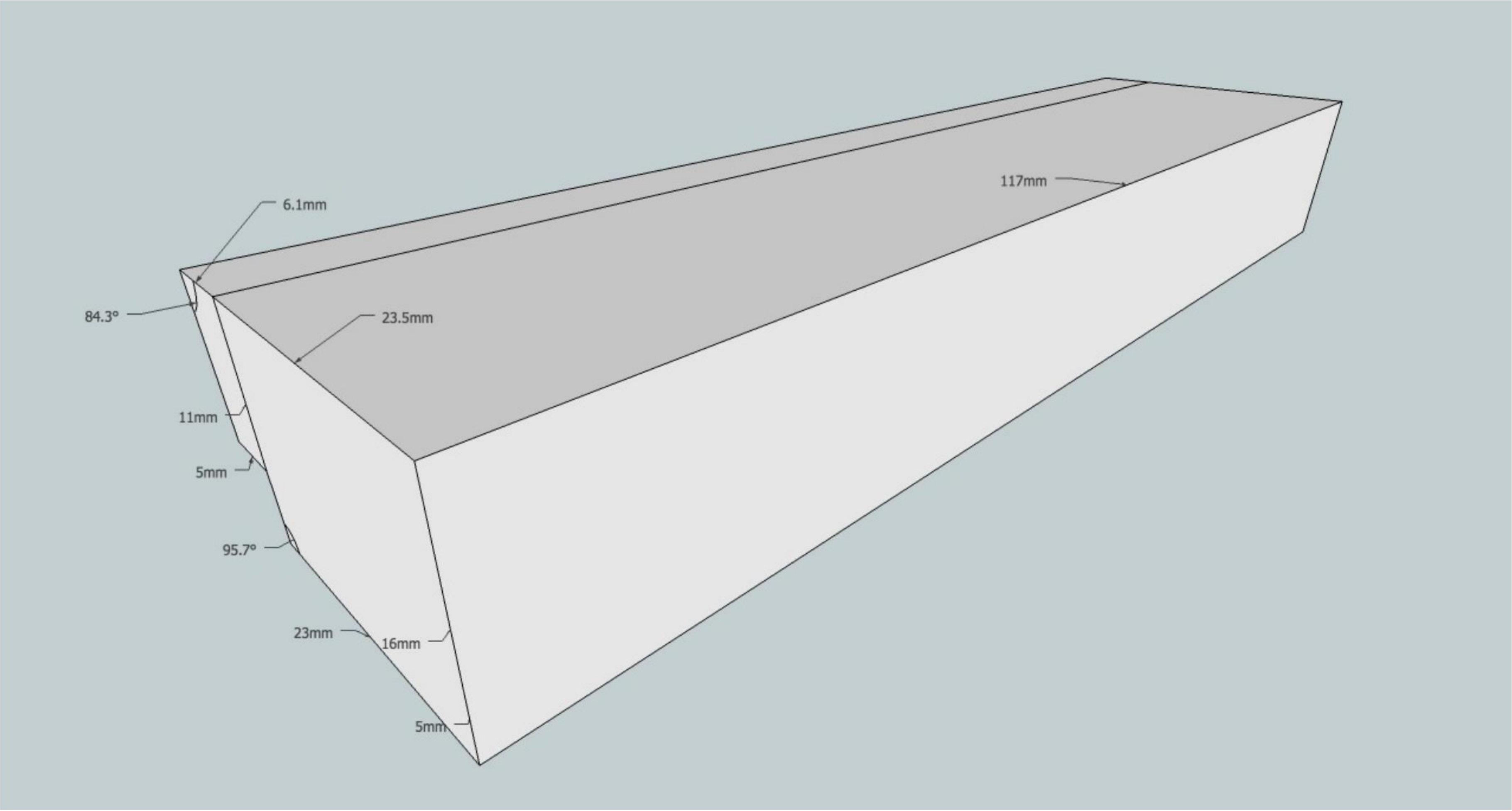
Attach a Screw Plate at similar angles to allow access to treble Chord Bar Comb



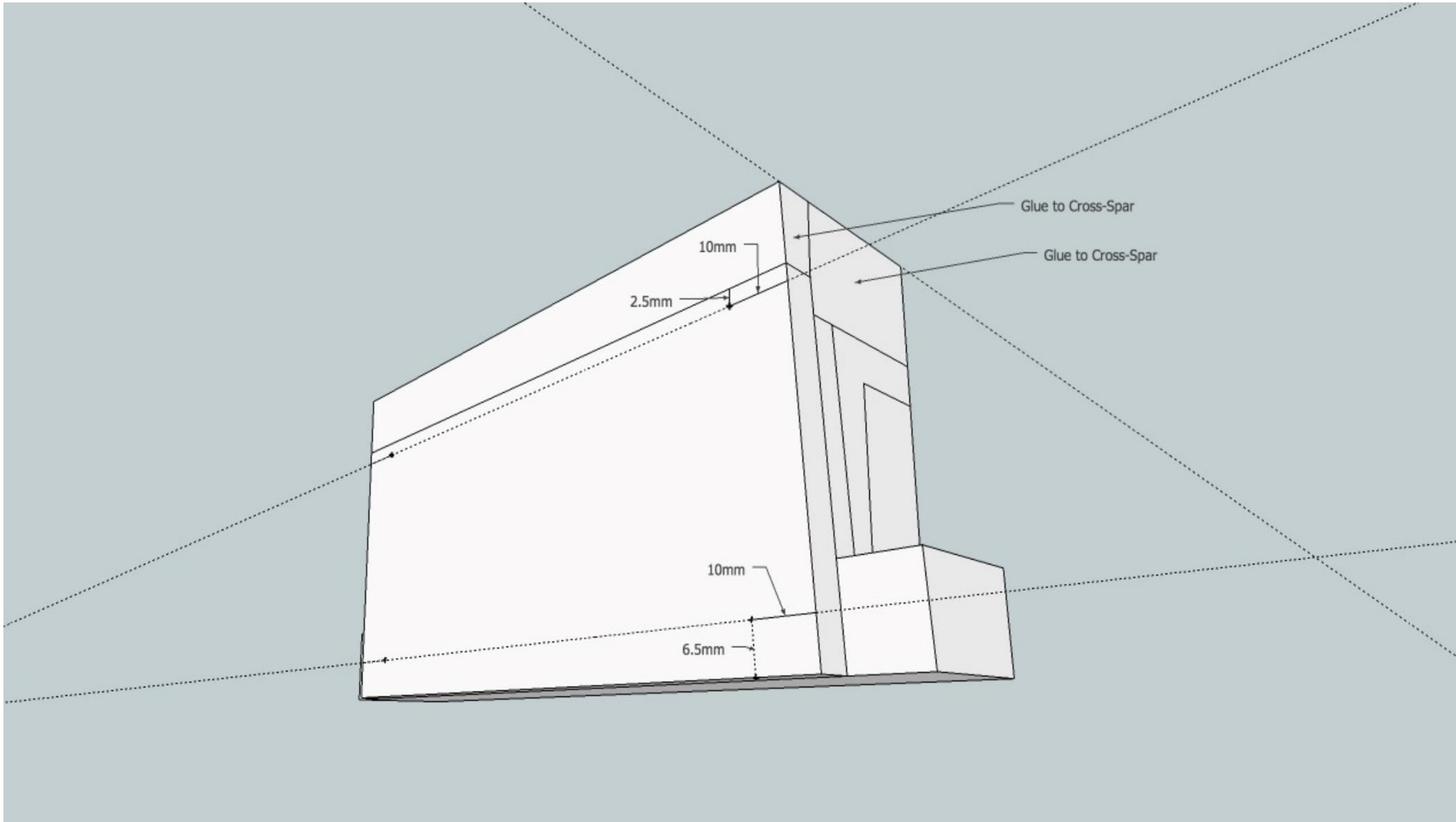
Top Platform



Top Platform

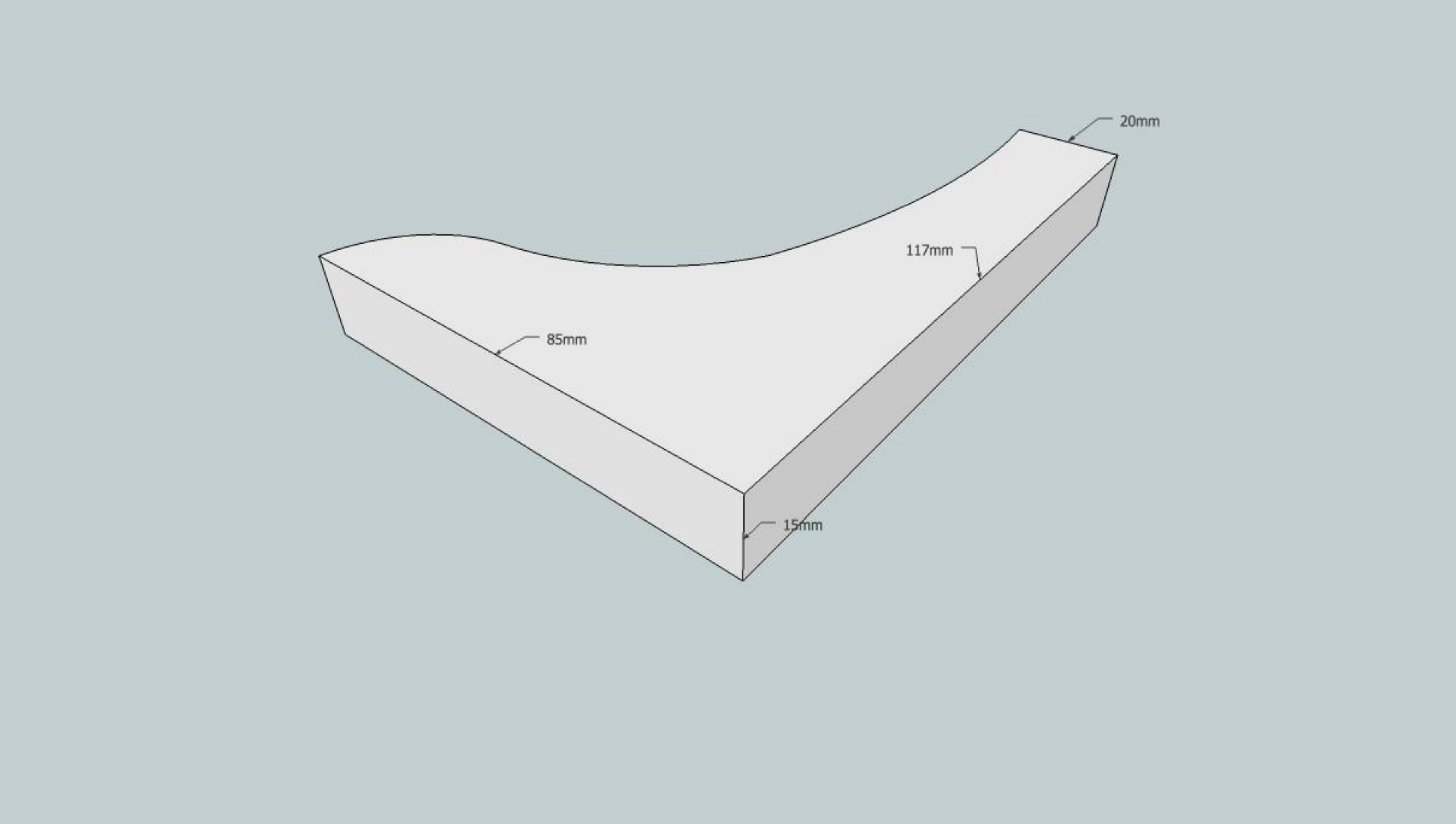


Shows screw points to attach Treble Chord Bar Assembly to Platforms.

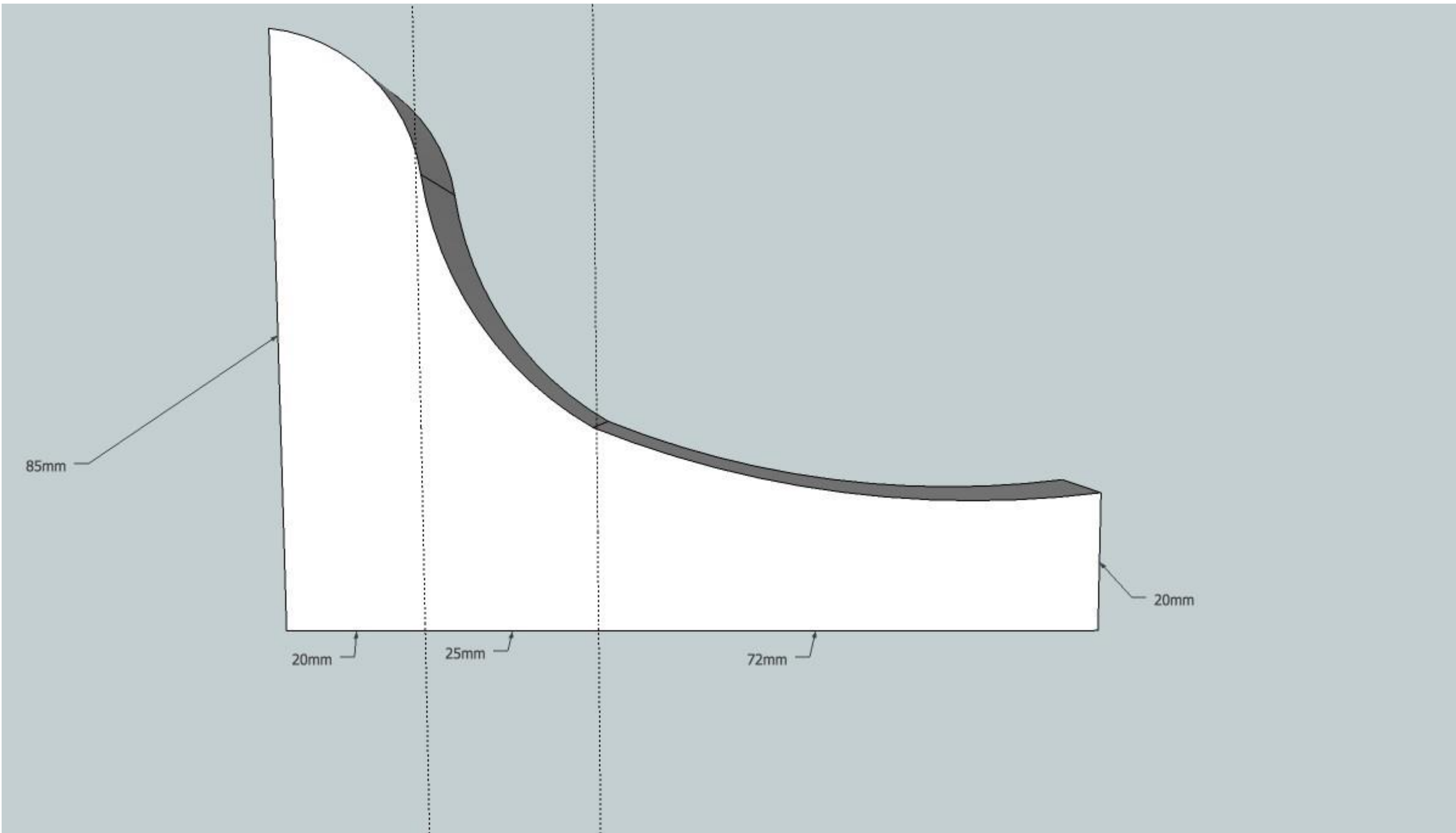


1.7 Spitfire Wing

Spitfire Wing



Round off curve edges — see photograph

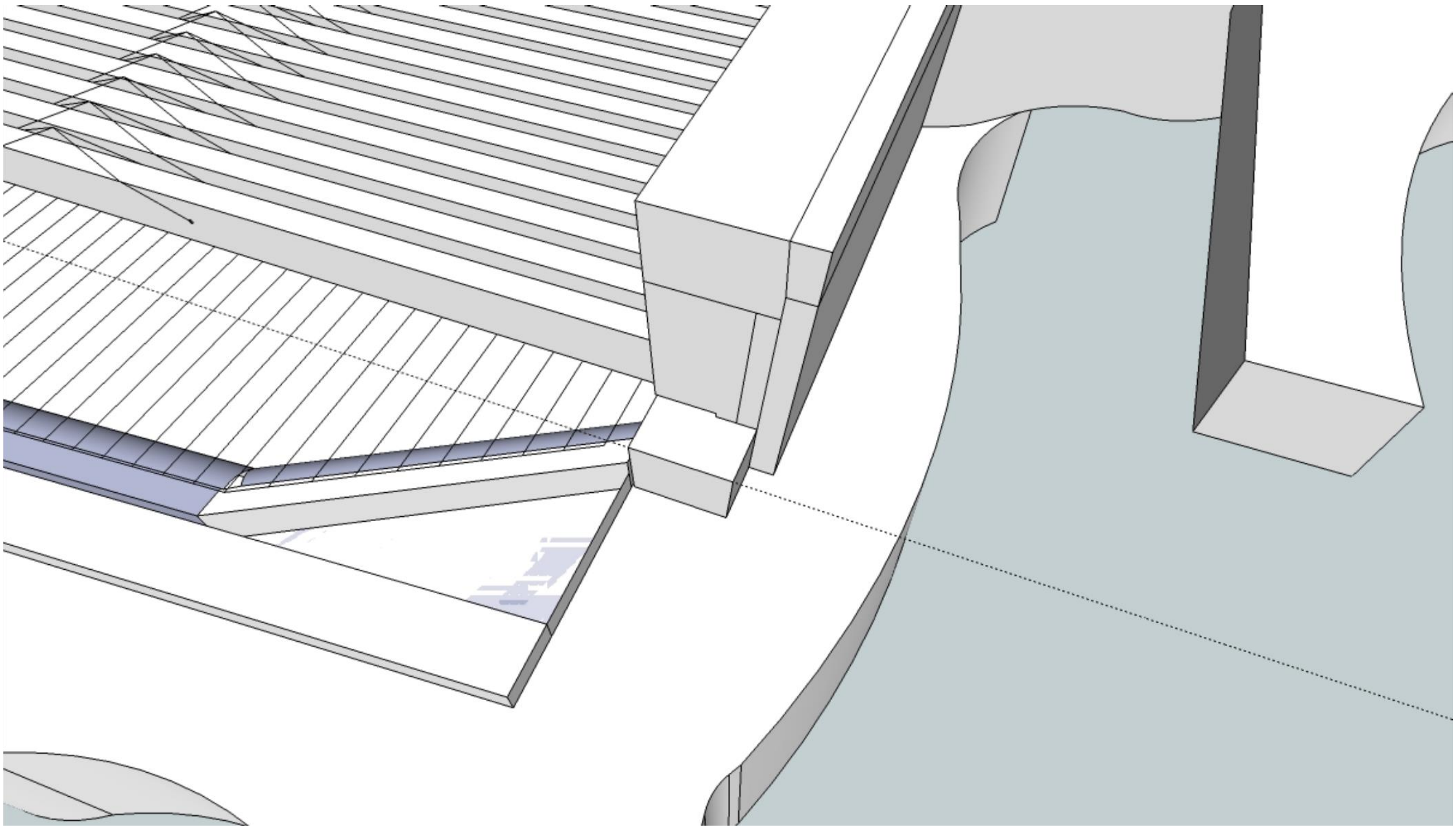


Images from prototype

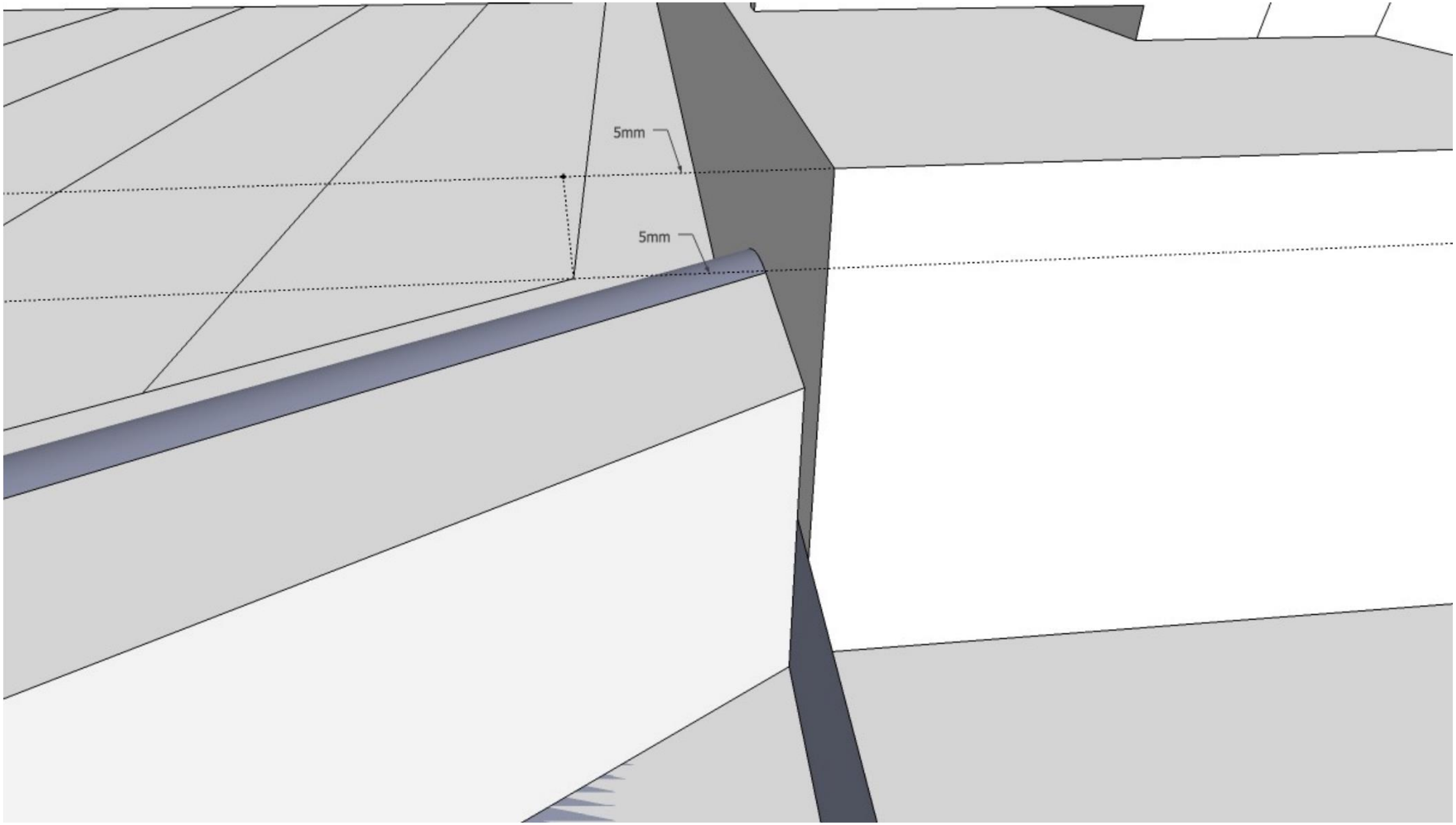
1.8 Attach to Harp

Key Position: orient Treble Action Platform end parallel to bridge point of last D string

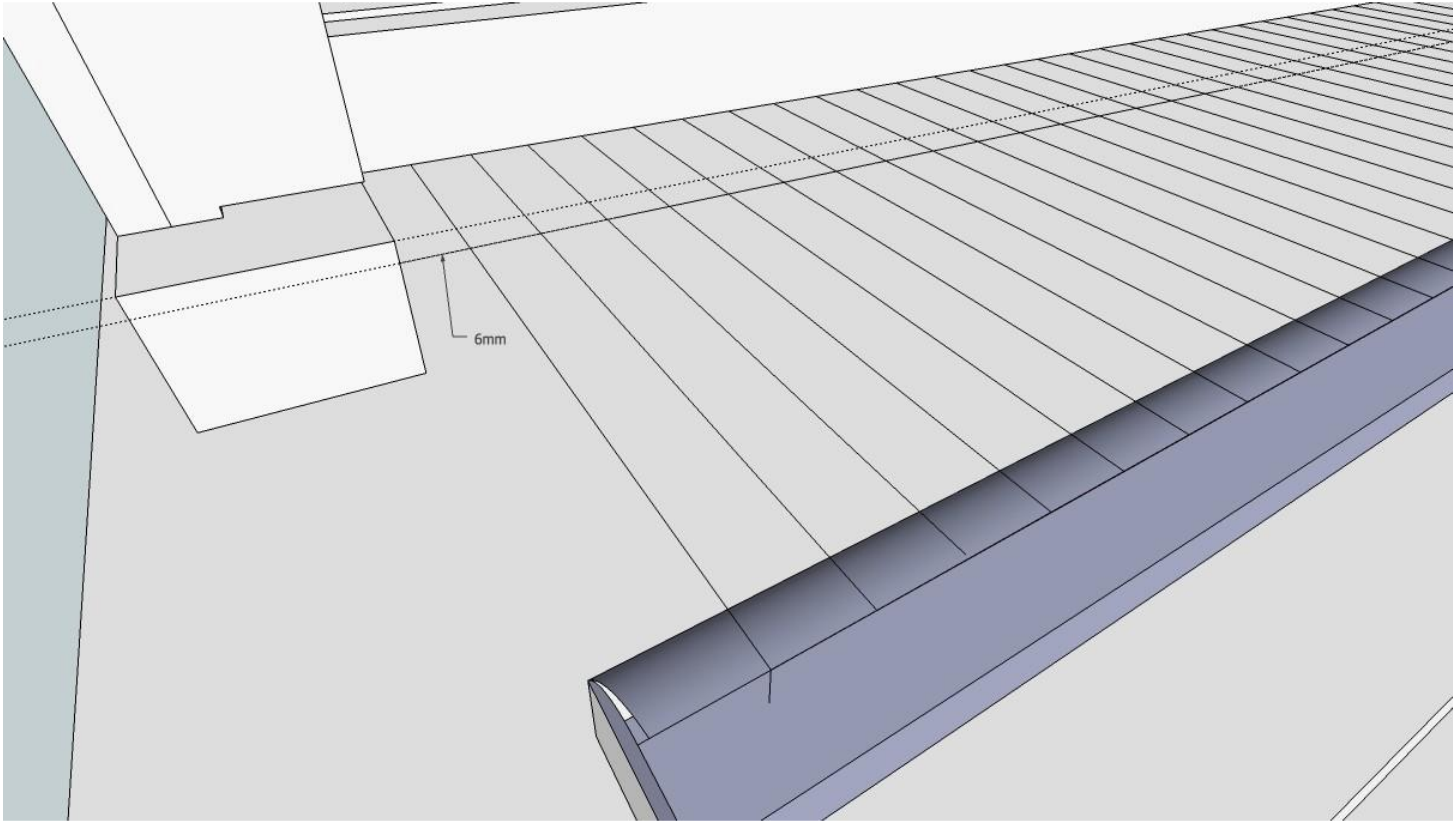
(Dead Cross-Spar hidden)



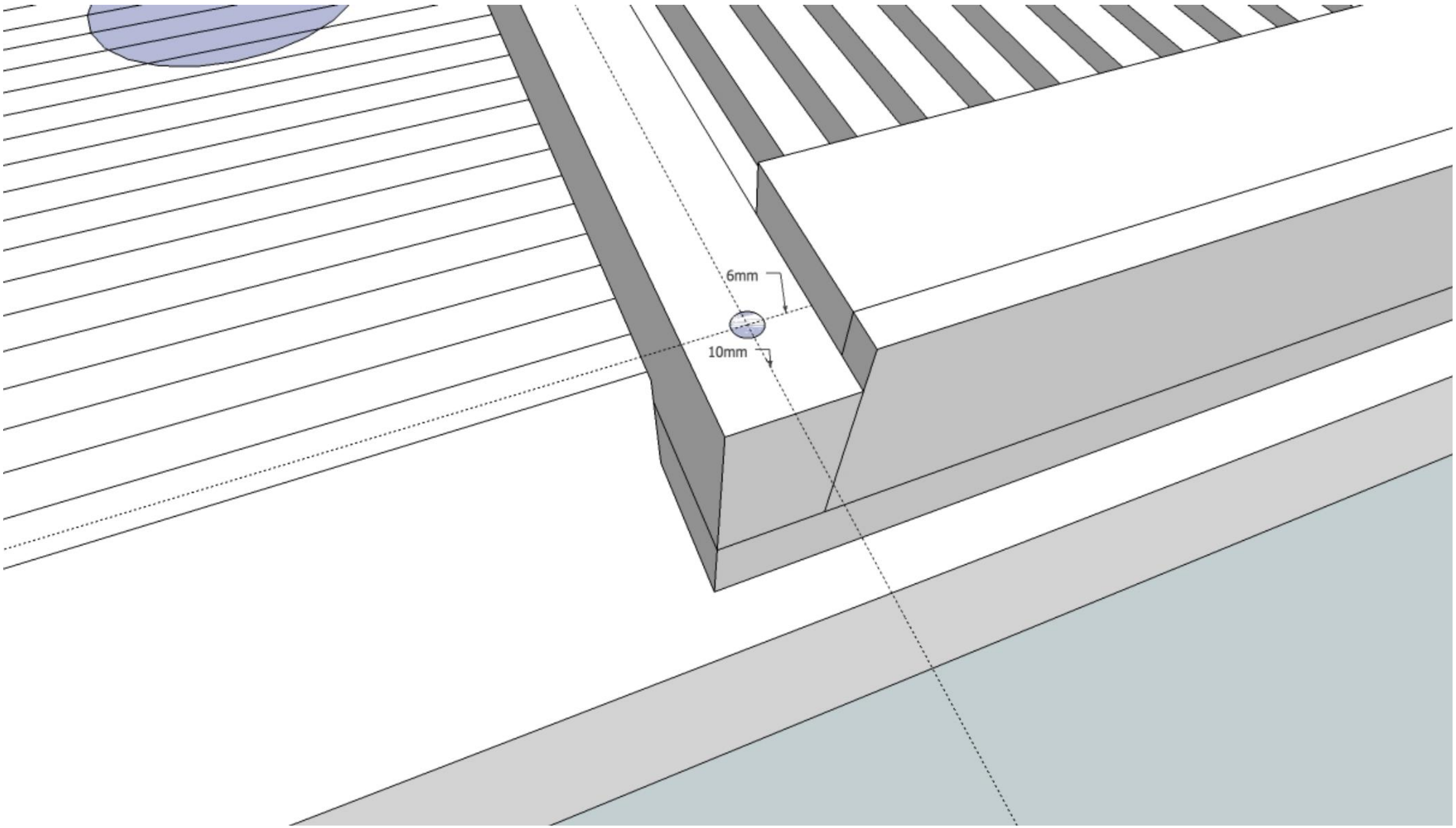
Magnified



Bass Side — parallel, and with slightly more room (bass strings need more room to vibrate!)

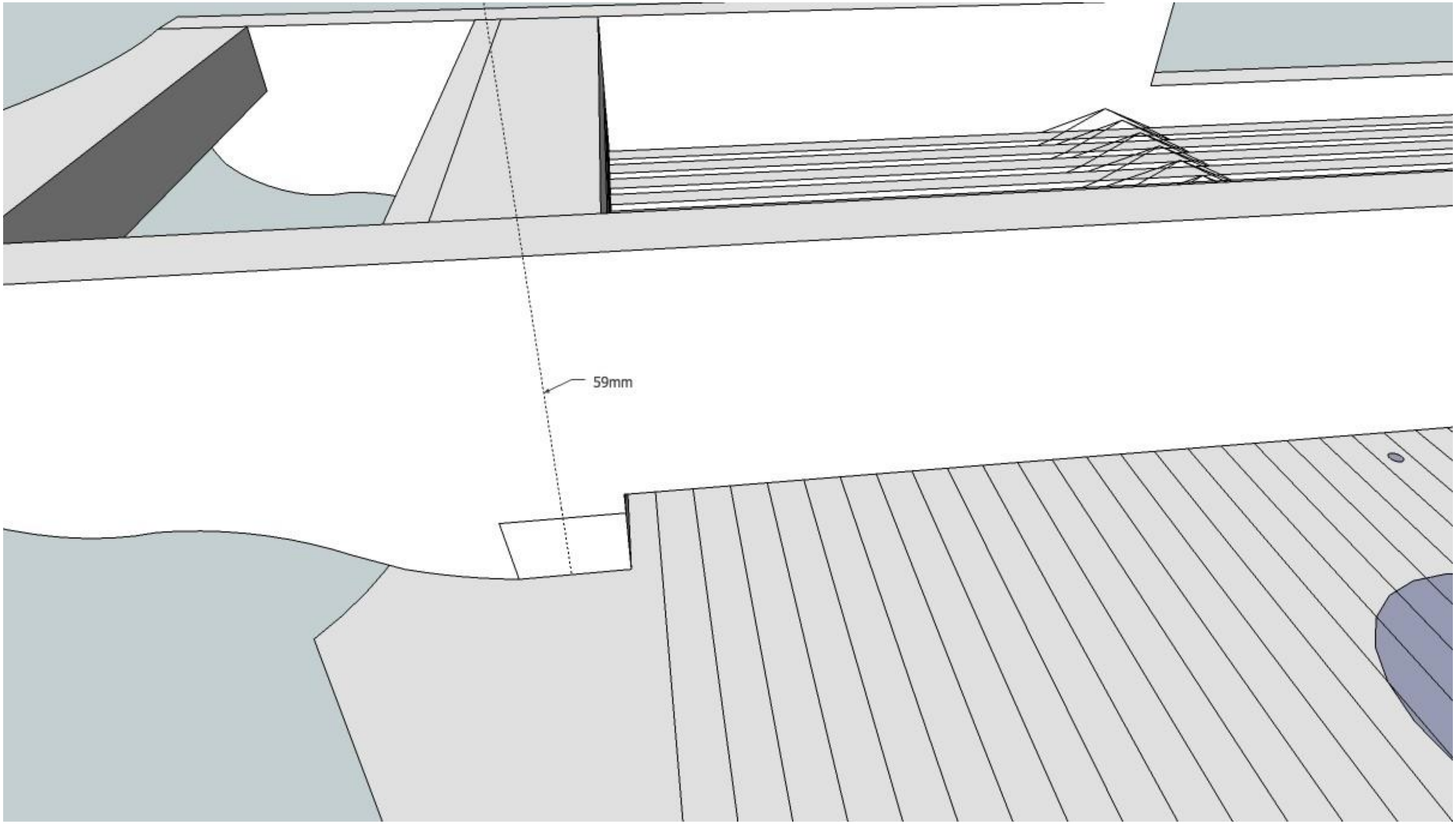


Solution One: Screw through Cross-Spar ends and Action Platform into Harp



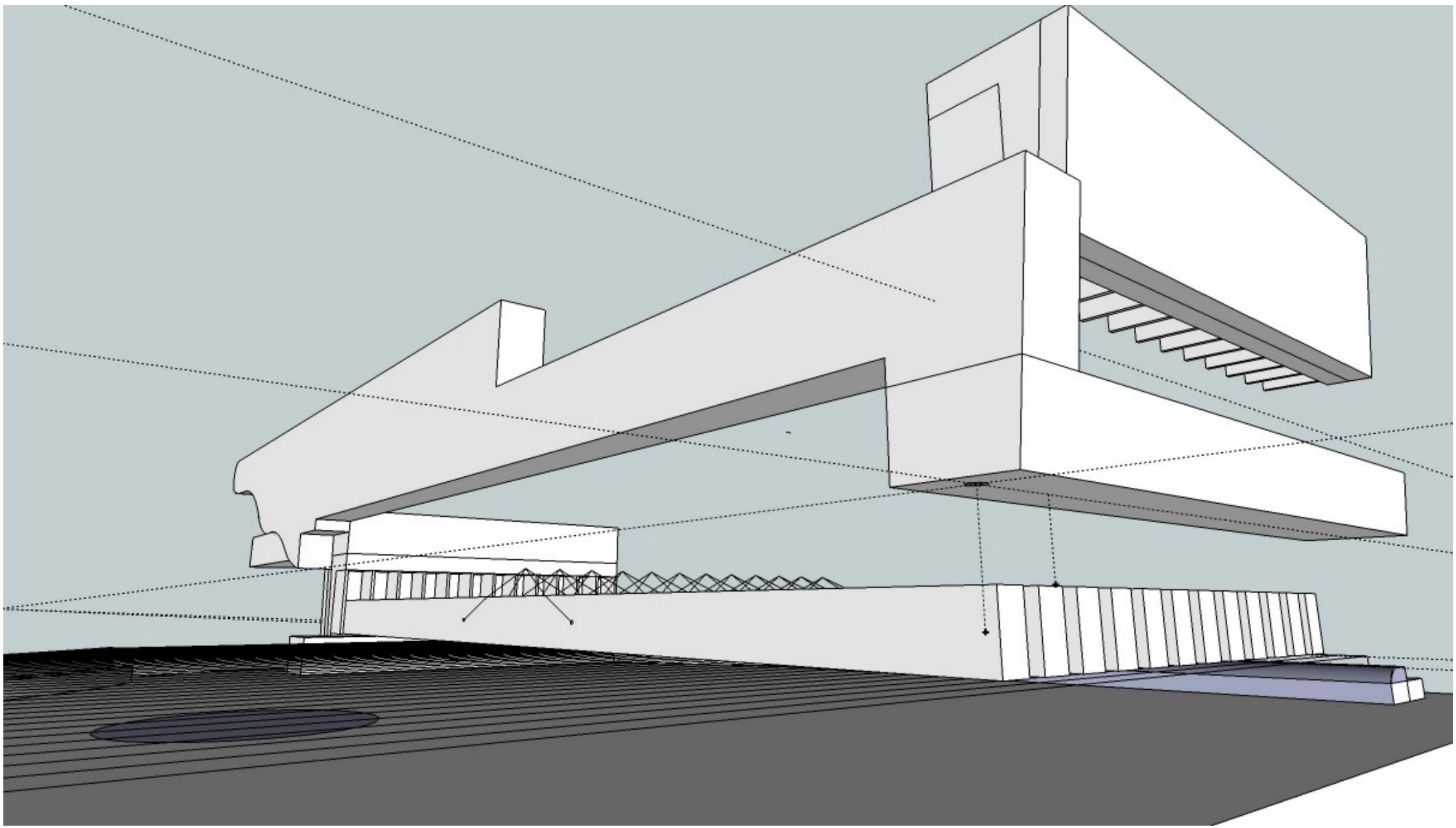
Solution One: Screw through Cross-Spar ends and Action Platform into Harp

Concern: Screw too long on treble side?



Solution Two: Screw up through Action Platform and/or glue

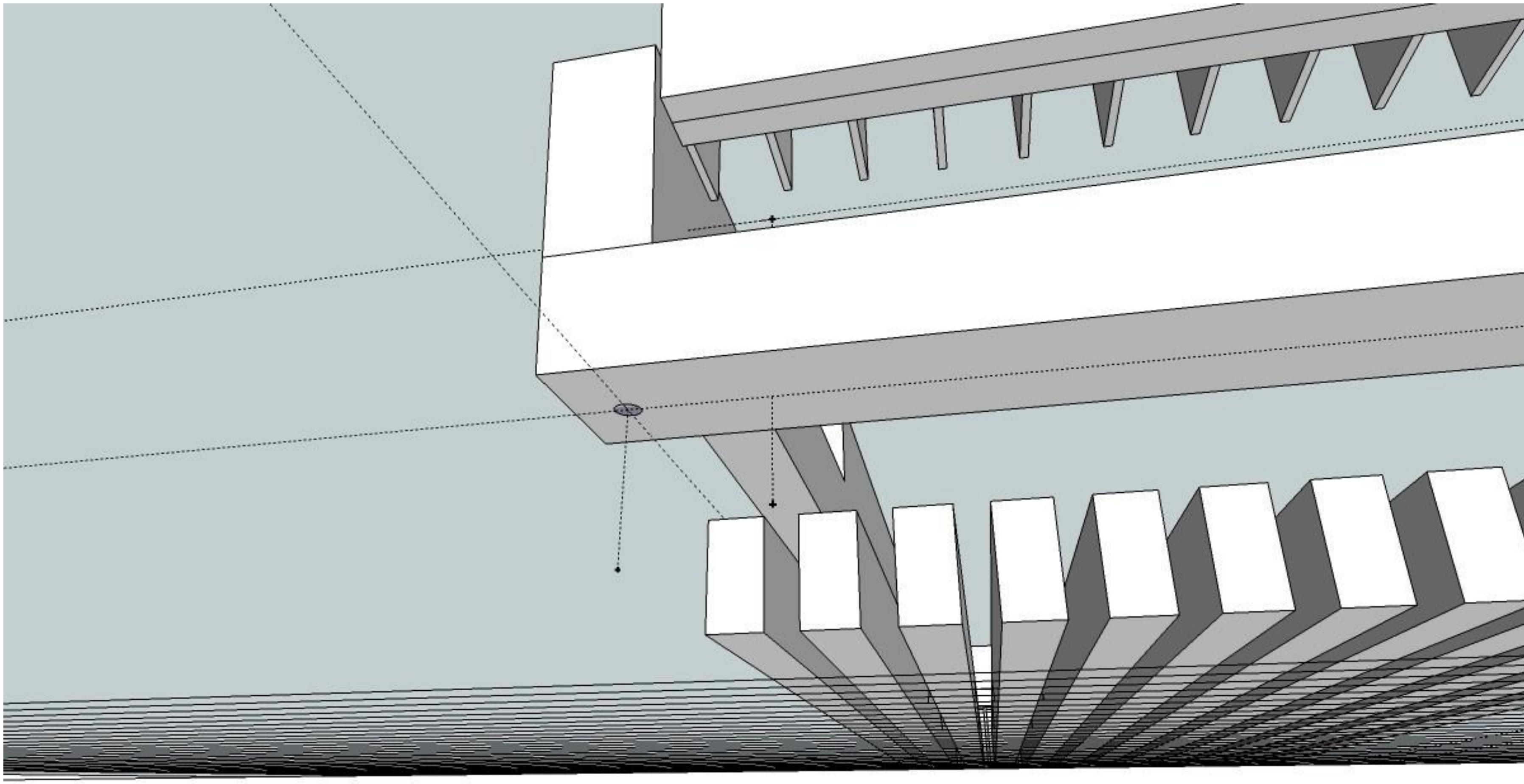
Screw down into harp further into Action Platform



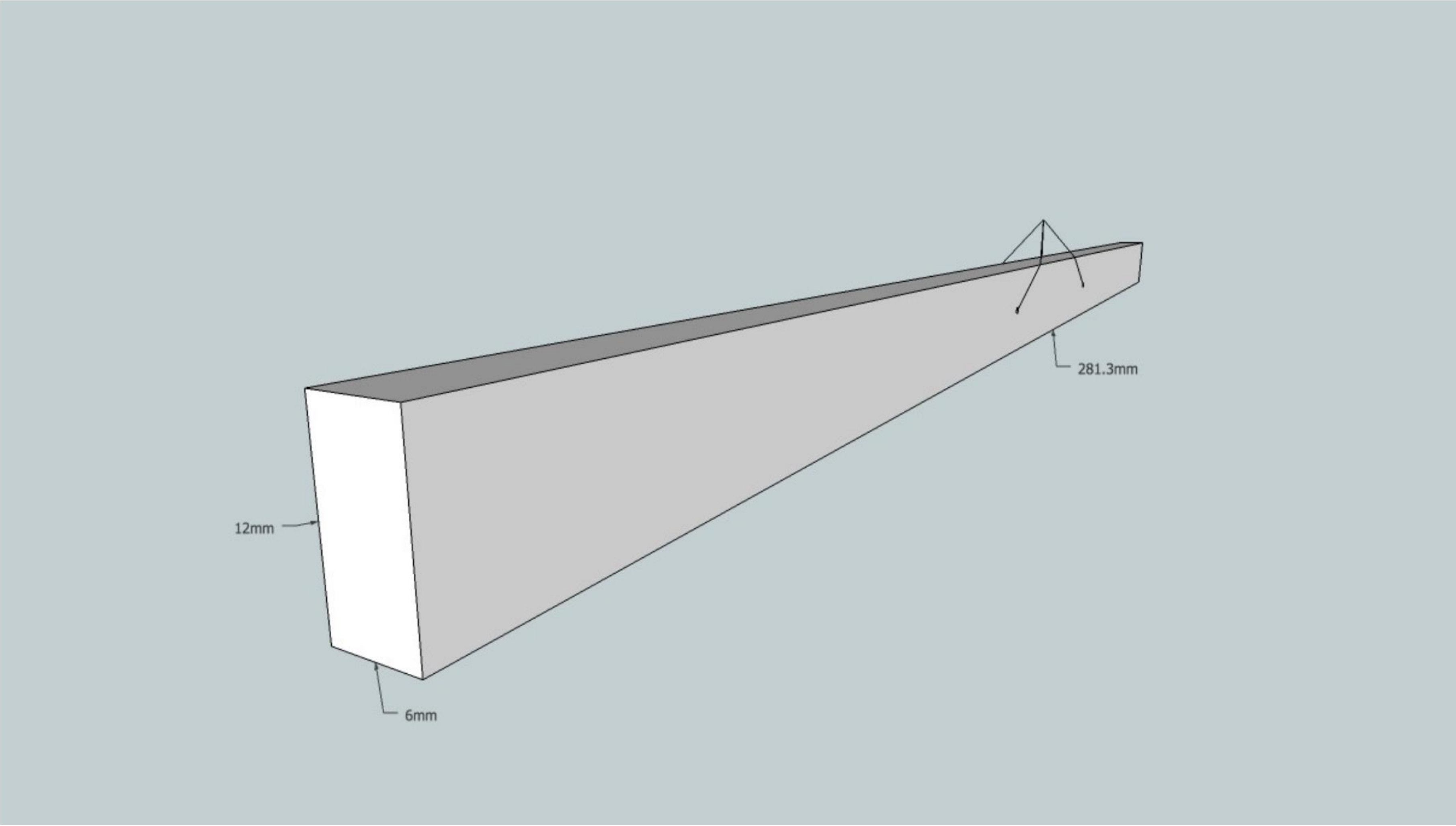
Solution Two: Screw up through Action Platform and/or glue

Screw down into harp further into Action Platform

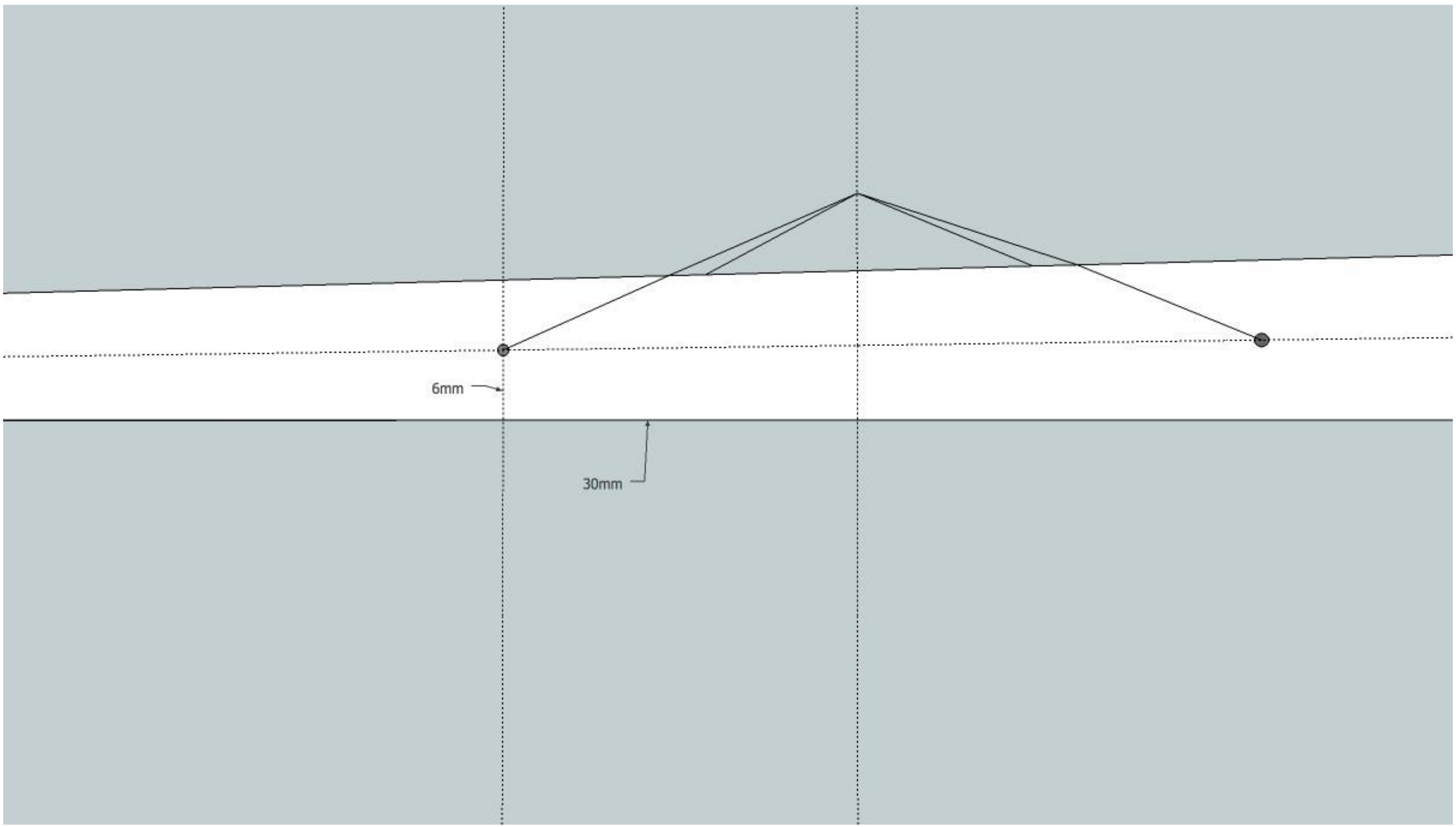
(Lesser) Concern: have to remove combs in order to remove entire action



1.9 Damper Bars


281.3mm
12mm
6mm

Drill Points

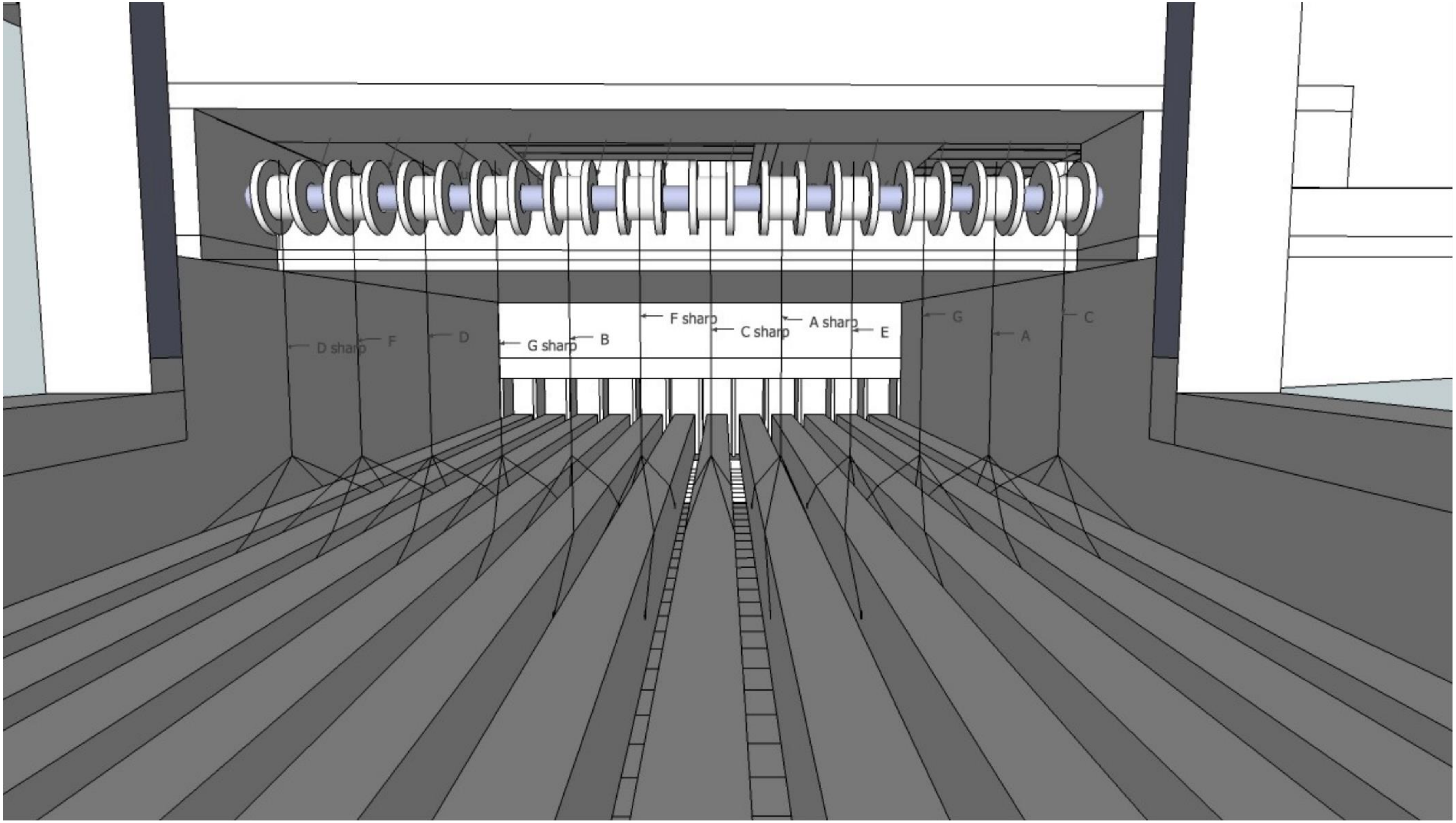


Drill Points

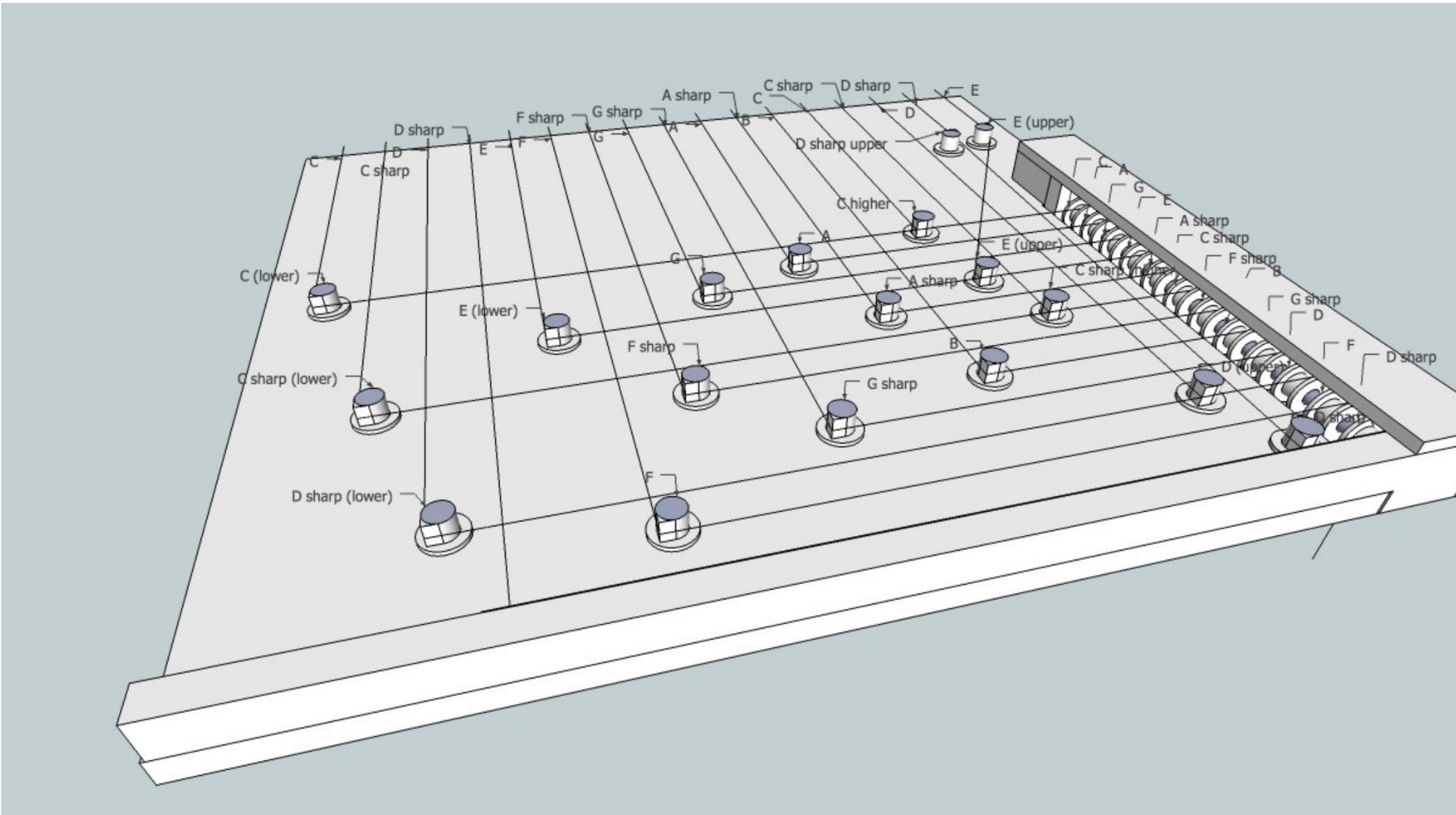
Try this first: from Toe end

D# F D G# B F# C# A# E G A C

This is the solution in previous prototype



Given this order I have calculated these drill points on the matrix. If there is a better solution I can redraw this. See discussion at end of section



Discussion of Difference — Schmidt Prototype to AA Prototype

1. Overall width of Lower Action from Toe to Dead end and cutting of chord bar comb
2. Simplification of cross-spars
3. Differences in hinge platform
4. Lower Action Platform height relative to string height
5. Cross Spar shape relative to string height
6. Removal of Lower Platform feet
7. Positioning on harp due to additional strings and different string schedule
9. Centre pulley point, increased width of keyboard housing and “reach round” (playing)
9. Playing space — distance between toe bridging point of highest string and Toe
Cross Spar
10. Treble Chord Bar Assembly

<u>1. Overall Width of Lower Action from Toe to Dead End</u>

Overall length from toe to dead end on Schmidt prototype is 151mm

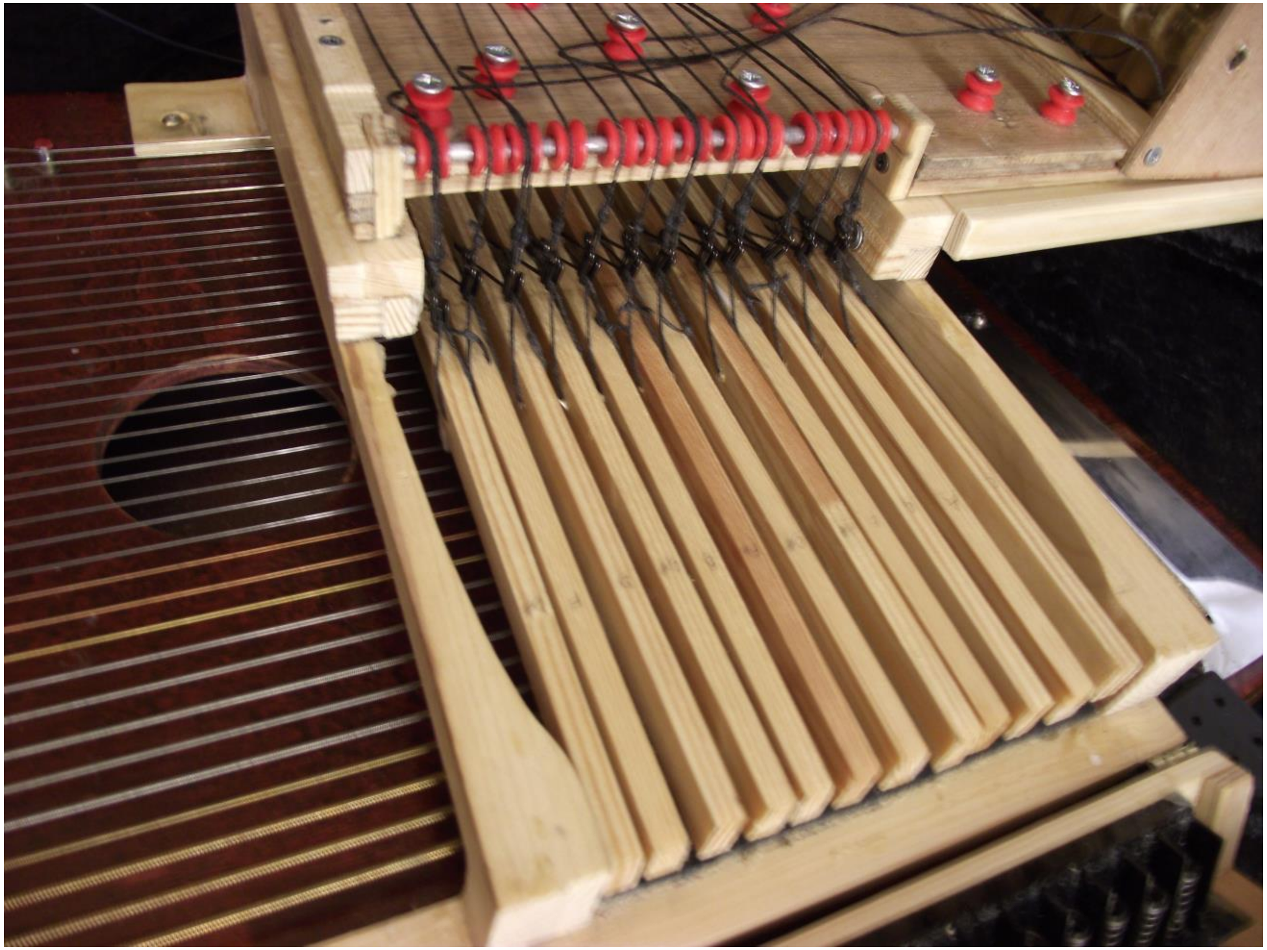
On the plans this length is 141mm — allowing 12mm for the Cross-Spars. Shorter = improvement

1. Overall Width of Lower Action from Toe to Dead End and Cutting of Chord Bar Comb

The length is longer on the Schmidt prototype because the Chord Bar Comb is cut differently.
Note the overhang in the picture; in fact all that is needed are the 12 compartments and a clean cut either side. The springs can be pulled out with pliers.

2. Simplification of Cross-Spars

12mm width for Cross-Spar should be plenty — as you can see I indented the Cross-Spars on the Schmidt prototype so that they were very thin (corrected in drawings for this prototype build)



Beginning from the bass side:

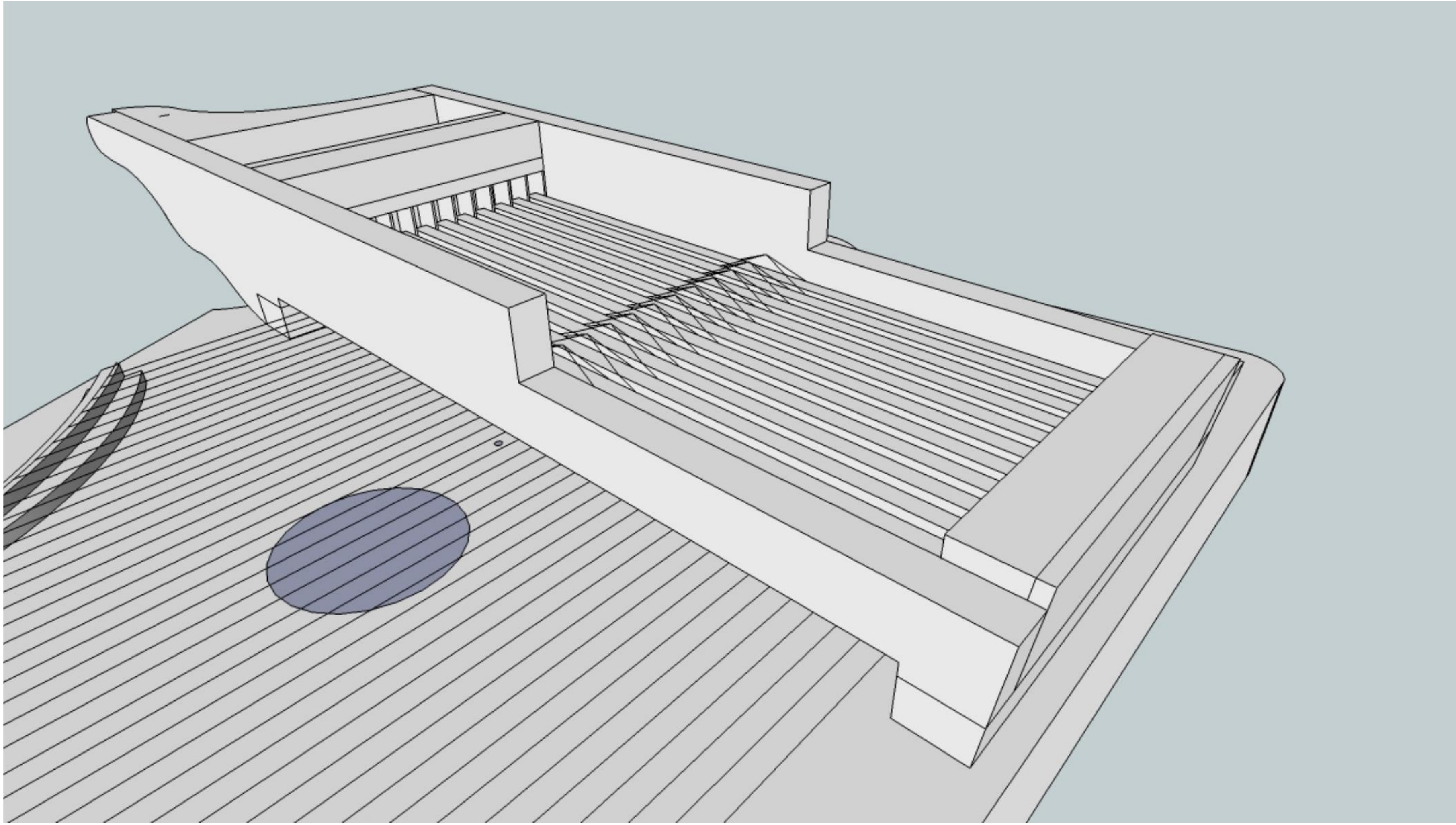
The end of Cross-Spar was cut to 90° on Schmidt prototype. This meant that small inserts had to be produced both sides to meet the awkward angle that the comb sits.

Another problem that had to be rectified was the overall height key should be 10.4cm above the strings.

This is why there is an extra layer inserted here.

The Treble Chord Bar Assembly is locked in in the Schmidt prototype

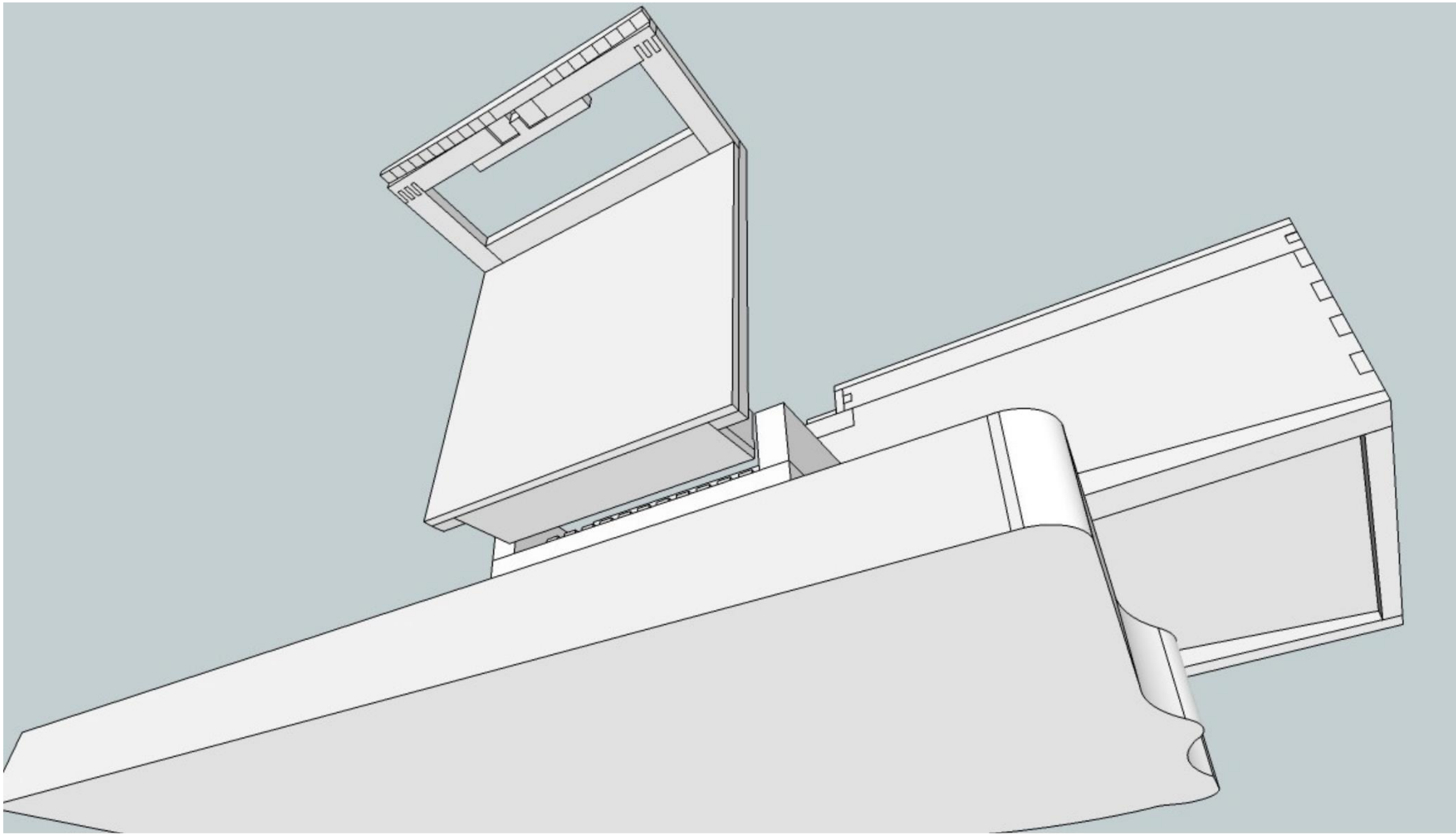
The re-design simplifies all this — Cross-Spars are single pieces, but with two awkward non 90° cuts. Another difference: note how the Cross-spars go right down behind the Action Platform on the treble side. This produces a different curve to the Schmidt prototype. The purpose of this is to frame the screw plate at the back of the Treble Chord Bar Assembly



3. Differences in Hinge Platform

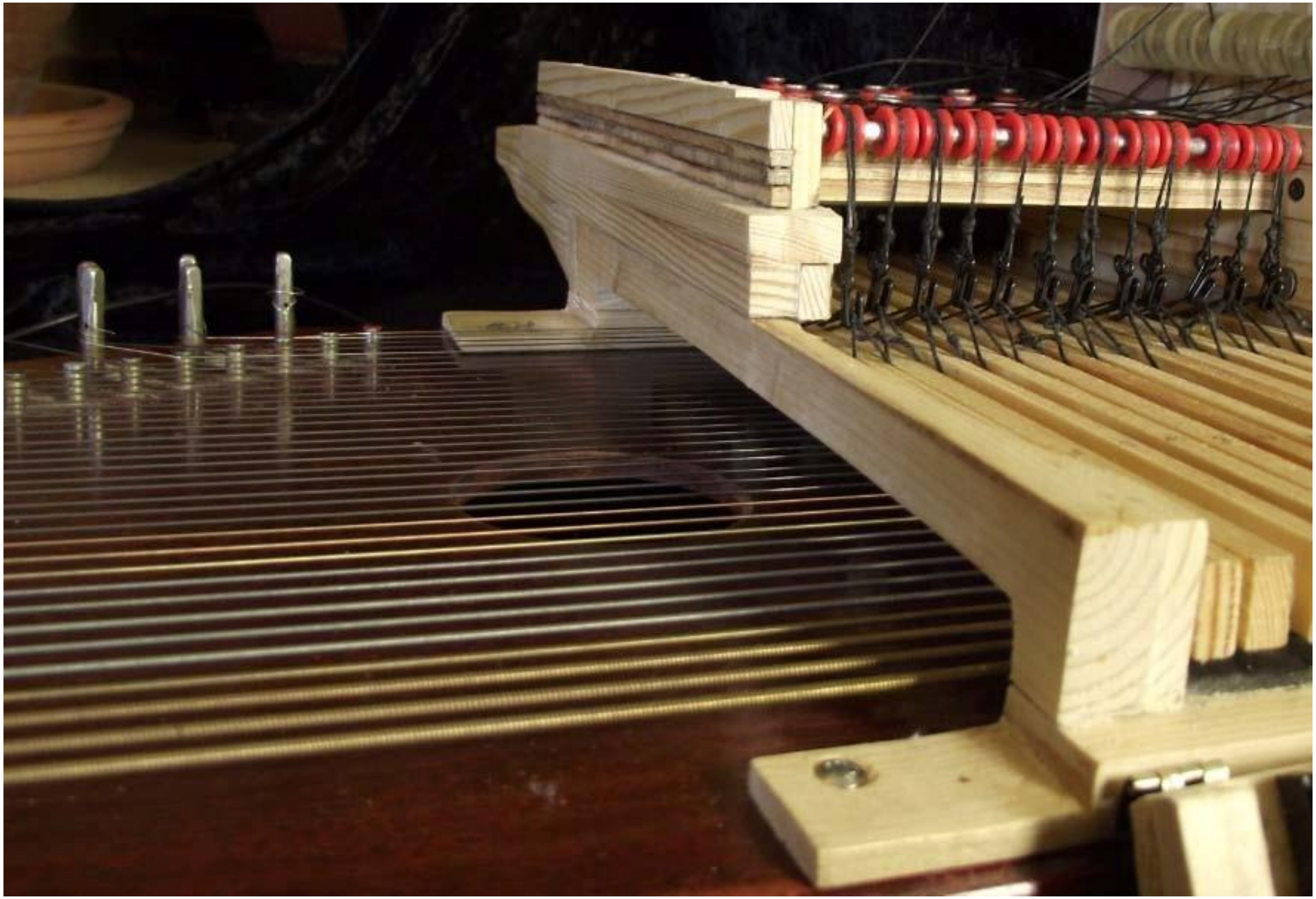
This shape is tidied up

So the new lid opens like this



4. Lower Action Platform Height Relative to String Height

I have adjusted the platform height to the string height indicated on the AA drawing. I used damping felt of depth 7mm



5. Cross Spar Shape Relative to String Height

I have lowered the bottom of the Cross-Spars with respect to the strings. There is 6mm clearance.

6. Removal of Lower Platform Feet

The Schmidt prototype had extending feet (extending down the playing surface). These are a pain in the neck when playing, particularly on the treble side, I have removed them in the new plan.

7. Positioning on Harp Due to Additional Strings and Different String Schedule

The initial position is parallel to the bridging point of the last string (described earlier). This is the same as for the Schmidt prototype. However, it is a different string on the new harp (D). An alternative might have been to place parallel to C anyway — however, this would have meant that the first two damper positions from the dead end could not be used by C# or D. Given that we are adding bass strings, so there are further unknowns, I did not want to limit possibility here. Although there are 12! theoretical possibilities, its amazing how many of them can be ruled out very quickly!

10. Centre Pulley Point – Increased Width of Keyboard Housing, Increased Width of Harp and “Reach Round” (Playing)

AA

137.8mm Bass side

156.5mm to Action platform (5mm past last string)

Schmidt

126mm bass side

135mm to Action Platform (5mm past last string)

I have experimented with these differences with some “air harp” — they seem fine

9. Playing Space – Distance Between Toe Bridging Point of Highest String and Toe Cross Spar

AA 59.4mm

Schmidt 60mm

Improvement – despite extra strings, due to inventive bridge shape, and shorter lower action. Further improvement by getting rid of extending feet!

<u>10. Treble Chord Bar Assembly</u>

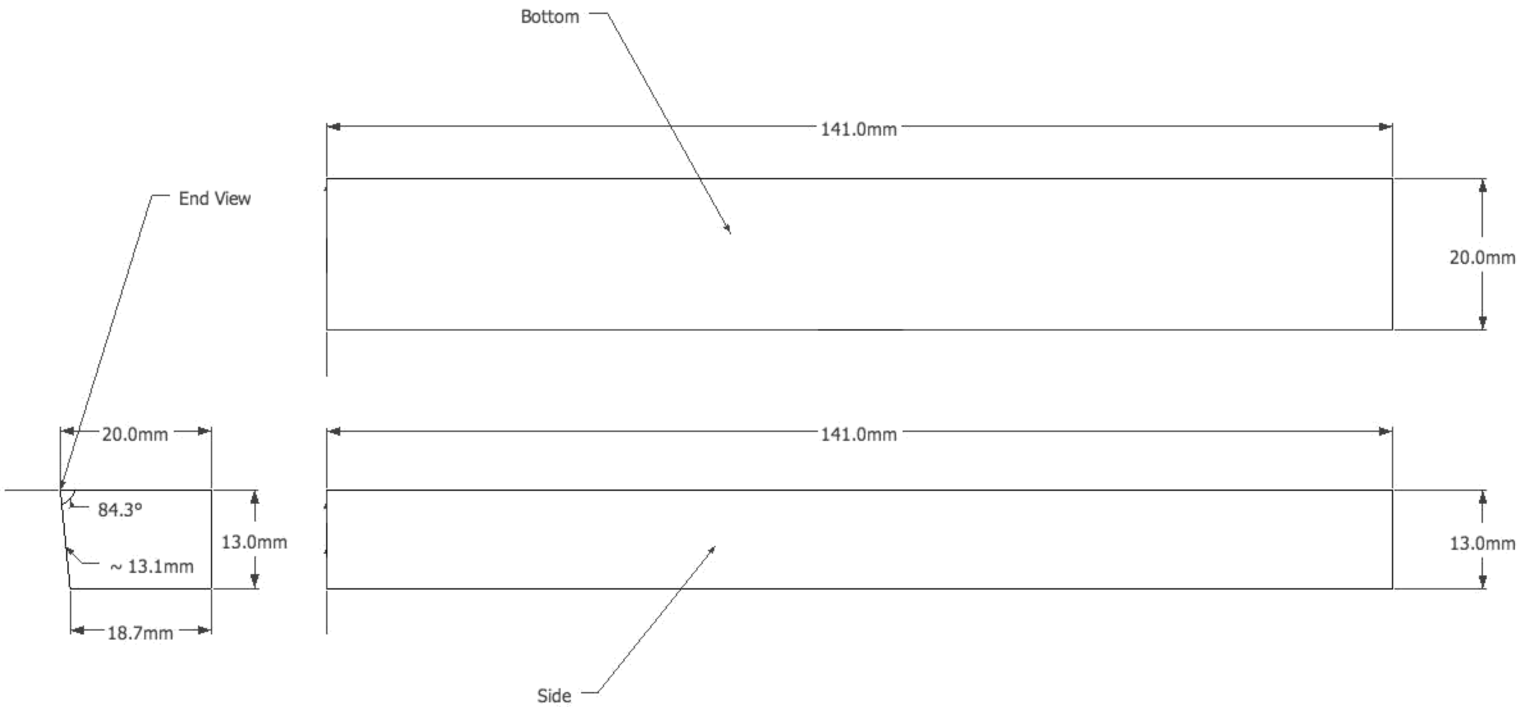
Access to Treble Chord Bar Assembly due to simplification of Cross-Spars.

1:1 Parts List and Templates

1 Lower Action

x2

1.2 Action Platform



1 Lower Action

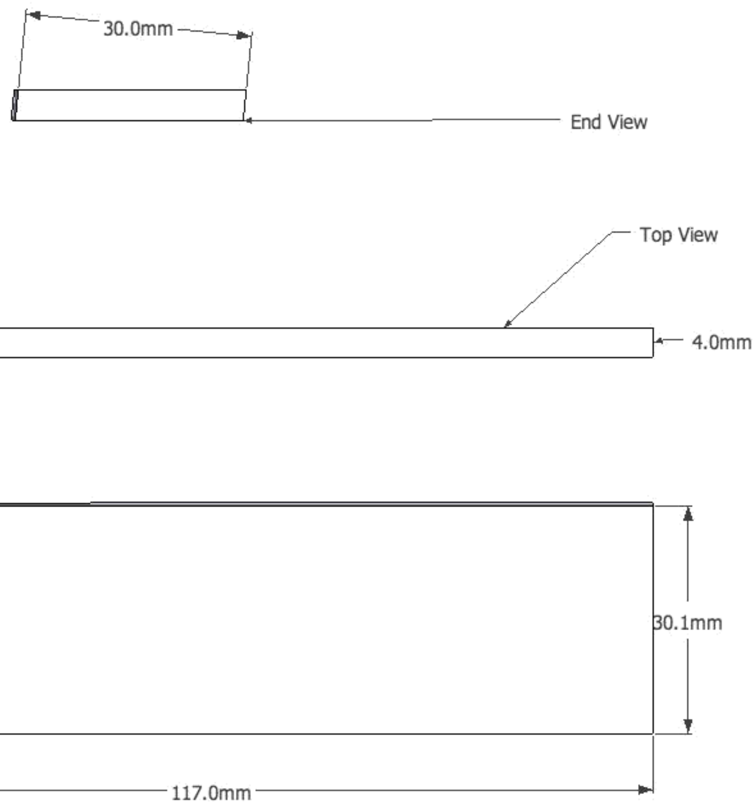
x2

1.2 Action Platform

1 Lower Action

x2

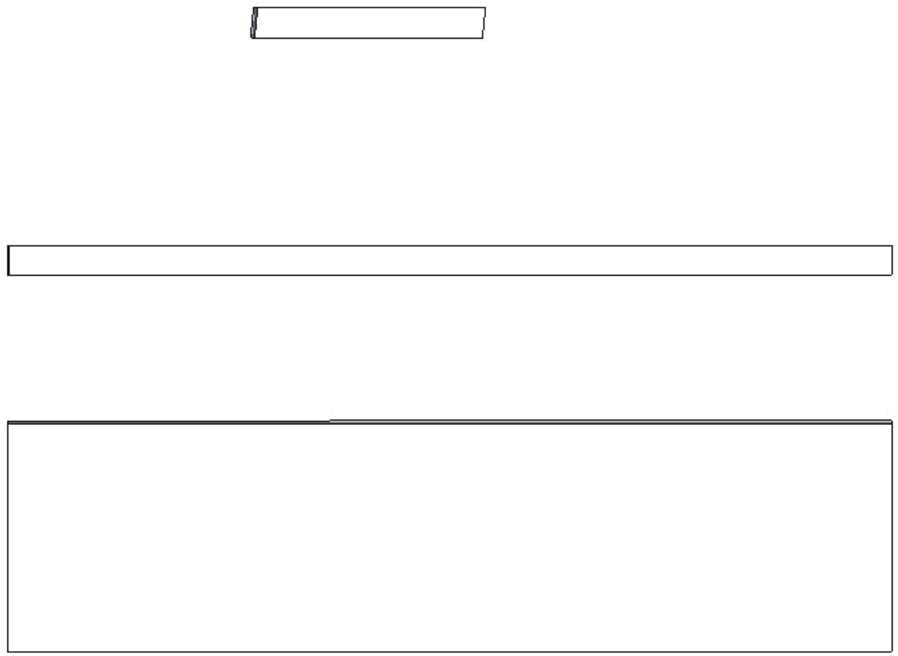
1.1 Comb Backing



1 Lower Action

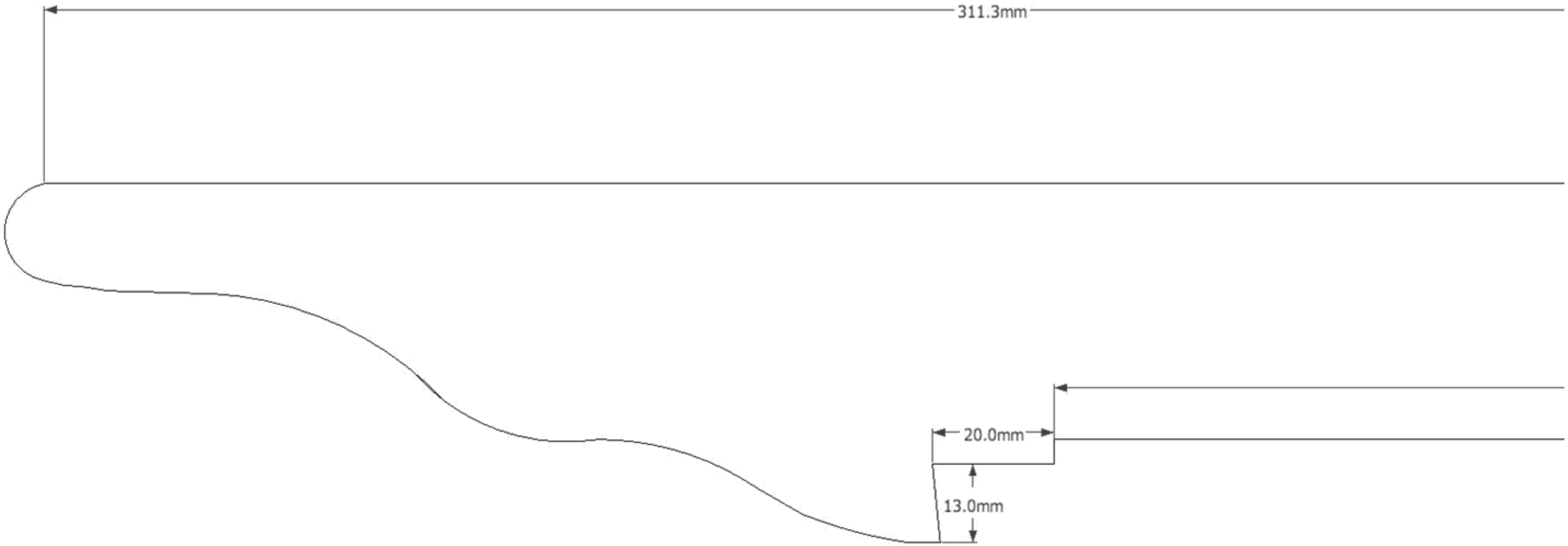
1.1 Comb Backing

x2



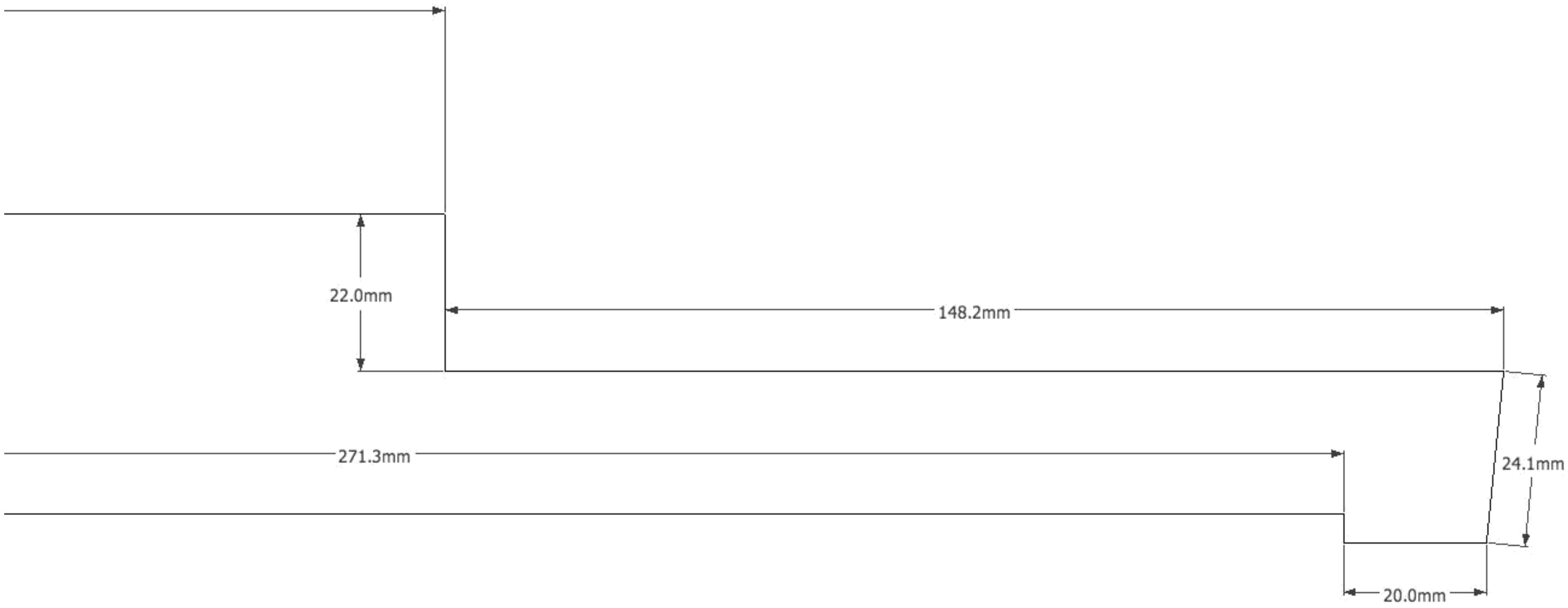
1 Lower Action

1.4 Toe Cross Spar



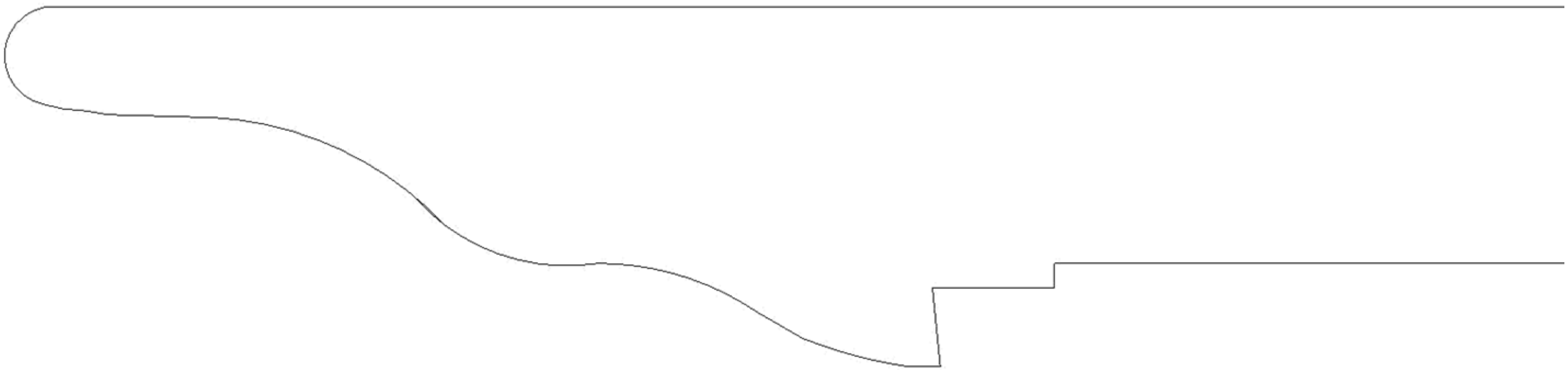
1 Lower Action

1.4 Toe Cross Spar



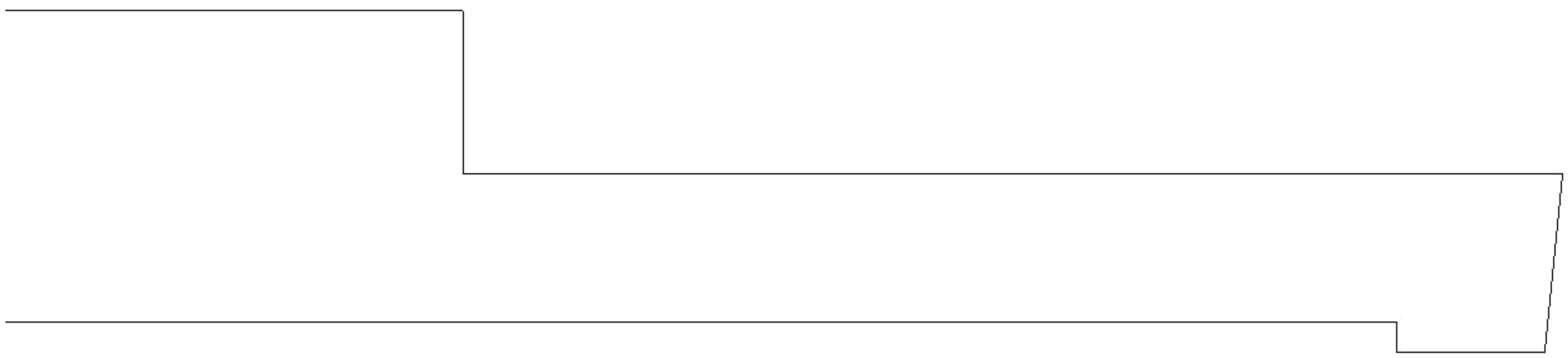
1 Lower Action

1.4 Toe Cross Spar



1 Lower Action

1.4 Toe Cross Spar

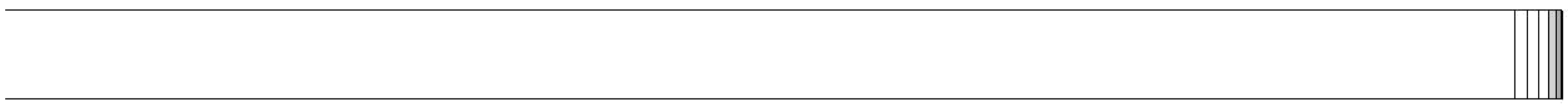


1 Lower Action

1.4 Toe Cross Spar (Top)

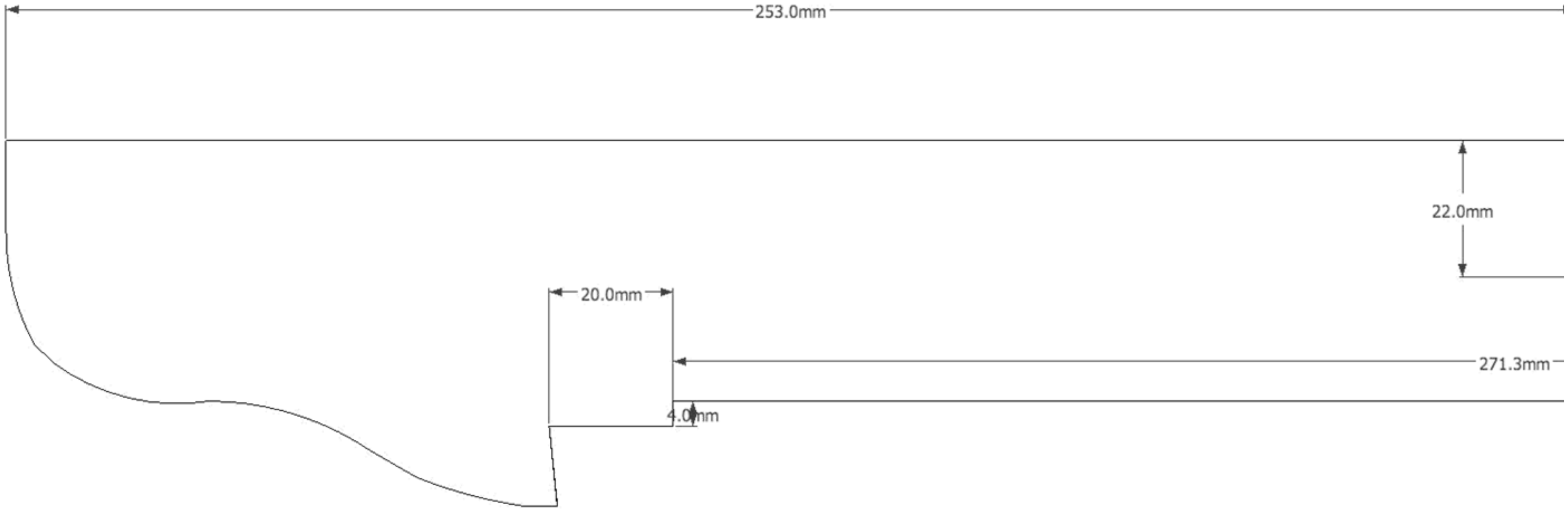
1 Lower Action

1.4 Toe Cross Spar (Top)



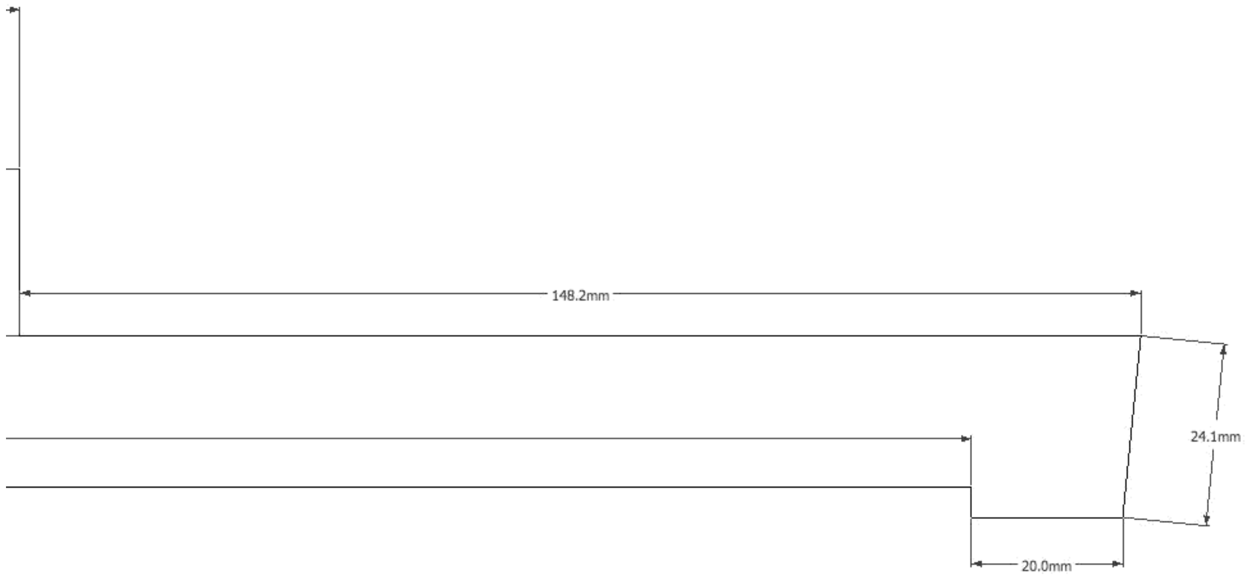
1 Lower Action

1.5 Dead Cross Spar



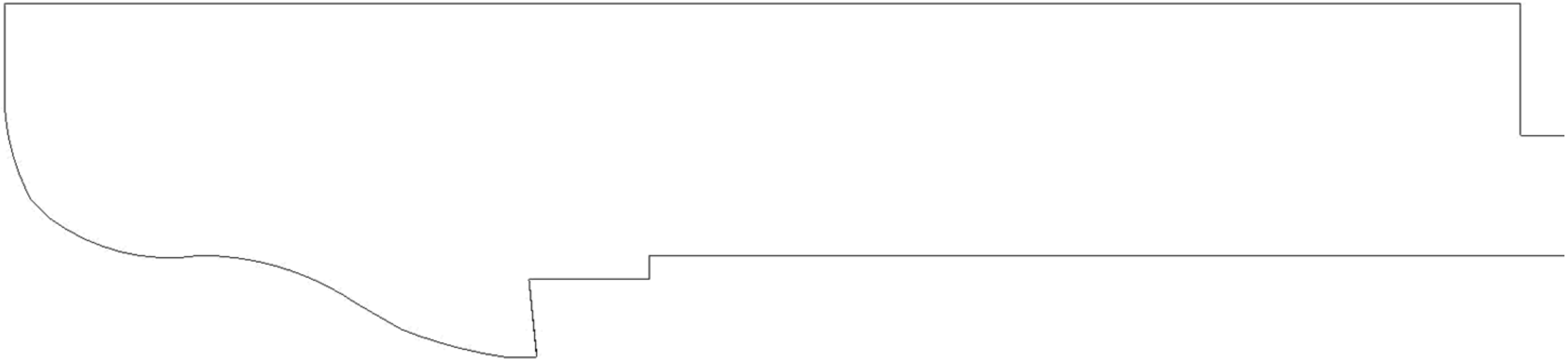
1 Lower Action

1.5 Dead Cross Spar



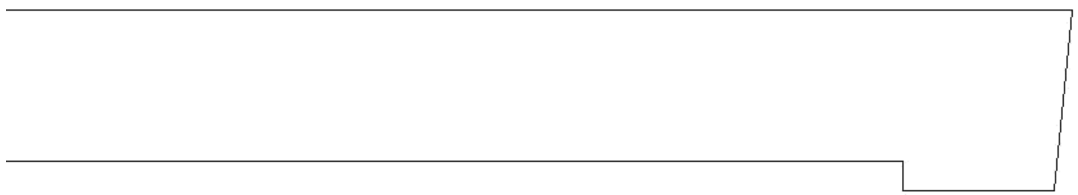
1 Lower Action

1.5 Dead Cross Spar



1 Lower Action

1.5 Dead Cross Spar



1 Lower Action

1.5 Dead Cross Spar (Top)

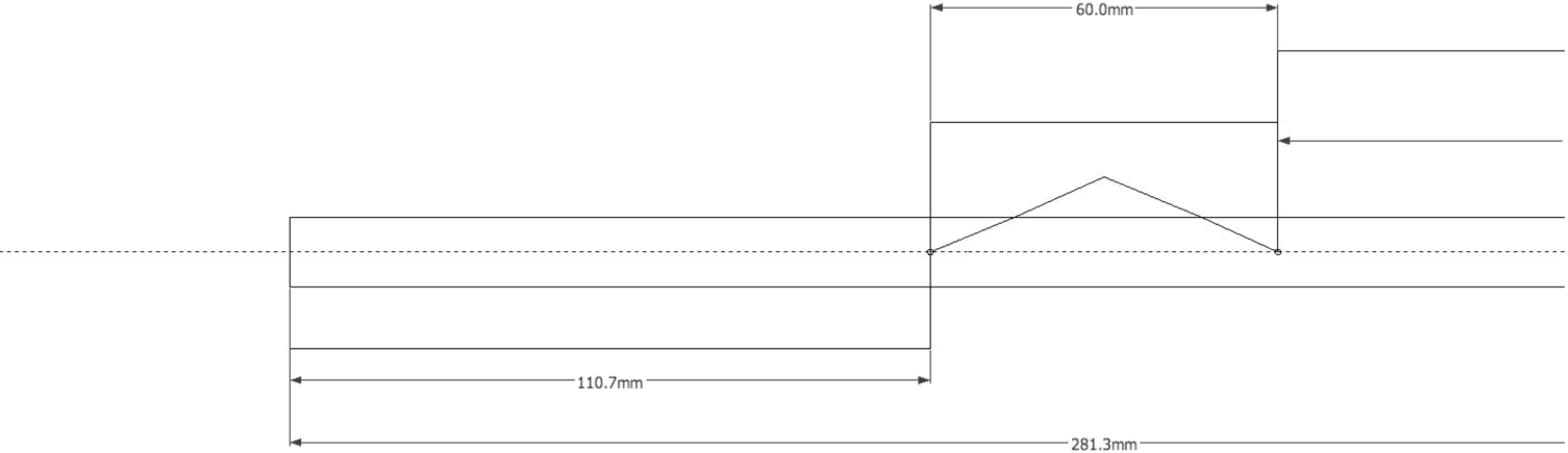
1 Lower Action

1.5 Dead Cross Spar (Top)

x12

1 Lower Action

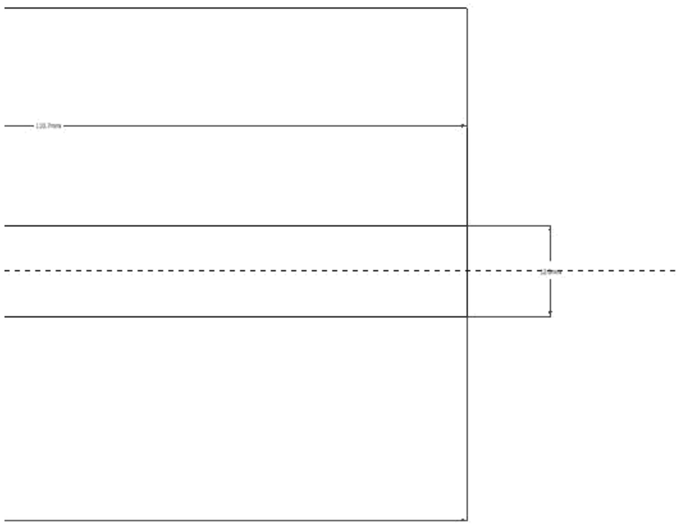
1.9 Damper Bars



x12

1 Lower Action

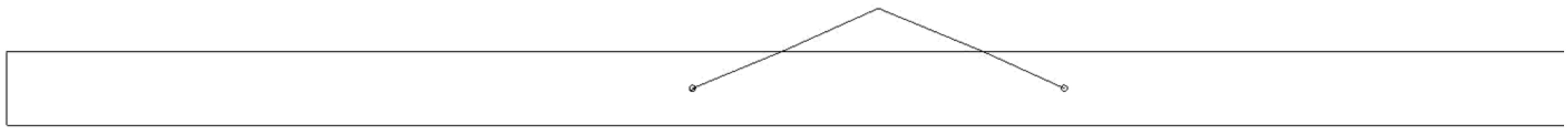
1.9 Damper Bars



x12

1 Lower Action

1.9 Damper Bars



x12

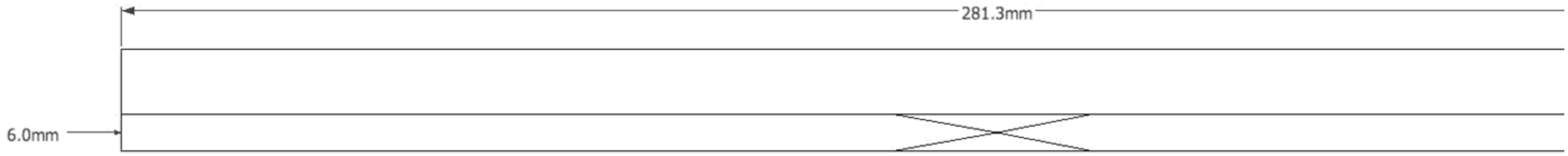
1 Lower Action

1.9 Damper Bars

x12

1 Lower Action

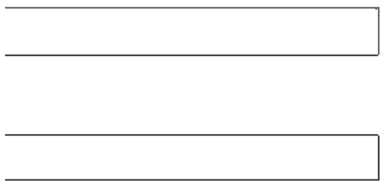
1.9 Damper Bars (Top)



x12

1 Lower Action

1.9 Damper Bars (Top)



x12

1 Lower Action

1.9 Damper Bars (Top)

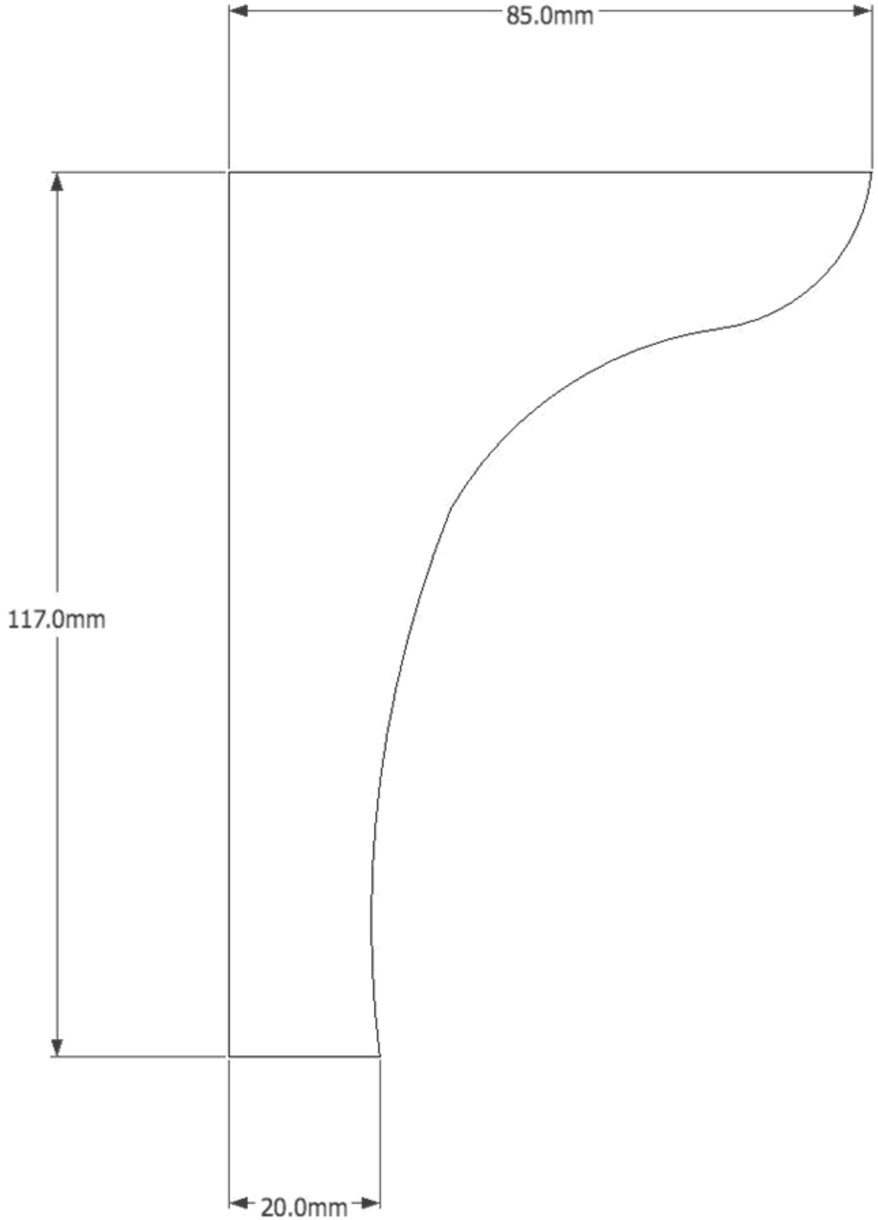
x12

1 Lower Action

1.9 Damper Bars (Top)

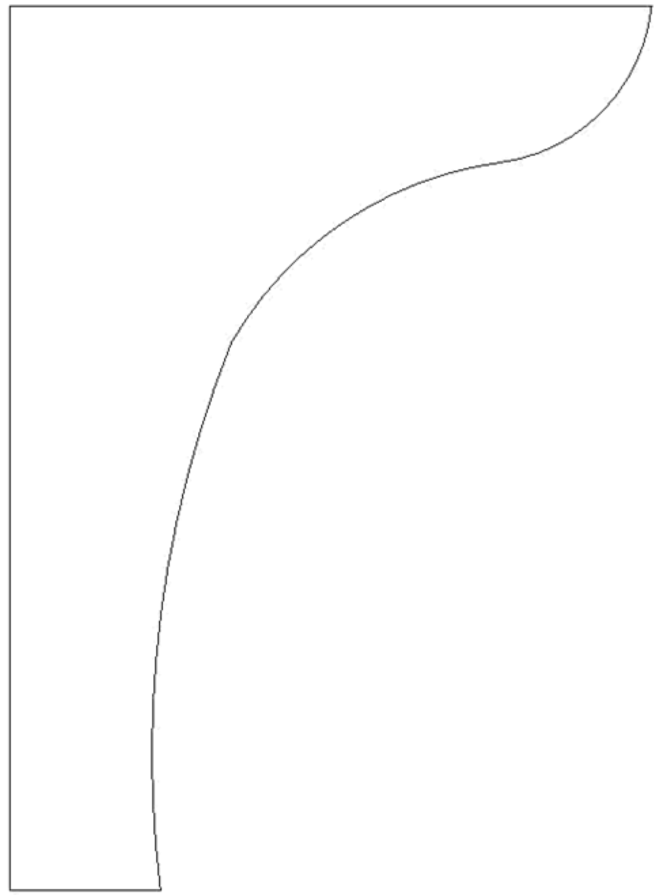
1 Lower Action

1.7 Spitfire Wing



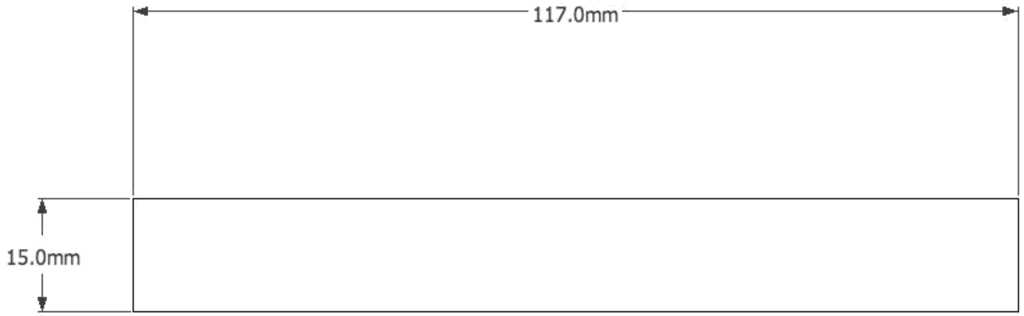
1 Lower Action

1.7 Spitfire Wing



1 Lower Action

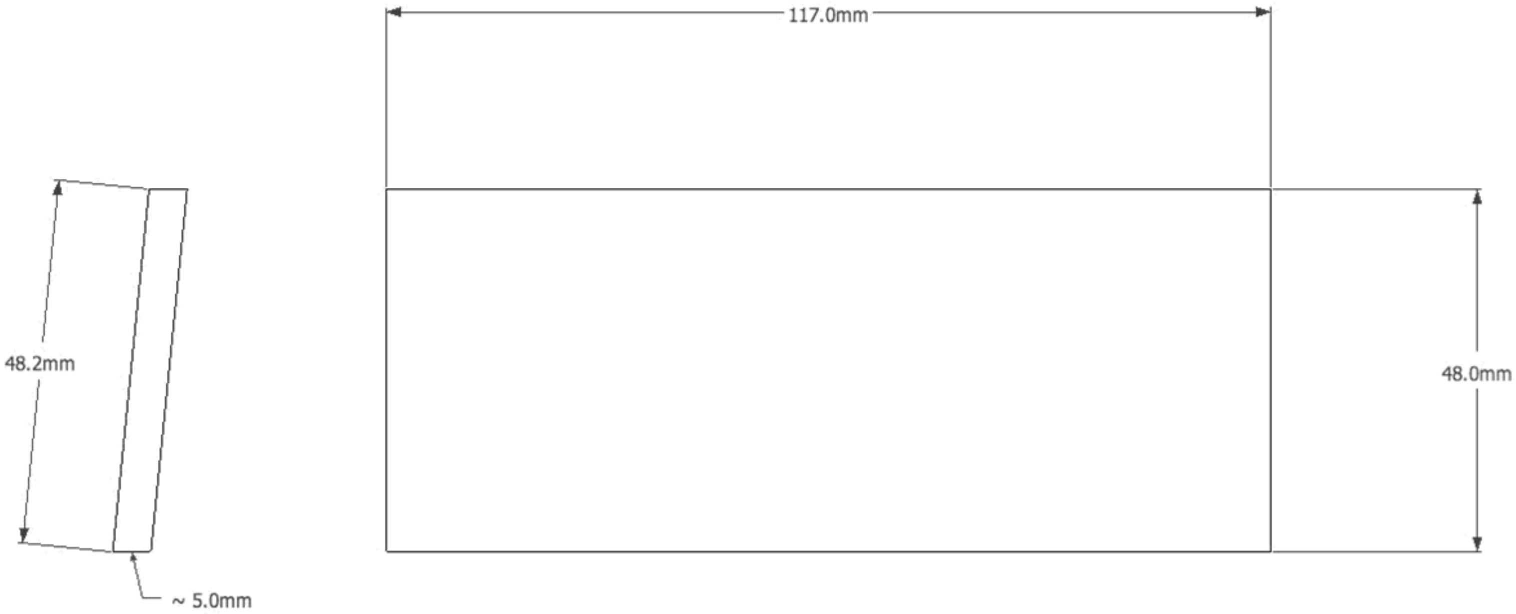
1.7 Spitfire Wing (Top)



1.7 Spitfire Wing (Top)

1 Lower Action

1.6 Screw Plate

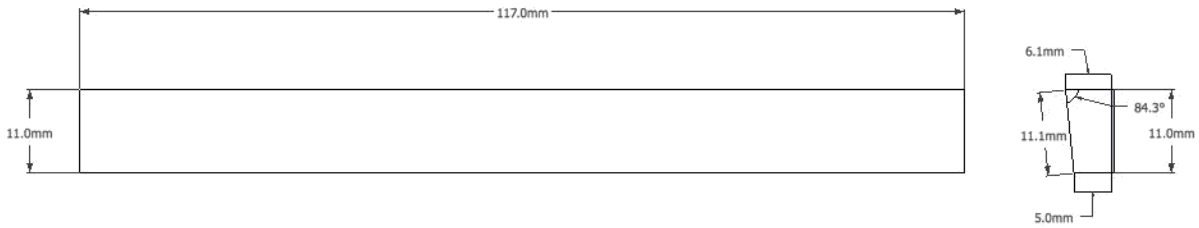


1 Lower Action

1.6 Screw Plate

1 Lower Action

1.6 Top Plate 1

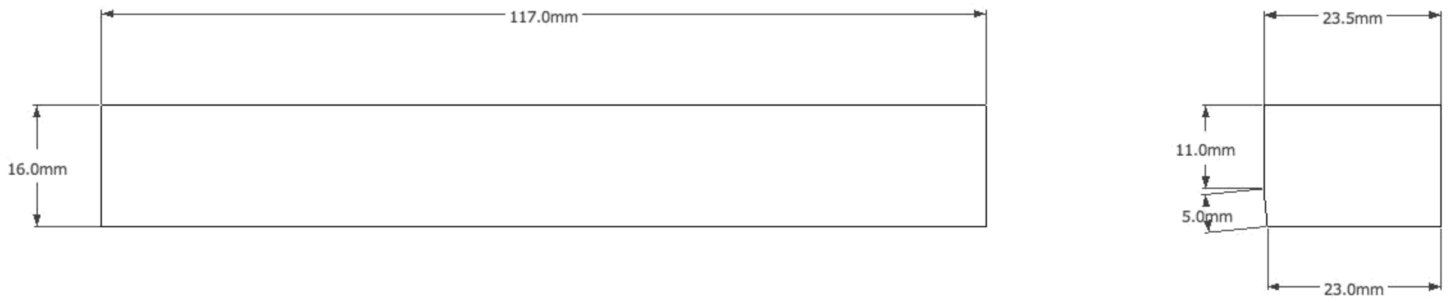


1 Lower Action

1.6 Top Plate 1

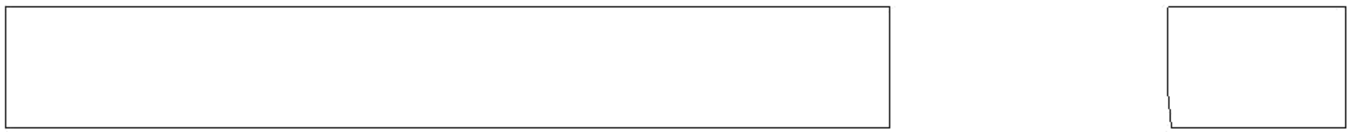
1 Lower Action

1.6 Top Plate 2



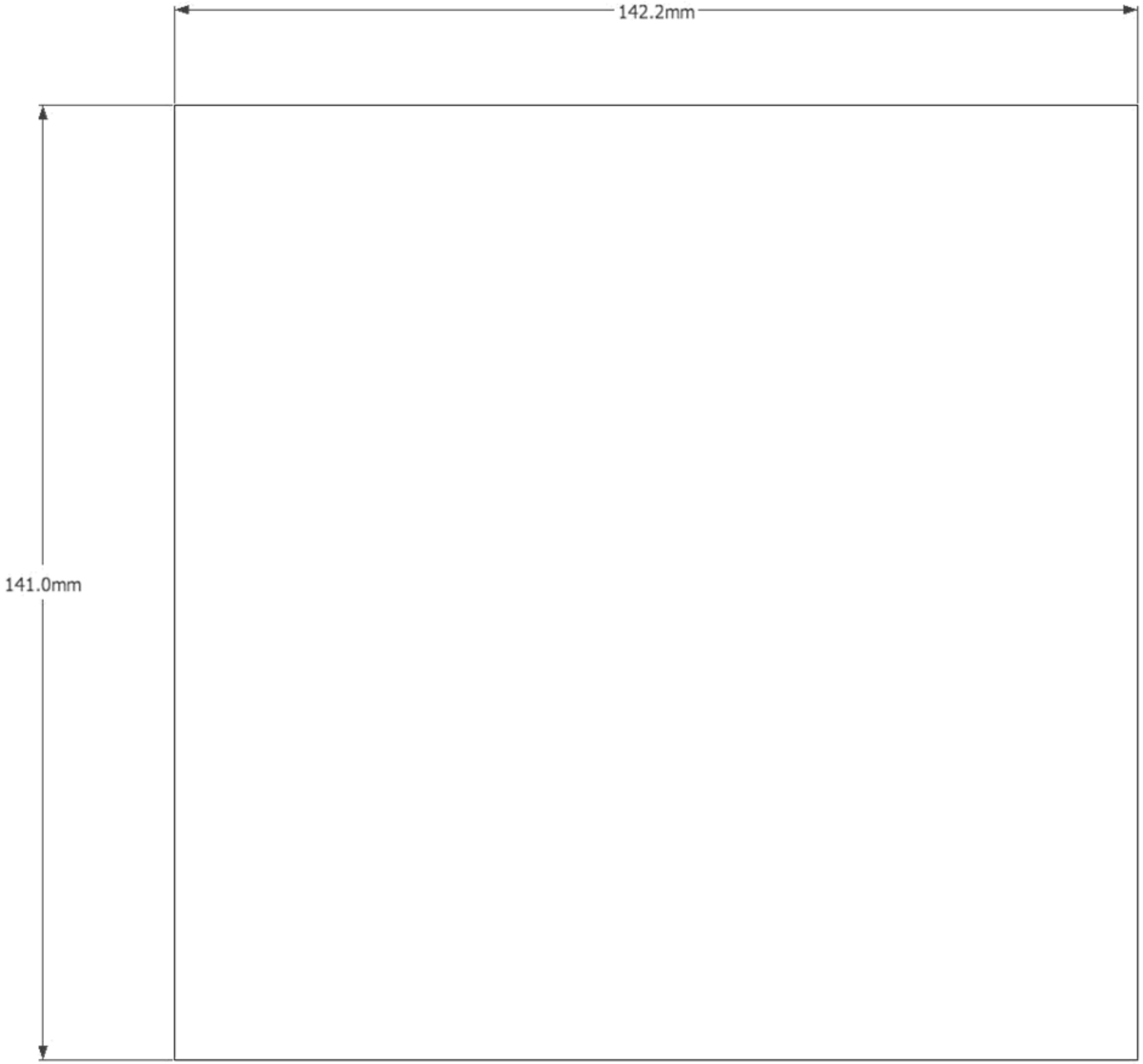
1 Lower Action

1.6 Top Plate 2



1 Lower Action

2.1 Bass Lid

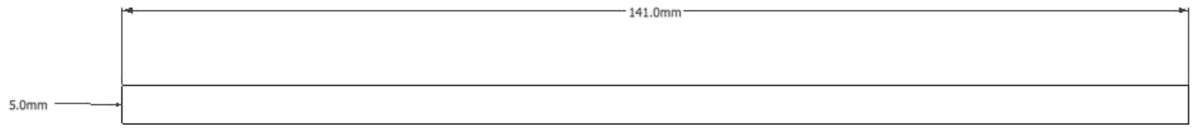


1 Lower Action

2.1 Bass Lid

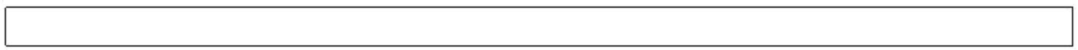
1 Lower Action

2.1 Bass Lid (side)



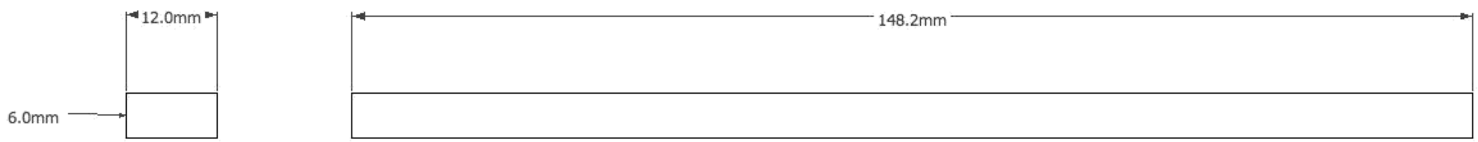
1 Lower Action

2.1 Bass Lid (side)



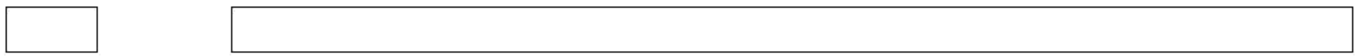
1 Lower Action

2.1 Lid Side Arm (from cross spar block) x2



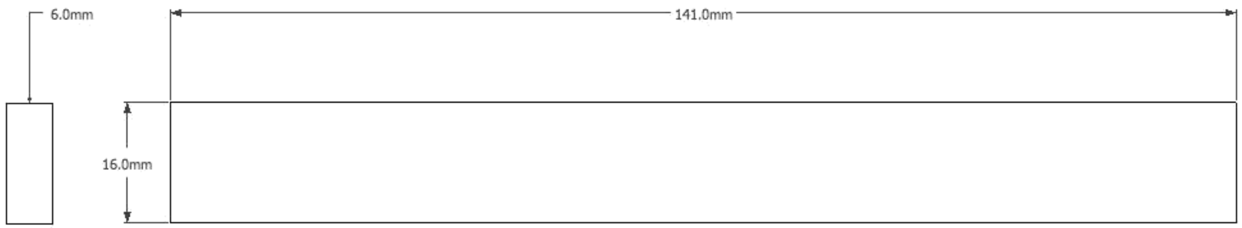
1 Lower Action

2.2 Lid Side Arm x2



1 Lower Action

2.3 Lid Handle



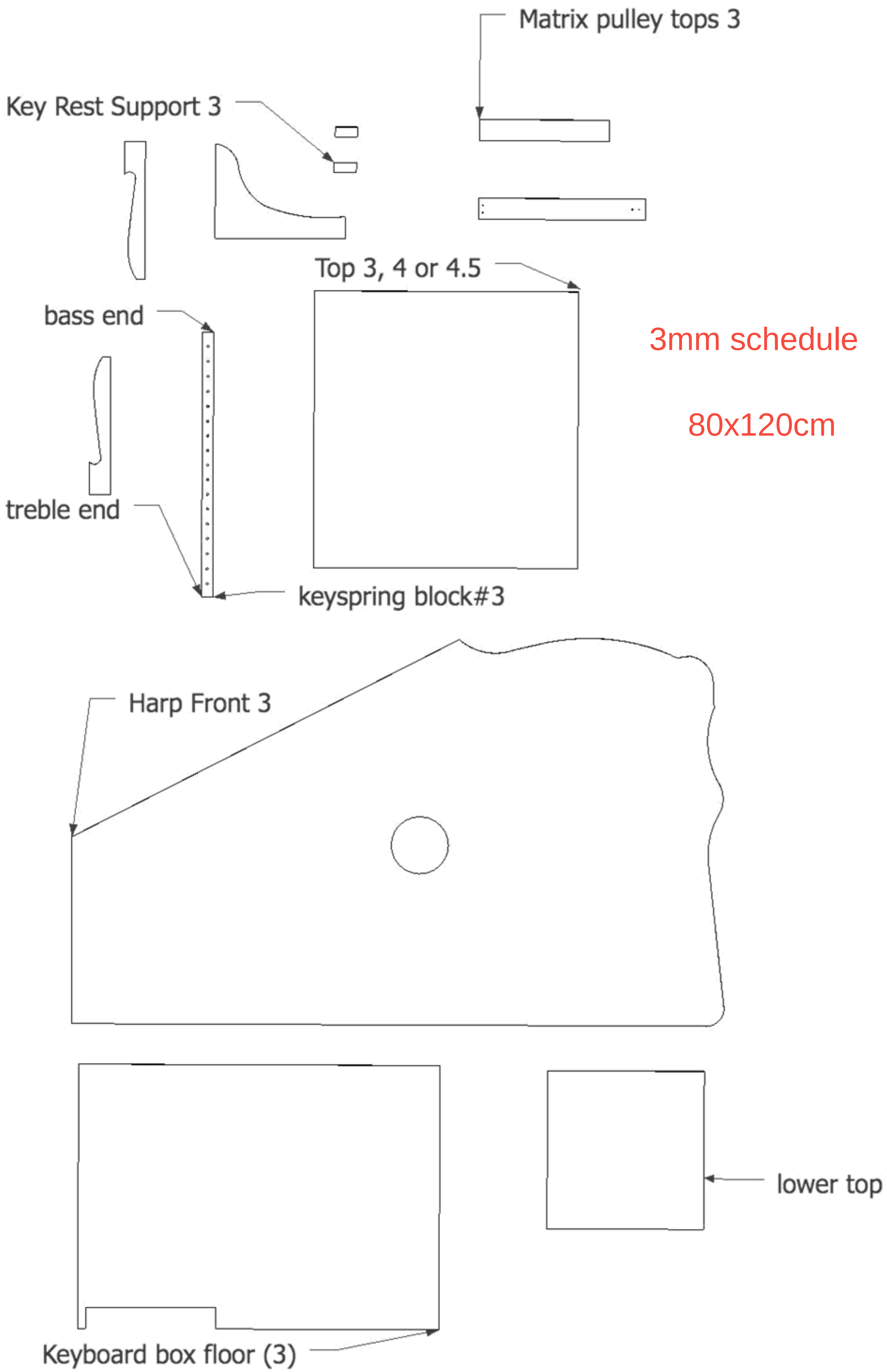
1 Lower Action

2.3 Lid Handle

Appendix 5

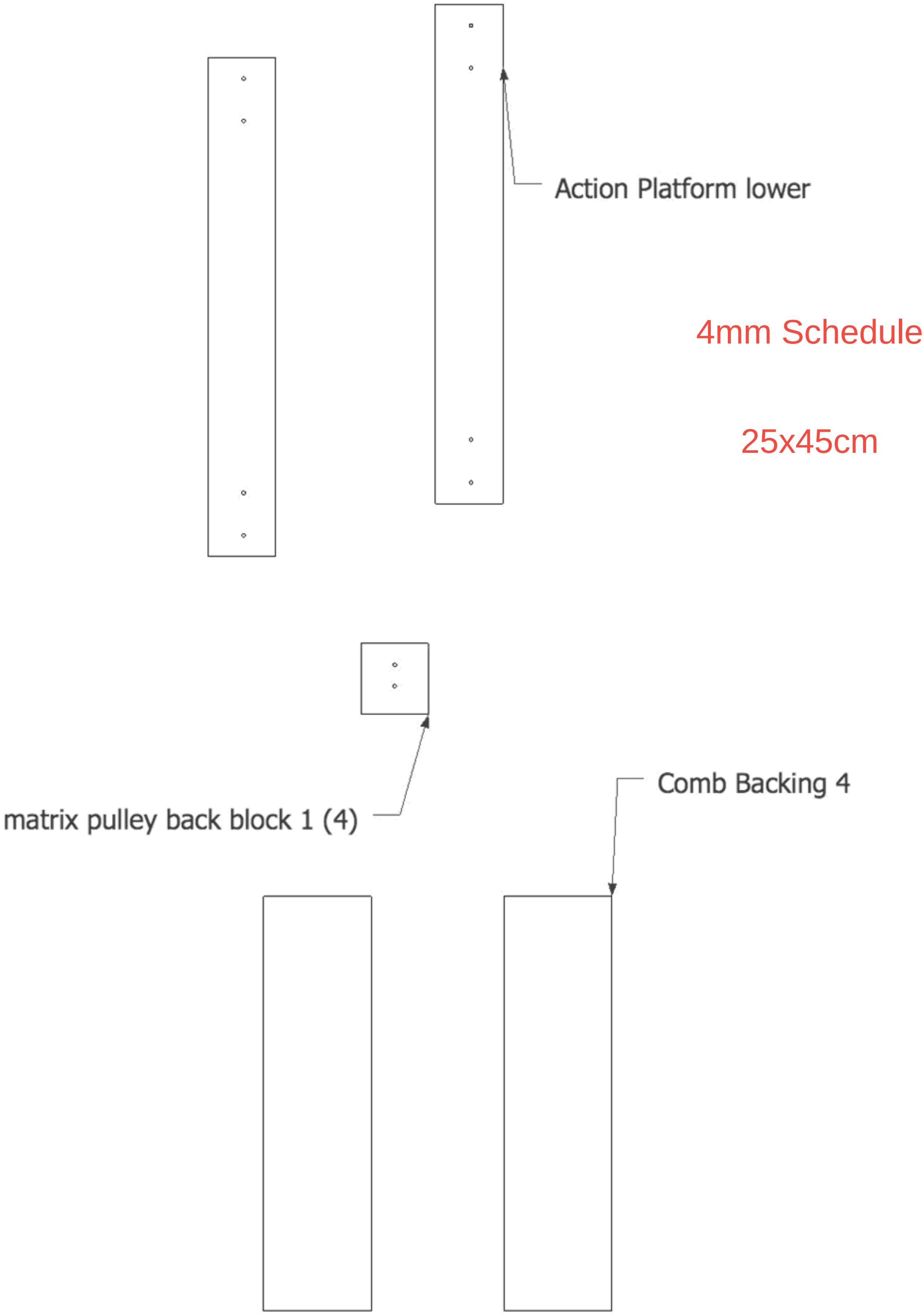
CNC Schedule

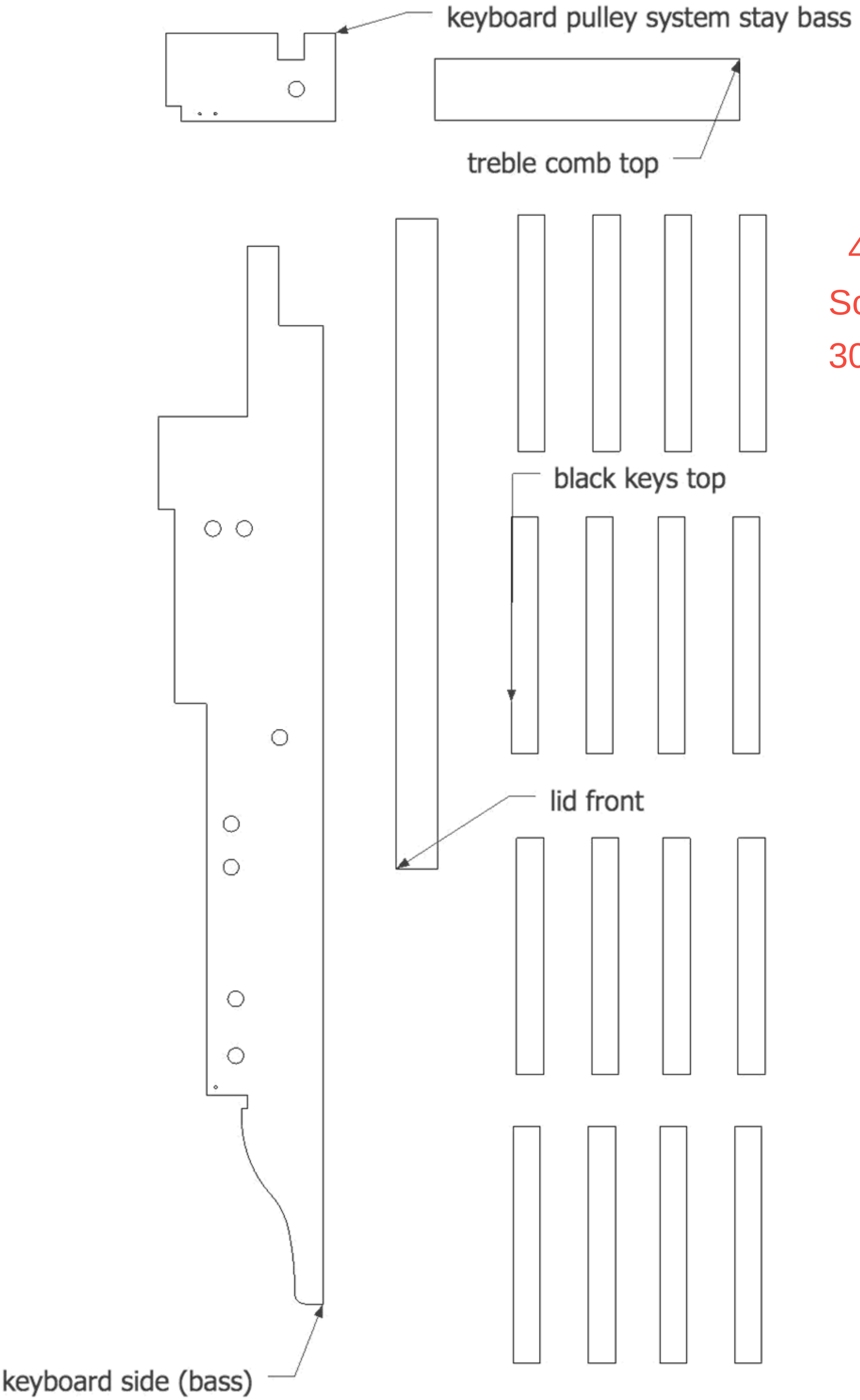
Key to Parts



3mm schedule

80x120cm

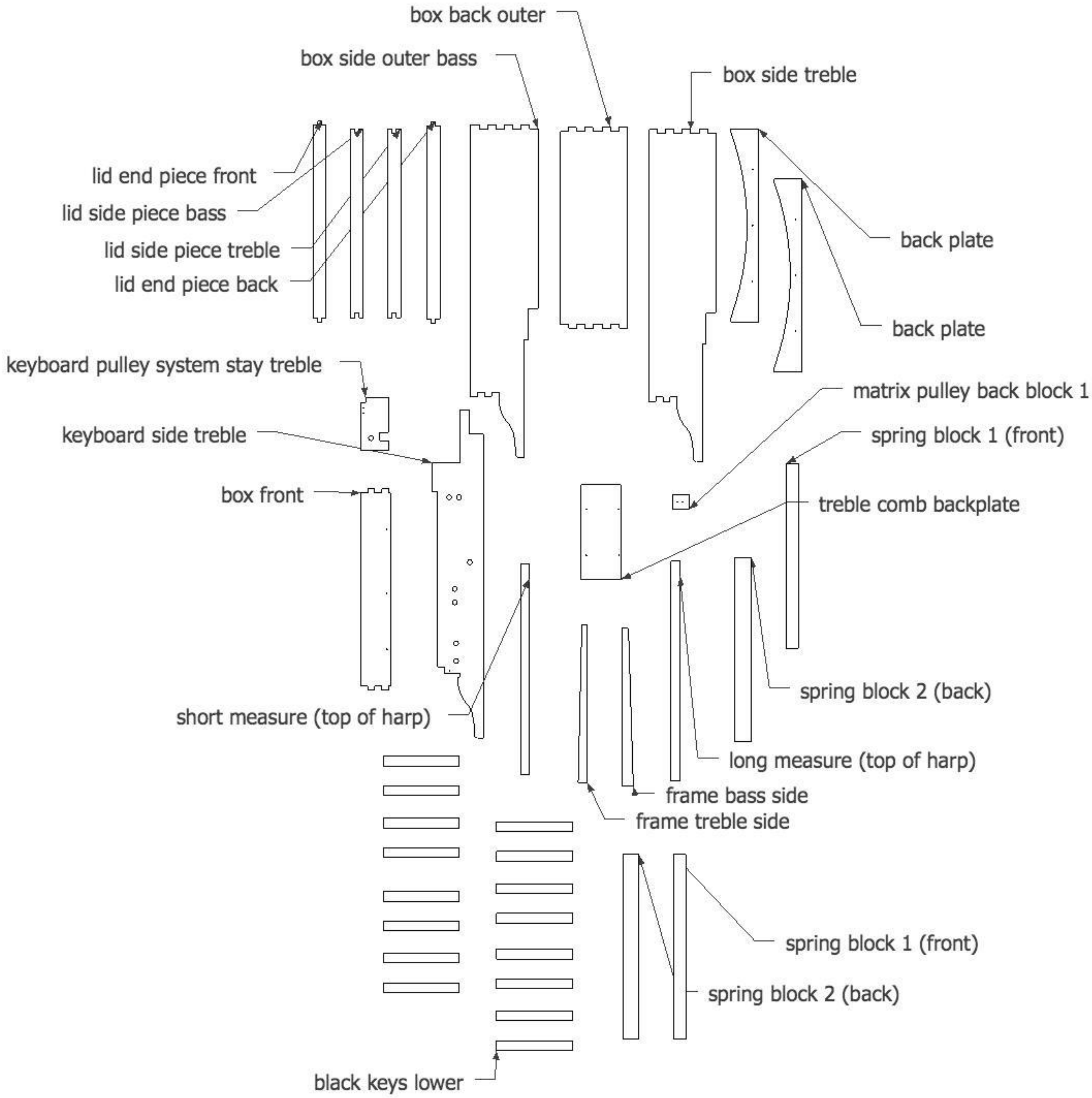

Action Platform lower
4mm Schedule
25x45cm
matrix pulley back block 1 (4)
Comb Backing 4



4.5mm
Schedule
30x55cm

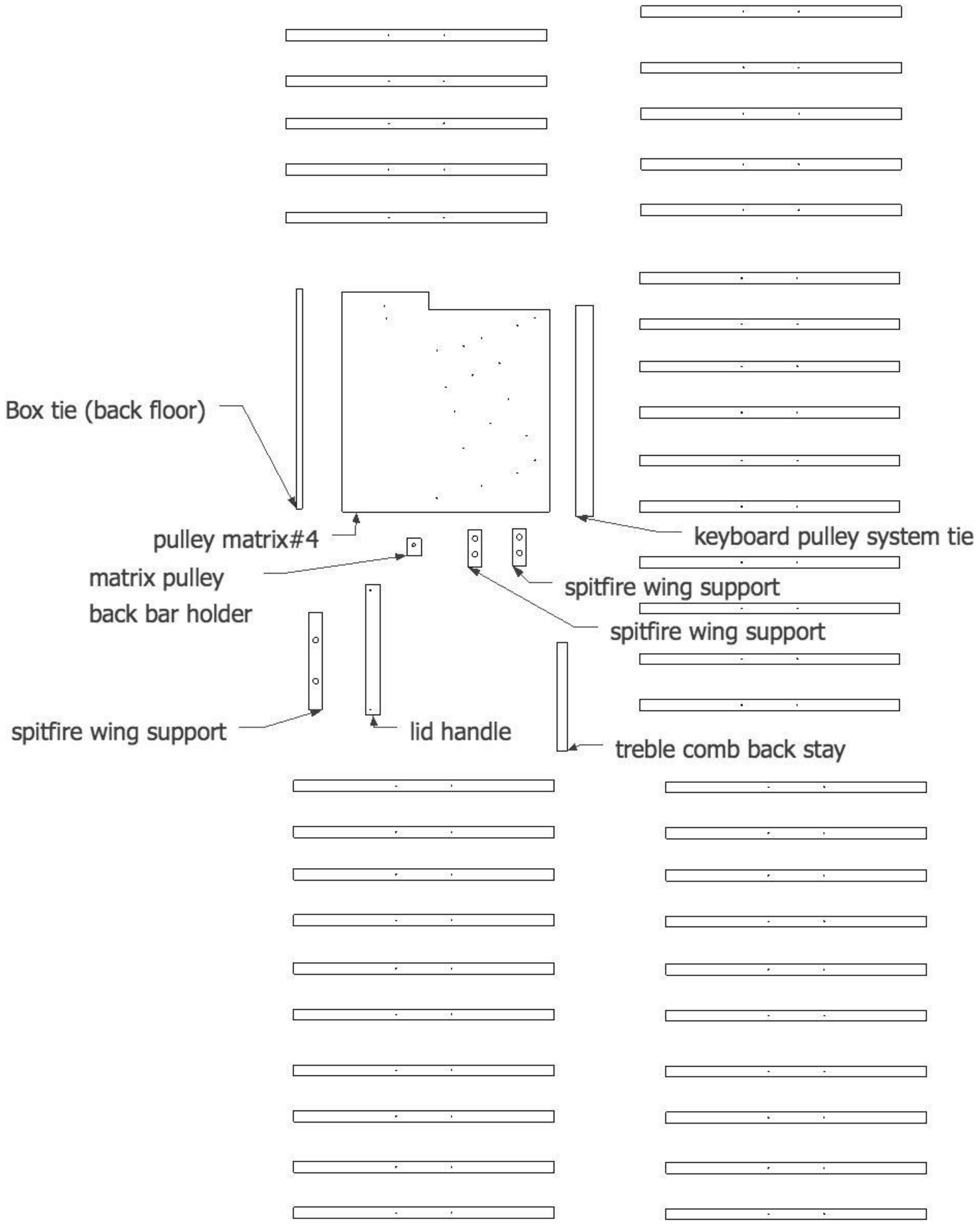
5.5mm schedule

120x160cm



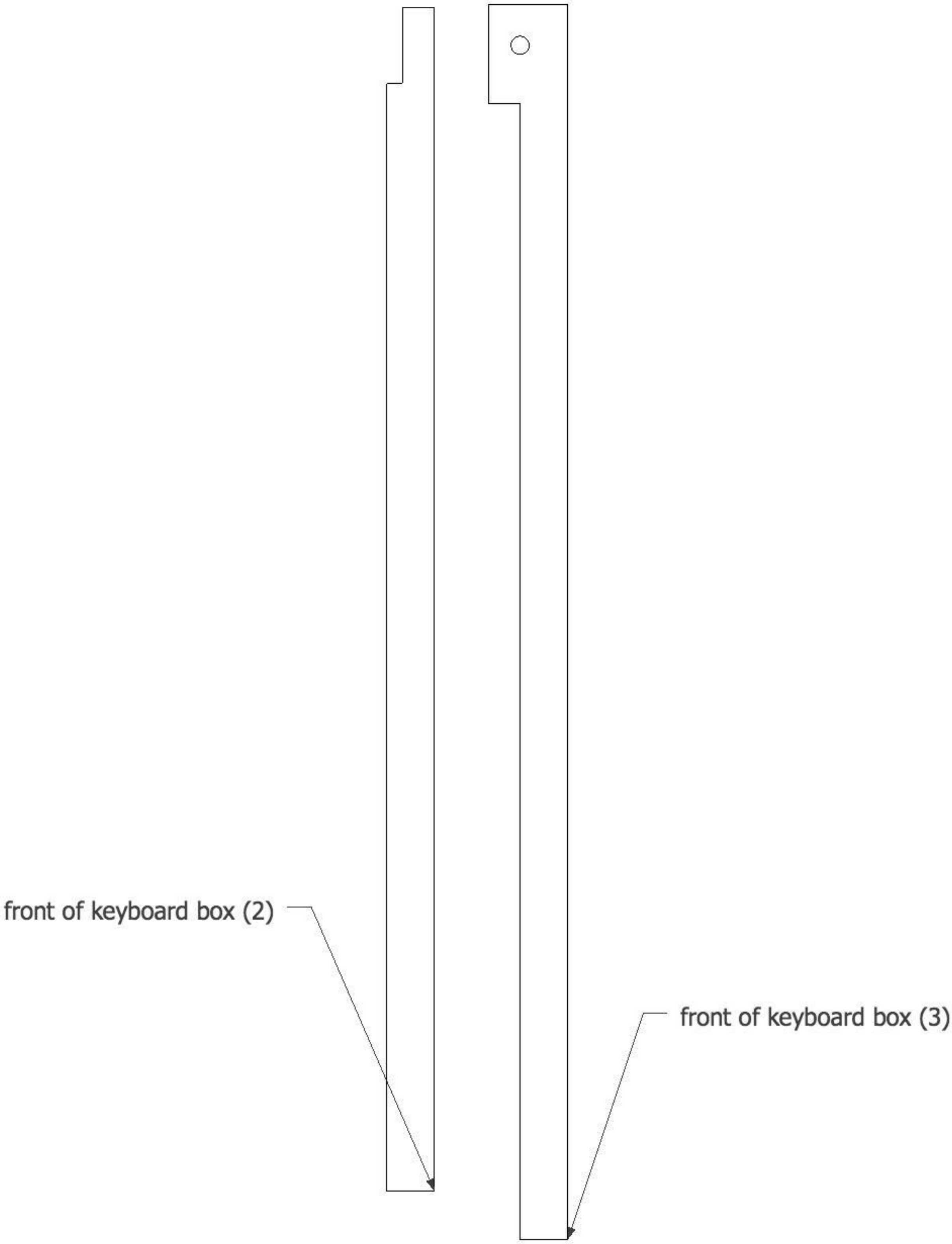
6mm schedule

100x150cm



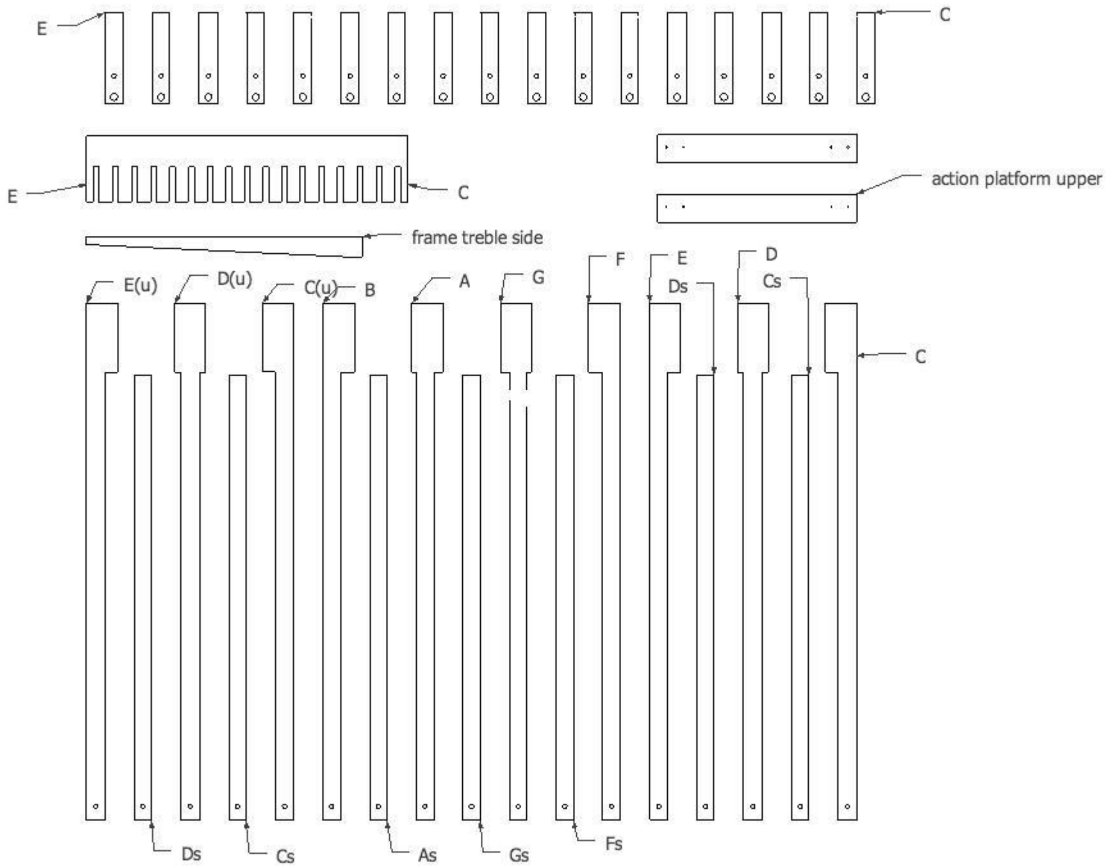
7mm schedule

30x30cm



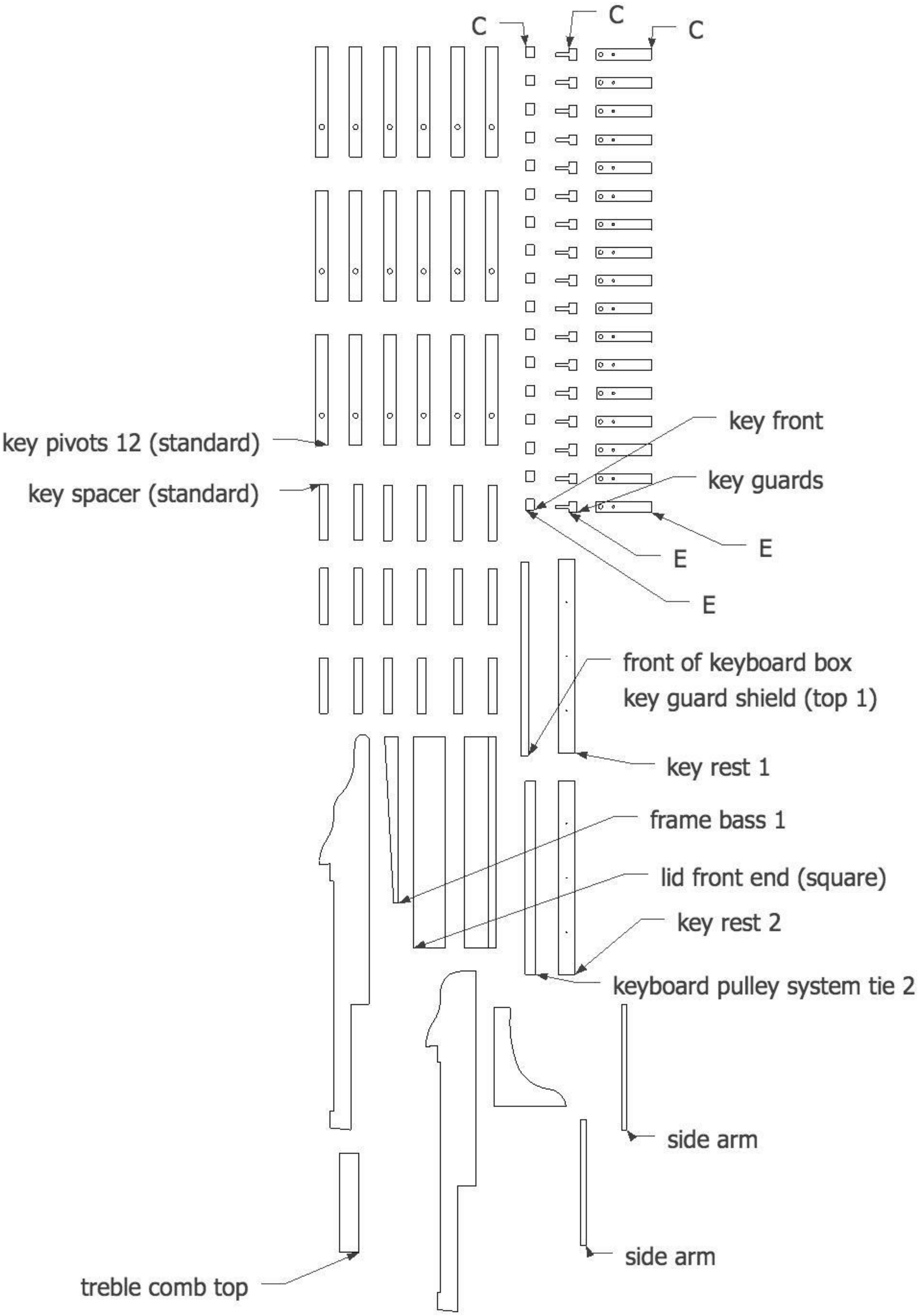
9mm schedule

70x75



12mm schedule

100x200cm



Appendix 6

Showcase Score – Snow all the way to the Cage

Snow all the way to the Cage...

Brissenden 2015


10
mf
f
f
13
mp
ppp
f
mf
mf
pp
16
f
p
mp
ppp
19
mf
mp
damp
damp

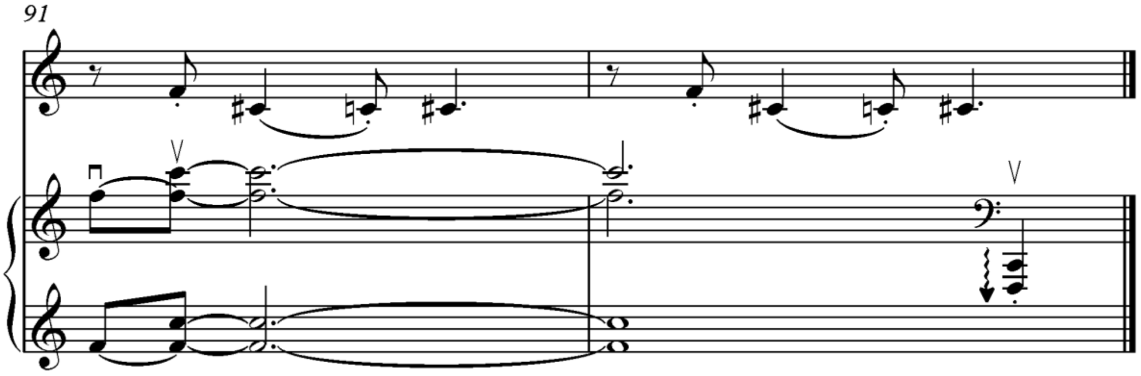

23
poco piu mosso
damp
damp
poco piu mosso
26
rit.
a tempo
29
f
rit.
a tempo
mf
pp
32
rit.
tempo primo
p
rit.
tempo primo
p
p


35
38
41
44
damp
damp


48
tr
tr
tr
P
P
P
P
P
P
52
3
3
3
3
P
P
P
P
54
3
3
3
3
P
P
P
P
56
3
3
mp
P
P
P
P
P


59
mf
f
slow gliss
p
ff
63
Flute
mp
ppp
67
72
mp


76
mp
mf
f
mp
ppp
80
P
84
mp
88
p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