Prototype 5

Year	2014-15
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 1. Photographs of Prototype 5 and Assessment of the 16 Design Criteria

I began this build in earnest in the academic year of 13-14. 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 Raph. 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.

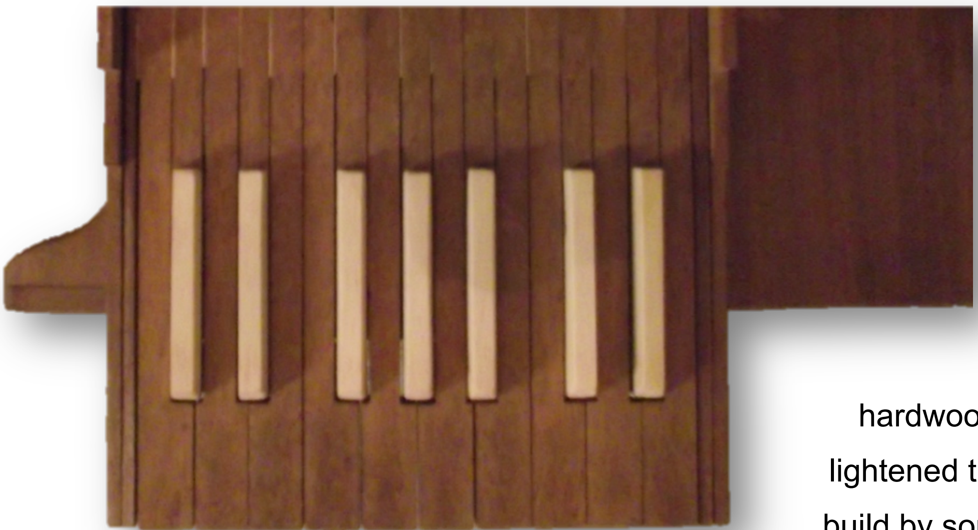


Figure 2. Prototype 5 keyboard viewed from above

Figure 3. 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.

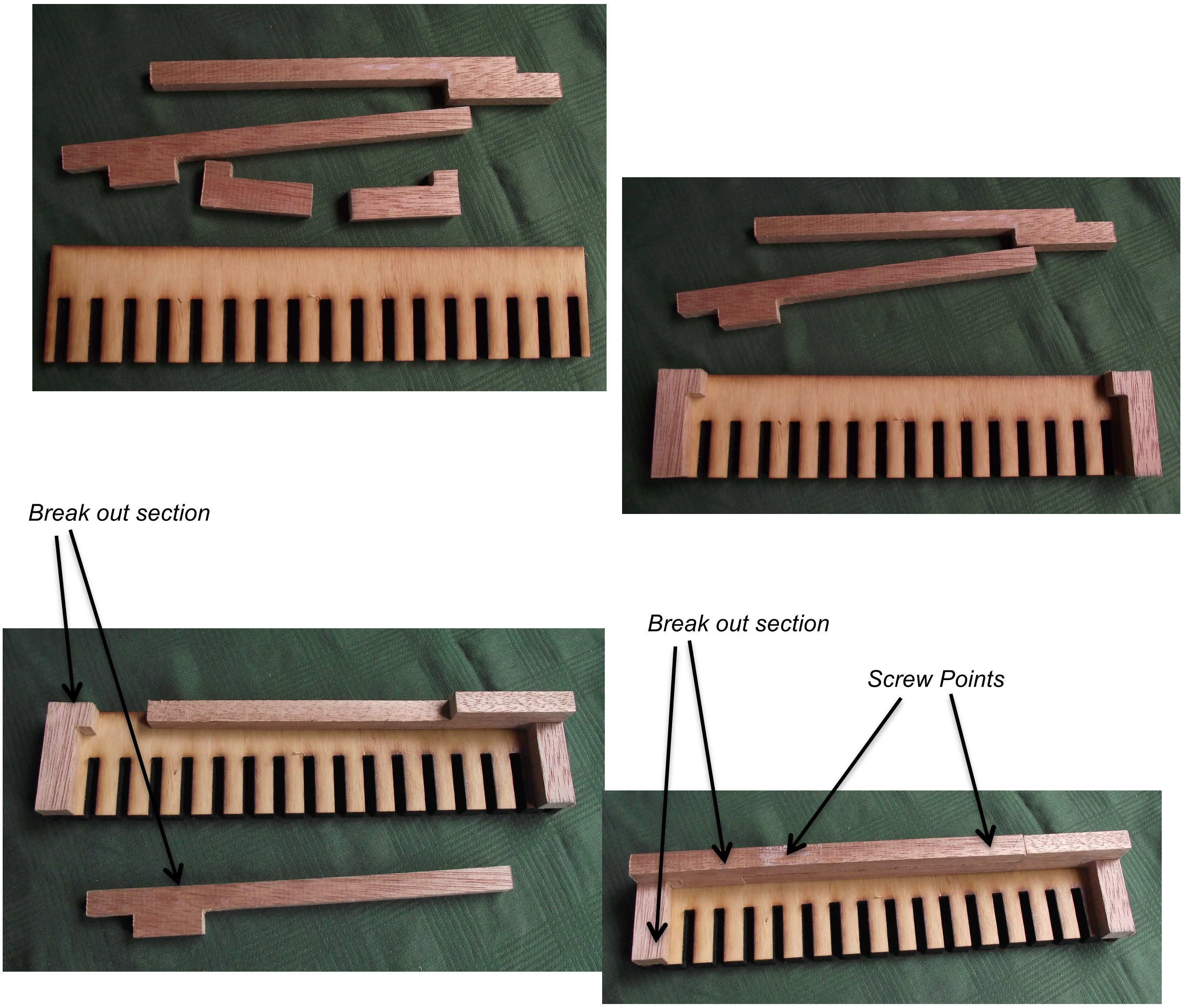


Figure 4. Keyguards, parts designed to provide easy breakout for maintenance at the middle of the mechanism

Figure 5. 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.

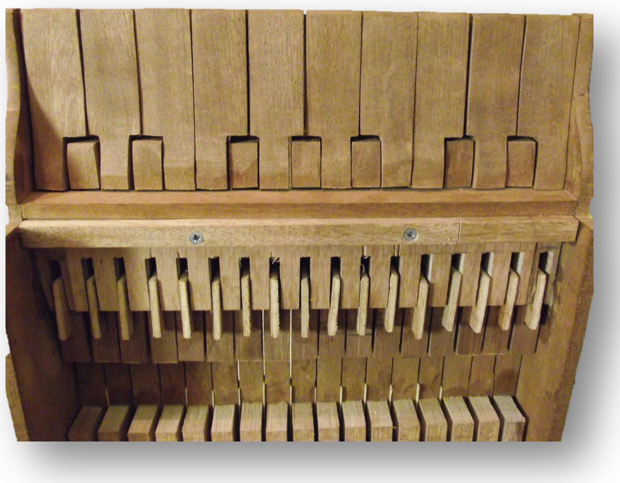


Figure 6. Keyboard (extension) springs

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 7. 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 8. 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. I remain critical of this mechanism however, and, most particularly the access for maintainance, which is problematic due to the fixing of the keyboard pulley system. Quick access to the system is limited by the pulley string tension – various changes are suggested in subsequent discussion towards prototype 6.

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.

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.

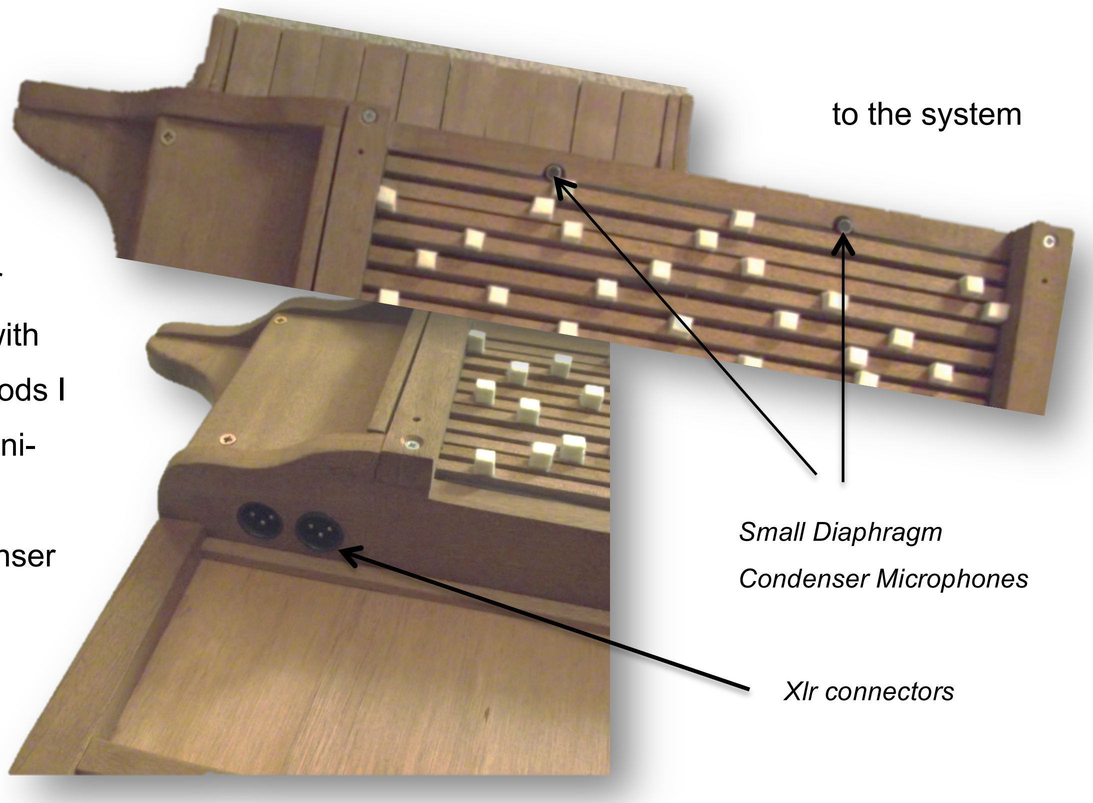
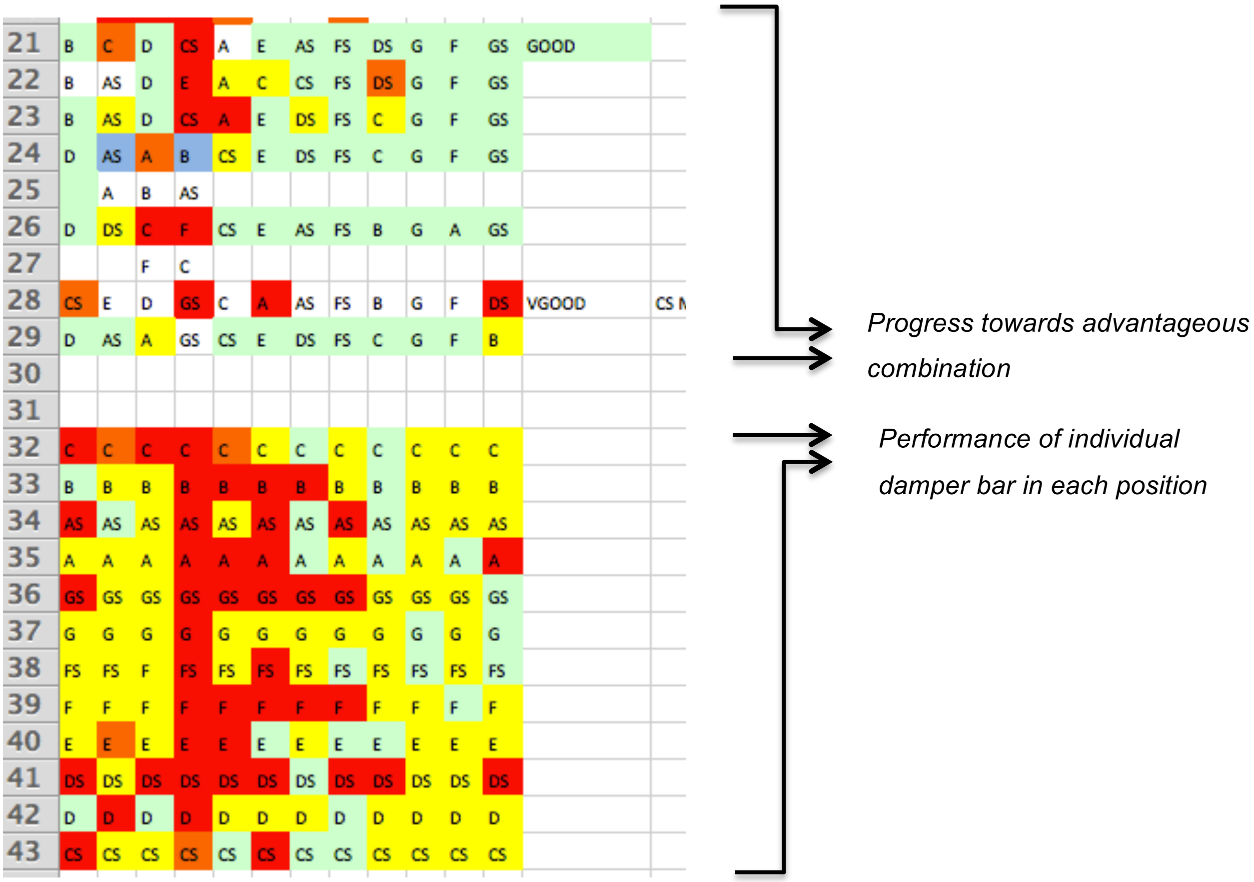


Figure 9. Integrated amplification in prototype 5

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 N
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		

Figure 10. 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. 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 (based on feet which protrude through the strings), which clearly compensates for the lack of cross-coupling potential. Indeed on further reflection, I considered 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 except the bar itself; all that is required is to add a suitable cutaway space to the next damper bar to allow the outrigger to function. The information within the spreadsheet even provides the correct orientation for the outrigger (towards position three). A further round of improvements is therefore planned for prototype 5, and routine implementation of both strategies for prototype 6.

Figure 11. 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.

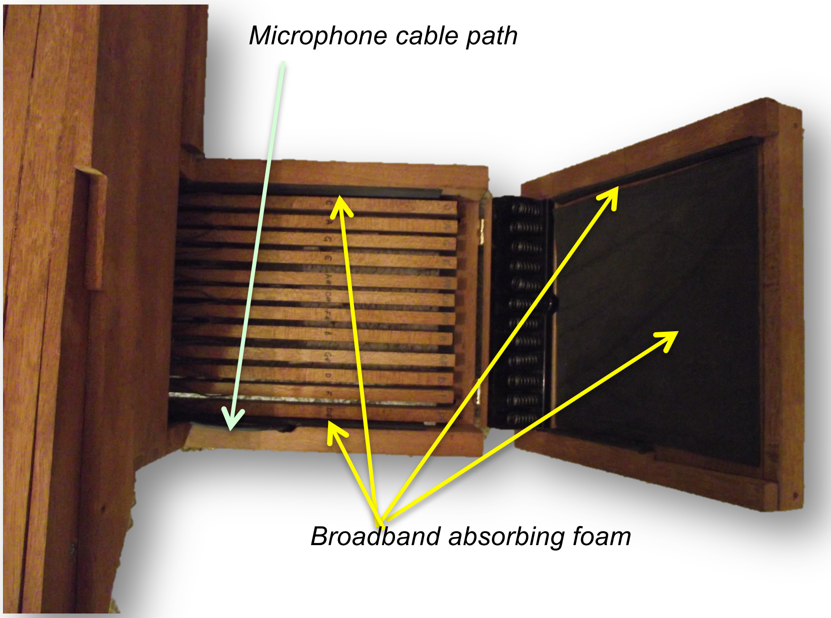


Figure 12. Acoustic treatment of the lower action chamber

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 13. 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.