Appendices

Appendix A

Reference points, "Critical" dimensions and Fudging

After building a few harps I noticed that I was spent a lot of time measuring and worrying about how the parts were going to fit together. I found that I could eliminate a lot of the worry and wasted time if settled on some key reference points and dimensions to build from. Boats are usually built form a keel centerline or wire strung between the stem and stern posts. Buildings are laid out from the cornerstone.

The soundboard is the heart of the harp. I use it as the reference plane that everything else is built from. When I design harps, the client specifies some key parameters (the number of strings, and spacing). Depending on the sound and tension they want, I set the angle of the strings to the sound boards, and the rest of the instrument is fleshed out from there.

So, as you build sound boxes, realize that you are simply making the foundation that lay under the soundboard. As I build, I key in on 5 basic parameters:

- -Sound board length - it needs be long enough
- -Sound board width at the treble and bass end
- -The angle of the cap plate has to be right so the neck fits without any big gaps.
- -The base plate needs to be close to a certain angle so the harp does not topple forward or back.

Even significant errors on these parameters can be compensated for by

Fudging

I try to stick to plan, but errors inevitably creep in from time to time. As I examine more and more work from custom builders, I have begun to suspect that they are good at avoiding errors in the first place. But, they are even better and fixing errors and making adjustments *ex post facto*. Here are some of the tricks I have used to adjust what was built to the planned design. In the engineering world, they are often called field modifications.

-Angle of the cap: An additional piece of wood (I call it a collar) can be glued to the top of the sound box. In a contrasting wood it looks decorative, even

deliberate. A miter saw set to a compound bevel can cut the collar to an angle that matches the bottom of the neck.
-Angle of the base: I fine-tune the balance of the harp right before finishing by trimming the feet. You can shave a ½" or so, which gives a surprising amount of latitude before the base begins to look too queer.
-Length of the soundboard: It is OK to be an inch or two long, the foot of the pillar just hits the soundboard a little higher. If that bugs you aesthetically, you can add space between the strings on the bottom octave. If the shell is too short, you can add up to 2" by adding an apron (under the base) or a collar (on top of the cap). I did this on one of my first stave backs, and most of my clients actually WANT them to make the harp look fancier. Go figure.

Appendix B

Ten Things Ma shoulda told me about Epoxy

Epoxy is wonderful stuff. It tolerates significant joint gaps and requires little clamping pressure. You can mix in additives to make the schmutz perfect for the bonding requirements. But you can screw up, so here are some lessons learned from 10 years of working with the stuff.

1. Measure carefully. An unjust mix will not cure, and is practically impossible to clean up to do again.
2. Mix thoroughly. A partially mixed batch will not cure, and (c'mon now, everyone together) is practically impossible to clean up to do again.
3. Pre-coat joining surfaces, especially ply end-grain with the neat (un thickened) epoxy. End grain really sucks the stuff up and can result in a glue starved joint that will fail.
4. Wood flour (or baking flour for that matter) is thixogen, and when enough is added to the epoxy, it will make the mixture thixotropic, like a good thick peanut butter. This is a very useful property; learn to use it to your advantage.
5. When in doubt, mix a smaller batch. When the hardener is mixed with resin, the reaction gives off heat, which accelerates the reaction giving off more heat. It will get away from you.
6. Uncured epoxy can be cleaned with Vinegar
7. Cured Epoxy can be removed with hours of sanding and scraping. Maybe.
8. Work clean, use gloves, and mask off areas you don't want epoxy on.
9. Don't test or move the joint till the residue in the mixing pot has cured.
10. The phone will usually ring right after the resin has been added to the hardener.

Appendix C

Setting up a Vacuum bag and mold

Get a working Vacuum pump, regulator and bag

I started by setting up a reliable vacuum bag and system. After several false starts, I found www.Joewoodworker.com. Using the directions from his website, a salvaged vacuum pump and about $140 of odd parts, I was able to make a fool proof system in about 10 hours. That included a big heavy duty 30 mil vinyl vacuum bag. I veneered a few soundboards and box backs till I was familiar with the press, my adhesives (PPR resin and Raka Epoxy). I practiced with a veneer saw, a sanding block and veneer tape and a saw till I could consistently get a nice tight veneer seam.

Home built vacuum pump, resevoir and regulator,
From www.joewoodworker.com website.

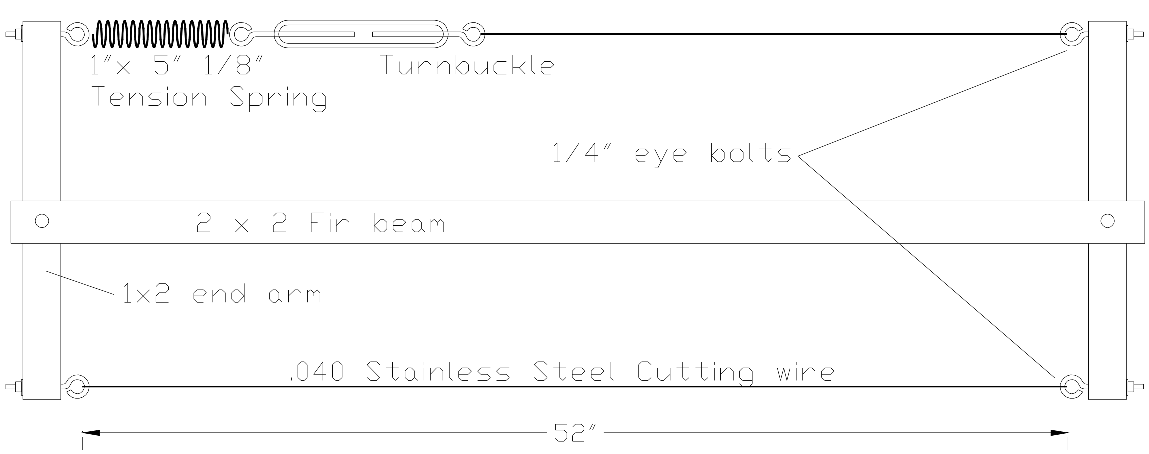
Appendix D

Building a Foam mold for Vacuum Bagging Round Back Shells

Lee Gayman found that airplane builders made large wing coamings using structural foam. Builders cut the foam using a heated nichrome or stainless steel wire.   For $170, we ordered enough large cell polystyrene foam from Aircraftspruce.com to build four nice molds.   Later on, I found that model aircraft builders will build up foam blocks by gluing together thinner laminations of insulation foam from Home Depot.   This is the same blue or pink stuff used to insulate walls. It is cheaper and easier to get, and is dimensionally stable in the press. The literature on the internet indicated that either foam would give off toxic, noxious fumes as it is cut with a hot wire, but the aircraft spruce foam is supposed to be less toxic.

If I had to build a new mold, I'd probably just buy a sheet of the rigid 2" pink foam from Home Depot and glue successive layers of it together then refine the shape with a big long sanding/fairing board like the surf board builders do.   Sawing/sanding a mold is a bit more tedious than using the hot wire, but is probably quicker for building one or two simple molds.

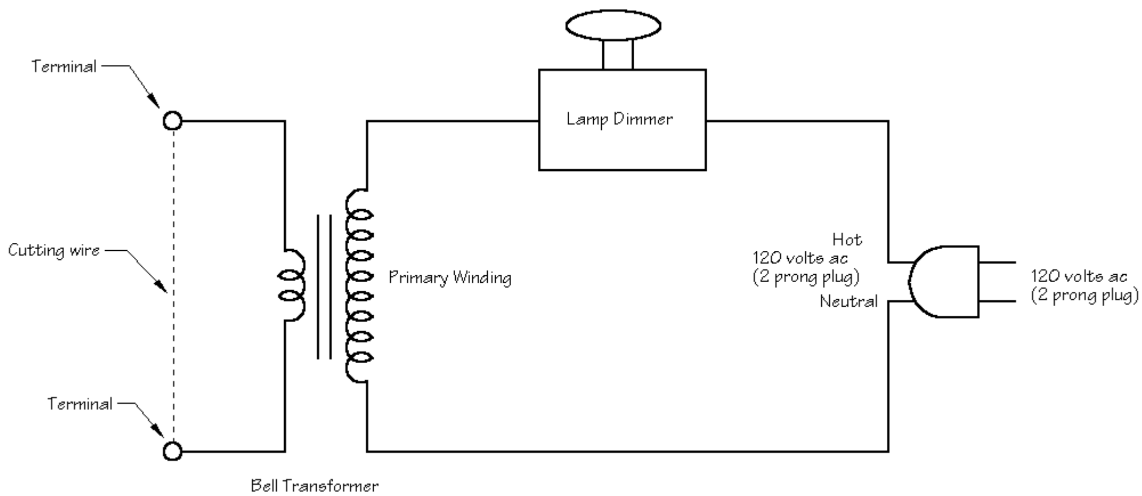
The first challenge was to build a loooonnnnngg hot-wire foam cutter. The tricky part was making a fixture to hold a 4' length of hot wire under tension. We used a frame similar to a bow saw, but had to make a few modifications to keep the wire from breaking as it cooled and contracted after the current was turned off and the wire cooled.



Frame for the cutting wire

The spring and turnbuckle allow the cutting wire stay in tension when it is hot without breaking when the current is turned off and the wire cools and contracts. The spring deflected an inch or so, and I estimate we had about 70-100 lbs of tension on the cutting wire. We cut slots into the ends of the main beam that would allow the end arms to pivot. The stainless cutting wire (.040 stainless) and top tension wire (bailing wire) were simply twisted back onto themselves to fix them to the eyebolts.

The wiring is simple, using a doorbell transformer and dimmer to regulate the current going through the wire.



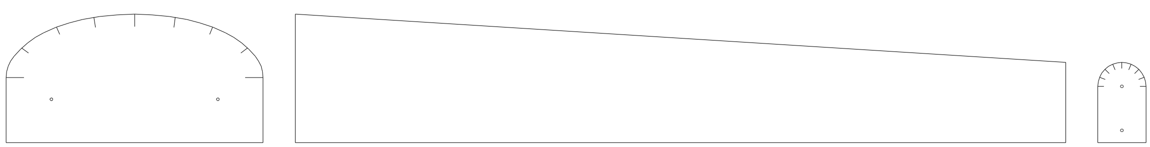
Wiring diagram from http://www.dansworkshop.com, "foam cutter"

Before we connected the leads from the transformer to the eyebolts of the lower (cutting) wire, **we did some thinking about safety**:
-We turned on the shop exhaust fan so that it would draw fumes away from us.
-We had a fire extinguisher on hand.
-The idea of a very hot stainless cutting wire breaking and snapping back onto one of us while cutting was a little disconcerting, so we wore face shields and long sleeved jackets.
-We realized we were working with a long unshielded wire with current running through it, so we cleared the area of metal and worked on a wooden bench. We agreed on a safe place where we could put down the frame without burning anything or shorting the wire to ground.

-We did a dry run (with the current off) rehearsing the motions of the cut and where we would put the frame down, who would cut the power in an emergency, etc.

We did a few test cuts, and found a setting that kept the wire hot enough to cut through the foam at a reasonable pace. If you are going to cut through a 4′ section of foam, make a practice cut on a four foot section of foam. If you move too fast, the wire does not stay warm enough and will drag and bend. If you move to slow, it burns away excess foam. We found feed rate of about 6-10″ a minute (on the bass end of the mold) worked well.

The shape of the mold is governed by at the ends by two end-plates of Luan. We cut them to shape and secured them in place to the end of the foam block with two 8d nails.



The shape of the end plates and side view of a mold

The hash marks on the end plates allow the cutters on each end (this is a two person job) to keep in sync with each other as they drag the hot wire along the edge of the end plates. The wire needs to move a lot faster at the bass end. It will need to move about 26 inches while the treble end only covers 8 or so.

If the molds have some surface roughness, don't worry – ours did. We found it easy to smooth with a random orbital sanders or simple fairing boards which allow you to make the molds baby-butt smooth.

Lee thought that fiber glassing the mold would make it last longer. A fiberglass coating will allow you wax the mold (which keeps you from expoxying the shell onto your mold). I told him we needed a mold for building a harp, not a surf board. I simply use a barrier layer (butcher's paper) to keep from gluing the shell to the form.

Appendix E - Sourcing Wood for Sound Boards

Burke Girvan (253-952-4310, Sitka Spruce Sales, 10114 Taylor Street East, Edgewood, WA 98371) is the most consistent source I have found for harp sound boards.   If you give him the width and thickness you need, he can supply you with some of the nicest Sitka Spruce I've seen. He charges about $50 for the stock to build a board that is 48" long, 16" wide and 5/16" thick. It can take several weeks for an order to arrive here on the East Coast.

There are lots of other sources and alternatives, and if you are willing to invest some time and effort, you may be able to save some money.

You can find a number of suppliers that cater to the Luthier Trade on the internet. Billets for Guitar and Cello Tops are traditionally made of top grade Sitka Spruce and have worked well for me. They can be pricey though. You may ask if they have unmatched sets or blemished boards that you could use in a harp to get a price break. I have also heard that there are some piano repair suppliers that supply spruce for sound board replacements, but I have never been able to identify a contact.

Aircraft Spruce sells 20 lbs of Sitka Spruce cut in a $25 "bargain box". These are cutoffs from spars, the lumber they saw up into boards used in airplanes from nice clear, tight grain spruce. Some of the pieces have significant run out, or are too narrow to use. There will be more waste, but if you have your own band saw and time, you should be able to get three to five soundboards out of a box.

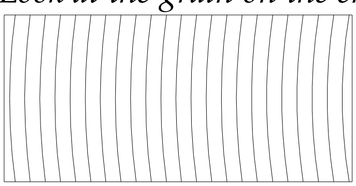
With spruce becoming outrageously expensive or impossible to find, harp builders will have to try some other wood species.   I have used redwood 2x6's found in the bowels of an old lumber yard. I have seen and heard excellent results from builders that use Western Cedar, Sassafras, Engleman spruce, Douglas fir or Spanish cedar. If you are going to use other species in a design that specifies Sitka Spruce, you may want to look up its properties and make the appropriate adjustments. The U.S. Forrest service has an excellent publication that you can download on the internet called the *Wood handbook--Wood as an engineering material*. Chapter 4, Mechanical Properties of Wood, provides reams of data on wood. Most builders shoot for a light, stiff board when they build Nylon or gut strung harps, so if you want something that sounds like spruce look for substitutes with similar properties.

When I consider lumber for a soundboard, I ask myself these questions.

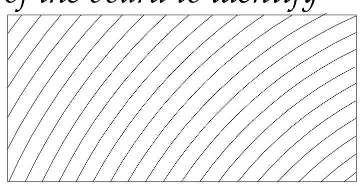
Is it well seasoned? Many violin builders insist on billets that have been air dried and seasoned for at least seven years. They feel that it has superior acoustic properties over Kiln dried wood. The prolonged drying process and humidity cycling of the seasons does make for a more stable wood. I have not had problems with wood that has been seasoned for three years or so. If you can not find out how long it has been seasoning, you can use a scale, a small sample, and the kitchen oven set at 175 degrees Fahrenheit to determine the moisture content.

Is it Rift or Quarter Sawn? Quarter of Rift sawn will be more stable than flat sawn lumber. This reduces the likelihood of sound boards cracking along the seams between the boards. Customers will also expect a quarter or rift sawn board.

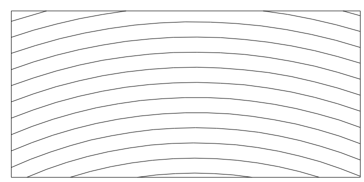
Look at the grain on the end of the board to identify



Quarter Sawn



Rift Sawn



Flat Sawn

How much run out and waste is there? You will need to discard sections of a board with sap pockets, knots, checks, or wavy grain. If the grain of the board does not run along its length (significant run-out), it will need to be corrected while re-sawing and there will be more waste.

What is the ring count? Some builders insist on certain ring count (20 or 40 growth rings per inch). As a general rule, trees that grow slowly make for stronger, more stable lumber, but I do not use ring count as hit-or-miss requirement. Many commercial makers build fine instruments using boards that range as low as ten to fifteen rings per inch, so I try to consider ring count as one parameter in balance with the other characteristics I am seeking.

Appendix F,

Selecting Adhesives

Different builders have their favorites – and this prejudice is usually a result of familiarity. Glues work best when the builder is familiar with the adhesive's working properties and how it will perform. As I built more and more harps and tried different glues, I found I would vary my choice based on how well it would perform *for the task at hand*.

I rely on Yellow glue for many "general construction" applications – gluing string ribs to sound boards, knee blocks, and square back sound boxes and gluing staves into a shell.

For critical joints or joints that require gap filling, I will use epoxy. This includes gluing the cap and base into stave back and round back shells, attaching sound boards, and splines for reinforcing the neck or joining the neck to the pillar.

I use powdered resin in the vacuum press because it is more economical than epoxy and does not bleed through the veneer like epoxy usually does.

I use Cyanoacrylate (Superglue or CA glue) for quickly repairing reattaching lifted veneer, torn out splinters or leveling cracks that need to filled prior to varnishing

Here is a basic rundown of the pros and cons for these and other glues that are widely used by harp builders.

Yellow Carpenters Glue – it is widely available and most builders have used it so they are familiar with its working properties

Pros	Cons
Economical ~$20/gallon	Needs a tight joint (~1/64 inch)
Convenient to use	Needs moderately high clamping pressure
Cleans with water before cure	Can creep under sustained stress
Non-Toxic	Softens at temperatures above 120° F
Sets in an hour, good strength in 2-4 hours	Shelf life of about a year

Hide Glue – Traditional instrument builders laud hide glue because it is fairly easy to take it apart and reassemble it for repairs.

Pros	Cons
Good history (Still holding up in articles that are thousands of years old	Needs to be mixed fresh every 2-3 days,
Repairable	Requires thermostatically controlled glue pot (~$90)
Sands well	Requires a tight joint (~1/64 inch)
Non-Toxic	Requires Moderately high clamping pressure for 4-8 hours
Moderately priced, ~$11 quart	Cools quickly so open time is limited. Challenging to do a large or complex assembly
Good shelf life in flaked form	Can soften in humid environments and temperatures above 120° F

Powder glue is mixed with water

Pros	Cons
Reasonable cost ($20 for a 5lb pail)	Must be mixed, batches only last 2-3 hours, excess must be thrown out
Non-Toxic Cleans up with soap and hot water	Needs a tight joint (~1/64 inch)
Good thermal, creep resistance, even in damp environments	Needs moderately high clamping pressure
Shelf life 18 – 24 months if stored in cool dry place	Should be clamped for six hours, full strength in 24

Epoxy

Pros	Cons
Does not need require tight fitting joints	Expensive ~$40-80 per gallon
Does well with light clamping pressure.	Must be measured accurately, mixed thoroughly.
Adaptable – color, consistency and strength can be tailored for application with additives.	Hard to clean up, most use latex gloves
Long shelf life	Pot life is 20-30 minutes, excess must be discarded
	Should be clamped for 4-8 hours, full strength in 24 -48
	Large globs of adhesive will clog sand

	paper.

Cyanoacrylate (CA) glue

Pros	Cons
Very strong	Fairly toxic
Good Shelf Life	Very expensive, $3.25 for ½ oz.
Sets quite rapidly – hold assembly together, no extended clamping required. Great for quick repairs	Drips cure very hard, glue lines must be kept thin to prevent blotches in the finish
	You can glue your fingers together

Appendix G – New Design Checklist

Aesthetics

Do the lines of the bridge pins and tuning pins sweep in a nice fair curve?

Ergonomics

1. Is the String Spacing reasonable? For modern gut/nylon strung harp, this will be no closer than 3¼" in the top octave and 4½" in the bottom octave. Reproductions historical harps can be tighter, i.e. the wire strung Clarsach may by much tighter, as close as 2¾" per octave.
2. Are their any unusual looking gaps between the strings (strings too far apart or too close together)
3. Is the harp's weight centered over the feet? The center of gravity is usually just about in the center of the triangle formed by the neck, pillar and sound box. If the box is particularly heavy that center may shift an inch or to towards it. The center of gravity should fall half way between the tips of the front and back feet.
4. Are the feet/base wide enough and deep enough to provide adequate stability for the instrument?
5. The soundboard width should be less than 3.5 inches at the treble end to allow the harper to access those strings without bending the wrist excessively.
6. Is there adequate clearance to comfortably get the right hand thumb onto the highest string?
7. Do the sound holes provide adequate access for stringing and tightening the internal bolts securing the pillar and neck?
8. Are there any big jumps in the Tension-to-Length ratio for the strings?

Functional

1. Is there clearance between the Bass string and the pillar? When you look at the profile view, the pillar can go beneath two of the bass strings, but the pillar should be beyond the bottom ¾ of the bass string.
2. Are the eyelets adequately sized to allow the knots on wound strings through them on the bass end?
3. Does the neck extend below the bridge pins an adequate distance to mount sharping levers? I develop a table for each lever type and check this distance once each octave

For Truitt Levers

String Length	Distance required below bridge pin
5	3/4
10	1
19	1-5/8
30	2 -1/4

40	2-3/4
49	3

Structural Rigidity

1. Is the neck thick enough? The thickness required for a stable neck is a function of the harp's tension, the distance it spans, and the species of wood used. Some rules of thumb. A 36 string harp with 1200lbs of tension will need a cherry neck that is at least 1½" thick. A 26 string medium tension harp will need a cherry neck that is 1¼" thick. You may be able to use a slightly thinner neck for lightly strung harps. Softer woods will require a thicker neck.
2. Is the pillar thick enough? The thickness required for a rigid pillar is also a function of the harp's tension, its length, and the species of wood used. If in doubt, use a T-section neck or laminate an extra layer of material to the outer edge.
3. The sound board will move up and the pillar will move down as the harp is brought under tension. Have appropriate allowances been made for this movement? If the design does not show an outer string rib, the strings will be a bit shorter, requiring an additional allowance.
4. If the pillar is not bolted to the string ribs, is the connecting structure (base, sound box) strong and rigid enough to transfer the load from the foot of the pillar to the bass end of the soundboard? Can it withstand this strain for an extended period of time?

Acoustics

The acoustics will depend a lot on what the sound and volume you are trying to achieve. In general I ask myself,

1. Do the scantlings of the soundboard and string ribs match the string tension and soundboard width? High tension on a lightly built board can sound good, but may implode. Conversely a heavy board on a light set of strings will sound dead.
2. Are any of the strings too long for the desired pitch (leading to string breakage)? Too short (poor or dead tone)?