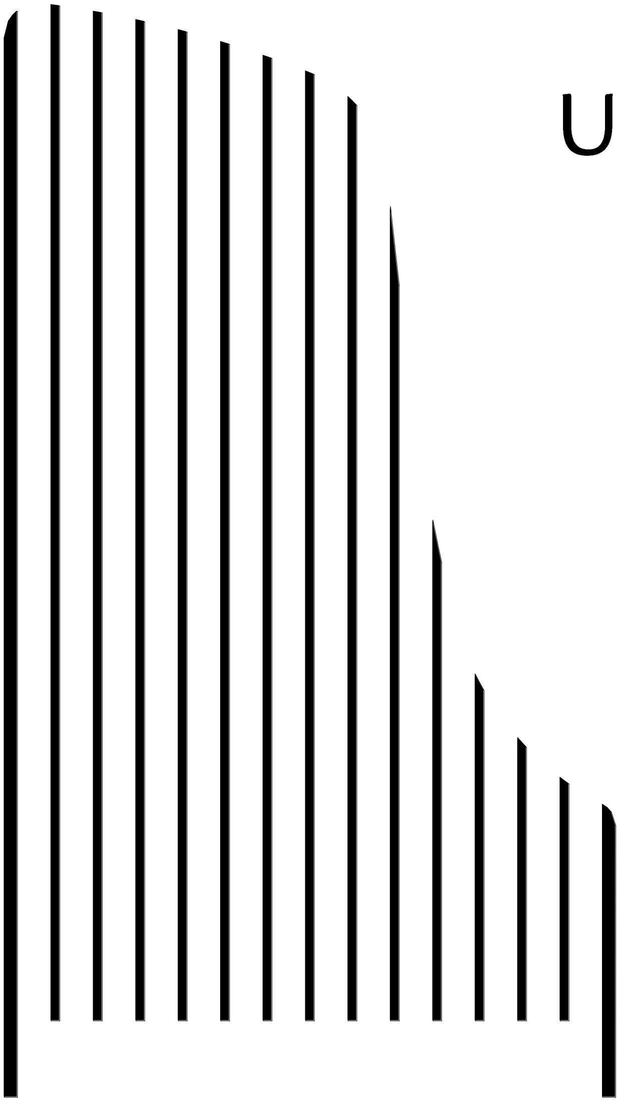


Understanding the Modern Piano

A brief look at how the piano is built & how it works

This seminar will provide an overview of how the piano works. Beginning with a brief look at the fortepiano of the 18th century, we will end up considering nearly every part of the modern piano and how they all fit together to create the sounds we hear.

We'll touch each of the major aspects of piano design and piano structure and construction: the soundboard & ribs, the bridges, the plate and strings and, if there is time, the keys, the action and hammers, and the damper action.

Finally, we will tie all of these elements together and try to make some sense out of the whole. Then we introduce some ideas about how this knowledge can all be applied to the piano in your customer's living room — or the one in your shop.

As always, your questions are welcome throughout the class

How design, structure and construction influence the acoustic performance of the modern piano.

Written & presented by
Delwin D Fandrich

1) Piano scale making—up to the Vant piano

- From c1700 to c1780—invention, development of action, some strengthening of case. Still very similar to harpsichord.
- From c1780 to c1800—brass strings used in bass, separate bass bridge, higher tension scales strain all-wood framework.
- From c1800 to c1820—more power demanded to fill larger halls with larger audiences, Higher tension scales and increasing keyboard compass. Still more strain on the all-wood framework, metal gap-spacers are used to strengthen frame.
- From c1820 to c1850—still more power demanded from instrument. More keys added to compass. Drawn wire capable of extremely high tensions introduced. More sophisticated iron framing introduced to support still higher scale tensions.
- From c1850 to c1860—the *modern piano* is developed. The 88-note keyboard gains prominence, scale tensions exceed 45,000 lbs (20,500 kgf). Full, one-piece cast gray iron plates become standard. Overstringing becomes standard. Massive wood framing becomes standard. The Steinway format becomes standard. The instrument reaches its limits in terms of power—the instrument is no longer the limiting factor; the physical capabilities of the human hands and fingers now limit the maximum acoustic power output of the instrument.
- From 1860 on there has been a general consolidation and homogenization to one dominant style. Most subsequent development has been aimed at production speed and efficiency.
- From 2000 on—what happens next?
  Electronic instruments win the power race. Now what?

2) The art of piano scale making

The drawing of a scale is generally made in a locked room, by one of the very few scale makers, and a great secrecy is made of their work. —1927. Albert B Vant, Piano Scale Making,.

- Piano design in 1927—the problem of the locked room
  - Characteristics of piano design in 1927
  - Does this period represent the end of an era?
- What is *piano design*?
  - Every part of the piano—
    - Stringing scale & string layout
    - Plate, plate mounting, plate brace layout, pinblock, tuning pin & hitch layout
    - Soundboard, ribs & bridges
    - Rim & belly assembly, keybed—including aesthetics of shape & design
    - Action & keys
  - Aesthetics
- Drawings, etc.
  - Scale stick
  - Cross-section drawings
  - Plan drawing
  - Patterns & templates
- Requisite knowledge & background
  - Experience? Imagination? Inspiration?
- Design secrets—only an issue if new design development work is being done
- Design lethargy? Fear of the unknown? The *it's good enough* syndrome?

3) The challenge of small pianos

- Tone performance—what should a small piano sound like?
  - Bass: clarity & balance
  - Tenor: dynamics—short, stiff strings
  - Killer-octave: depends on rim shape & soundboard characteristics
  - Tonal balance: often sacrificed for *power*
  - Bass/tenor cross-over: dependent on break location
  - Treble: best part of the scale
- Action performance?
  - Action stacks are the same
  - Keys— short working length, greater side offset, etc.
  - Touch weight more critical due to short arc distance
- Price/performance ratio?
  A tale of two pianos:

5’ 1.5” (156 cm) @ **$40,600**	5’ 2” (157 cm) @ **$14,200**
A_1 speaking length ≈ 45.5” (115.6 cm)	A_1 speaking length ≈ 45.0” (114.3 cm)
Soundboard size ≈ 1660 in^2 (1.071 m^2)	Soundboard size ≈ 1630 in^2 (1.052 m^2)
Soundboard construction – solid spruce	Soundboard construction – solid spruce
Continuous bent rim—maple	Continuous bent rim—European beech

- Design & manufacturing margin of error
  A matter of cost and philosophy:
  - *Hand-made* = Imprecise and variable
  - *Machine made* = precise and consistent

3) The challenge of large pianos

- Tone performance—what should a large piano sound like?
  - Bass: intentionally overpowering but clear, oh! so clear!
  - Tenor: designers choice
  - Treble: little difference between this and smaller pianos
  - Bass/tenor cross-over: dependent on scaling
  - Tonal balance; more difficult to achieve
  - Killer-octave; can be problematic due to typically large soundboard size
- Action performance?
  - Action stacks are the same
  - Keys—working length, offset, etc.
  - Key bending more critical due to length
- Price/performance ratio?
  Another tale of two pianos:

8’ 10 ½” (270 cm) @ **$92.600**	9’ 0” (275 cm) @ **$47,800**
A_1 speaking length ≈ 79.3” (≈2,015 cm)	A_1 speaking length ≈ 79.6” (≈ 2,022 cm)
Soundboard size ≈ 3,245 in^2 (≈ 2.094 m^2)	Soundboard size ≈ 3,450 in^2 (≈ 2.226 m^2)
Soundboard construction – solid spruce	Soundboard construction – solid spruce
Continuous bent rim—maple	Continuous bent rim—European beech

- Design & manufacturing margin of error.
  A matter of cost and philosophy:
  - *Hand-made* = Imprecise and variable
  - *Machine made* = precise and consistent

4) Where to start

- Why a new scale?
  - Copies & direct derivatives
    - Repeats existing problems
  - New design
    - Tone performance

    - Introduces new errors
    - Limits innovation
    - Style and aesthetic
- Piano size & type
  - Type—all *modern* designs are *overstrung*—as opposed to *flat-strung* (i.e., *straight-strung*)—why?
    - 👍 Flat scales impose lower torsional stresses on the plate.
    - 👍 Flat scales do not force variations in hammer mass through the bass section.
    - 👎 Unless the strings are brought together, the bass bridge of the flat-strung piano is close to the rim.
    - 👎 If the strings are squeezed together, the bridge pinning is very tight—leads to bridge failure.
    - 👎 Overstringing the bass makes the acoustical design of the bass/tenor crossover difficult.
    - 👎 Overstringing (usually) requires spreading the strikeline and its attendant key offset problems.
    - 👎 Overstringing does not allow an appreciably longer A_1 bass string as is frequently thought—
      - 👍 Except in short grands and verticals where the string angles are considerably greater
    - 👍 Overstringing the bass section does allow a more central placement of the bass bridge on the soundboard/rib assembly without crowding the bridge
  - Size—a question of market position
    - Length—design for market position
    - Width—pianos are generally wider and bulkier than necessary
    - Footprint—if the o/a width is reduced the piano can be longer and still not have the visual bulk of most small- to mid-size pianos
- Design considerations vs. production quantities—compromises for high production

5) Producing the sound—strings and the stringing scale

- The piano's tone character originates in the string which is set in motion by an impact from a variably elastic felt and wood hammer
  - On impact the strings motion is very complicated. This initial period is the *transient state*, or *impact state* motion. The transient or impact state motion is made up of:
    - Various non-harmonic motions of the many frequencies generated at hammer impact, i.e., *broad-band noise*
    - The beginnings of *harmonic motions* based on the resonant frequency of the string
  - The non-harmonic motions—transient vibrations—are quickly damped
  - The harmonic motions that remain is the *steady state* motion and is based on the hammer strike point, the mechanical characteristics of the taut string—its length, mass, tension, etc.
    - Technically, *the piano string is not a steady state oscillator*—no energy is supplied to replace that lost to friction and to the soundboard—but through most of the scale its sustain time is great enough that it does reach a more-or-less steady state motion.
    - Steady state motion is *motion in a system that has forgotten how it started.*
- *Scaling a piano is the process of selecting a combination of string types, string lengths and string diameters for each note that vibrate at a chosen fundamental frequency and will give a desired balance between transient state motion (the impact sound) and steady state motion (the sustain sound) when struck by hammers of varying mass, elasticity and velocities.*
  - And laying out everything so that all the various parts fit and work together in a pleasing manner in the length and width footprint allotted.
- The process of scaling a piano and assembling it are done in essentially the reverse order.

STRING SCALE PROPERTIES—SOME RELATIONSHIPS

Note: All equations & formulas shown in this outline are used to illustrate relationships, they are not working formulas.

d = *diameter of string (in mm)*
In = *Inharmonicity*
f = *frequency or pitch (in Hz)*
k = *a numerical constant*

K = *a numerical constant*
Lsp = *Strike point distance (in mm)*
T = *Tension (in kgf)*
Z = *Impedance*
Y = *Young's modulus* ($Y = 1.9 \times 10^{11}\ N/m^2$ *for steel.*
L = *Length of string (in mm)*
Ns = *Number of strings in unison*
Tc = *Hammer/string contact time*
J = *Stiffness*

- String tension (***T***)

$$T = {(fd)^2}\Big/{398.0 \times 10^6}$$

  - *String* tension = the tension of each individual string, regardless of type or configuration.
  - *Unison* tension = the sum of the tensions of all of the strings of a unison.

- Unison loudness or power—string impedance (**Z**).

$$Z = \sqrt{N_s/T}$$

  - A function of string length, string tension and type (number of strings per unison, wrapped, plain, etc.).
  - Should be uniform throughout the scale—not overbalanced by any one part.

- String inharmonicity (***In***).

$$I_n = Kd^2 \Big/ f^2L^2$$

  - A function of string diameter (stiffness)—within a given string scale.
  - For a fixed string length, ***In*** is directly proportion to string diameter.
  - Short, large diameter strings will have high ***In***.
  - Long, small diameter strings will have low ***In***.
  - Smooth ***In*** curve—smooth across scale breaks. Bass ***In*** should be smooth and consistent.

- String stiffness (***J***)

$$J = \frac{\pi^2 Yd^2 kL^2 K}{32}$$

where $K = 1.9 \times 10^{11}\ N/m^2$

THE STRINGING SCALE—A TENSION SCHEME.

- Two basic approaches:
  - The *uniform string tension* scale. The tension of each string—including the bass wrapped-string unisons—is more-or-less uniform.
    - Per Wolfenden: the tension of the individual wrapped strings is ≈ 15% higher than the adjacent steel strings but length is a regular progression.
  - The *uniform unison tension* scale. The tension of each unison—including the bass wrapped-string unisons—is more-or-less uniform.
- Designing the stringing scale for tone. The string scale can be designed for a particular type of tone:
  - *Low tension scales*—i.e., individual string tensions between ≈ 150 & 160 lbs (68 & 73 kgf)
    - Generally a clean, clear—pleasant—sound.
    - Easy to get good tonal dynamics with a broad range of hammer characteristics.
    - Can have reasonably good sustain if the scale and soundboard assembly are well matched.
    - Can have good volume but are not generally considered *powerful* pianos.
    - Requires light, flexible soundboard.
  - *High tension scales*—i.e., individual string tensions above ≈ 180 to 190 lbs (82 to 86 kgf)
    - Generally reserved for performance pianos, concert pianos, etc.
    - Usually have a harder, punchier sound—sound carries well.
    - More difficult to get good tonal dynamics. Fussier with hammer characteristics.
    - Capable of good to excellent sustain.
    - Typically have good volume, or *power.* but harshness always lurks on the edge if the hammers are not well matched to the scale. Strident sound if hammers are overly hard and/or dense.

- How these tensions are obtained will also affect the tone quality of the piano.
  - Short string lengths & large wire diameters:
    - Relatively higher overall string stiffness & inharmonicity.
    - Tension will be at a lower percentage of the strings' breaking point.
    - Tone will be *harder* and *brighter* within a given tension range.
    - Tuning stretch will be wider, treble will be tuned some sharper.
  - Long string lengths & small wire diameters:
    - Relatively lower overall string stiffness & inharmonicity.
    - Tension will be at a higher percentage of the strings' breaking point.
    - Tone will be clearer, more *pure* within a given tension range.
    - Tuning stretch will be somewhat narrower, treble will not be tuned quite so sharp.

NOTE A–85. EXAMPLE TAKEN FROM F/150 (SECOND ROW) & VANT SCALE (BOTTOM ROW).

LENGTH *(MM)*	LENGTH *(INCHES)*	DIAMETER *(INCHES)*	TENSION *(POUNDS)*	INHARMONICITY CONSTANT
59.0	2.32	0.032	157	15.3
60.8	**2.39**	**0.031**	**157**	**12.8**
62.8	2.47	0.030	157	10.5
60.0	**2.36**	**0.032**	**163**	**14.7**

NOTE F–33. EXAMPLE TAKEN FROM F/150 (SECOND ROW) & VANT SCALE (BOTTOM ROW).

LENGTH *(MM)*	LENGTH *(INCHES)*	DIAMETER *(INCHES)*	TENSION *(POUNDS)*	INHARMONICITY CONSTANT
864	34.0	0.043	150	0.21
906	**35.7**	**0.041**	**150**	**0.18**
968	38.1	0.039	155	0.13
857	**33.7**	**0.041**	**134**	**0.23**

DEVELOPING THE SCALE

- The tenor/treble section:
  - Logarithmic scaling—much talked about, rarely implemented.
    - The bridge should *jog* to accommodate log scaling across plate brace scale breaks.
  - The voicing problems at the tenor/treble section breaks result from poor bridge design, poor soundboard & rib design and poor string scaling across the break.
- Start at C-88 and work down using a log multiplier to scale lower string lengths.

THE LOW TENOR SECTION

- The hook—necessitated by the desire for a short bass section.
  - No one knows why this was considered desirable. Steinway did it? Why?
  - With the bass/tenor crossover so far down in the scale the tenor bridge "*must be foreshortened in a manner that is appropriate*" (See Wolfenden) or you run out of room at low end of the tenor bridge.
  - In practice this feature dumps string tension (and energy) at the low end of the tenor bridge.
    - Partially compensate for very low soundboard impedance at the end of the bridge—the bridge *end effect* but at the expense of string harmonic content.
    - Requires making low tenor strings abnormally large or dropping tensions—or both.
      – Gives a dull, nasal sound. Voice cannot be blended by hammer voicing.
  - There is no scaling requirement for placing the bass/tenor cross-over as far down as it is in most pianos.
    - Especially verticals and smaller grands—i.e., a 180 cm (5' 11") grand should have 30 to 32 wrapped string unisons.
- The problem of mixing plain wire tri-chords and wrapped bi-chords on the same bridge.
  - Often done at the low end of the tenor bridge because of foreshortening.

    - Good scaling practice dictates that the wrapped strings adjacent to plain steel strings be shortened to blend inharmonicity and power—not possible if kept on a single bridge.
    - Wrapped strings in the tenor section should be on separate transition bridge (or otherwise offset).
- The problem of tri-chord wrapped strings.
    - Unless *much* shorter than adjacent plain-wire strings they present tuning problems.
    - Small diameter copper is hard to wrap in high production.
    - When they are made significantly shorter than the adjacent plain-wire unison, they introduce voicing and/or inharmonicity problems.
    - No matter how well this transition is handled, it presents a voicing challenge to blend power, tone quality and tuning curve.
- The bass/tenor crossover.
    - Tonal transition at the bass/tenor break is both a string scale and a soundboard/bridge design problem.
    - Both transitions—from plain to wrapped strings and from tenor bridge to bass bridge—do not have to take place at the same scale point.

THE BASS SECTION

- The speaking length of A_1.
    - Longer is not necessarily better?
    - Especially in short pianos, the speaking length of the low bass strings is usually too long.
        - Another *sales feature* that opposes good tone production.
- Number of *bass notes* (that is, unisons placed in the plate bass section)—is there an ideal?
    - No—for any given scale length and piano length there is an ideal transition point from plain to wrapped, but not for scale layout.
    - Determined by string angles, desired placement of plate bracing, etc.
    - Number of unisons with wrapped strings—is there an ideal?
        - Yes. For any given scale and piano length there will be at least a theoretical ideal.
        - This ideal is rarely found on old scales.
        - This is not the same as the number of *bass notes* or bass unisons.
    - The number of mono-chords—is there an ideal?
        - Determined by o/a diameter of the wrap and by the minimum allowable space between the lowest bi-chords. And by the tension limits on the core of the highest mono-chord.
        - In very short scales this limit may be reached by B–15 or C–16.
        - In very long scales this limit may be as low as D–6 to E–8.
        - In general there will be more mono-chords in shorter pianos, fewer in longer pianos.
    - Number of bi-chords
        - It is convenient if there are an even number of bi-chords in the bass section, and that there be an odd number in the tenor section.
        - The dictates of good scaling don't always cooperate.
- Length of backscale.
    - In small pianos the backscale is generally *much* too short through the low bass section.
    - Length must be adequate to allow good mobility of the bridge and soundboard assembly at the lowest anticipated fundamental frequency.

MODIFYING THE ORIGINAL SCALE

- Some common problems with existing stringing scales.
    - Short treble strings—especially through killer octave.
    - Bass/tenor break—especially excessive drop in tension at low tenor—hockey-stick bridge.
    - Clarity of tone through bass section—especially mono-chords.
- Solving the stringing scale problems.

- Scaling limitations imposed by existing plate, bridges & soundboard assembly.
  - Offset between string lengths between low tenor & top bass.
  - String configuration—i.e., wrapped tri-chords?
  - Transition between mono-chords, bichords, etc.
  - Sweep of bridge.
  - Location of V-bar.
  - Hammer strike point—especially across bass/tenor break.

THE STRIKE LINE & SCALE STICK

- The entire piano is centered around the strikeline and the scale stick.
  - Strike line is an imaginary line along which the hammer strikes the string.
  - Typically 1/12 to 1/15 of the speaking length in the treble, tapering to ≈ 1/8 at approximately mid-scale.
    - It is typically held to ≈ 1/8 through the low tenor—from approximately C-40)—and bass section.
  - The strike line is laid down and the scale stick centers are marked off.
    - Scale stick centers must allow room for action parts clearance, plate brace clearance, etc.
    - Scale stick centers #1 and #88 determine width of scale.
  - String angles worked out to provide clearance between the tenor and bass bridges for the plate *belt*.
    - It's nice to keep the low tenor bridge somewhat away from the rim.
    - It's also nice to keep the bass bridge more or less centered on the soundboard panel.
    - It is virtually impossible to achieve both of these goals in short scales—see drawings.
  - String termination points—i.e., the agraffes and V-bar and the leading bridge pin centers—are all referenced to the strike line and scale stick centers.

6) The plate & scale layout

- The plate design is developed around the stringing scale and the string layout.
- Function & design criteria:
  - The plate must support essentially all of the string load.
    - String load varies from just under 35,000 to ≥ 45,000 pounds (≈ 16,000 to 20,500 kgf) overall.
    - String load is spread over of plate. Typically 8.000 to 12,000 lbs (≈ 3,650 to 5,450 kgf) per strut.
    - The plate *horn*, or *horns*, transfers some string load to belly bracing system.
  - The plate must hold the strings in the proper relationship with the soundboard bridge.
  - The plate must adequately terminate the front end of the speaking string.
  - The plate provides the back hitch and bearing arrangement for the string.
- Most modern piano plates are one-piece castings made of gray iron.
  - Either sand cast or vacuum cast technologies are now being used.
    - Sand casting is the traditional method. Relatively slow, but gives good results.
    - Vacuum casting yields an excellent as-cast finish. Very fast and economical in high production.
  - The gray iron used in plates has high compression strength (50,000 + lbs.) but relatively low tensile strength (30,000 ± lbs.).
  - Gray iron has a high carbon content.
    - The high carbon content, along with physical characteristics resulting from how the casting is poured and cooled, gives it very low plastic deformation.
    - High carbon content—in the form of graphite—makes this metal easy to machine.
- Other materials.
  - Winter/Aeolian built about 100,000 pianos with aluminum plates from 1945 into the 1950s.
  - Cast steel—the early Steinway *bell metal* plates—or welded steel.
  - Built-up steel—Baldwin built several hundred during the 1970s.
- Mounting, or *setting* the plate.
  - The continuous ledge, or wood spacer. A continuous strip of wood planed to a specific height fitted

around parameter of inner rim between the soundboard and the plate flange.

  - Spacer blocks. Wood spacers of the correct height are placed adjacent to the plate bolts between the soundboard and the plate flange.
  - Dowels or blocks. Wood dowels cut to a specific height and fitted to each side of the plate bolts.
  - The *floating* plate (Baldwin style). The plate has threaded holes with machine bolts going through the plate and driven into undersize holes in the inner rim.
- Front string termination.
  - *Loose* string termination—or *tuned* front duplex.
    - Feature claimed to enhance tone performance in the upper tenor and treble sections.
    - Requires *tuning* the length of the string segment between the V-bar and the counter-bearing bar with impossible precision—it's a moving target.
    - This feature accounts for significant energy losses across the termination point and into the duplex.
      – Remember, gray iron readily absorbs energy.
    - If everything is working perfectly, the design can provide the illusion of enhanced *power*, but at the cost of sustain. It has the most effect on the initial transient string motion.
    - Most termination string noises in the treble section (capo tastro bar/V-bar section) come from the termination problems associated with this feature.
  - *Positive* speaking length termination.
    - Usually has somewhat shorter front duplex lengths.
    - Usually has somewhat steeper string deflection angles.
      – Must have one or the other.
    - Termination efficiency depends on the combination of the string deflection angle and duplex length.
    - If the duplex length is very short enough it can use smaller deflection angle—i.e., as found with the typical vertical piano V-bar/pressure bar arrangement or with the vertical agraffe.
    - A long duplex length requires high deflection angle to ensure string termination.
  - Agraffes.
    - Insures proper string alignment.
    - Susceptible to string termination noises.
    - Low mass and stiffness. *Flagpole* easily. Theoretical energy losses.
  - Capo tastro bar.
    - Adds mass to the string termination mechanism—whatever that might be.
      – Is that mass really necessary? Consider Sohmer, Baldwin SD-10, Heintzman, Steingraeber.
  - V-bar.
    - Can be difficult to locate while casting. The mold for the V-bar is located in the cope.
      – This problem can be alleviated by using a separate V-bar casting. Or inverted agraffes (Chickering).
    - Has no provision for obtaining or maintaining proper string spacing.
    - Often not properly shaped by factory.
    - Subject to developing string grooves in use. This problem can be also be eliminated by using a separate V-bar casting made from some harder metal. Manganese bronze, for example. Or by hardening the V-bar (which introduces its own problems.)
    - Inverted agraffes—takes the place of the V-bar.
      – Insure proper string spacing.
      – Shape can be more carefully controlled. Does not depend on hand shaping at factory.
    - Individual termination pieces.
      – Used by Baldwin to tie capo tastro bar to tuning pin panel.
      – Can be made of any metal using any shape. Baldwin's are made of hardened steel.
      – String deflection angles are still critical. This would probably be the best system to date were it not for the shallow string angles and relatively long duplex lengths.
  - Vertical V-bar/pressure bar system.
    - Typically a very effective and low-noise system.

    - Relatively shallow string deflection angles, but short duplex string segments. Terminates efficiently, few string noises and strings render well.
- Back string termination.
  - Establishes vertical relationship with bridge.
    - Typically, this is a fixed point established by a separate or cast-in bearing bar.
    - In European pianos strings often rests on a very hard felt strip. Wood is also used.
    - Baldwin style uses a vertical hitchpin and makes the vertical alignment of the string adjustable.
      – The so-called *Accu-set* pin—a solid, friction-fit pin with an annular groove located close to the top of a stiffer and more massive solid pin—makes stringing easier but reduces vertical alignment.
  - Establishes length of back scale.
    - Backscale may be *tuned* to form an aliquot segment but it is not particularly advantageous.
    - Length of back scale is not especially critical, but must be long enough to not impede the motion of the bridge/soundboard assembly.
- Plate damping.
  - Energy coupled to the plate from the strings is lost.
    - Gray iron has a high damping capacity, that is, mechanical energy coupled to the plate is readily converted to heat.
    - Long considered an advantage of gray iron it does reduce string sustain time.
      – It's long past time for some experimental work here.
    - There are other ways to keep extraneous vibrations from making plates ring besides converting substantial amounts of otherwise useful energy into heat.
  - Plates are damped by their mounting systems.
    - Or not, as in the case of the dowel mounting system or the threaded stud suspension system.
      – The stud suspension system was (presumably) developed to keep from damping the plate.
  - Nosebolts provide mass coupling to heavy wood members.
    - Nosebolts mass-couple plate panels to belly bracing.
      – Nosebolt coupling raises the mechanical impedance of the plate assembly.
    - Wood belly bracing provides damping for plate.
    - The Steinway treble *bell* mass couples the treble plate panel to the inner/outer rim assembly. The effect is the same as if a standard nosebolt/bellybrace system were used. It's not magical.
- Pinblock mounting and support.
  - Plate flange provides a positive stop for pinblock.
    - Assuming, of course, that the pinblock actually contacts the plate flange.
    - Pinblock is (usually) fastened to the plate tuning pin panel via a series of wood screws. These screws will support at least some of the stress from the strings pulling against the pinblock.
    - Pinblocks are sometimes glued and screwed to the rim and/or stretcher. This also provides for pinblock stability, but does not substitute for the pinblock mating with the plate flange.
- Pinblock & tuning pin configuration.
  - Open–face pinblock.
    - Allows the string to be held close to the pinblock surface.
    - Reduces *flagpoling*. Pianos usually easier to tune and have greater tuning stability.
    - Usually harder to fit and keep structurally sound.
  - Drilled pinblock panel w/o wood plate bushings.
    - Tuning pins were originally intended to contact the edge of the small hole drilled in the plate.
    - String is wrapped somewhat higher off of the pinblock surface.
    - Tuning pins *flag-pole* —some find tuning them difficult and experience tuning instability.
    - With *traditional* pinblocks (3-ply, 5-ply, etc.) the tuning pin must contact the plate to prevent splitting the pinblock—hence the extreme back angle on the tuning pins.
  - Drilled pinblock panel with wood plate bushings.

    - The plate bushing was developed to guide the drill bit during pinblock drilling.
    - The plate bushing contributes to the long term tuning stability of the piano only if it becomes a structural and load-bearing part of the system.
      – The best example of this being the Knight phenolic bushing.
    - The wood bushing is captured between the cast iron plate and the mild steel tuning pin.
      – As the tuning pin *flagpoles*, the bushing crushes.
      – As the moisture content of the maple bushing increases, the bushing crushes.

7) From the strings to the soundboard—the bridge system

- Bridges are just what the name implies. They are a bridge coupling energy from the strings to the soundboard. And more.
  - They bridge the gaps between the ribs.
  - They provide a slightly flexible termination point for one end of the piano string.
  - Along with the agraffe/V-bar, the bridges define the speaking length of the stringing scale.
  - They transfer the downforce from the *down-bearing* string plane to the soundboard assembly.
  - They transfer energy from the vibrating string to the soundboard assembly.
  - They add both stiffness and mass to the soundboard panel assembly.
- Bridge construction—properly designed and built, the type of bridge construction has little, if any, effect on tone performance.
  - Solid bridge body with no separate cap.
  - Solid bridge body with solid cap.
  - Vertically laminated bridge body with solid cap.
  - Vertically laminated bridge body with no cap.
  - Any of the above with horizontally laminated cap.
  - Horizontally laminated bridge body with no separate cap—none is really needed.
- The bass bridge.
  - Most bridges on traditional pianos are shaped to a reverse curve.
    - Results in an awkward wrap loading sequence and a distorted stiffening of the soundboard.
    - Shape of bass bridge should be determined by the log scale used to set string speaking lengths.
    - Straight bridge are easier to work with than are the reverse curve bridges.
  - The attachment point on soundboard.
    - Should be relatively close to the center of the soundboard—side-to-side.
    - Should be spaced away from the soundboard edges.
  - Cantilevers are not good things but are often used—especially on very short pianos.
    - Their purpose is to allow maximum string length in the low bass and still permit the attachment of the bridge to the soundboard per the above.
    - Their disadvantages are numerous.
      – They add unwanted mass to the bridge assembly.
      – They form a flexible coupling to the soundboard that absorbs energy.
      – They place a torsional stress on the soundboard assembly that distorts it over time.
      – They cause the string plane to lose downbearing (string downforce) as they distort.
    - Cantilevers are not necessary in any scale of any size. They can *always* be designed out of the system. And should be!
- The impedance problem at the bridge ends.
  - The ends of the bridges present a more flexible and less massive load to the strings.
  - Lack of stiffness and mass is compensated for by adding various bridge extensions, placing ribs immediately under the ends of the bridges, etc.
  - Coupling the tenor and bass bridges together—per Steinway B & D, and now others—is another method of adding stiffness and mass to the low end of the tenor bridge, but at the expense of the mobility of the

low end of the bass bridge.

- Another approach is the Baldwin *Tone Extender*. A mass-load is added to the end of the bridge. For best results it should be coupled with an added spring load.
  - Usually the problem includes lack of stiffness, not just mass.

8) The voice of the piano—the piano soundboard

SOUNDBOARD MYTHOLOGY (*ALL OF THE FOLLOWING ARE FALSE OR, AT BEST, ONLY PARTIALLY TRUE.*):

- Only selected *tonewood* can be used for soundboards. Each board must be tested for proper *resonance.*
- The best soundboard wood is grown on the north side of the mountain. *(Or maybe it was the south… East? Perhaps it was really the west side…take your pick—I think I've heard them all at one time or other.)*
- Kiln drying kills the *tone* of tone wood.
- The best soundboard wood has 18 to 20 grains per inch. Or was that 8 to 10? Tighter grain boards should be used in the treble and wider grain boards should be used in the bass.
- Varnish (or was that shellac?) finishes enhance the sound because they are *natural* finishes.
- Lacquer kills the resonance of the soundboard. (Because it's *unnatural*?)
- The soundboard is the *soul* of the piano. If you change the soundboard, the piano is worthless.
- Old soundboards (pianos) sound better than new soundboards (pianos).
- To function properly, soundboards must be *resonant.*
- Soundboards are *amplifiers.*
- Large soundboards *amplify* better—i.e., produce more power—than do small soundboards.

A FUNCTIONAL DEFINITION OF THE PIANO SOUNDBOARD:

- The piano soundboard assembly—that is, the soundboard panel, the rib assembly & the bridges—functions as a transducer. That is, it transmits energy from one system to another and it converts energy from one form to another.
- In structural terms, because piano soundboard panels are so thin, the wood used must be treated as an anisotropic material, i.e., it is much stiffer in one direction than it is in the other.
- To make the panel equally stiff (at least approximately so) in all directions it has a system of stiffening ribs glued to one side of the panel. (Occasionally to both sides, i.e., J. Bauer, etc.)
- The soundboard is a clamped-edge vibrating panel.
  - Occasionally, it has been designed as a semi-hinged system. (Marshall & Wendell by Chickering)
  - We have been experimenting with partially floating systems, per Rippen and Fandrich verticals.
- The piano soundboard is a driven plate.
  - As installed in the piano, the soundboard assembly is not a *freely vibrating*, or *resonating*, assembly.
    - At least, it shouldn't be. Ideally, the soundboard assembly should be *non-resonant.*
  - The soundboard assembly is not an energy source.
    - It is a forced oscillating system. It vibrates only because it is directly linked—closely coupled—to another vibrating system; the strings.
    - It should respond uniformly to the vibrations in the strings and coupled through the bridges.
    - In real life, soundboards do not respond predictably to the vibrating energy in the strings.
  - Soundboard resonances are a source of many voicing problems.

THE ENERGY SPECTRUM IN THE SOUNDBOARD

- The soundboard's response to energy input.
  - Ideally, the soundboard is designed to respond to all of the energy waveforms transferred to it from the string through the bridges. In reality it does not.

  - Depending on its design and physical characteristics, it may reject vibrating energy at certain frequencies and resonate strongly at others. It acts as a selective filter.
- Soundboard frequency response is a function of—
  - Its overall and local stiffness to mass ratio.
  - The design and placement of the ribs and bridges.
  - Its area, shape and mounting system.
  - The amount of crown & the loading of the string downbearing.
  - The various stringing scale parameters, including the back scale.

WHERE THE ENERGY GOES

- Energy is dissipated within the speaking length of the string as heat due to internal friction.
- Energy is dissipated within the *non–active* or *non-speaking* portions of the strings and the plate—
  - If any string segments in the backscale or the front aliquot scale are resonating, useful energy is lost to friction both in the string and into the plate.
  - Wherever a vibrating string contacts the plate structure—including the agraffes, the capo tastro bar, the counter-bearing bars, etc.—energy is coupled to the plate and is dissipated as heat.
- Energy is dissipated within the bridge—
  - At the bridge pins in the form of heat due to pin flex and internal friction.
  - Within the bridge body due to internal friction.
  - Through unwanted bridge motion—i.e., “flag-poling,” or bridge “rolling” about an axis without appreciably moving the soundboard assembly.
    - Particularly true in “suspended” bass bridges.
- Energy is dissipated within the soundboard—
  - As heat due to the internal friction of the wood.
  - Wave cancellation within the soundboard assembly and in the air immediately adjacent to the soundboard assembly due to the “break–up” of the soundboard into local resonant modes.
- Energy is dissipated through the soundboard’s boundary system.
  - The belly rail flexes and “rotates.”
  - The rim flexes.
- Some very small percentage of the wave energy in the strings is actually converted into sound energy and is radiated into the air surrounding the soundboard.
  - Even then, some acoustic energy is lost due to wave cancellation between the top and the bottom of the soundboard—particularly at lower frequencies.

THE SOUNDBOARD DEFINES & CONTROLS THE CHARACTERISTIC VOICE OF THE PIANO

- The soundboard can be designed to create a particular type of sound.
  - For best overall performance it must be balanced to the stringing scale and the hammers must be balanced to both.
    - *High tension* scales require stiffer and/or heavier soundboards.
      – Should also have longer string backscale lengths—difficult to get in small pianos.
    - *Low tension* scales require more flexible and/or lighter soundboards.
- When either stiffness or mass is altered to create these differing types of soundboard, it changes a parameter of vibrating systems known as characteristic, or mechanical, impedance.
- Impedance (**Z**) is the ratio of maximum force to maximum velocity.
  - This is a method of evaluating, or quantifying, a vibrating body's ability to release or accept energy.
  - In this case, energy from the strings is transferred to the soundboard via the bridge and then into the air as sound at some rate determined largely by the impedance of the soundboard.
  - Once set in motion by a hammer blow, the vibrating stings exert some amount of varying force against

    the bridges. The soundboard reacts by moving some measurable distance up and down in response to the motion of the strings.
      - How fast and how far the soundboard moves is determined by the mechanical impedance of that part of the assembly that is affected by the string in question.
      - Size alone is not the limiting factor in power output of piano. Controlled displacement is of the soundboard panel and its overall efficiency is.
  - The mechanical impedance of a vibrating system is a function of its inertia—mass—and its springiness, or elasticity.

- The general relationship for mechanical impedance is: $Z = \sqrt{Springiness \times Inertia}$
  - Impedance is frequency dependent. Real-life soundboards do have resonances, hence they are driven oscillators. Driven oscillators are:
    - Stiffness-controlled—at frequencies below its natural frequency v_o
      - At *low frequencies*, impedance is affected more by *springiness* than by mass.
    - Resistance-controlled—at frequencies at or near its natural frequency v_o
    - Mass-controlled—at frequencies above its natural frequency v_o
      - At *high frequencies*, impedance is affected more by *mass* than by elasticity.
    - There will always be an upper limit to the frequency range over which the soundboard is stiffness-controlled, a lower limit to the range over which it is mass controlled and both an upper and a lower limit to the range over which it can be resistance-controlled.
  - The internal resistance of the wood used in the soundboard assembly introduces a resistance component—i.e., internal friction—acting as an internal damper to the system.
    - Internal friction lowers ***Q***, helping to dampen oscillations at resonance.
    - Energy losses to the rim (as seen by the soundboard) are similar to resistive losses.
      - Compliance of the rim and bellyrail has a *resistance effect* on the soundboard.
    - Energy losses to the air (as seen by the soundboard) are similar to resistive losses.

SOUNDBOARD MASS.

  - Soundboard mass is the sum of all of the masses in, and connected to, the soundboard assembly, including—
    - The ribs. The number of ribs used, their length and cross-section—particularly their width.
    - The soundboard panel, particularly the thickness of the panel and its specific gravity.
    - The bridge, its length and cross-section, the mass of the bridge pins, etc.
    - The miscellaneous components such as screws, buttons, finish material, etc.
    - Some part of the mass of the attached strings, etc.

SOUNDBOARD ASSEMBLY STIFFNESS.

  - Soundboard stiffness is influenced primarily by—
    - The thickness of the soundboard panel and its MOE.
    - The number of ribs used along with their orientation.
    - The length, height and width of the ribs and the MOE of the material used.
    - The amount of crown and the manner in which it was developed.
    - The internal compression—across grain—of the soundboard panel.
      - Especially in *compression-crowned* soundboards.
    - The degree of deflection built into a soundboard system by string loading.
    - String length vs. tail length—the length from the back bridge pins to the back termination point.
  - Soundboard stiffness is greatly affected by the amount of crown designed into the assembly and how much that crown is compressed by the load of the string downbearing.
    - In their *unloaded* state, and through their normal deflection range, soundboards are not very stiff.

    - The dynamic stiffness of a soundboard system depends greatly on the amount of curvature—*crown*—built into it *and* the amount of pre-load from the downforce of the string plane pressing against it.
    - The static deflection of a soundboard from its free state is accomplished by arranging the string plane such that it *bears down*—hence, *downbearing*—on the bridge, bending the entire assembly.
    - A *loaded* board is much stiffer than an *unloaded* board within the normal range of movement.
- What is critical is how the soundboard appears to the bridges.
    - Placing the end of any bridge close to the rim raises the Z of the system as seen by the string.
    - The small piano soundboard will appear stiffer to the reverse-curve bass bridge since more of its length close to the rim.
    - Placing the bridge close to the rim increases the system *Z* at low frequencies.
        - They can be blocked entirely as the system begins to act as a high-pass filter.

THE EFFECT OF IMPEDANCE RATIOS ON PIANO TONE

- The amplitude of the reflected disturbance and the energy carried by it depends on the ratio of the characteristic impedances of the two media. In general:
    - *Low tension source to high Z load = Low attack volume, long sustain.*
    - *High tension source to low Z load = Loud attack volume, short sustain.*
    - *Balanced (matched) Z source & load = Good balance of attack volume & sustain.*

SOUNDBOARD SYSTEM CROWN

- As installed in pianos, soundboards are not flat panels—they have a specific curvature, or crown, built into them. The amount of curvature built into the panel determines the ultimate stiffness of the system.
- Compression-crowned soundboard panels.
    - Crown formed by a *stress interface* between the soundboard panel and the across-grain ribs.
- Crowned rib soundboard panels.
    - Crown formed by a curvature machined into the glue surface of the across-grain ribs.
    - All laminated soundboards must be rib crowned—it should go without saying, but…
- Combination systems.
    - Crown formed by some combination of both methods.
- Crown longevity.
    - Rib-crowning is proving to be longer lasting.

LONG-TERM CROWN STABILITY

- Some of the factors affecting the long term support and stability of soundboard crown are:
    - Rib Structure—
        - The ability of the wood fibers within the soundboard panel to resist compression across-grain.
        - The stiffness of each individual rib—*in a compression-crowned system, ribs actually resist crown.*
        - The number of ribs used and their configuration.
        - The effect of the rib/soundboard interface as it varies with wood moisture content.
    - The elastic limit of the wood used (in a compression-crowned board).
    - The elastic limit of the wood fiber is equal to the fiber stress proportional limit (FSPL).
    - Strained beyond this limit, wood fibers become permanently deformed and will not return to their original shape or condition when stress is removed.
- Compression set (in a compression-crowned board).
    - When exposed to increasing levels of moisture, wood fiber in a restrained panel will compress by the same amount it otherwise would have expanded.
    - Continuing to compress wood beyond the FSPL will crush the wood fiber and permanently deform it.
- 1% Compression Limit. On average, compression set occurs at ≈ 1% compression perpendicular to grain.

TONE CHANGES RESULTING FROM A LOADED SOUNDBOARD LOSING CROWN

- Crown *always* decreases with age—and with it, soundboard loading! Basic long-term support for crown must come from rib structure. As crown decreases, so does the stiffness of the soundboard assembly.
- As the soundboard stiffness decreases, so does its mechanical impedance—especially to lower frequencies.
  - Power and noise at hammer impact increases.
  - Sustain time decreases.
  - Sustain rate changes.

DOWNBEARING

- Downbearing is the deflection of a piano string that is drawn across a bridge that is slightly above a straight line between its front termination and back bearing point. The string *bears down* against the bridge.
  - Static downbearing is measured before soundboard is loaded.
  - Dynamic downbearing is measured after piano is strung and at pitch and soundboard is loaded.
- Downbearing is measured in several different ways—
  - *Distance bearing*. Measured in terms of the distance from the rear plate termination to a taut string stretched from the front string termination, across and just touching the bridge.
  - *Angle bearing*. Measured in terms of a string's angle of deflection across the bridge.
  - *Force bearing*. Measured in terms of a string's downforce (in lbs. or kg.) against the bridge.

DOWNFORCE

- Downforce is the force with which a string (or a set of strings) bears down against the surface of the bridge.
- String downforce tends to depress, or flatten, the upward crown built into the soundboard system.
  - The effect of string downforce is similar to placing a series of small weights along the length of the bridges.
  - A soundboard/rib structure in this condition is *loaded*.
  - A soundboard system in its unstrung, or free, state is *unloaded*.
- Downforce is resisted by the upward (spring) force of the soundboard assembly due to the spring effect of the compressed wood fiber within the soundboard panel and the stressed ribs.

SOUNDBOARD LOADING

- The effect of string downforce is to *bend and strain* the soundboard. The soundboard is deflected from its free state to its loaded position by the aggregate *downforce* of the entire string set. The amount of soundboard deflection is affected by—
  - The *overall string deflection angles* when the piano is fully strung and tuned to pitch.
  - The *total tension* of the stringing scale.
  - The *overall average length* of the backscale.
- The desired amount of soundboard loading for a given piano depends on many factors.
  - The *size of the piano*. In general, larger pianos require more downbearing than do shorter pianos.
  - The *shape of the soundboard*.
  - The *design stiffness of the soundboard/rib assembly*. This includes such factors as—
    - The length and crown radius of the ribs.
    - The rib cross-section area and aspect ratio.
    - The number of ribs used.
    - The method used to crown the soundboard, etc.
- In general, soundboard/rib assemblies with high design stiffness require less static downbearing than do more flexible soundboard/rib assemblies. Flexible soundboard/rib assemblies can tolerate a little more static downbearing before overloading the response characteristics of the soundboard.

SOUNDBOARD STRAIN

- The ideal amount of working strain for any given soundboard is dependent on its design and condition.
- New soundboards will require—and can tolerate—more working strain than old boards.
- In general, pianos with relatively long tail sections can tolerate more soundboard loading than can those with short tail sections.

SOUNDBOARD CHARACTERISTICS CHANGE WITH TIME

- Soundboard crown decreases over time.
- As crown decreases, so does stiffness.

AUDIBLE CLUES FROM THE PIANO SOUNDBOARD

- As stiffness decreases, so does **Zm**.
  - Mass does not change, so impedance to primarily lower frequencies decreases.
  - Soundboard more readily accepts lower frequency (fundamental) energy.
- Tone gets increasingly percussive.
- Sustain time decreases.

9) The foundation & structure—the rim & bellyrail assembly

- Functional & performance criteria. The rim and belly rail assembly has two primary functions.
  - It must solidly support the soundboard.
  - It must resist energy transfer to it from the soundboard.
  - It must stabilize and dampen the plate.
- Design criteria. To perform their acoustical function, the rim & bellyrail assembly must have:
  - Stiffness. The rim should be as stiff as is practical. Rim stiffness is a function of:
    - The MOE of the material used to make the inner and outer rims.
    - How thick the inner and outer rims are.
    - The design of the bracing system used.
  - Mass. The rim should be as massive as is practical. Rim mass is a function of:
    - The density of the material used, typically wood.
    - How much wood is used; i.e., how thick and how tall the inner and outer rims are.
    - The design of the belly bracing system. Depending on their location, braces can be used to add mass as well as stiffness to the rim assembly.
  - Center of gravity. The center of gravity of both the rim and the bellyrail should be as far below the soundboard attachment point as possible.
    - Both the bellyrail and the rim assembly will tend to rotate about their center of gravity in response to the energy in the soundboard.
    - The long side of most grands is poorly braced.
    - The treble section of the bellyrail in most pianos is even more poorly braced.
- Materials used.
  - Traditionally, US built pianos have used hard maple, occasionally oak.
    - Low-cost US pianos have used poplar.
  - European pianos have used beech, birch, etc.
  - Most Asian pianos now use *select hardwood.* This can be either good or not so good.
  - Construction. There are three basic types of rim construction.
    - The solid wood rim—including stacked & sawn.
    - The multi-part rim, i.e., rims using two straight sides with one or two laminated bent panels.
    - The continuous bent rim. These can be pressed in unit or separately.
  - Bent rims may be fabricated as either *one-piece* rims or *two-piece* rims.
  - The obvious exception is the Bösendorfer. Very light framing. Both inner & outer rims are of spruce.

It is accepted that they present a somewhat flexible support to the soundboard and vibrate slightly in response to the energy in the soundboard.

10) The rim & belly bracing system

- Design criteria: What are the primary functions of the belly bracing system?
  - Neither the rim nor the belly bracing system support much, if any, string tension.
    - Exceptions being those plates that are mechanically coupled to the belly rail or bracing system; usually at the bass/tenor break.
  - The rim & belly bracing system adds to overall rim stability.
  - The rim & belly bracing system should add to the rigidity of the belly rail.
  - Piano rim assemblies can be mechanically stable without being acoustically stable.
  - Rim & belly braces may be any of a number of woods. Traditionally spruce, pine, some maple.
    - Again, most Asian pianos use *select hardwood.*
  - Strategically placed rim brace-to-plate nosebolts.
    - Nosebolts stabilize and dampen the plate.
    - Sometimes used to *fine-tune* string downbearing.
    - The Steinway inner rim *bell* provides a method of mass-coupling the plate treble section hitch pin panel to the rim.
- The Mason–Hamlin Centripetal Tension Resonator.
  - Stiffens the rim assembly. Increases its mechanical impedance.
  - Does not support crown in the soundboard any more than any other rim assembly does.

11) The keybed

- Design criteria:
  - The keybed supports the action assembly.
    - It must be stiff and stable.
    - It must have good damping qualities.
  - The keybed positions and supports the outer rim arms.
  - The keybed supports and stiffens the bellyrail assembly.
  - The keybed supports the lyre and trapwork mechanism.
    - It must accept fasteners well.
- Type of construction.
  - *Solid.* Actually a misnomer. Solid keybeds are made of individual boards, usually tongue & grooved together and mortised into two end rails.
    - Individual boards can warp and twist.
    - Extremely careful manufacturing process required.
  - Laminated, veneer core.
    - Potentially very strong and stable.
    - If not properly glued-up, laminated panels can warp and twist.
  - Laminated, mdf/particleboard/strandboard/flakeboard/etc., core.
    - Potentially very stable.
    - Lack of inherent stiffness can be compensated for by strategically located *logs.*
    - Poor fastener retention. Can be compensated for by using inserts of various types.
  - Stressed skin or hollow construction keybeds.
    - I can't really think of much good to say about these except that they are lightweight.

12) The action & keys—miscellaneous thoughts & ideas

- Hammer strike points.
  - The hammer strike point ratios stay essentially the same regardless of the length of the piano.

    - If the hammer line must deviate from a straight line it is because of an error in the plate layout.
        - Poor initial design (strikepoint is off) or the V-bar has *slipped.*
- Key length.
    - Keys get longer as the piano gets longer.
        - The strike point at A–1 moves further toward the back of the piano.
        - On most concert pianos the strike line is angled to the front of the piano. The bass keys are longer than the treble keys.
- Key offset should be held to a minimum with all action configurations.
    - This might require some creative string layout work, but it can be done.
- Action geometry & key dip.
    - Keys should use as long a front lever arm as possible.
        - Some pianists are sensitive to the arc of travel used with many short keys.
    - Key travel (*dip*) should *never* exceed 10 mm.
    - Hammer travel (*blow distance*) should never be less than 42 mm.
- Hammers—must be appropriately sized to the instrument.
    - Large, dense hammers on a small scale will lead to distortion and strident sound.
    - Small, excessively soft hammers on a large, powerful scale will lead to a weak, thin sound.

13) The damper system

- The damper must stop the motion of:
    - The motion of the vibrating strings.
    - The motion of the vibrating soundboard.
- To stop the strings and soundboard from vibrating, the dampers must absorb the energy in them.
    - The damper is an energy absorbing mechanism of the type called an auxiliary mass absorber (AMA). The AMA consists of:
    - A resilient damper pad.
    - A mass load, or a mechanism to couple the damper pad to a mass load.
    - A mechanism to support the damper pad and hold it against the string or strings.
- Piano dampers work by absorbing energy from the strings until it has been dissipated into the damper pad.
    - Ideally, this would take place instantly. In the real world it takes some finite period of time.
        - There will always be some time period between the instant the damper pad contacts the strings and the point at which discernible sound ceases to be produced.
    - Damper efficiency is the measure of how long it takes to fully stop the vibrating masses to the point that no further sound is being produced.
- The damper system is also governed by the laws of mechanical impedance.
    - Impedance is frequency dependent.
    - High frequencies are mass-damped.
    - Low frequencies are spring-damped.
        - Best low frequency damping is achieved by using a massive damper that is spring assisted.

14) Improving the design—making the piano sound *better* than new

FIELD WORK—BLUEPRINT SYSTEM

- Check string bearing across bridge:
    - The amount of string bearing affects energy transfer efficiency both in total and at specific frequencies.

    In general:

    - Too much overall string bearing will reduce power. Sustain time might increase, but it will be slight.
    - Too little overall string bearing will increase initial attack power. Sustain time will probably be reduced.
    - Too much or too little string bearing on an individual string will have virtually no effect on overall tone.

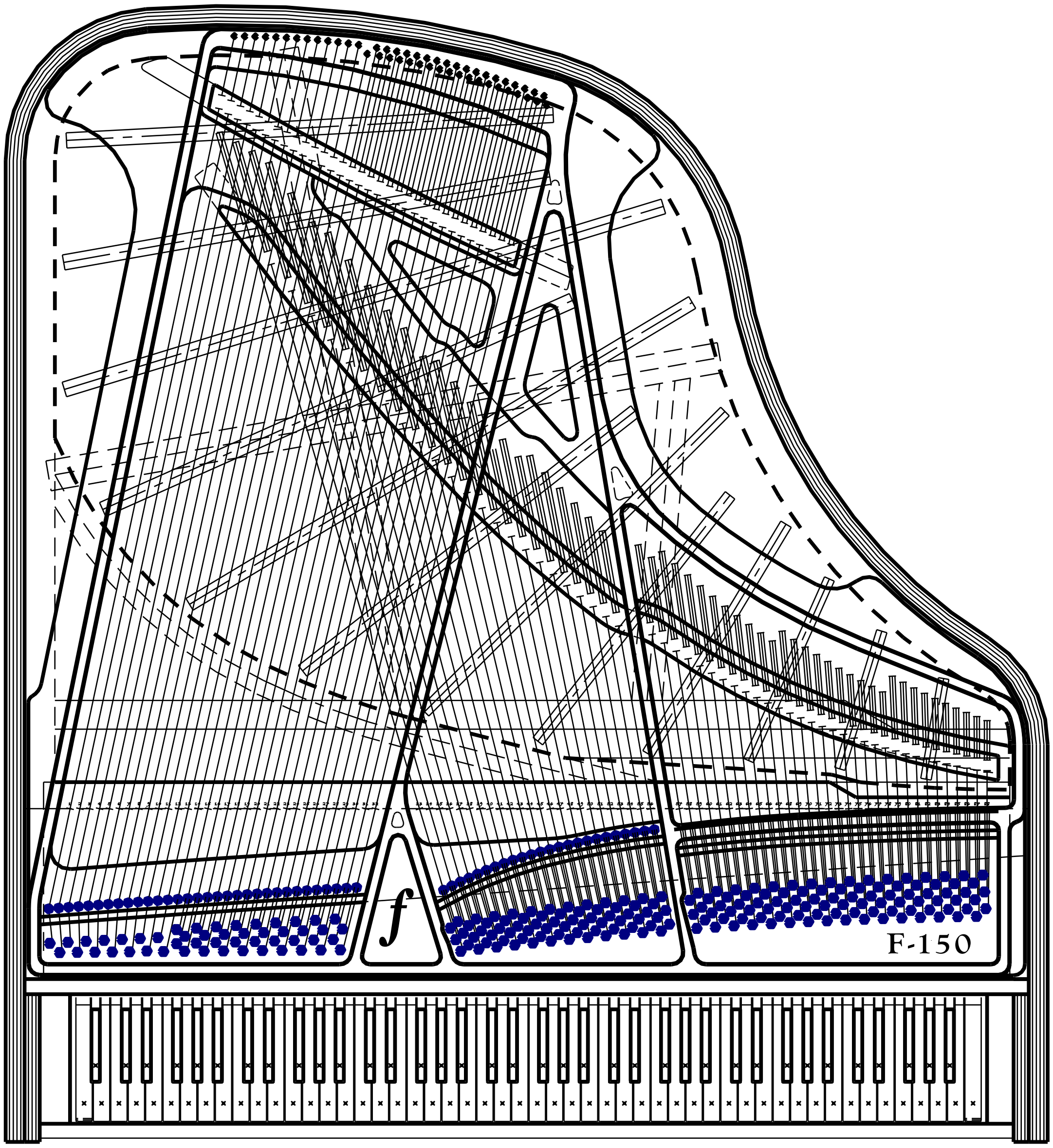
- Verify condition of hammers.
  - Have the hammers been over-needled? Over-lacquered? Over-shaped?
- Verify hammer shape, size and mass. (Size and mass are not the same thing.)
  - Are the hammers appropriate to the scale? Are they too massive or too light for scale?
  - Nearly all upper-tenor and treble hammers used in modern pianos are too massive.
  - Is the hammer shape intact? Or have they been "reshaped?"
- Verify correct hammer strike point.
  - Is the hammer strike line straight or offset? Which should it be?
  - Have the hammers been replaced following something other than the original hammer line?
- Evaluate the stringing scale.
  - Is the piano strung with the correct gauge wire?
  - Measure scale and check tensions. Do string tensions drop in the killer octave region?
- Check back string scale.
  - Is it very short? Can the back scale length be increased?
  - Can the aliquot bar be moved to increase the length of the back scale?
- Check condition of V-bar. Reshape as necessary.
- Check front string angle.
  - Can the front string deflection angle be increased?
- Soundboard weights & springs…an idea with some possible merit.
  A popular idea in the sixties and early seventies which passed out of favor—probably because they were promoted as a cure–all for every ill and were mis-used in many applications.
  - Mass-loading the soundboard in the killer octave region can help sustain—at least the upper harmonics.

SHOP REPAIRS AND MODIFICATIONS

- Bridge location.
  - Can speaking length of upper treble be increased by relocating the tenor/treble bridge?
- Belly rail stiffness and rim bracing.
  - Is the belly rail stiff enough?
  - Can additional belly bracing be fitted?
- String speaking length.
  - Is the speaking length (and string tensions) consistent through the upper two sections of the scale?
  - Would it be worthwhile to lay out a new bridge pin pattern?
- V-bar shape and condition.
  - Is the V-bar material too soft? Has it grooved excessively?
- Counter-bearing bars.
  - Are they high enough to provide an adequate string angle to terminate the speaking length of the string?
- Bridge design.
  - Does the tenor bridge have an extension?
  - Does it overlap the inner rim?
  - Is it too close to the belly rail?
  - Does the bass bridge have a suspense? Can it be removed?

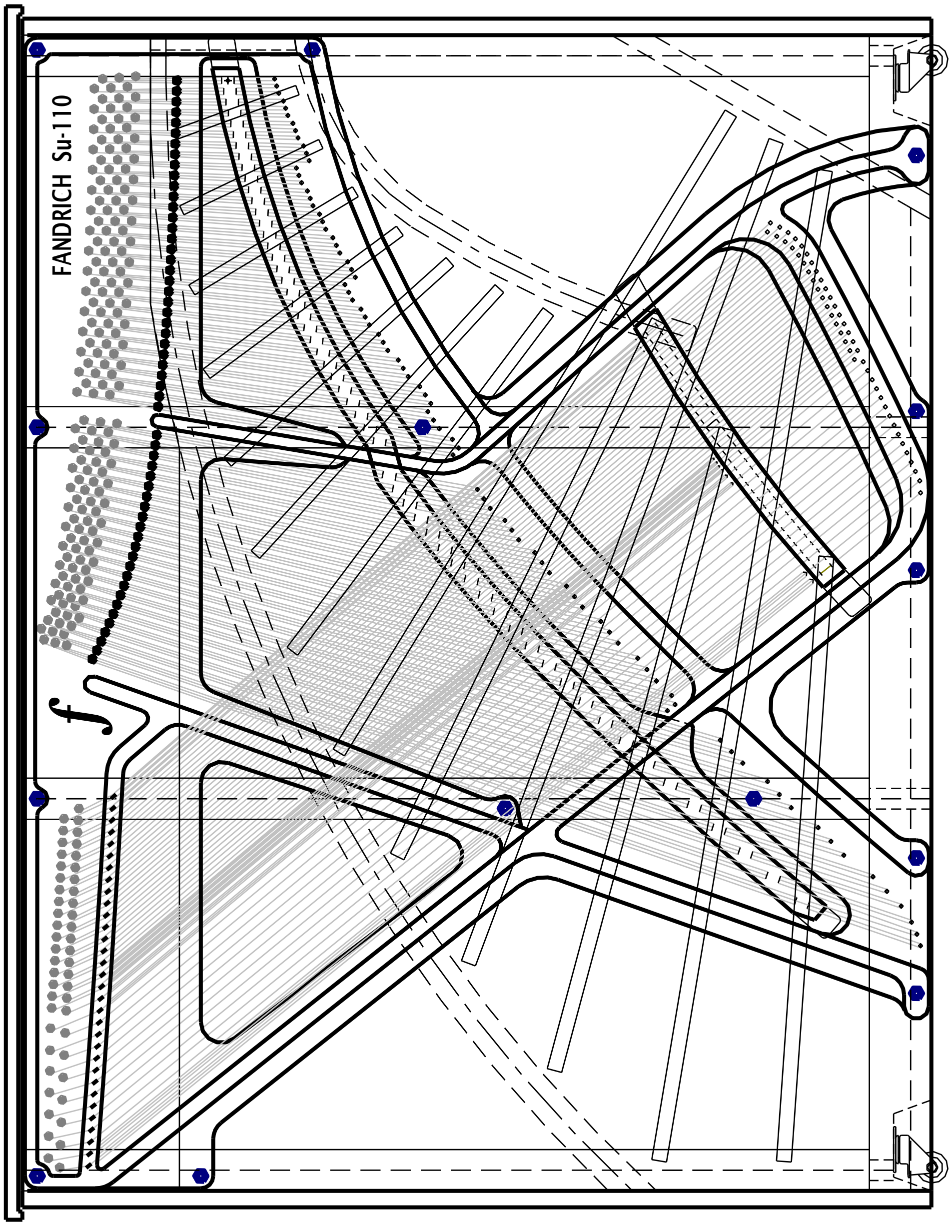
Notes

A Small Grand Piano Design Cartoon



© 2012 Delwin D Fandrich. Note: This is not a complete design. It is illustrated here for educational purposes only, and is to be used for this lecture only. This design is the property of Delwin D Fandrich, Piano Design & Fabrication. It may not be copied or reproduced for any reason or in any manner, mechanically or electronically. It may not be used for any other purpose or in any other way, private or commercial, without the express written permission of the author. To do so would be both illegal and unethical. If you or your company are interested in any aspect of this design, please contact the author at the address listed on Page 2 of this document.

A Small Vertical Piano Design Cartoon



© 2012 Delwin D Fandrich. Note: This is not a complete design. It is illustrated here for educational purposes only and is to be used for this lecture only. This design is the property of Delwin D Fandrich, Piano Design & Fabrication. It may not be copied or reproduced for any reason or in any manner, mechanically or electronically. It may not be used for any other purpose or in any other way, private or commercial, without the express written permission of the author. To do so would be both illegal and unethical. If you or your company are interested in any aspect of this design, please contact the author at the address listed on Page 2 of this document.