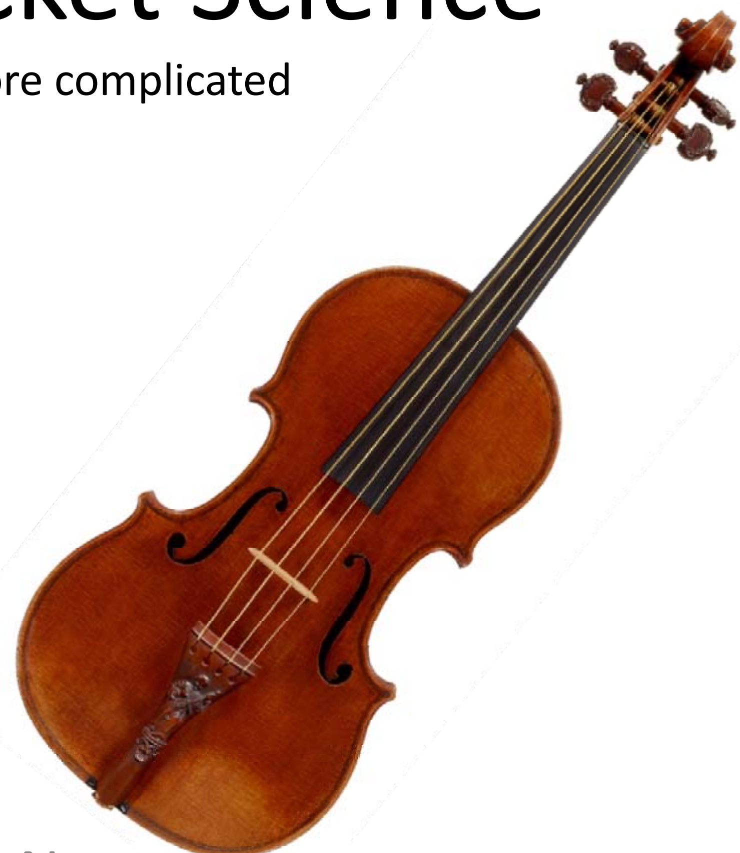
It Ain't Rocket Science

It's much more complicated



Don Noon

VMAAI Competition October 2012

- Yes, I AM a rocket scientist
  - And violins are far more complex than anything I ever worked on
- No, I haven’t figured it out yet
  - But some people seem to think my results have been good
- Maybe some of the things I think I know are correct… or maybe not
  - But in any case, here is what I think I know at the moment, what I do, and why

In the Beginning

- There's wood
  - Anyone that thinks it's NOT important can leave the room now
- And shape
  - Also intuitively obviously important: outline, arching, thickness, F-holes
- And the problem of determining how all these variables influence sound…
  - And deciding what is good, bad, or just different

Wood – background/theory

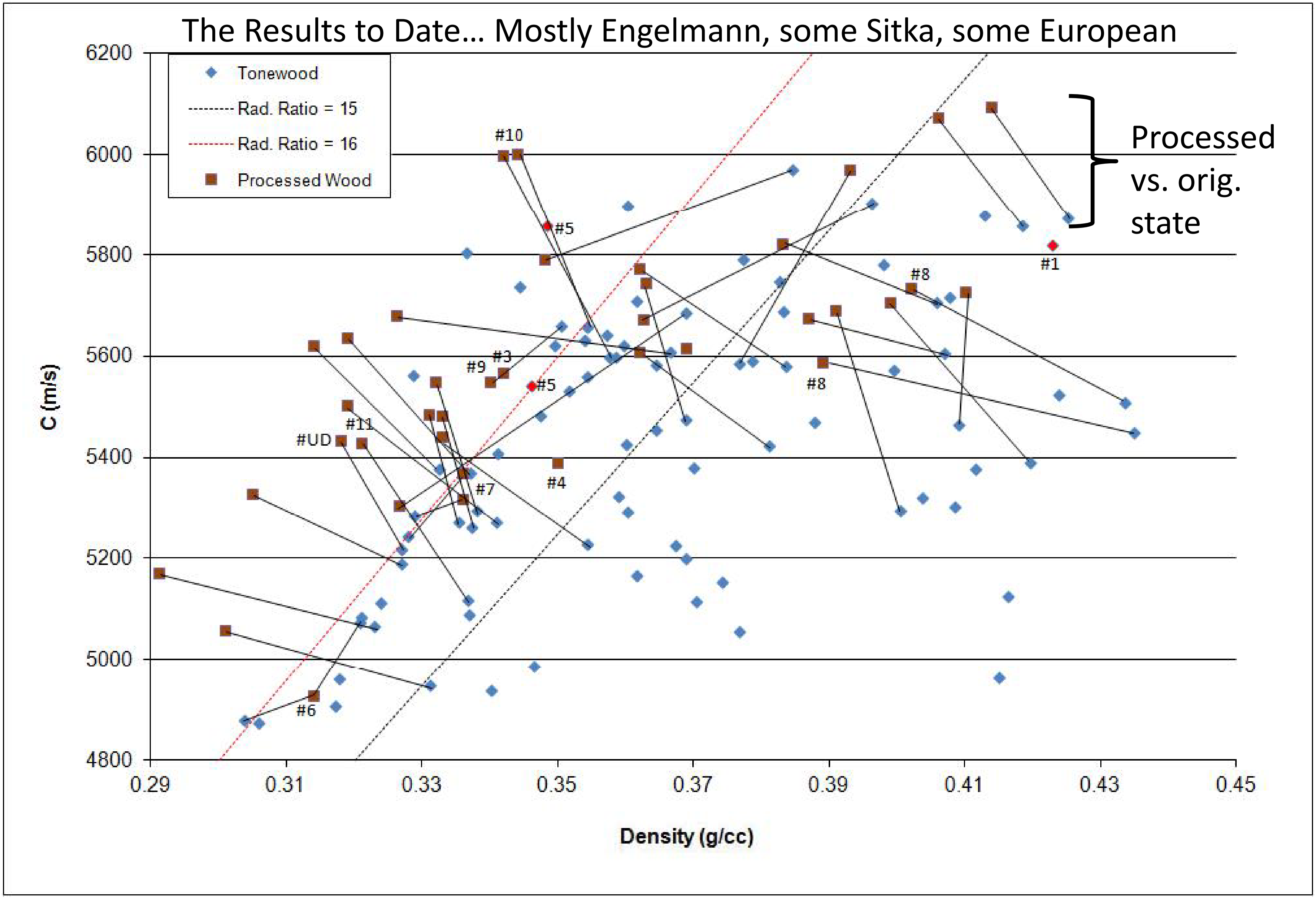
- Spruce is used for soundboards in almost everything… violins, pianos, guitars, harps… for apparent good reason:
  - The stiffness (along the grain) vs. density is phenomenal
  - For the cell wall material, C (speed of sound) is the figure of merit
    - C for spruce = 5000-6000 m/s (along grain), vs. ~5000 for steel, aluminum, and titanium. Only things like graphite composite, beryllium, and diamond have higher values
  - For a vibrating flat plate, Radiation Ratio (C/density) is the figure of merit
    - RR for spruce = 13-17, vs. 6.8 for beryllium and 5.0 for diamond, and 3 for graphite composite. Almost verything else is under 2.
    - If you want to use other materials and match the RR of spruce, you would need a very delicate laminated panel with a low-density core
- Wild card: damping
  - Properties have not had much investigation as to its importance on acoustics of violins
  - One paper (Bissinger) concluded it was not a big factor in good vs. bad instruments (but I'm not totally convinced yet)

Wood – lighter/stiffer = better?

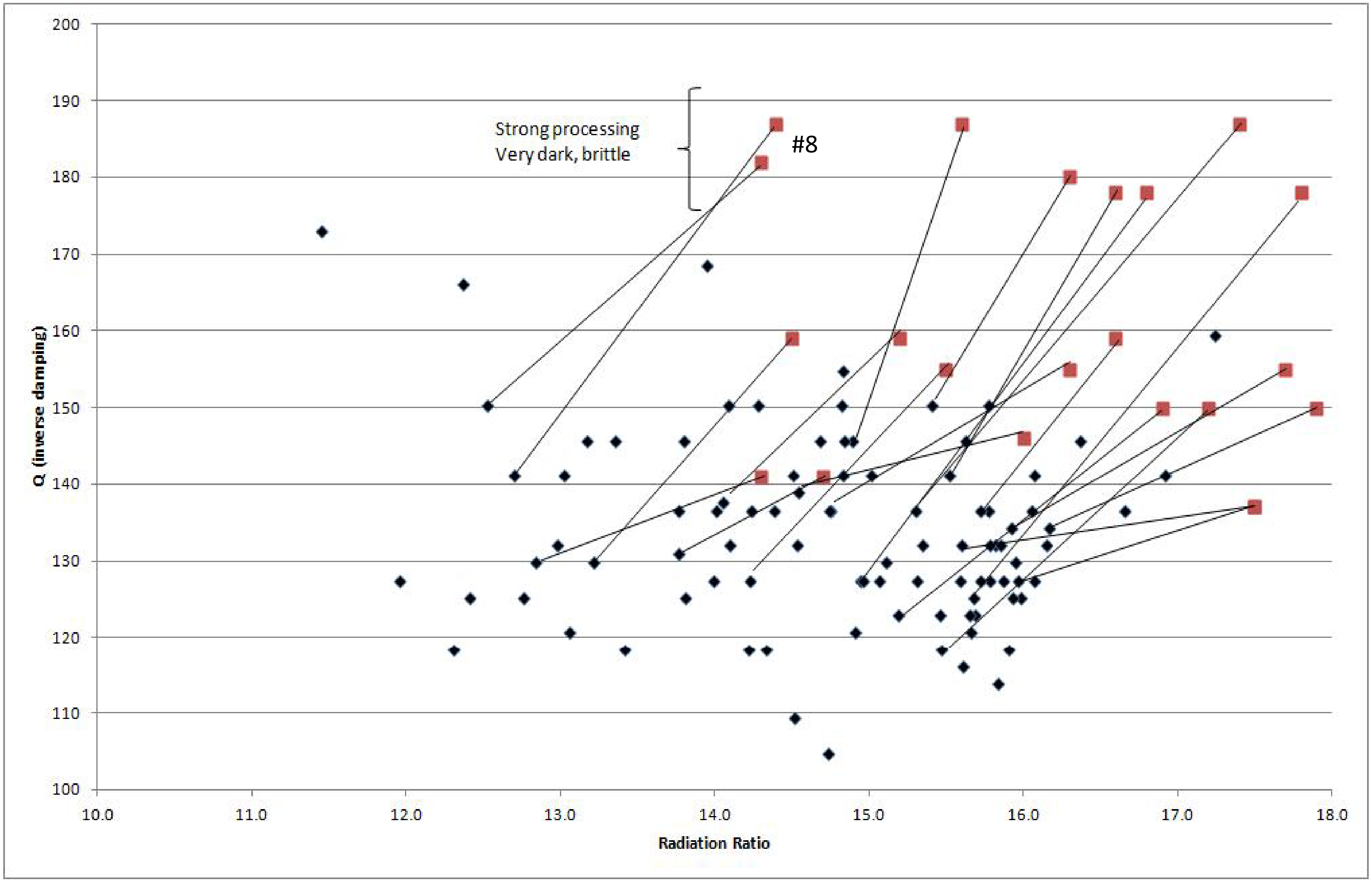
- So if we use spruce for soundboards due to these exceptional properties, shouldn't more exceptional be even better?
  - Measure wood properties, find the most exceptional stuff, and see how the instruments turn out
- Even more extreme properties can be obtained by processing
  - Not simple, but might be a method to fine tune whatever properties are desired
  - There is some reason to believe that chemical/physical changes occur slowly over time, and might be a large part of the belief in old=good
    - There is also some reason to believe that thermal processing causes many of the same changes, but can happen in hours instead of centuries
- Note: there are something like a dozen or more parameters to fully specify wood properties (actually infinite, when you include the local variations and how damping varies with frequency). I only present along-grain properties for simplicity
  - I have been recording crossgrain values, but have not yet noticed any correlation to the sound of the assembled violin
  - Also recording maple properties, but seems to be of lesser importance

Processing

- After some research, I settled on using thermal processing based on the “Plato” process:
  - First stage: Heat (~300F) and water vapor under pressure in oxygen-free atmosphere
    - Reduces density by converting hemicellulose into volatile acids
  - Second stage: Dry heat to remove the acid vapors and thermoset the remaining non-cellulose stuff (?)
- Variables of time, pressure, temperature determine the mix of properties, including how dark the wood becomes
  - Generally, more extreme processing = darker, lower density, some loss of strength, very brittle, lowest damping
- Danger: high-pressure steam, and hot acid vapor. Not good for people or equipment


The Results to Date… Mostly Engelmann, some Sitka, some European
Tonewood
Rad. Ratio = 15
Rad. Ratio = 16
Processed Wood
Processed vs. orig. state
C (m/s)
Density (g/cc)
6200
6000
5800
5600
5400
5200
5000
4800
0.29
0.31
0.33
0.35
0.37
0.39
0.41
0.43
0.45
#10
#5
#3
#9
#5
#11
#UD
#7
#4
#6
#8
#8
#1

More Processing Results (Damping) - partial data



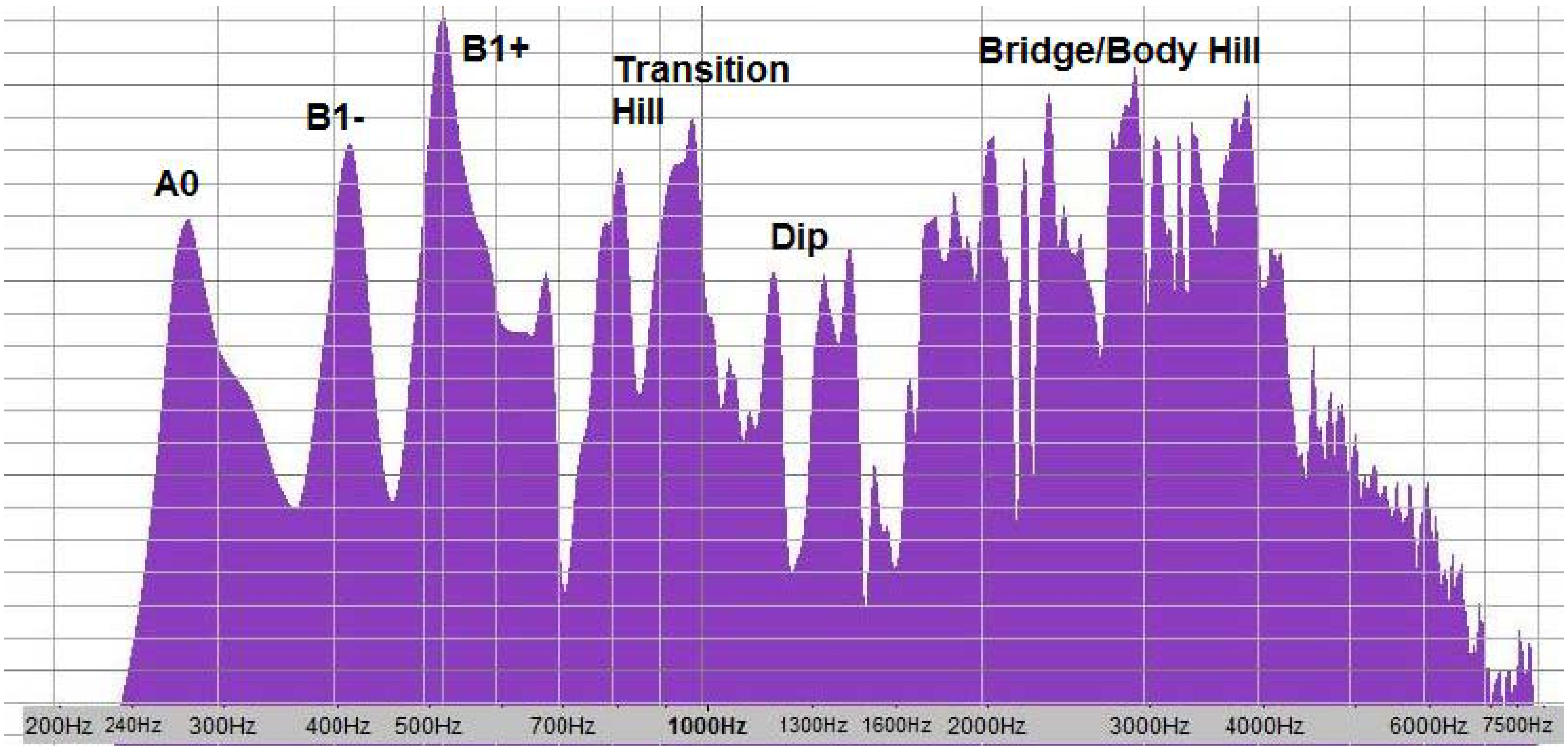
Summary/discussion of wood properties

- In theory, higher C, RR and lower damping should produce more sound
  - However: theory also predicts that the difference in sound will be fairly small… a fraction of a dB for 10% RR gain
    - But why not get every available advantage?
- Measurements of wood properties can help pick out what's good and what's not so good
- Processing produces significant, measurable changes in properties, theoretically better
  - At the cost of:
    - High effort
    - Darker wood (nice in moderation)
    - More difficult to work… brittle, splitty
    - Instrument more prone to accidental damage

Summary/discussion of wood properties - continued

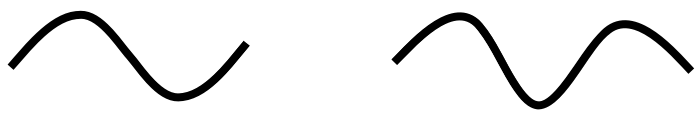
- The math gives low density wood a theoretical advantage in power. My personal experience:
  - Yes. But…
  - It isn't a well-distributed gain, and the extremes can give a result that sounds and plays "differently"
    - Weight, density, and stiffness affect various frequency ranges in different ways
  - High frequency response has been most difficult to get strong and even but without harshness
    - Low density wood is usually left thicker to avoid distortion, which will shift bending mode frequencies upward
    - Or perhaps due to observed tendency for low density wood to have higher damping?
- For a standard size violin, .35 - .4 density with high speed of sound and low damping is what I'd want
  - Or slightly lower density after processing… which I'll be doing on all spruce anyway

Before going on to shape…
Review of basic acoustic response:

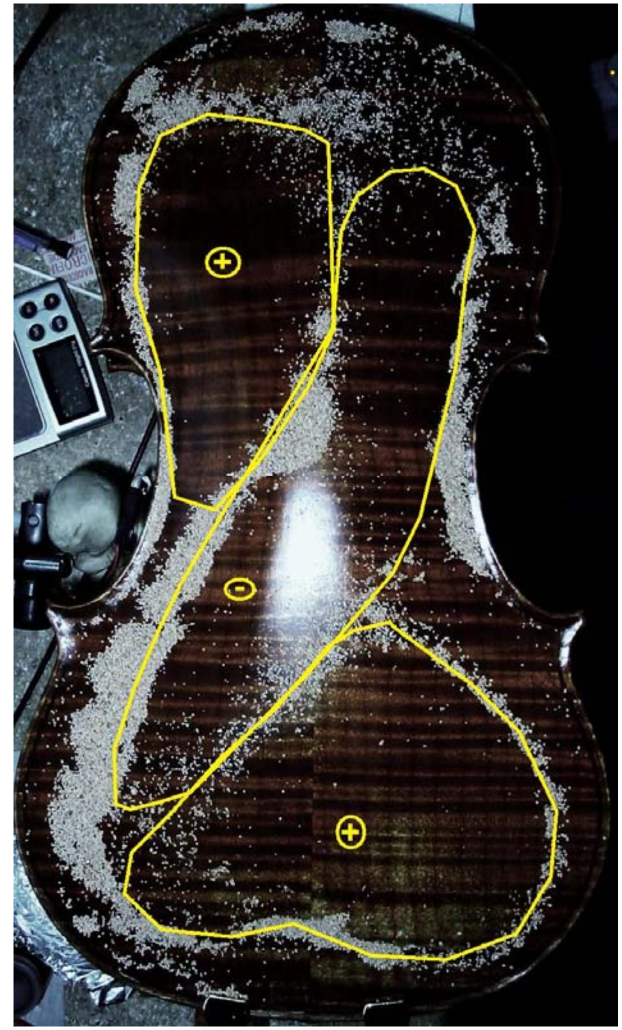


- A0: Air resonance, ~275 Hz (C#) … affected by body size & stiffness and F-hole area
  - I don't try hard to do anything about it, but if the frequency ends up higher than expected, it may indicate that the body is too stiff
- CBR (C-Bouts Rhomboidal): generally ~400 Hz (G)
  - Usually does not produce much sound, due to symmetric movement that does not result in much net volume change
  - Also a stiffness indicator… mostly for back
- B1-: First acoustically strong body mode, ~420-460Hz (G#-A#), longitudinal flex of back, crossgrain flex of top
  - If the frequency is too high or level too weak, I'll consider thinning the center of the top… IF it also feels too stiff in playing
  - Sensitive to chinrest mass… can be used for adjustment
    - Heavier => lower frequency, less amplitude & vice versa
- B1+: Usually the strongest body mode, ~510-560Hz (B-C#), crossgrain flexing of back, sortof longitudinal flex of top
  - Most affected by crossgrain stiffness of the back, primarily C-bout area
  - Suspect that corner blocks also add to stiffness that affects this mode

- Transition hill: back vibration is important as well as top; I think of it similar to beam bending modes 2 and 3

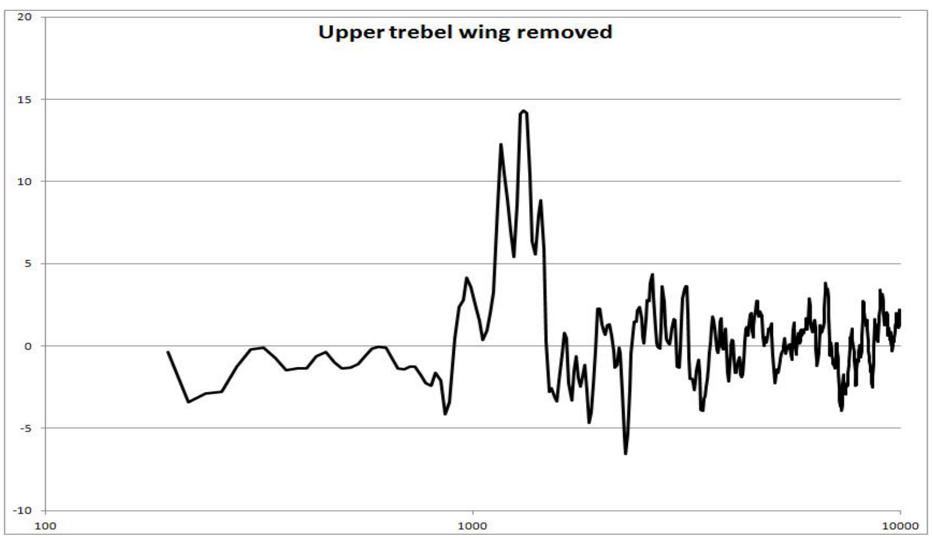


  - Several variations; several peaks
  - Very difficult to make effective modifications… like herding cats
    - And any modifications will affect all other modes to some extent
  - Driven mostly by trebel foot; soundpost drives back plate
  - Strongly influenced by arching
    - Low arch: more/stronger modes… power on E fundamentals
    - High arch: less/weaker modes… “sweeter” sound



987 Hz back vibration mode
Violin #9

- Dip: apparently shaped by F-holes and wings, with upper trebel wing most important
  - A Durup & Jansson paper (2005) showed dip/hill in flat plate created by F-like cuts
    - I repeated the test and found similar effect
  - My analysis of Strad3D animations: highest amplitude of wing vibration is in the "dip" area
  - Effect of cutting off upper trebel wing: increased response in "dip" area (bass wing has much less effect)
    - Conclusion: wing acts as a non-radiating resonator to reduce response



Difference in response after removing wing: Louder… but not a pleasant tone

- Bridge/Body Hill
  - Also referred to as the “clarity and brilliance” zone
  - Opinion: this is the most critical area for determining a great violin
  - Complex/chaotic vibration; numerous modes
  - Minimal technical analysis available
    - Paper by Jim Woodhouse on the influence of the bridge
      - My testing did not show the predicted effects
  - Strad 3D observation: upper bout vibrates most strongly, especially under the fingerboard and around the upper block
    - Confirmed by “mode sniffing”
    - Confirmed by ear: playing music thru driven bridge, high frequency sounds seem to originate mostly in upper bout
  - Hypothesis: graduation treatment at edges and blocks is important
    - Evan Davis at Oberlin showed analysis indicating fixed edges might make for more efficient sound radiation
    - At high frequency, all modes should theoretically have active areas (antinodes) near the fixed edge
  - Hypothesis #2: low damping is important
    - Because I can’t think of any other good reason to account for the fairly large observed differences between instruments
    - Bissinger measured damping and could not show a significant difference between the internal damping of good and bad instruments (not super-accurate measurements)

Random thoughts on vibration

- Net volume change of body during vibration is important for lower frequencies
  - For A0, B1-, B1+, it is all-important
  - For “transition hill”, it is still a factor
  - For higher frequencies, importance drops off
- The violin does not, never did, and never will behave like a speaker cone (therefore do not try to thin out the edges of the plates)
- Building to precise free-plate taptones is an exercise in numerology but not the key to greatness
  - As an approximate guideline, they are effective and convenient in deciding when to stop thinning
  - Too many unaccounted variables are in play, rendering taptones imprecise anyway
  - Great violins have a fairly wide range of taptones; awful violins can have “good” taptones… so the key is elsewhere

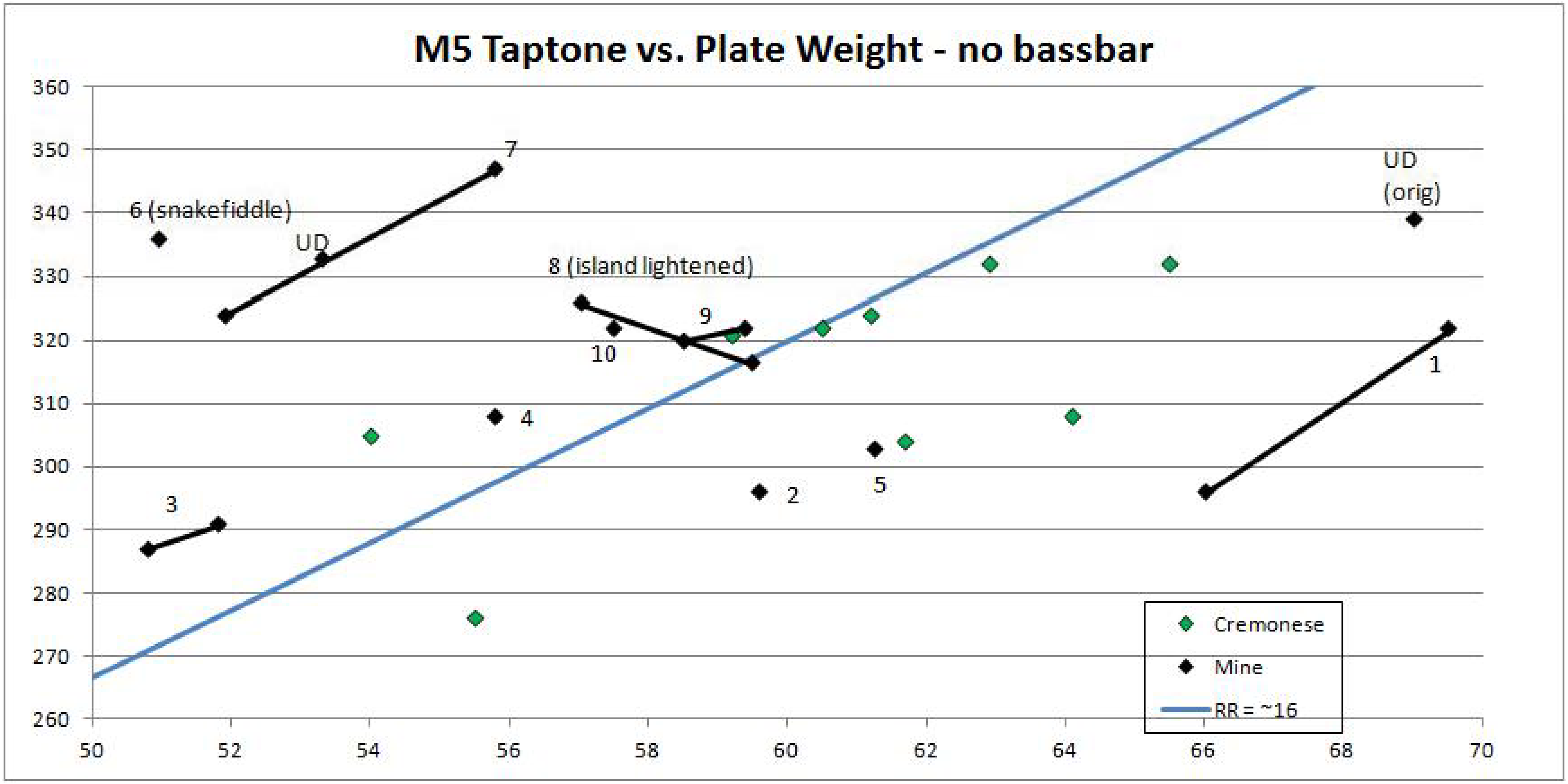
How does someone build a violin using all this information??

- Technology-Assisted Trial and Error
    1. Use “good wood”… or at least know what you’re using
    2. Build something reasonable (Strad poster or similar)
    3. Does the sound match the goal? (Playing and spectrum response)
    4. If not, why? (Decide what frequencies and resonances need changing, use mode shape information to decide what to change in the design of the next instrument)
    5. Build another one
    6. Go back to #3 (and evaluate if the changes were effective or not)
    7. Shortcut: try modifying the existing instrument, if thinning is determined to be the “fix”

Some more specifics on my method

- While I won't give out detailed specs (which are always changing anyway), what I'm building is not far from the Titian or Plowden
- I decide on a plate arching/graduation concept
- Radius template used for the center area of the long arch
- All other arching is freehand (not a recommendation; it's just what I do)
- Graduation to the concept, but left slightly thick
- Smooth graduation transitions; large radius gouge used at edges and blocks
- Thin out using M5 taptone and weight chart (bending stiffness is also measured in an absolute manner, but M5/weight seems more useful and easier)
- Very thin glue used on top, strung up and played/tested unvarnished to see if modifications are needed
  - Adds another learning cycle without a new build
- Re-glue top with stronger glue and finish up
  - (and, often in my case, open it up again later for more diddling)

Latest update to M5/weight map, including before/after modifications



More detail on M5/weight

- Data from Joseph Curtin's taptone article in The Strad used for reference
- "Radiation Ratio" line is an educated guess
  - Slope is based on flat-plate bending; position is based on Curtin estimates
  - Not quite mathematically correct, as arching likely plays a role
  - Graduation pattern can also affect the result
  - Plate data often disagrees significantly from the wood properties measured prior to carving (don't know why)
- No "perfect" value… but 310-330 Hz and 56-62 grams seems to work best
  - Wood properties strongly determine what final values you can achieve
  - Denser wood may not be as powerful, but can still have great tone
- THIS IS A GUIDELINE, NOT A GOAL!!
  - You can thin out the plate in certain ways to get to a specific M5/weight goal… but that's DUMB
  - Keep the graduation concept, just thin evenly and use the chart to help decide when to stop

What is the goal for tone?

- Still learning that one
- Dunnwald first attempted to establish objective measures of good tone
  - Although I agree with them in general, I think that numerical values miss out on the finer points, and there are important qualities that don't show up on the response spectrum

Semi-objective goals

- “Signature modes” (A0, B1-, B1+) around the normal frequencies, no levels too weak or too high
  - For full/round tone on G, D, A
- “Transition hill” as broad and even as possible
  - For even power on the upper A string and lower E string
  - Some great instruments have a spike in this range (Titian)
  - Narrow spikes in the response seem acceptable; broader “mountains” give more audible coloration
  - High relative levels in this range are not desirable, unless you want power at the expense of crude sound
- Bridge/body hill (2kHz-4kHz) as strong and solid as possible
  - Overtones for clarity, brilliance, projection… all the good stuff
  - Extending the hill below 2kHz is good
  - Too much response above ~5kHz can sound harsh
    - But might be fine for a soloist in a large hall, where these high frequencies don’t carry too far

THE REAL GOAL

- Sounds good and plays well in the opinion of the person who will use the instrument
  - Everything else is just a shortcut or tool to help get there