A Computational Investigation of Wood Selection for Acoustic Guitar

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Abstract

The acoustic guitar is a stringed instrument, often made of wood, that transduces vibrational energy of steel strings into coupled vibrations of the wood and acoustic pressure waves in the air. Variations in wood selection and instrument geometry have been shown to affect the timbre of the acoustic guitar. Computational methods were utilized to investigate the impact of material properties on acoustic performance. Sitka spruce was deemed the most suitable wood for guitar soundboards due to its acoustic characteristics, strength, and uniform aesthetic. Mahogany was deemed to be the best wood for the back and sides of the guitar body due to its greater sensitivity to pressure difference, strength, and impedance matching with Sitka spruce.

A Computational Investigation of Wood Selection for Acoustic Guitar

The acoustic guitar and its predecessors can be traced back for millennia, all the way to the lyres of the ancient world. Since then, there have been many iterations of stringed instruments, or chordophones. Chordophones are instruments that use vibrating strings to produce sound. However, the volume of sound from these strings alone is relatively low. Therefore, these strings are attached to materials with desirable vibrational and acoustic properties to amplify their sound. On the modern acoustic guitar, six steel strings are held in tension across an instrument of various woods that resonates with the plucking of the strings. The material properties of the woods used in guitar manufacturing greatly affect the sound of the acoustic guitar.

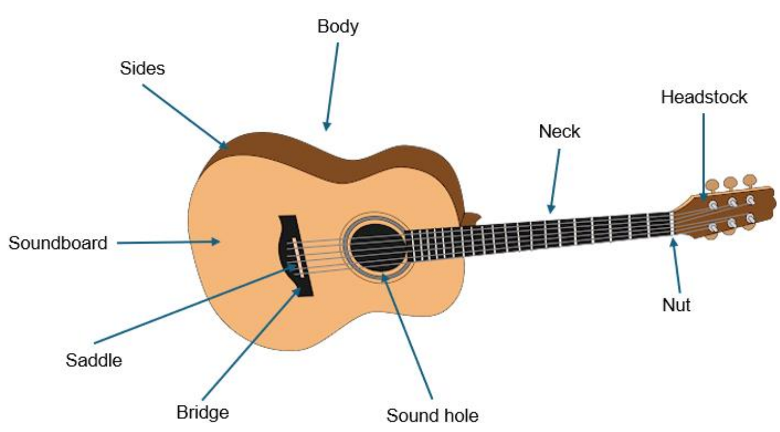
Literature Review

Guitar Terminology

Before an in-depth study of acoustic guitar woods can be conducted, a proper understanding of the construction and functionality of the guitar needs to be established. Figure 1 contains a diagram reviewing the main parts of an acoustic guitar (Open Clip Art Library, 2014).

Figure 1

Guitar Part Terminology Diagram



The flow of energy through the instrument can be examined by tracing the interactions of materials. The energy input into the system is from the player to the strings. The vibrating portion of the string stretches from the nut at the top of the guitar to the saddle in the middle of the large wooden soundboard. The string is then anchored beyond these points at the headstock and bridge, respectively. As the first transmitters of vibration, the nut and the saddle are made from hard, strong materials like bone or synthetic plastics. At the base of the guitar, the saddle is embedded in a small wooden piece called the bridge. The bridge is typically made of a hardwood that can carry on the vibration to the main acoustic chamber of the guitar: the body. The body of the guitar contains the soundboard (or top), back, and sides. This portion of the guitar is what is mainly responsible for its tone. The vibration of the strings and the wood produce pressure waves that resonate in the guitar body and project sound outward through the sound hole (Ray et al., 2021). The wood used for the soundboard must therefore be carefully chosen to allow for an efficient transfer of vibrational energy while also maintaining structural integrity of the instrument.

Desirable Characteristics of Guitar Timbre

The difficulty regarding a guitar’s timbre, or distinctive sound, is that there is no scientific “best” sound. Human perception of tone is a complex problem that starts with the transduction of vibrational energy to acoustic pressure waves and then enters the realm of psychoacoustics and neuroscience as those pressure waves are transduced by the ear into electrical impulses for the brain to process. One ethnomusicologist described this complex system as a “paradox of timbre” considering how the timbre of an instrument can be quantified quite well by scientific means, yet the human perception of it varies greatly (Fales, 2018). The timbre of an instrument boils down to the quantities of pitch, loudness, and duration. For example, when one plays the A string on a guitar, the fundamental note vibrates at 110 Hz. Additionally, this fundamental vibrational mode produces additional harmonics at integer multiples of this frequency (220 Hz, 330 Hz, 440 Hz, etc.). The relative amplitudes of these harmonics, or *overtones*, represent the timbre of an instrument. The concept of timbre explains why singing a pitch of 110 Hz and playing a pitch of 110 Hz on a guitar sound radically different, even though they have the same fundamental frequency. A guitar sounds like a guitar because the brain has grown accustomed to that pattern of relative amplitudes of overtones, i.e. its timbre. Instruments with different timbres playing the same melody have been shown to affect the emotions differently (Hailstone et al., 2009). Researchers theorized that the brain associates musical timbre with emotion due to the sharing of acoustic characteristics with the human voice (Juslin & Laukka, 2003). The brain processes vocal timbre in order to ascertain the feelings of the speaker. This same process happens with timbre for musical instruments. This means that timbre variations within an instrument can affect the listener differently.

Even with the timbre of a guitar being just waves of differing frequencies and amplitudes, there seems to be a general consensus (among musicians *and* non-musicians) of what is a “good” tone for the instrument. Adjectives describing musical sounds can be somewhat subjective, but there are a few that seem to be widely accepted as good qualities for guitar tone.

Loudness

Loudness is one of the most important aspects of an acoustic guitar. The greater volume that an acoustic guitar can output differentiates it from an electric guitar, which outputs very little acoustic sound without electronic amplification. Loudness for chordophones has come a long way throughout history. The earliest instruments used animal intestines (referred to as “gut strings”) for their instruments. It was not until the early 1900s that C.F. Martin & Company produced steel strings and made the instrument a lot louder than its predecessors (de Ste. Croix, 2014). Steel's material properties allow it to produce a much louder and brighter sound than the gut strings. The term "brighter" is used to classify steel's ability to produce high-frequency content at sufficient amplitude. While string evolution is an important factor that changed guitar loudness, experimentation with different woods and geometries also helps to increase loudness. Guitar soundboards are only about 1.5-3 mm thick, which allows them to be thin enough to vibrate well, yet thick enough to support the tension of the strings. These soundboards also contain a cutout called a sound hole that allows the resonance of the guitar body to be projected out into the air in front of the instrument. Loudness is important for the guitar as it characterizes its ability to resonate with string vibrations.

Homogeneity

While general loudness is an important factor, a certain level of amplitude needs to be present in all frequency ranges. This is the concept of homogeneity: a consistent natural amplification across the frequency spectrum. The frequency spectrum is often divided into lows (bass), mids, and highs (treble). Guitar companies will often market their products as having a "clear, balanced tone," which speaks to their homogeneity. One study of the frequency response of guitars deemed "good" vs. those deemed "bad" found that the good guitars had enhanced resonance at the fundamental frequency of the guitar as well as strong upper harmonics. Bad guitars in this study exhibited significant damping of certain frequencies and were not as resonant across the frequency spectrum (Šali & Kopač, 2000). Therefore, the wood for a guitar must be chosen to produce ample loudness of the fundamental as well as overtones that are not sufficiently damped.

Mechanical Properties

While the analysis of vibrational wave propagation through a material is complex, the relative efficiency of a material is generally a function of just a few parameters. One of these parameters is the Young's modulus, E. The Young's modulus (or Modulus of Elasticity) for a material is a measure of its stiffness. Equation 1 showcases the formula for Young's modulus (Callister, 1997).

$$E = \frac{\sigma}{\varepsilon} \tag{1}$$

The numerator, σ, represents the stress in the material, which is equal to the force per unit area of that material. The denominator, ε, is the strain of the material, which is a measure of the length that the material deforms relative to its original length. Another mechanical property of a material that dictates its behavior under vibrations is its density, ρ, which is a measure of mass per unit volume. A third characteristic used for analysis of a material's characteristics is its yield strength, σ_y. Yield strength is the stress at which a material no longer behaves elastically. As a material is loaded with a force, the stress and strain increase linearly with the slope being the Young's modulus (Huang et al., 2020). After a certain level, the material no longer exhibits this linear relationship. Materials after this point will undergo plastic deformation where the strain of the material outpaces the stress that it is being loaded with. After a certain point, the material will fracture (Budynas & Nisbett, 2021). Yield strength for guitar woods needs to be high enough to ensure that no noticeable plastic deformation occurs in the wood when it is held in tension by the strings.

Vibrational Modes

Any object in 3-dimensional space can move along or rotate about each of the 3 distinct axes, constituting 6 degrees of freedom. This also applies on the molecular level to atoms and compounds that make up materials. Atoms are constantly vibrating on their own, but atoms in a solid can be made to vibrate in a coupled manner with an input signal. In a guitar, the soundboard will vibrate in accordance with the pitches of the strings that are being played. Soundboards (and all other objects) have a natural resonant frequency, as well as other frequencies, or modes, at which they vibrate well. These vibrational modes are distinct frequencies that will make the material vibrate, based on its mechanical properties (Kraka et al., 2022). Researchers have identified two primary natural frequencies of the guitar: one corresponding to the air moving through the sound hole and another corresponding to the natural frequency of the soundboard. The frequency of air naturally moving through the sound hole is called the Helmholtz frequency and is often in the range of 90-130 Hz (Caldersmith & Rossing, 2010). The phenomenon of Helmholtz frequency can be experienced as one blows air across the opening of a glass bottle to produce a pitch. The soundboard's fundamental frequency is typically in the range of 170-250 Hz (Hess, 2013). This is a solid material property that does not depend on air moving around the material. This fundamental mode corresponds with a mode shape in which the antinode lies near the bridge of the guitar. Mode shape and frequency have been shown to vary with guitar geometry due to the dependence of vibrational modes on atomic structure and material properties (Russell et al., 2003). Additionally, even guitars that are nominally identical have been shown to produce different modes due to variations in wood processing and instrument manufacturing (Paté et al., 2015).

While previous research has covered fundamental frequency and frequency response, each study was typically only done for one or two different variations of wood type and instrument geometry. The purpose of this research is to compare a greater number of variations in guitar construction without the need for manufacturing a new instrument each time. By verifying simulation data with previous research that suggests a fundamental soundboard mode of 170-250 Hz, this thesis seeks to create a methodology for comparing multiple guitar woods using simulation software (Hess, 2013). The scope of this thesis is limited to wood selection for the guitar body, but the methodology could be expanded in the future to investigate soundboard thickness, moisture content, bracing structure, etc.

Mathematical coding software (MATLAB) will be used to calculate and plot acoustic indices that represent how a material performs. Simulation software (ANSYS Modal) will be used to extract the vibrational modes that each wood vibrates well at. This software will output the frequency of each mode along with parameters such as participation factor and its square, effective mass. These parameters represent how much of the material is excited by each frequency. Some frequencies excite a large response in the material in a way that moves much of the material’s mass and therefore the surrounding air. Other vibrational frequencies may operate in a manner that does not move as much of the material. Wood types that exhibit beneficial acoustic characteristics while also being sufficiently strong, easy to manufacture, and aesthetically pleasing will be the best types of wood to use in guitar manufacturing.

Method

Data Input into MATLAB

While there are many different species of wood, only a certain handful are used for guitar bodies. Common woods used for this part of the guitar were chosen across a range of densities and Young’s moduli. The five woods selected for comparison are pine, cedar, poplar, Sitka spruce, and mahogany. Mechanical properties of these wood types are shown in Table 1 (Meier, 2023).

Table 1

Mechanical Properties of Common Woods Used for Guitar Bodies

	Pine	Cedar	Poplar	Sitka Spruce	Mahogany
Density [kg/m^3]	350	370	420	425	600
Young's Modulus [GPa]	8.50	7.70	10.9	10.8	9.31
Yield Strength [MPa]	45	52	70	70	74

The values from Table 1 were inputted into MATLAB, a mathematical coding software. The mechanical properties for each material were input into an array for each property with indices corresponding to the order that they are listed in Table 1. A string array of wood names was also created to allow for consistent indexing and labeling when plotting the results of the computational study.

Measures of Acoustic Performance

Speed of Sound

The speed at which sound propagates through a solid medium is determined by its Young’s modulus and density, as shown in Equation 2 (Wegst, 2006). From the arrays of material properties in MATLAB, values for the speed of sound in each material were calculated and plotted.

$$c = \sqrt{\frac{E}{\rho}} \tag{2}$$

Acoustic Conversion Efficiency

Acoustic Conversion Efficiency (ACE) is a measure of how well a material converts vibrational energy within the material to acoustic pressure waves in the air surrounding the material. Woods with a high ACE are ideal for guitar soundboards as they convert string vibrations to sound pressure well, resulting in a louder tone from the instrument. An ACE factor for each material was computed and plotted in MATLAB using Equation 3 (Zoric & Kaljun, 2018).

$$ACE = \sqrt{\frac{E}{\rho^3}} \quad (3)$$

Sensitivity to Pressure Difference

Sensitivity to Pressure Difference (SPD) is a measure that indicates how well a material resonates with a pressure difference in the air. While ACE indicates how the vibrations of the material are translated to the air, SPD is a measurement of how sound waves in the air produce vibrations in the material. Woods with high SPD values will be ideal for the back and sides of the guitar as these parts respond well to the sound pressure waves created by the vibration of the soundboard. The calculation for SPD involves a material's yield strength and Young's modulus, as shown in Equation 4 (Cotton, 2021). Values of SPD for each wood were compiled and graphed in MATLAB.

$$SPD = \frac{\sqrt{{\sigma_y}^3}}{E} \quad (4)$$

Acoustic Impedance

Acoustic impedance, Z, is a useful measure that determines energy transfer at a boundary between materials. In electrical circuit analysis, electrical impedance is an accumulation of all the measures that inhibit the flow of electrons. This includes dissipative, inertial, and capacitive energy losses. In the electrical domain, dissipative losses output heat on the surroundings, inertial losses produce a magnetic field, and capacitive losses produce an electric field. While not identical, this understanding of impedance can be transposed to the acoustic domain to represent how the initial vibrational energy is converted into other forms of energy (Wolfe, 2012).

Impedance also governs the interaction between two materials transferring energy. The concept of impedance matching is important in understanding energy transfer from one material to another. If two materials have vastly different impedances, the energy will mostly be reflected at the boundary layer instead of transferred from one material to the next. A demonstration of this concept would be to hold a shoelace at one end and attach a thick rope to the other end. Oscillating one end of the shoelace produces a wave that propagates throughout the length of the material. This wave reaches the interface between the two materials and largely gets reflected back to the shoelace while passing minimal energy on to the rope. These materials have impedances that are not close to each other and therefore do not transfer energy well. On the contrary, if another shoelace were attached to the original one, the materials would have the same impedance and the wave would propagate along the full length of both materials. The concepts of impedance and impedance matching are important to understand in guitar manufacturing because there are many interfaces between different materials. The equation for acoustic impedance is shown in Equation 5 (Wegst, 2006). Values for acoustic impedance of each wood type were computed and plotted in MATLAB.

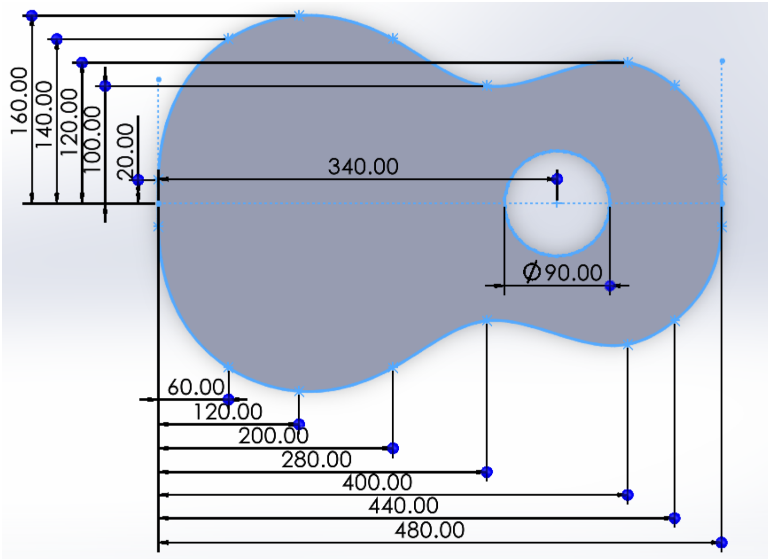
$$z = \sqrt{E\rho} \tag{5}$$

ANSYS Modal Analysis

The material properties for each of the 5 woods were entered into ANSYS, a simulation software. These properties consisted of density, Young’s modulus, and Poisson’s ratio. The geometry of a guitar soundboard (Fig. 2) was modeled in SolidWorks and then put into ANSYS for meshing. A 2 mm mesh size was applied to all the faces of the material, as shown in Figure 3. A fixed boundary condition was applied to the sides of the soundboard, as this is where it would mount to the sides of the instrument and be held in place. A Modal analysis was done to extract the maximum amount of vibrational modes within the human hearing range of 20-20,000 Hz.

Figure 2

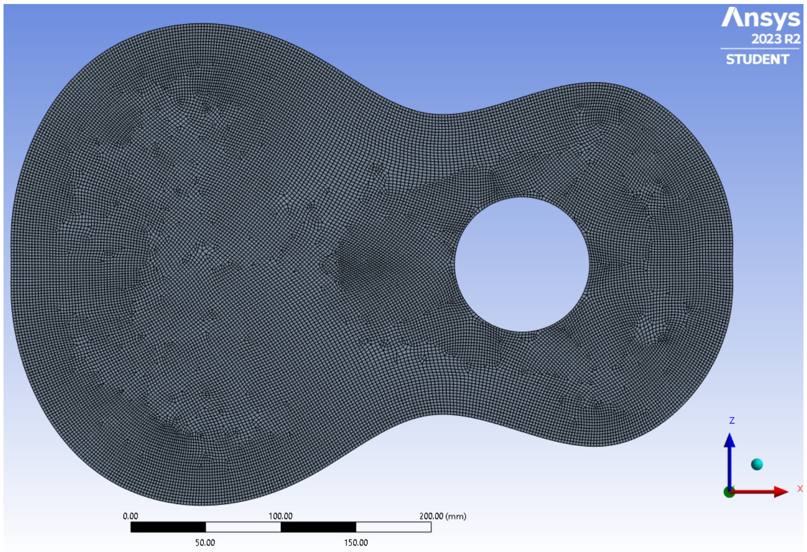
Guitar Soundboard Dimensions in Millimeters for Simulation Model (in X-Z plane)



Note. Thickness of the soundboard is 2.5 mm.

Figure 3

Mesh of Guitar Soundboard in ANSYS With a 2 mm Mesh Size



Results

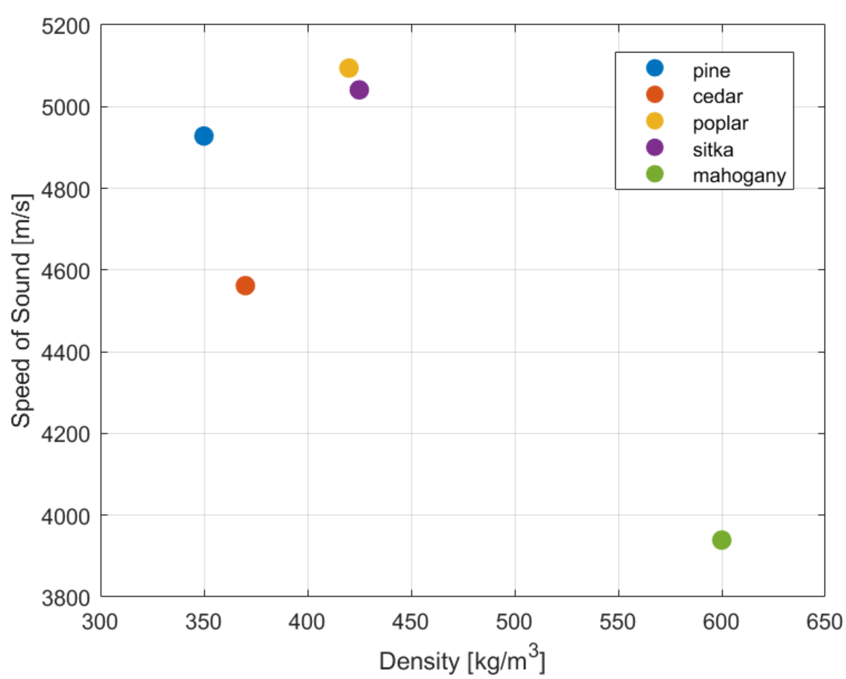
First, the results from the comparison of acoustic indices in MATLAB are presented, followed by the results from the ANSYS Modal analysis.

Speed of Sound

The speed at which sound travels through each type of wood is plotted in Figure 4. Overall, there is a negative linear trend compared to density, with some variation in the middle.

Figure 4

Speed of Sound vs. Density for 5 Wood Types



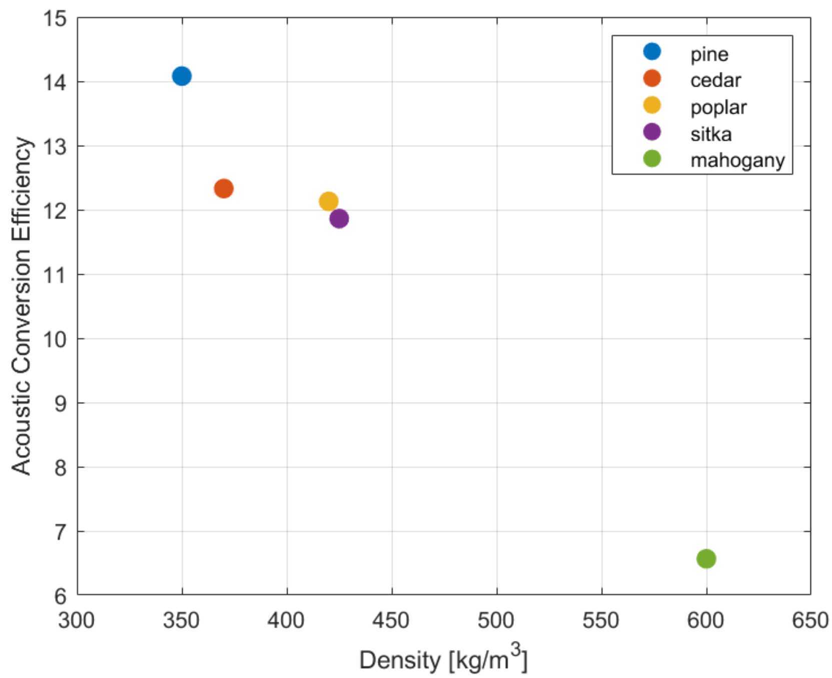
The wood with the highest speed of sound was poplar, with a propagation speed of 5094 m/s. Closely behind was Sitka spruce, with a value of 5041 m/s. The wood with the slowest speed of sound was mahogany at 3939 m/s. The values for pine and cedar fell between the two extremes and leaned closer to the higher end of the spectrum. Compared to poplar, mahogany exhibited a 22.7% slower speed of sound for vibrational waves.

Acoustic Conversion Efficiency

The plotted results for Acoustic Conversion Efficiency showcase a negative linear trend with density, as showcased in Figure 5. This is due to the ACE equation's greater emphasis on density.

Figure 5

Acoustic Conversion Efficiency vs. Density for 5 Wood Types



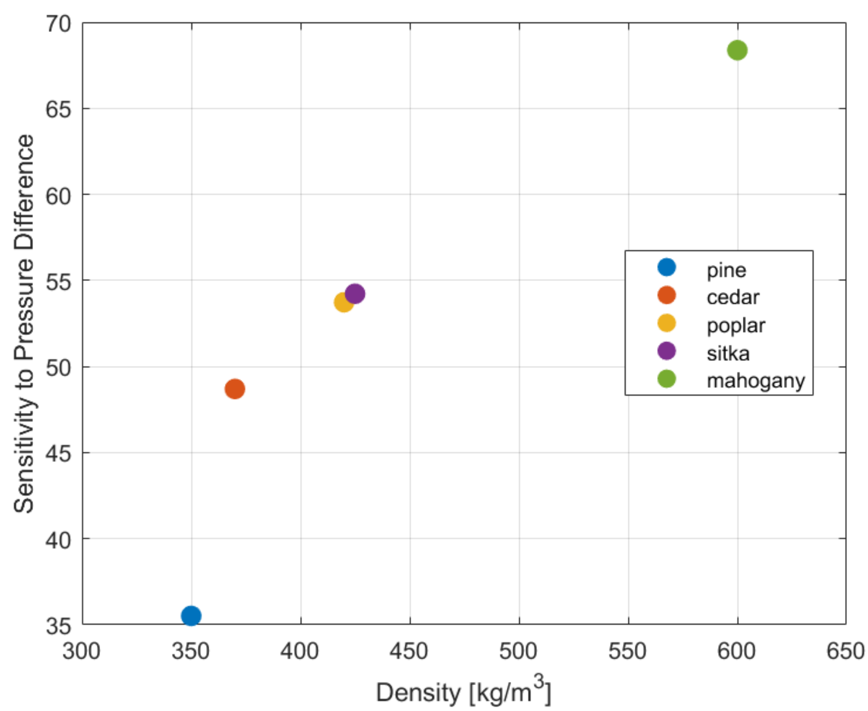
Due to Acoustic Conversion Efficiency being a unitless index, the numerical values do not have any real-world significance. However, their relative values can be compared. Pine had the highest efficiency of the group, with mahogany having the lowest. The values for cedar, poplar, and Sitka spruce all fell near each other in the upper range of values. Poplar and Sitka spruce fell near each other once again due to their similar densities and Young's moduli. Relative to pine, mahogany had a 53.4% lower Acoustic Conversion Efficiency.

Sensitivity to Pressure Difference

The Sensitivity to Pressure Difference showcases a material's ability to vibrate as a result of air pressure waves impacting it. The SPD values for each wood are shown in Figure 6.

Figure 6

Sensitivity to Pressure Difference vs. Density for 5 Wood Types



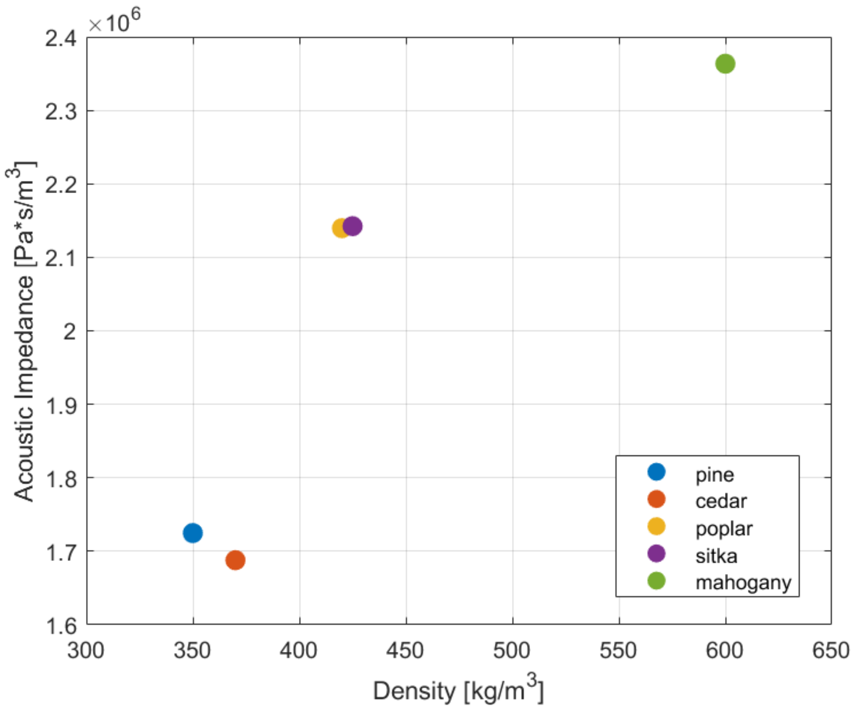
While the other charts showed a general negative trend with density, the SPD plot shows a positive trend. Mahogany ranked the highest, while pine had the lowest sensitivity. The middle values of poplar and Sitka spruce were once again highly correlated. These two woods also fell more closely to the mean value for SPD and were not as biased towards the lowest density value of pine as in the previous plots. Compared to the highest value of mahogany, pine showed a 48.1% lower Sensitivity to Pressure Difference.

Acoustic Impedance

Acoustic impedance characterizes a material's ability to transduce vibrational energy to other forms of energy. The computed acoustic impedance values for the 5 woods are shown in Figure 7.

Figure 7

Acoustic Impedance vs. Density for 5 Wood Types



Mahogany displayed the highest acoustic impedance while cedar had the lowest. The values for poplar and Sitka spruce were once again closely related. Pine and cedar also had very close acoustic impedances. Compared to the highest value of mahogany, cedar had an acoustic impedance that was 28.6% less.

ANSYS Modal Results

The ANSYS Modal analysis produced values for the frequency of each mode, as well as participation factor and effective mass in all 6 directions of motion. The specific direction of note for the purposes of this analysis is the Y-direction. This is because the X-Z plane contains the large area of the soundboard which will therefore produce the greatest pressure waves when oscillating in the Y-direction. The ratio of the sum of effective mass for all modes to the total mass of the soundboard was 0.91 or higher for each of the woods. This indicates that the sum of all these vibrational modes accounts for 91% of the material's mass movement in the Y-direction. The most influential modes are the ones that account for the most movement of material in the Y-direction. From the ANSYS results, the most influential modes were mode 1 (the fundamental) and mode 3. These modes accounted for about 42% and 12%, respectively, of the mass movement in the Y-direction. This mode 1 fundamental represents the natural frequency of the soundboard and is on par with literature values that place it in the realm of 170-250 Hz (Hess, 2013). The Helmholtz frequency that represents airflow through the sound hole is not present in this ANSYS Modal analysis due to it being purely a solid analysis without the inclusion of a fluid, like air. A summary of the frequencies and effective mass ratios for the two most influential modes is shown in Table 2.

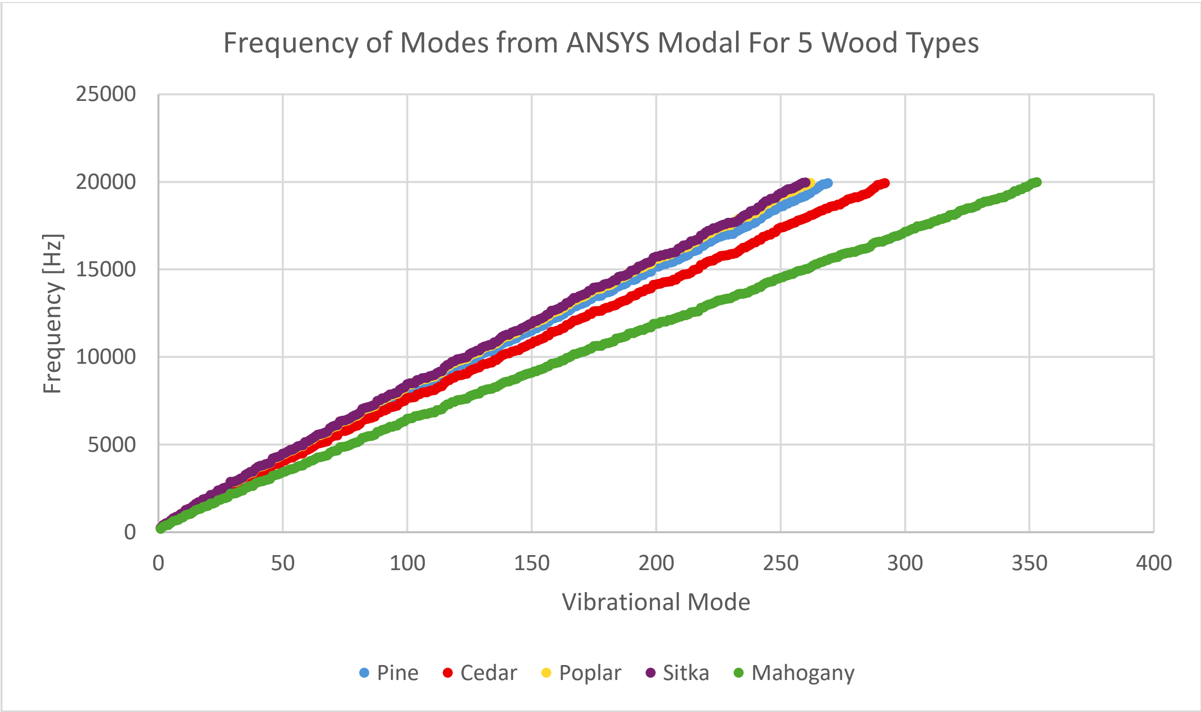
Table 2

Frequency and Effective Mass Ratio of the Most Influential Modes for 5 Wood Types

	Pine	Cedar	Poplar	Sitka	Mahogany
Mode 1 Frequency [Hz]	238.34	224.42	244.64	247.33	188.89
Mode 1 Effective Mass Ratio	0.4227	0.4225	0.4228	0.4225	0.4228
Mode 3 Frequency [Hz]	487.66	455.48	502.33	502.60	388.14
Mode 3 Effective Mass Ratio	0.1211	0.1186	0.1222	0.1190	0.1224

Mahogany exhibited the lowest natural frequency at 188.89 Hz while the Sitka spruce soundboard had the highest natural frequency of 247.33 Hz. A similar trend in relative frequency follows for mode 3, the next most influential mode in terms of effective mass ratio. The solution in ANSYS Modal was set up for the solver engine to calculate any vibrational modes within the frequency range of human hearing, 20 Hz to 20 kHz, and a plot of the complete results of all the modes are shown in Figure 8.

Figure 8



The largest number of modes were calculated for mahogany, due to its fundamental being significantly lower than the others. The modes of Sitka and poplar were highly correlated, with pine also showing close adherence to those two woods.

Discussion

Interpretation of Plots

The speed of sound plot from MATLAB demonstrates how fast vibrational waves travel through each material. This is analogous to how light gets refracted as it slows down in materials like glass or water. Changing the speed of a wave alters the way that it is perceived by the observer. Additionally, the speed of sound in a medium decreases with the moisture content of the material. This is because the speed of sound in water is roughly 1500 m/s while these woods exhibited speeds in the range of 4000-5000 m/s (Cutnell & Johnson, 1997). Therefore, having higher water content in wood will reduce the speed of sound and the energy transfer of vibrations. Guitar makers, or luthiers, tend to use wood with lower moisture content and therefore a higher speed of sound for the top of a guitar. On an atomic level, dry wood contains atoms that are tightly packed together and vibrating in sync with each other. Pure water has molecules that vibrate more independently of each other as they are not packed in a tight grid. A mixture of wood and water will deteriorate the sustain and loudness of the instrument as vibrational energy is being discharged to liquid molecules that do not transduce vibrations as well as solid molecules. Poplar, Sitka spruce, and pine all exhibited high speeds of sound which make them beneficial for use on guitar soundboards.

Acoustic Conversion Efficiency (ACE) represents a material’s ability to translate internal vibrations to acoustic air pressure waves. Woods that exhibit a high ACE will be desirable for the soundboard of the guitar, as this is where small vibrations from the strings are amplified into the air. Soundboards have a large surface area compared to other guitar elements because they are trying to displace as much air as possible. Pine, cedar, poplar, and Sitka spruce all have good Acoustic Conversion Efficiency. These 4 materials are able to produce sufficient amplification of the string vibrations while mahogany would not be able to produce as loud of a sound.

Sensitivity to Pressure Difference (SPD) follows the inverse trend of Acoustic Conversion Efficiency. SPD showcases the ability of atoms in a solid material to be vibrationally excited from air pressure waves. Materials with high SPD will be able to resonate well with incoming pressure waves. This is a good characteristic for wood to be used on the back and sides of the guitar. The vibrations from the string are transduced from the bridge of the guitar to the soundboard, where the soundboard amplifies the frequencies through coupled vibration. This coupled vibration produces air pressure waves that propagate out from the soundboard. The wood on the back and sides of the guitar will experience some vibration through the travel of waves through the material, but the larger effect will be from the pressure waves in the air created by the soundboard. Wood used for the back and sides must be able to intake these pressure waves and vibrate in sync with minimal energy losses. Woods with high SPD exhibit this characteristic, and that is why mahogany is often a top choice for the back and sides of a guitar body. While mahogany may fall short in characteristics that make a great soundboard, its properties align well for it to be used on the back and sides of the guitar.

Acoustic impedance (Z) is of great concern when designing a guitar. Not only do the individual values of Z matter, but also the relative values of Z at energy transfer junctions of the instrument. Materials with a high Z value convert the vibrational energy well to other forms. These other forms include dissipative energy losses that are passed on to the air in the form of pressure waves. Impedance also includes inertial effects of the wood's mass vibrating. Mahogany, poplar, and Sitka spruce all have relatively high acoustic impedances. In regard to impedance matching, it is best to join materials that have similar impedances. For example, a guitar top from Sitka spruce that has a back and sides made from mahogany will result in a generally good conversion of energy at the boundary due to their similar impedances. On the contrary, if the top was made from cedar, there would be a greater imbalance in impedances, and more of the incident vibrational waves would get reflected at the interface instead of penetrating into the next material.

From the ANSYS Modal analysis, distinctions are shown with how each wood represents frequency ranges relative to each other. Woods like Sitka spruce, poplar, and pine have very similar vibrational modes. Cedar's fundamental mode was a little lower in pitch than the three aforementioned woods. Mahogany's fundamental and second-most influential overtones were significantly lower than all other woods. These results indicate that cedar and mahogany tend to accentuate lower frequencies and attenuate higher frequencies. When these woods are used for guitar soundboards, it can lead to a tone that lacks some clarity in the high end compared to other woods. When woods like Sitka spruce, poplar, and pine are used, the guitar will represent high frequencies better and have a brighter sound.

From the MATLAB and ANSYS analyses, it would suggest that poplar and Sitka spruce would be the best materials for use on the guitar's soundboard as they had beneficial values in the majority of measures of acoustic performance. Additionally, the data from the MATLAB computations suggest that mahogany would be the best material for the back and sides of the guitar due to its high Sensitivity to Pressure Difference as well as its close impedance matching with poplar, and Sitka spruce.

Further Considerations

Personal Preference

While music can be examined through a mathematical lens, the reality is that music is much more complicated than that. The average consumer is not thinking about Acoustic Conversion Efficiency when they go to buy a guitar at the local music store. They merely just play a bunch of guitars and pick the one that sounds the best within their price range. The definition of "best" however differs from person to person. While one guitarist may like a guitar that is super loud so that they can be heard, another player might like a more subdued tone. This may cause someone to opt for a guitar with a cedar top, which did not score super high across all the acoustic performance measures. This simply means that the guitar did not convert energy as efficiently. However, the resulting tone of this could be something that a player desires. Cedar is often described as a "warm" tone. Since low-frequency waves have more energy, cedar can convert them sufficiently to acoustic pressure waves. However, the high-frequency waves that have less energy are more affected by energy losses in cedar and are not heard as much. This results in a skew of homogeneity that some may find desirable depending on their tastes.

Another important consideration is price. Certain woods are more expensive than others due to their scarcity and/or sound. Mahogany is a great acoustic wood in the right context, but a guitar with a mahogany back and sides might be out of somebody’s price range. On the cheaper end of the spectrum though, some consumers may not be willing to get past the loss of tonality incurred by crafting an instrument with more economic woods and manufacturing techniques. A lot of cheaper models will use a laminate of thin layers of wood instead of solid pieces. This negatively affects the sound as it dampens vibrations in the system. Laminated wood will have grain lines that run parallel to the thickness of the piece. Solid wood tops will have grains that run perpendicular to the wood thickness (*Choosing an acoustic guitar.* 2024).

These considerations show that choosing a guitar is not just a mathematical or scientific problem, but also an economic one. This economic challenge can also be viewed from the guitar manufacturer’s perspective. Higher quality tonewoods are often scarce and have to be harvested at the right time and maybe even transported between continents. Hawaiian Koa is an example of a tonewood used in chordophones like guitars and ukuleles. Koa is a rare wood that is often only found in more expensive models. Koa was not examined in this analysis, but it has similar mechanical and acoustic properties to mahogany.

Material Strength

Another important consideration in guitar manufacturing is that the instrument needs to support a great deal of force. Therefore, the guitar must be designed to utilize materials that can sufficiently handle these forces. Pine exhibited some good acoustic performance characteristics in this study, but its softness often leads manufacturers to stay away from it. Not only would it have poor structural integrity in holding the strings in tension, but it may also get dinged-up easily. Guitars need to be strong and durable to sustain the normal wear and tear of regular playing. The mechanical and acoustic properties of pine do not lead to it being a top choice among guitar manufacturers. Different woods can be used for different instruments, but some just do not exhibit a good cross between mechanical and acoustic performance. By plotting characteristics of different wood types, researchers have found certain correlations between mechanical properties of each wood and the types of instruments those woods are suited for (Wegst, 2006). For example, woods that have low densities and high speeds of sound are good candidates for guitar soundboards. Woods with higher densities but lower speeds of sound may not be as well suited for soundboards, but make good candidates for other instruments, such as the wooden bars of a xylophone. Balsa wood is a material with a high speed of sound, but its low density and strength lead it to not being used in instrument manufacturing.

Material Finish

The guitar is not merely a musical art piece, it is also a visual art piece. Guitar players want an instrument that looks as good as it sounds. This is why it is important to understand the aesthetic properties of these materials. Sitka spruce is probably the most recognized guitar top. It has a light tone that holds its hue with finishing. It also has a tight grain pattern and minimal burls or nots, which produce a clean surface, as shown in Figure 9.

Figure 9

Sitka Spruce Top on a Yamaha Guitar

Poplar on the other hand does not have the same finish. While it exhibits similar mechanical and acoustic properties to Sitka spruce, poplar lacks the same aesthetic appeal. Poplar does not have the same clean, tight grain pattern that Sitka spruce has. Poplar also tends to have more knots and burls in it, affecting its appearance and uniformity. This may be desirable for someone based on personal preference, but from a guitar maker's perspective, it is hard to get all instruments to look and perform the same when using poplar due to its inconsistency.

Sonic Trends & Psychology

Human decisions are not only dictated by their personal preference; they are also dictated by the opinions of the general public. Societal trends have been experimentally proven to alter people's behavior (Wagner & Gooding, 1987). Certain trends in the music world will serve to alter the definition of desired guitar tone in the consumer's brain. One example is the surge in popularity of the rubber bridge guitar, created by Rueben Cox (Menasche, 2023). The rubber bridge guitar utilizes a piece of rubber across the saddle and bridge, where the strings interface with the instrument. Typically, a bone nut is used as the saddle with a hardwood on the bridge to transfer the most amount of energy to the soundboard. However, with the rubber, a lot of that energy is lost and produces a quieter sound with less high frequencies. This muted sound has become very popular with artists like Taylor Swift, Olivia Rodrigo, and Phoebe Bridgers using it on their records. This is an example of a societal trend overtaking the scientific definition of ideal guitar tone. With the case of a rubber bridge guitar, musicians are willing to sacrifice efficient energy conversion to achieve a sound that is unique and inspires creativity within them.

Conclusion

The guitar is a complex instrument made of various materials that all transfer energy between each other. Through a computational analysis of the mechanical properties of each wood type, the acoustic performance of the woods can be examined. Furthermore, the interactions between these woods can be evaluated to determine the best combinations of woods to use in a guitar body. Due to its excellent acoustic characteristics and consistent, clean aesthetics, Sitka spruce seems to be the best choice for the soundboard of an acoustic guitar. For the back and sides of the instrument, mahogany would be the best choice for its ability to resonate and sustain tones. If one is looking for a wood with similar acoustic properties to Sitka spruce and is not worried about the aesthetic, poplar may be a good option for a guitar top. This research serves to create a computational method for comparing guitar parameters in order to more efficiently provide data to those who are looking to fabricate or purchase a guitar with certain acoustic characteristics. Despite this highly analytical framework, it can be seen that music is not mere fact but rather an amalgamation of engineering, psychology, and aesthetics, which all serve to amplify the beauty of the art.

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