Why the Ukulele Sounds Happy

Physics 406 Spring 2016

University of Illinois at Urbana-Champaign

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Abstract

The goal of our project was to understand more about ukuleles and why they seem to sound happy. We played and recorded different musical notes on the ukulele and compared them to notes on a classical guitar. We analyzed the notes using a MATLab wave analysis program provided by the professor. The professor also did modal analysis on the ukulele over the weekend. Our report will go over background, the experiment, our data, and graphs. We conclude that the distinct happy and sweet sound the ukulele makes is due to the presence of higher harmonics which are a result of the shape of the ukulele and its material composition.

Introduction / Background

Taken from Lecture Notes "Tone Quality - Timbre"

A pure note has one distinct frequency, whereas a complex note is a superposition of notes that have different frequencies, phases, and amplitudes. A complex note played on a stringed instrument will have a dominant frequency called the fundamental frequency. Other notes heard in the complex note will be integers multiples of the fundamental frequency are are called harmonics. Most notes produced by musical instruments, including stringed instruments like the ukulele and classical guitar, are complex notes. Using Fourier analysis, the complex tone can be broken down into its component waveforms and by analyzing the properties of the different harmonics, a person can analytically understand the properties of musical notes and how they constructively and destructively interfere with each other and why the same note played by different instruments can still sound very different. Notes that do not have a strong presence of higher harmonics are thought to sound more 'mellow,' while notes that have higher harmonics have a 'bright' sound.

The harmonic composition of a tone is related the specific instrument. Differences in the material or dimensions of the instrument result in changes to the harmonics. The musician playing the instrument can also influence the harmonics in the way they play the specific note.

Specifically for stringed instruments, the farther the string is plucked from the center, the higher the harmonic content. Steel strings also produce notably higher harmonics than those of nylon. Another stringed instrument property that contributes to the harmonics is the sound hole and cavity. The note produced by plucking the string enters the sound cavity which has certain resonances. Certain note harmonics will resonant with the sound cavity and be amplified, giving the overall note composition a different harmonic content than without the sound cavity.

Experimental Setup and Apparatus

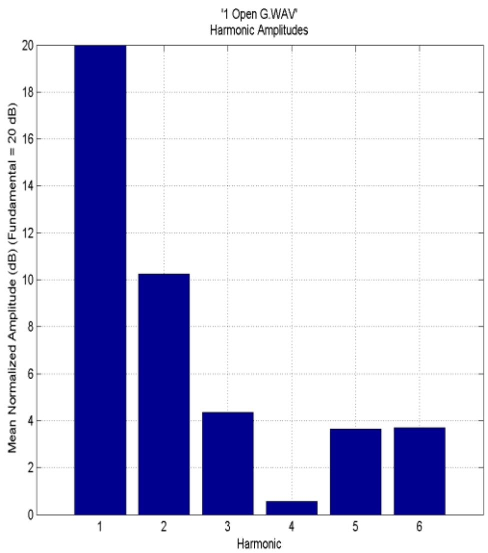
We used a Lanikai Soprano Ukulele and a Yamaha Classical Guitar Model CG-150SA. We started off by recording several different ukulele notes.The ukulele has four strings that when in tune and played open, without any fingers touching the strings, correspond to the notes A, E, C, and G. Additional notes were played and recorded by the ukulele by shorting the strings wavelength by pressing a string against the fret on the backboard. When recording the notes, the strings were plucked by thumb and were plucked over the sound hole.

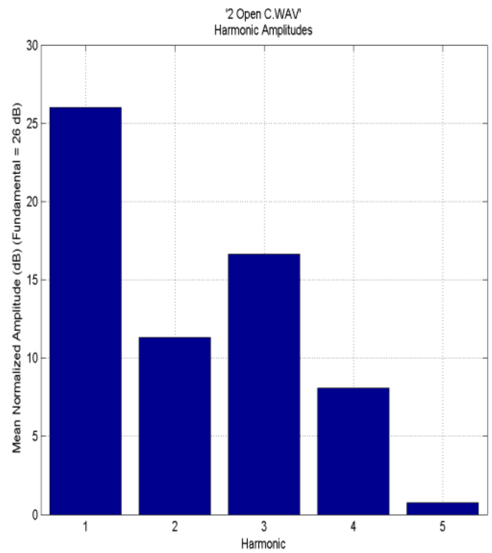
The professor performed modal analysis of the ukulele over a weekend. The purpose of this analysis was to understand the how the instrument reacts to different frequencies. The experiment had to be done over the weekend because it was analyzing how the instrument reacts to vibrations and during a normal class period there would be a lot of disruptive vibrations. The ukulele was suspended by bands so that it could vibrate freely without disturbance from outside sources. Various frequencies were provided as input to the ukulele at certain points and the output was measured at different points.

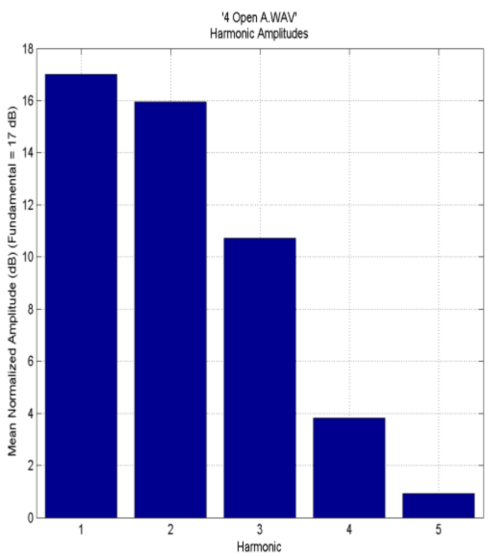
Data & Graphs

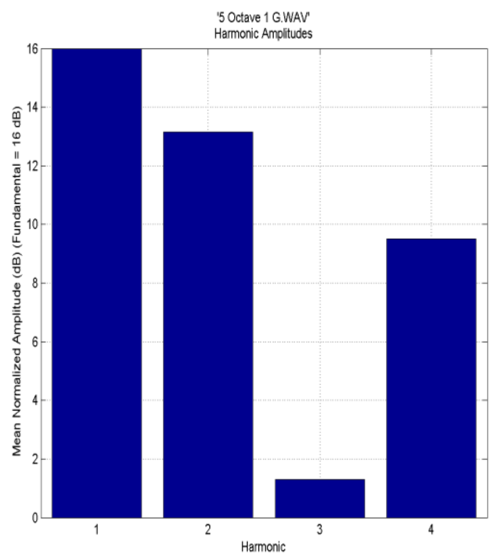
Ukulele Waveform Analysis

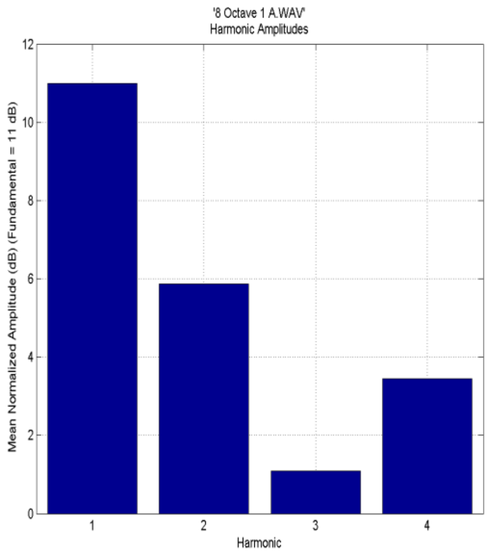
When analyzing the waveform, the program produced a number of graphs, but only certain graphs were relevant. We paid closest attention to graphs that detail the different frequencies of the harmonics, that compare amplitude and frequency of the complex note and that compare the amplitudes of different harmonics.

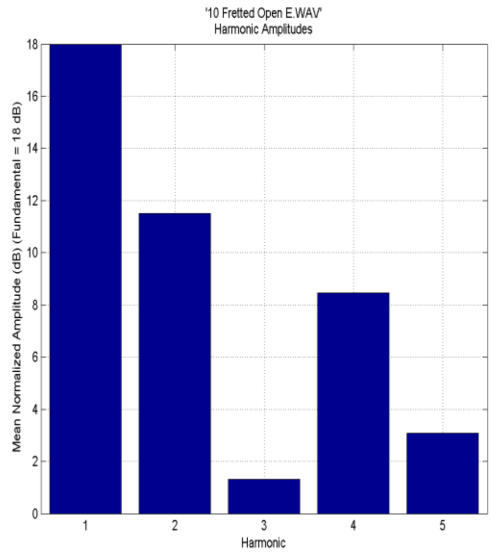


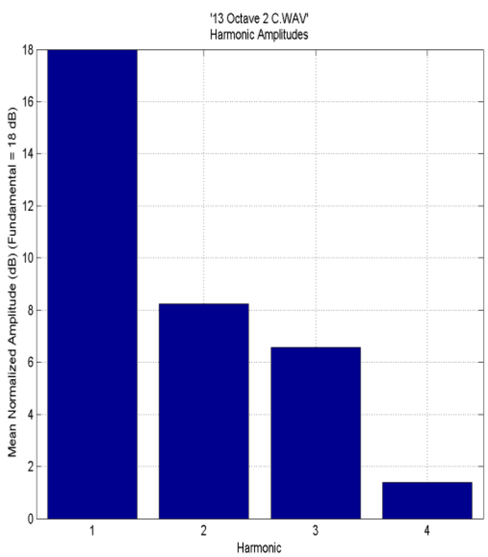


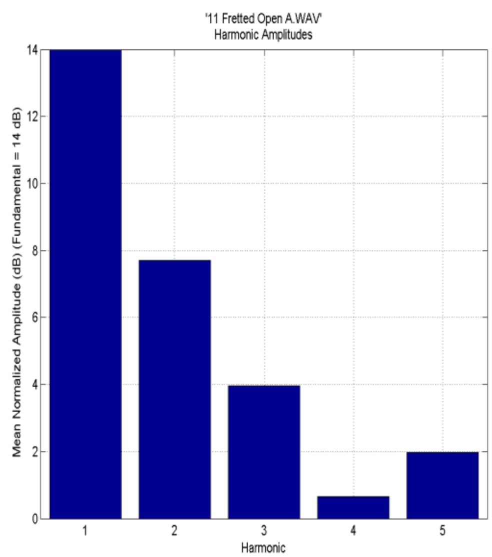


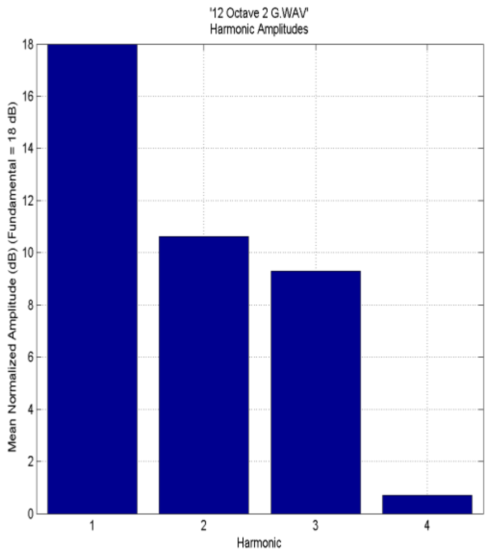


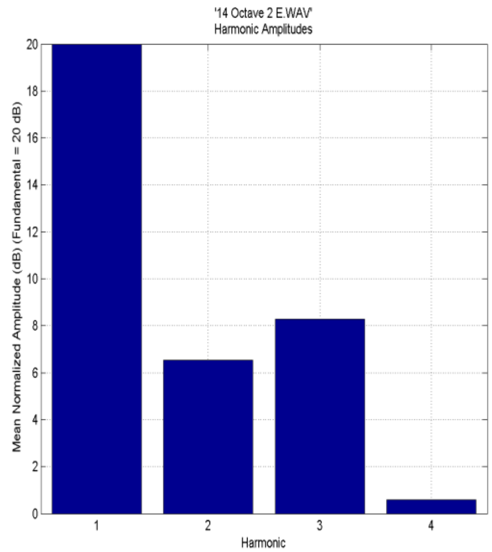

'8 Octave 1 A.WAV'
Harmonic Amplitudes
Mean Normalized Amplitude (dB) (Fundamental = 11 dB)
Harmonic

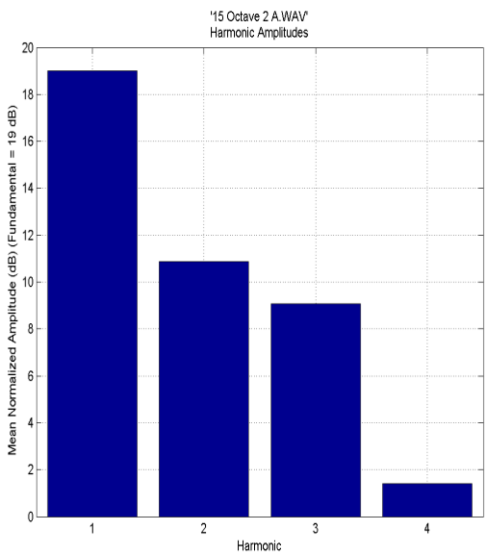

'10 Fretted Open E.WAV'
Harmonic Amplitudes
Mean Normalized Amplitude (dB) (Fundamental = 18 dB)
Harmonic


'13 Octave 2 C.WAV'
Harmonic Amplitudes
Mean Normalized Amplitude (dB) (Fundamental = 18 dB)
Harmonic


'11 Fretted Open A.WAV'
Harmonic Amplitudes
Mean Normalized Amplitude (dB) (Fundamental = 14 dB)
Harmonic

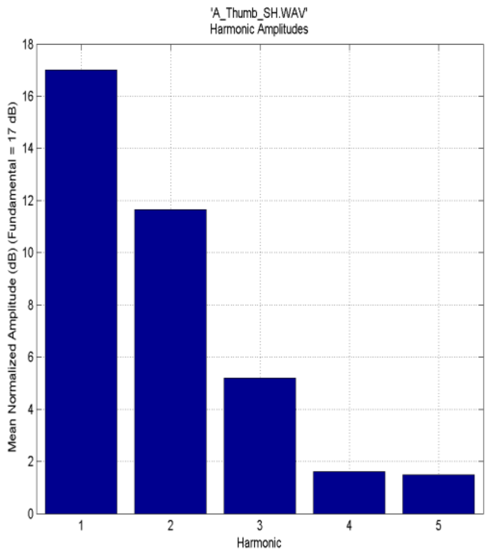


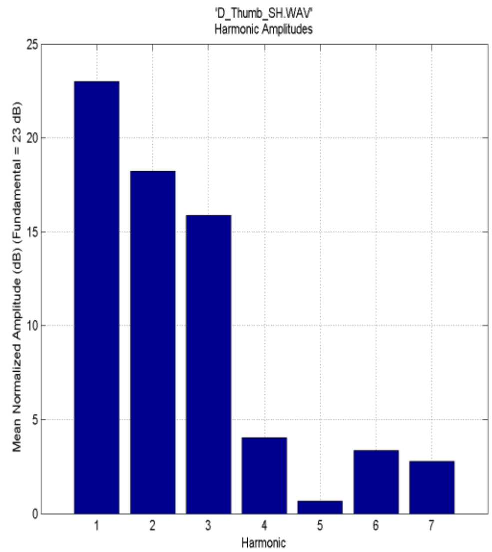


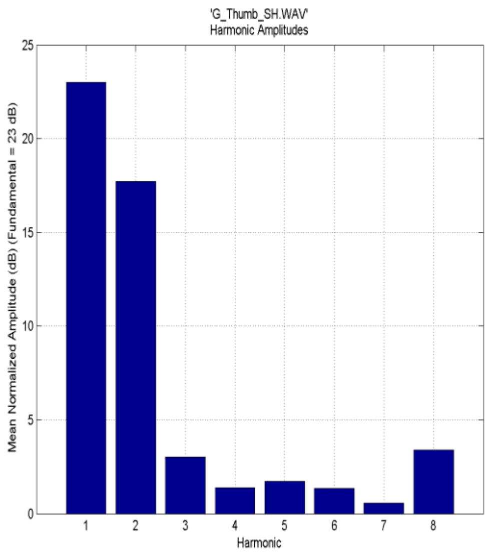


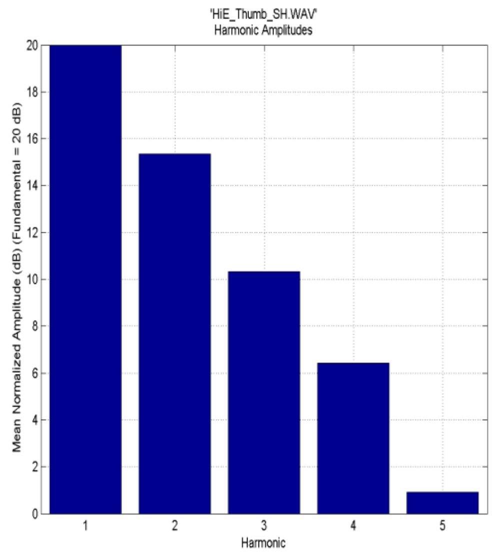
Classical Guitar Waveform Analysis

We wanted to compare the data to another stringed instrument, so we used notes from a Yamaha Classical Guitar CG-150SA already available and performed the same waveform analysis as the ukulele. We analyzed a few of the notes notes on the Classical Guitar in the same way we did the notes on the ukulele. We made sure the type of string, how the string was plucked, and the location the string was plucked were all the same as the ukulele.



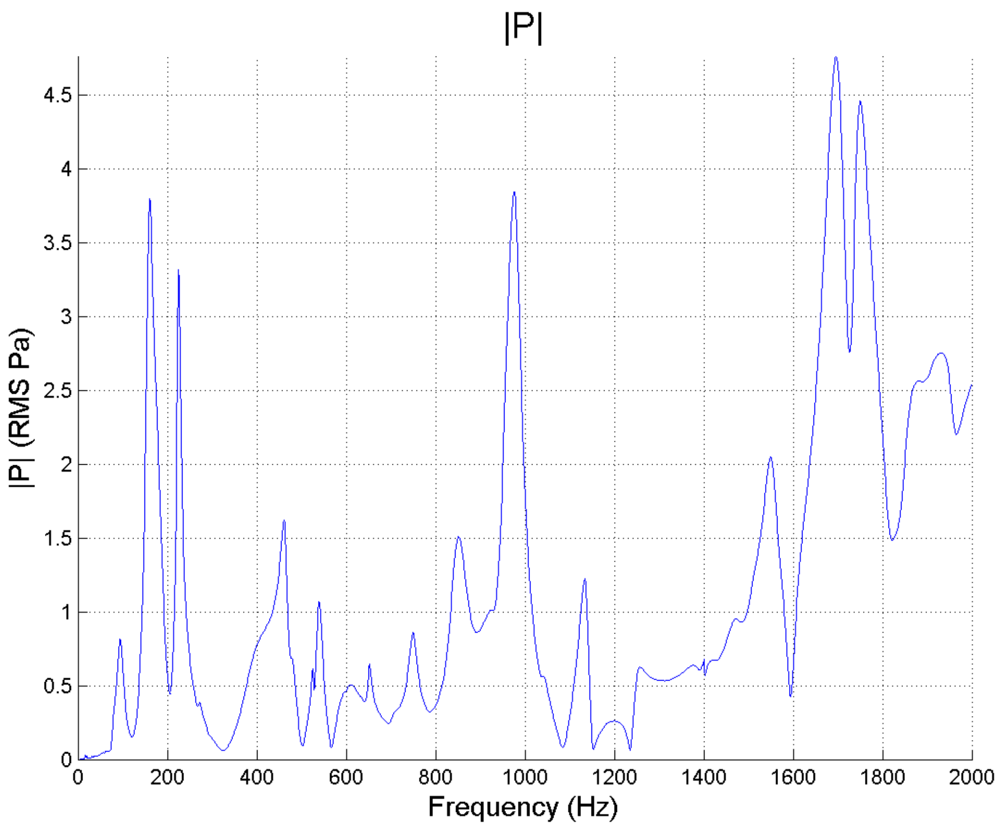




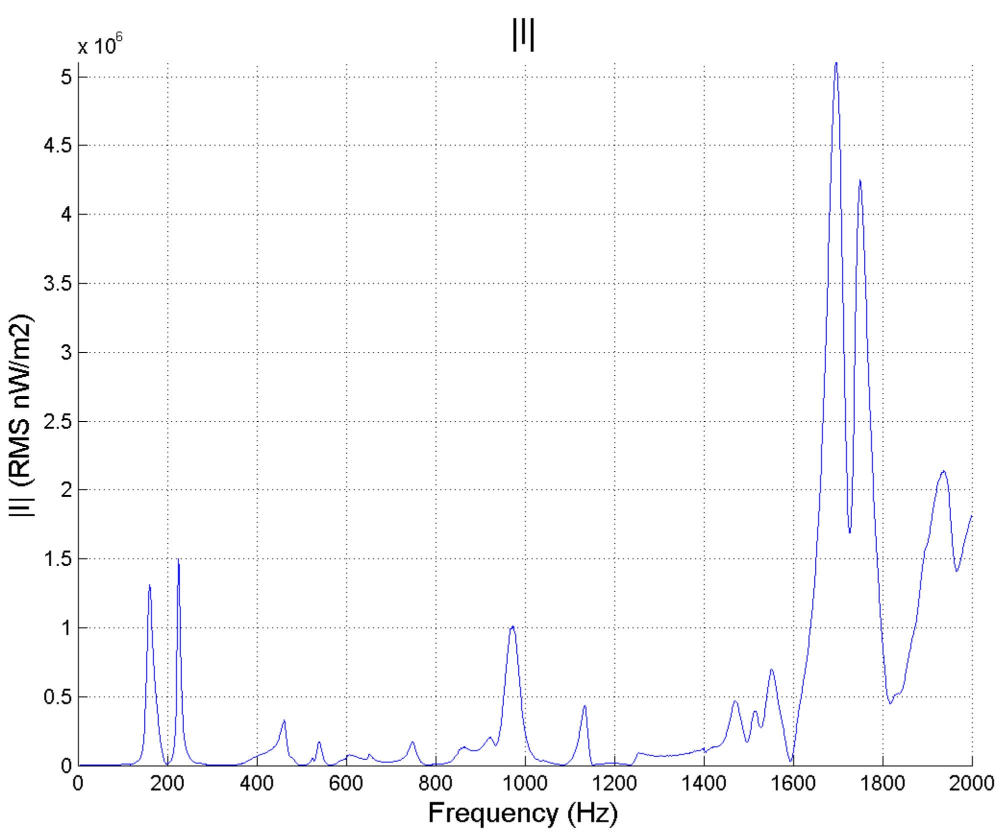


Ukulele Modal Analysis

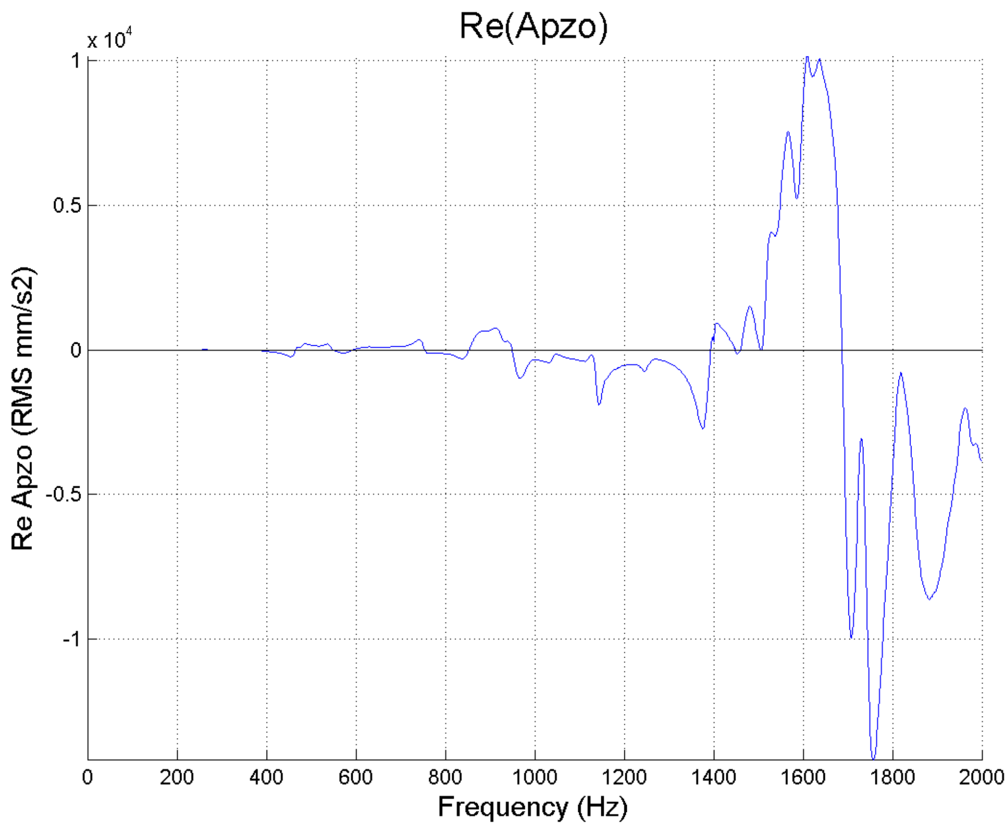
The key objective of the modal analysis was to understand the vibration properties of the ukulele. Take note that in certain ranges of frequencies, the data reacts and shows the cavity is resonating. Here are graphs where the frequency between 1500 Hz and 2000 Hz reacts.

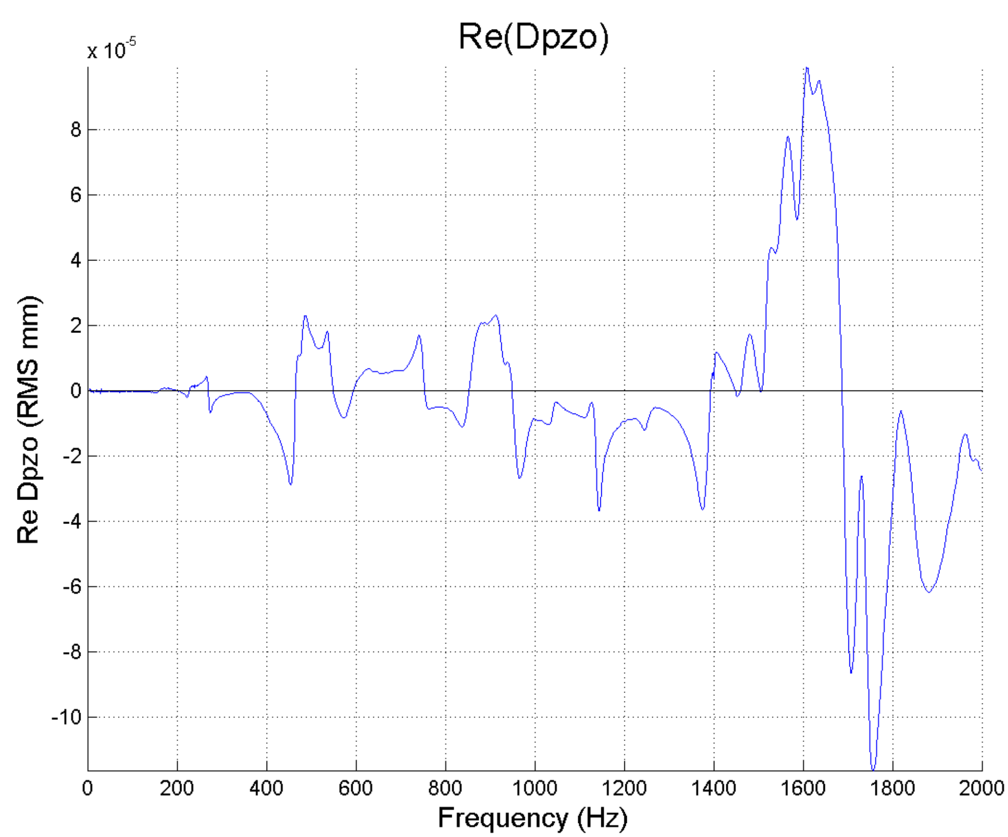


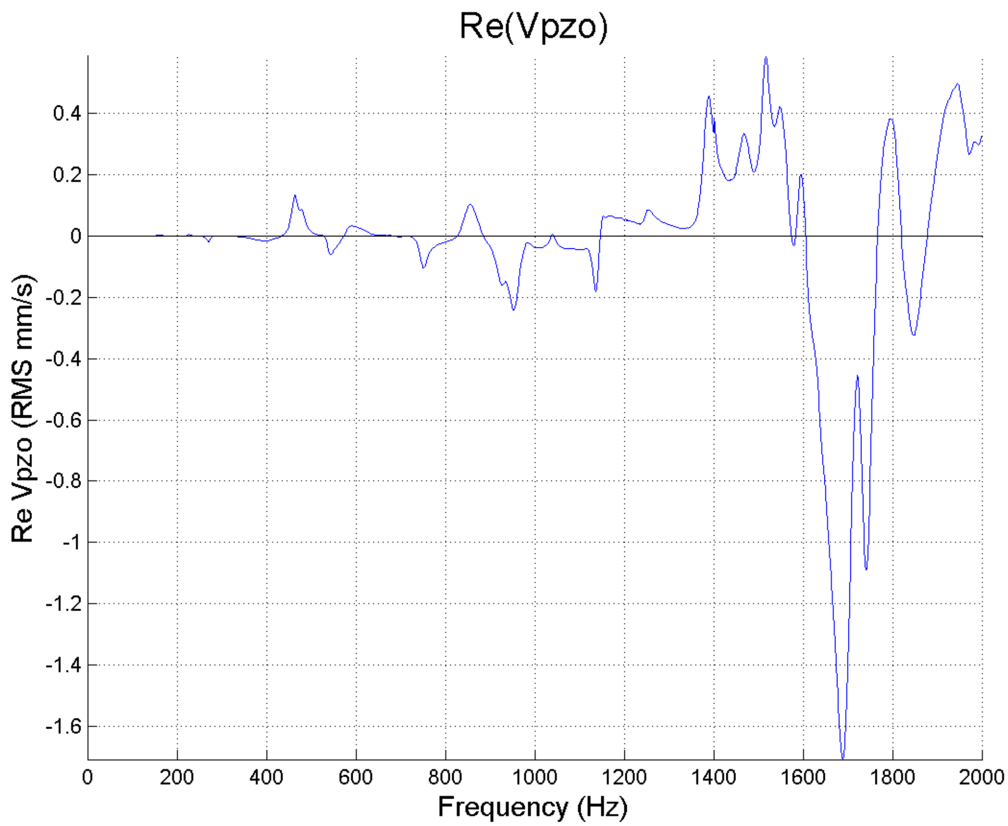
|P|
|P| (RMS Pa)
Frequency (Hz)

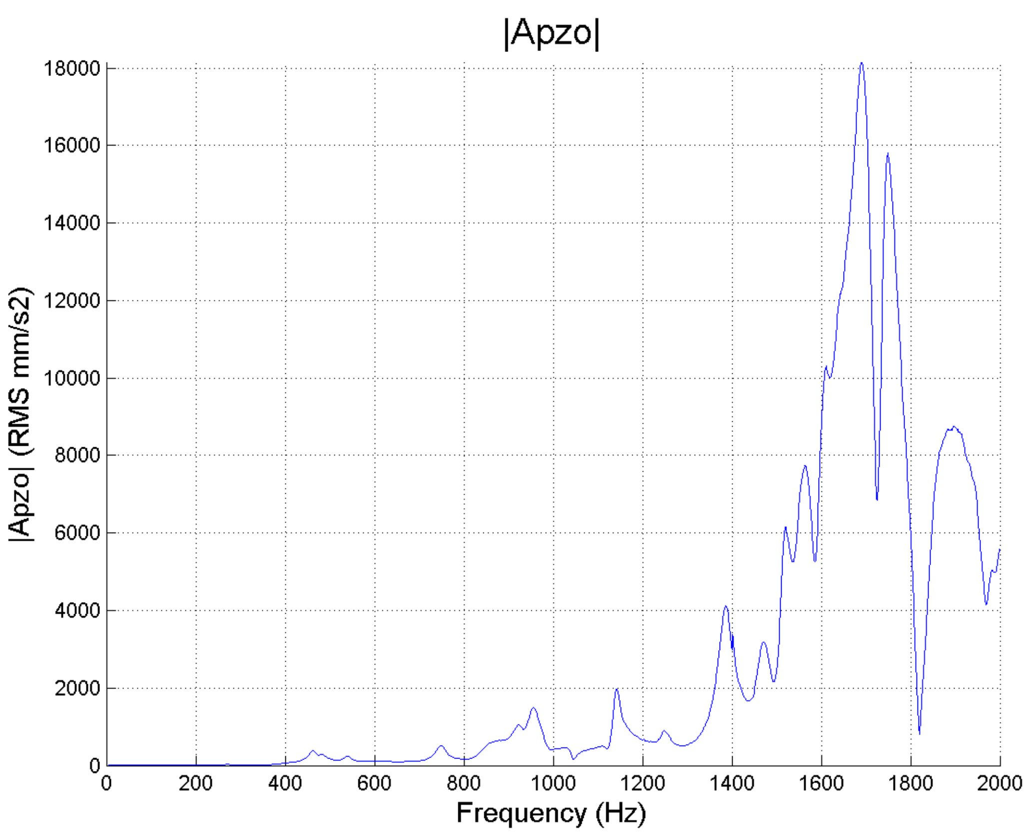


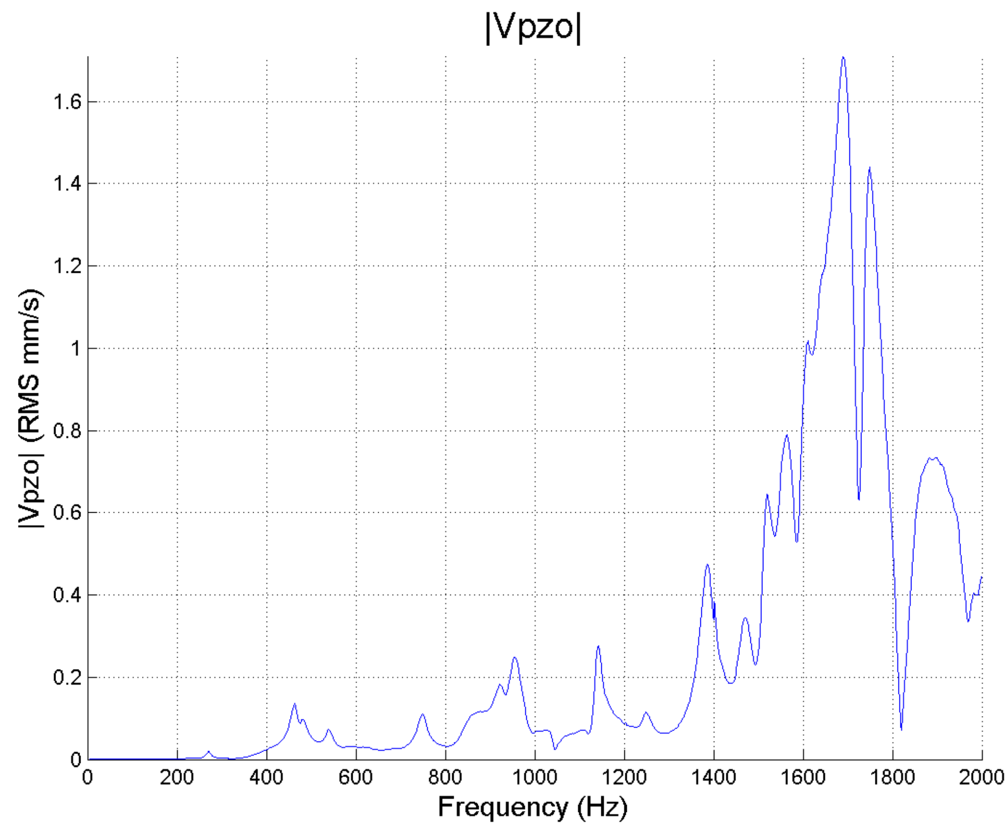
|I|
x 10^6
|I| (RMS nW/m2)
Frequency (Hz)

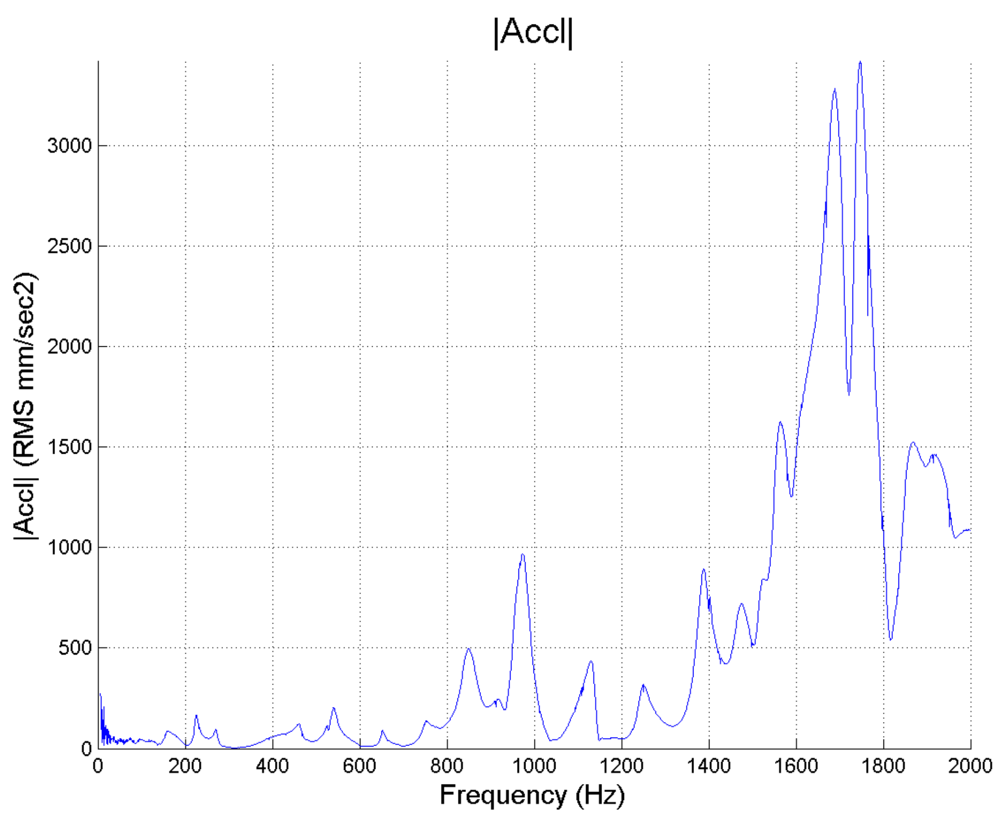

Re(Apzo)
x 10^4
1
0.5
0
-0.5
-1
Re Apzo (RMS mm/s2)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (Hz)


Re(Dpzo)
x 10^-5
8
6
4
2
0
-2
-4
-6
-8
-10
Re Dpzo (RMS mm)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (Hz)


Re(Vpzo)
Re Vpzo (RMS mm/s)
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (Hz)


|Apzo|
|Apzo| (RMS mm/s2)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Frequency (Hz)


|Vpzo|
|Vpzo| (RMS mm/s)
Frequency (Hz)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
200
400
600
800
1000
1200
1400
1600
1800
2000


|Accl|
|Accl| (RMS mm/sec2)
Frequency (Hz)
0
500
1000
1500
2000
2500
3000
200
400
600
800
1000
1200
1400
1600
1800
2000

Conclusion

We observed that higher harmonics are present in notes played by both instruments. This is due in part to the material nylon and the location of where the string was plucked, both increase the higher harmonics. The difference in the sound of the tone results from the specific amplitudes of the higher harmonics. The amplitudes of the harmonics for the classical guitar tend to decrease linearly with increasing harmonics. This is generally true for the ukulele as well, but it is clear that harmonics produced by certain notes are amplified and stand out more resulting in the data that shows a stronger presence of higher harmonics from the ukulele notes. These higher harmonics are what produce the brighter, happier notes of the ukulele. Since we controlled for the type of string and location the string was plucked, that meant the biggest variable was the difference in the sound cavity. From the modal analysis performed, we can see that there is a reaction between approximately 1500 Hz and 2000 Hz, which corresponds with the third or fourth ukulele harmonics. As shown in the graphs, the third or fourth harmonic on the ukulele has a higher amplitude, we conclude this is likely resultant from the resonance produced by the ukulele’s sound cavity.