Flute Acoustics

Amanda Newton, Dr. Gordon Ramsey

Introduction

This comparative study of instruments in the flute family will identify factors that affect the sound produced by these instruments. The instruments studied are Native American (NA) flutes in B and G, soprano and tenor recorders, and transverse flute and piccolo. The spectra of these instruments and their physical measurements will be analyzed. This study focuses on factors including the boundary condition at the mouthpiece, the hole sizes, and the body size and material. Studying this is very useful to musicians who aim to create a certain sound with their instrument.

Theory

While all these instruments are in the flute family, they have different shapes. This impacts the standing waves they produce. The transverse flute and the two NA flutes are cylindrical, while the piccolo and two recorders are slightly conical. Figure 1 shows the standing waves formed in the case of cylindrical, conical, and open and closed boundary conditions. It's assumed all flutes are open-open cylinders, but this will be evaluated in this study. The fundamental frequency for a certain length of the tube is also dependent on open or closed ends of the cylinder. Respectively, the frequencies for open and closed ends are $f_1 = \frac{v}{2L}$ and $f_1 = \frac{v}{4L}$. The procedure involved used Logger Pro and a microphone to plot the frequency spectra for different notes on each instrument, which we took data from to create the spectra plots for each instrument.

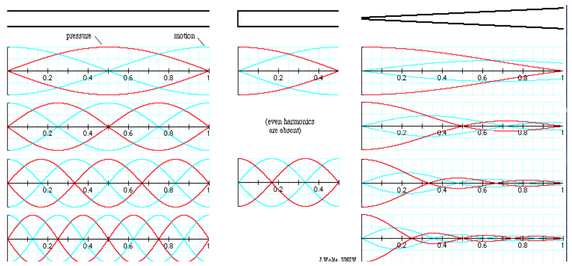

Figure 1: Standing Wave Boundary Conditions [2]

Instrument Comparisons

Range – The instruments in Figure 8 have similarly high frequency ranges. As seen through the spectra, though, their range alone doesn't impact the behavior of their spectra. Other ranges showed similar patterns.

Material – In Figure 9, the blue and orange spectra are instruments made of wood, and the gray and yellow spectra are instruments made of grenaditte, a manufactured wood with plastic. A weak correlation for more harmonics in wood than grenaditte is found, which is consistent with other comparisons; plastic materials typically have more harmonics than wood.

Picconet – An experimental instrument with a clarinet mouthpiece with a piccolo body. The Helmhotz frequency of the clarinet mouthpiece appears as an enhanced 4th harmonic in Figure 10, but the range of harmonics and their relative intensities are consistent with the piccolo, suggesting boundary conditions impact the spectra significantly, but the overall shape is determined by the body of the instrument.

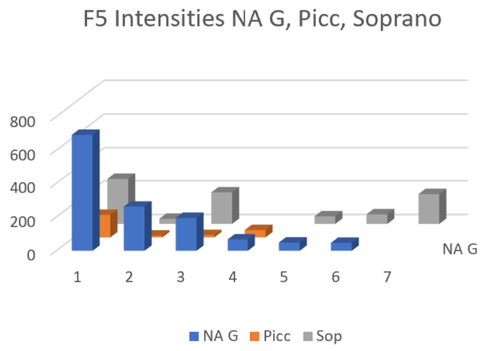

Figure 8: Range Comparisons

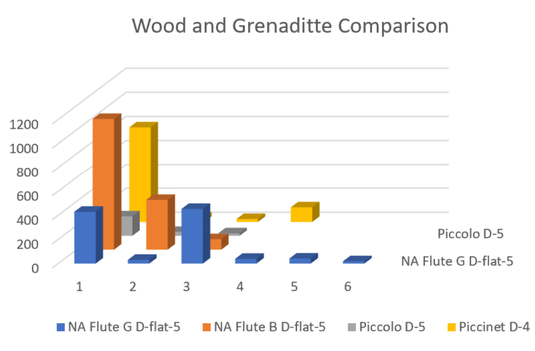

Figure 9: Material Comparison

Instrument Spectra

Overall trials for each instrument were very consistent. For both the Native American flutes B and G, the odd harmonics dominated the spectrum, with about 6 harmonics measured. For the G NA flute, intensity increases toward the middle of the frequencies.

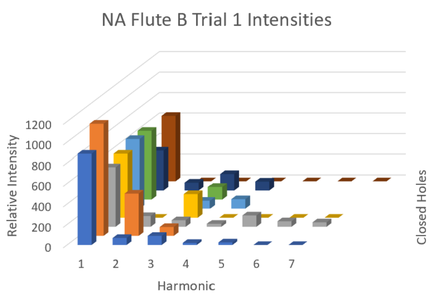

Figure 2: NA Flute B Spectra [1]

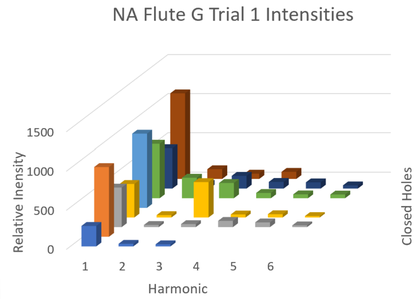

Figure 3: NA Flute G Spectra [1]

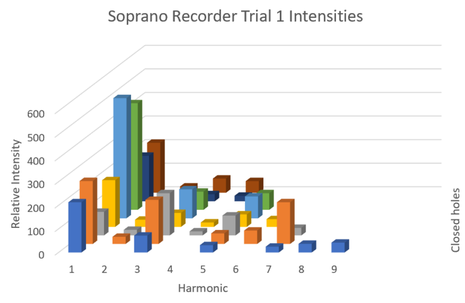

Figure 4: Soprano Recorder Spectra [3]

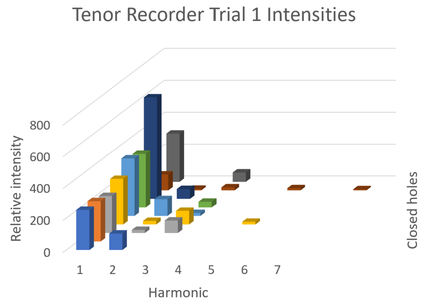

Figure 5: Tenor Recorder Spectra [4]

Both the soprano and tenor recorders' spectra have a strong dominance of odd harmonics. For the soprano recorder, the number of harmonics greatly increases as frequency increases. For the tenor recorder, the number of harmonics stays around 3.

Both the flute and piccolo have around 5 harmonics consistently. Both the flute and piccolo's 3rd harmonic notably increases in intensity as frequency increases. The overblow and open fingerings are both consistent in frequency and spectra for the flute and piccolo, but the flute overblow has less frequency and a shorter standing wave truncation than expected, and the piccolo overblow has more frequency and a longer standing wave truncation than expected.

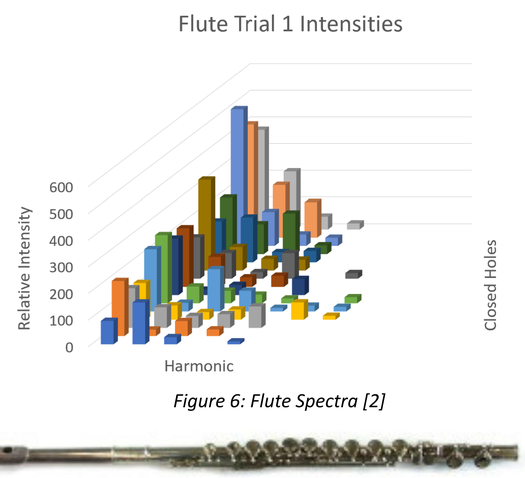

Figure 6: Flute Spectra [2]

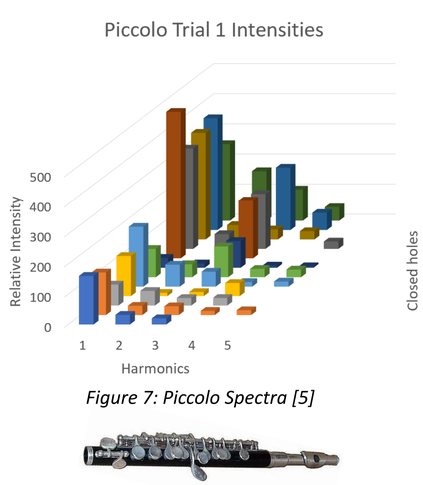

Figure 7: Piccolo Spectra [5]

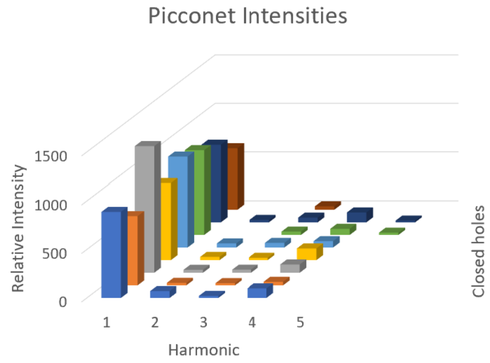

Figure 10: Picconet Spectra

Results

The odd harmonics dominance in the spectra of the NA flutes and recorders suggest that the instruments act as an open-closed system. This can be explained by the fipple mouthpiece in the NA flutes, which momentarily closes the end creating the wave, and the very small opening in the recorders, causing turbulent flow in the wave production. The flute doesn't have even or odd harmonics dominant, suggesting the flute acts as an open-open cylinder. The piccolo also has a slight preference to odd harmonics, which can be explained by the scaling of the piccolo's mouthpiece to the flute's; the small piccolo mouthpiece causes more turbulent flow.

The material dependence of the spectra observed matches the theory. The wood instruments have less harmonics, the plastic have more harmonics, and the grenaditte mix behaves more like an imperfect wood instrument. The range dependence was seen in more complex instruments with keys, the flute and piccolo, where the intensity varied with frequency. The instruments with less keys had more consistent intensity across frequency. The next steps in this project are to calculate the effective standing wave truncations for each instrument at each frequency, and how that relates to instrument design.

References:

[1] "Flutes", High Spirits Flutes, highspirits.com

[2] Joe Wolfe, "Open vs Closed pipes (Flutes vs Clarinets)", The University of New South Wales, (2005), newt.phys.unsw.edu.au/jw/flutes.v.clarinets.html

[3] "Soprano", Yamaha, (2024), usa.yamaha.com/products/musical_instruments/winds/recorders/abs_resin_soprano/index.html

[4] "Tenor", Yamaha, (2024), usa.yamaha.com/products/musical_instruments/winds/recorders/abs_resin_tenor/index.html

[5] "Piccolo", Wikipedia, (Feb 2024), en.wikipedia.org/wiki/Piccolo