A Brief Study of Helium as a Medium For Acoustic Propagation

Physics of Music Final Project Phys 406
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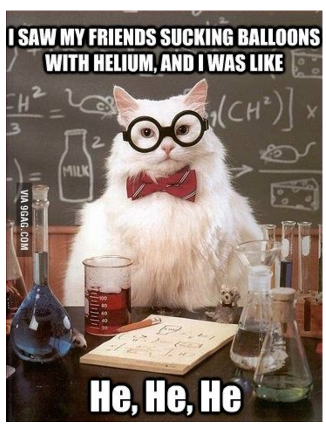

Fig. 0.1 The Authors felt that this required a caption
The editors felt otherwise, as a compromise this was put in place

Abstract

This study is intended to determine the effects of Helium as a medium for acoustic propagation in a musical context. We began with an initial comparison between the presence and absence of helium inside the resonant cavities of both the Violin and the Cello. After an initial qualitative analysis of acoustic differences we moved to have a few systematic recordings of both instruments doing a harmonic analysis. After a few weeks of these we moved to a Frequency Sweep using the Hp spectrum analyzer.

Acoustic Properties of Helium

The difference in how dense the air is surrounding a vibrating string is somewhat effective in changing the qualities of how it resonates inside a chamber. Normal Air has a density of 1.205 kg/m^3 at NTP and 1.293 kg/m^3 at STP with a speed of propagation of sound is 343 m/s at NTP. Whereas Helium has almost a tenth the density and three times the speed of sound.

Density: 0.1664 kg/m^3 at NTP and 0.1785 kg/m^3 at STP

The speed of Propagation of sound is 927m/s at NTP

This allows for the sounds to travel quicker inside the cavities of both instruments, thus maintaining energy for longer.

Qualitative Analysis

What we did was record the open strings of both instruments. First without helium and then with Helium. Using the small tube we inserted the helium into the cavity. To keep the light gas inside the cavities of both instruments we placed masking tape over the F holes.

The first time we recorded the violin it was evident that the sounds were different. A richer and fuller tone. With the cello we did not find as much of a difference but we would tend to believe that it was because of lack of saturation, after this attempt we were sure to put more in the successive attempts.

As well we observed an increase in volume. When we switched over from the air to helium the microphone had to be decreased in sensitivity from full to 6/10 in order to gain the same effective volume. Unfortunately the variance in the loudness quality of the instruments does not allow this to be compelling.

Bowed Recording Analysis

For an analysis of helium's effect under playing conditions several bowed notes were recorded with and without helium on both the cello and violin. The open G2 on the cello was particularly stable and generally representative of the trend displayed in other pitches. Figures 1 and 2 below the relative amplitudes of the strongest harmonics with the first being the loudest, and the next harmonics being the first seven of higher pitch and not much weaker than the first by two orders of magnitude. In fig. 1 the first harmonic is the fundamental G2, the second is G2's octave harmonic G3, and the rest are the highest peaks displayed in fig. 3. However in fig. 2 the strongest amplitude was actually at the octave harmonic of the fundamental, G3, the second harmonic displayed in fig. 1; the corresponding fig. 4 shows that the fundamental is actually much weaker than many of the harmonics. This shift in the strength of the fundamental is not the only substantive shift in harmonic balance. Figures 1 and 3 show that the upper harmonics are generally much louder in helium than air, and that there is a nonlinear amplification.

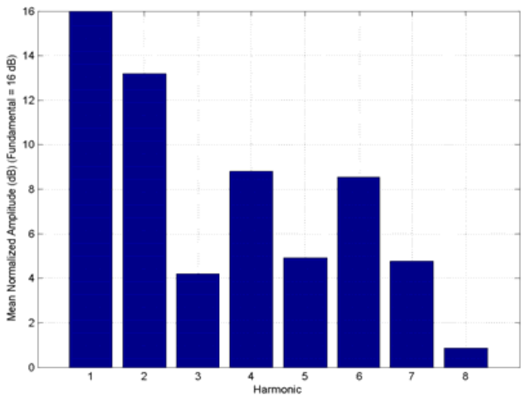

Fig. 1 Relative Harmonic Amplitudes in Air

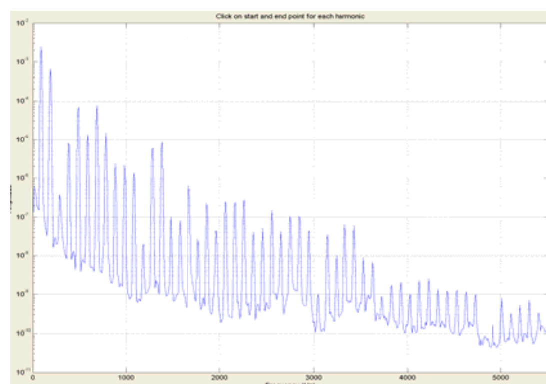

Fig. 3 Relative Harmonic Amplitudes in Air

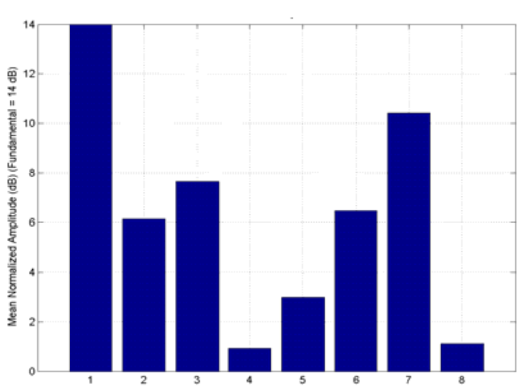

Fig. 2 Relative Harmonic Amplitudes in He

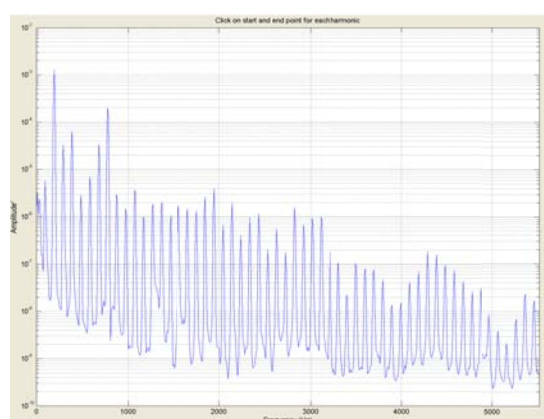

Fig. 4 Relative Harmonic Amplitudes in He

Subjectively, this gives the cello a noticeably different timbre with more resonance in the upper harmonics. The missing fundamental is still the perceived pitch and not heard as much weakened. The spectrums generated from the recordings (fig. 5) consistently showed these general trends of higher amplitude upper harmonics (all the way to around 5 KHz) and change in balance of the strongest harmonics when helium was used. Unfortunately, since the cello was constantly bowed during recording nothing can be extrapolated about the effects of helium on the sustain patterns of different pitches from this data; this is one of the defining characteristics of an instrument's timbre and it may be informative to record staccato or pizzicato samples in future investigations to observe the effects on sustain.

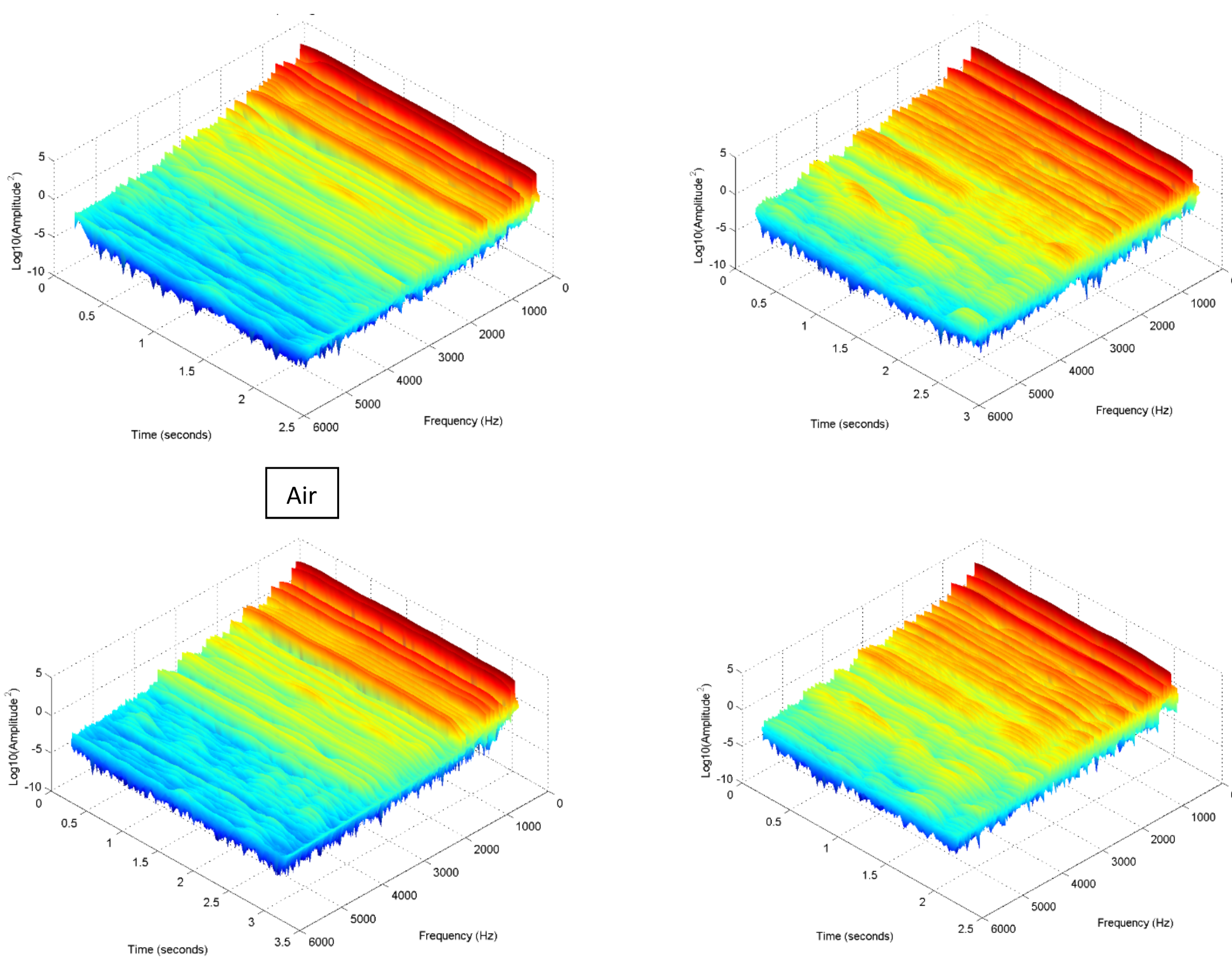

Fig. 5 Harmonic Amplitudes Spectrum

The percieved “missing fundamental effect” discussed above is similar to those in double reed instruments like the oboe and bassoon shown in the spectra in figures 7 and 8 (their fundamentals are the spikes lowest in frequency, respectively the 4^{th} and 2^{nd} highest amplitudes)[1]. However, in the helium filled cello the fundamental consistenly has the 6^{th} highest amplitude as in fig. 6.

This phemenon is particularly pronounced in our samples recorded at G2 as opposed to other pitches. Despite the fact that the bowed string continues to resonate at G2’s 98Hz it that pitch has low amplitude because it seems that the body of the has an antinode at that frequency when filled with helium. This antinode can be seen in our tests of the the resonant frequencies of the cello body in the frequency sweep discussed later.

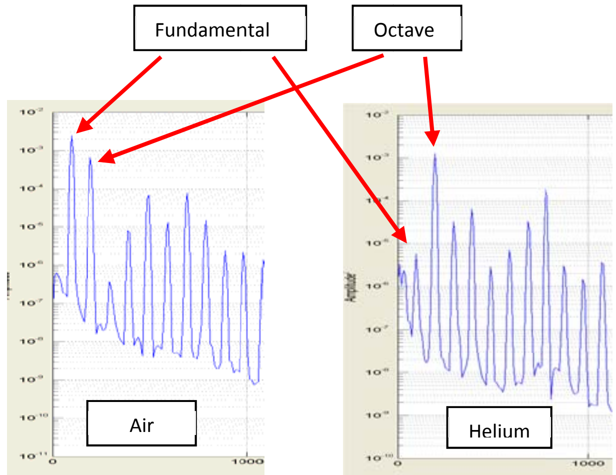

Fig. 6 Missing Fundamental in Cello with He

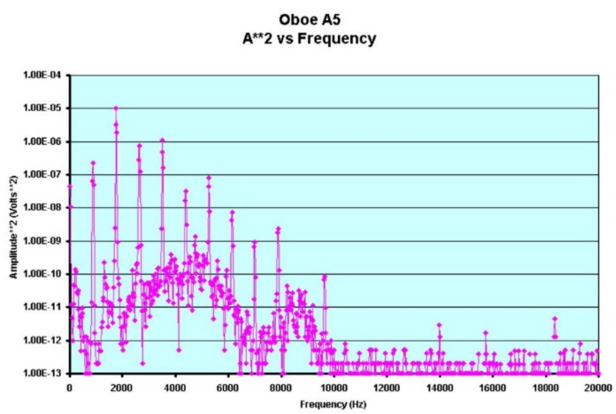

Fig. 7 Missing Fundamental in Oboe[1]

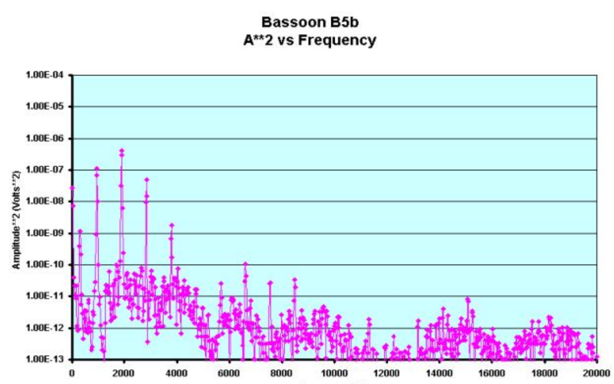

Fig. 8 Missing Fundamental in Bassoon[1]

[1] Errede, S. Pitch vs. Frequency [PDF document]. Retrieved from: http://courses.physics.illinois.edu/phys406/Lecture_Notes/P406POM_Lecture_Notes/P406POM_Lect7.pdf

Effects on Resonance

The second main test of helium's effects was made using an HP frequency analyzer to generate white noise vibrations in a piezoelectric transducer rested on the front plate of the cello at the bridge (where the internal soundpost, which carries vibrations from the strings to the rest of the body) while another transducer placed on various points of the front plate was used to detect the vibration of the cello. Because the test was intended to test the body cavity alone the strings, which would resonate strongly enough to drown out the body's resonances, were stopped from vibrating with foam mutes. Unfortunately, after looking at the data taken, it seems that the curvature of the front plate of the cello created a reproducibility problem; only the measurements taken when the cello was filled without moving the pickup show meaningful correlation between the air and helium resonances. Fig. 9 was created without moving the pickup between air and helium filled runs of the analyzer. It clearly shows the strong antinode in the helium filled runs around G2's 98Hz as discussed above, and also the trend of generally

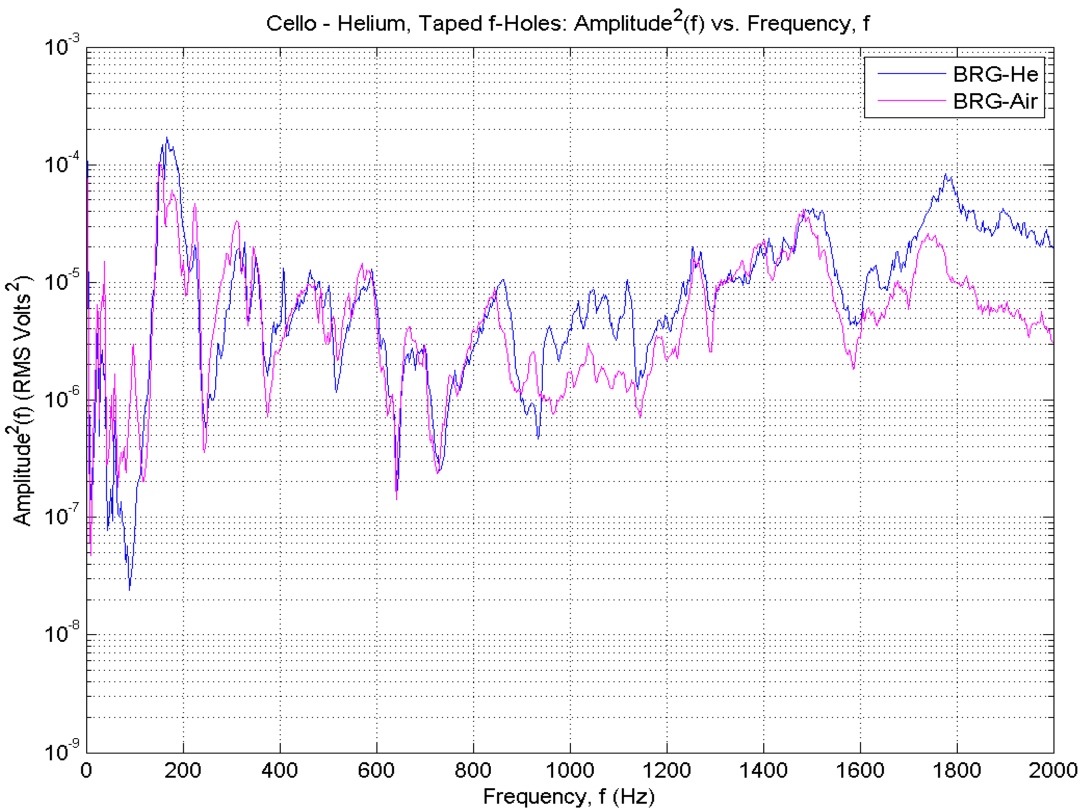

Fig. 9 Cello Body Resonances, with and without helium

amplified higher harmonics. Seeing the generally good correspondance between helium and air trials in the lowe register, it would seem that body resonances fail to explain much of the shifted ratios of the strongest harmonics in any given bowed note.

Conclusion

The idea that Helium changes the propagation of sound is almost common sense to say that it is present. The differences can be seen in our data but it would take much more in depth and wider ranges of experiments to tie down the exact effects. The effects it would have on the instruments chosen would be effectively useless as the idea of filling the cavities of classical instruments would not only be cost effective but inefficient as they would not be airtight and would leak expensively.

In additionally the change in resonance in the cavities which are specifically designed for air propagation would leave some hole in the resonances as we saw above in the HP analysis. There will be anti-resonances as shown, where the speed of the Helium will change the acoustical geometry of resonances.

Afterwards

It would be interesting to see a more in depth analysis of the HP frequency sweep. Perhaps using the lockin-amplifiers to do a slower and more specific data. With the inconsistency in placement in the HP Sweep. We could not do this as it was too long to have the Helium flowing through the instruments overnight. As well performing more frequency analysis with the strings including fingered as well as open notes to get consistent data. Additionally it would be worth using something of higher density such a Sulfur Hexafluoride or carbon dioxide to see how the lower speed would affect the resonances.