Factors Affecting the Frequency Produced by Resonating Bamboo Tubes

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Abstract

Bamboo has been used to make flute-like instruments for millennium. While the formation of standing waves in rigid cylindrical tubes is well understood, bamboo tubes are typically neither completely rigid nor cylindrical, leading to the possibility that sound produced might diverge from theoretical predictions. The frequency of sound produced from bamboo tubes with one open end was therefore studied. Bamboo tubes of different length, radius, and hole position with respect to the tube mouth were prepared. The rim of each of the tubes was tapped with a metal rod and the resonant sound analysed. First, the effect of the length of the bamboo tube on the frequency produced was investigated for tubes ranging in length from 15 to 30 cm. The result showed that the longer the tube, the lower the frequency, matching the theory for a cylindrical tube. Next, the effect of the position at which a hole is drilled in the tube on the frequency was studied, with holes drilled at positions ranging from 5 to 25 cm away from the tube's mouth. The results showed that the further the hole was from the mouth, the higher the frequency. Lastly, the effect of the radius of the tube was observed and showed that the bigger the tube, the lower the frequency, and the higher the period, following the theoretical prediction.

Keywords: Bamboo tube, resonance, frequency, tube length

1. INTRODUCTION

Bamboo, scientifically known as Bambusoideae, is a subfamily of tall treelike grasses of the family Poaceae, comprising more than 115 genera and 1,400 species. Bamboos are distributed in tropical and subtropical to mild temperate regions, with the heaviest concentration and the largest number of species in East and Southeast Asia, for example, Japan and Thailand, and on islands of the Indian and Pacific Oceans. Bamboo wood is a light weight, flexible, tough, and high tensile. It is highly versatile raw material for different work such as building material, utensils and musical instruments (Britannica). Flute-like instruments have been made from bamboo since time immemorial. Many groups have their own instruments that are made from bamboo such as the Indian Bansuri and Venu, the Chinese Dizi, and the Filipino Kulintang (Sachs).

To understand the design and sound output of bamboo flutes, sound production in cylindrical tubes is important. The basic parameters that affect the frequency (*f*) and period (*T*) of the resonant standing waves produced in a cylindrical tube which is closed at one end are the length (*L*) and radius (*R*) of the tube. The period of the standing wave which is formed in such a tube can be modelled by the equation:

$$T = \frac{4(L+C)}{v} \quad (1)$$

where *C* is the end correction (Anderson, 1928). The length of the end correction is dependent on the radius of the tube, as:

$$C = 0.66R \quad (2)$$

as determined by Boelkes and Hoffmann (2011).

Figure 1 is a representation of the fundamental standing wave (red) formed in a cylindrical tube (black) with one open end, with the tube length (L), radius (R), and end correction (C) indicated. The closed end of the tube is a displacement node (pressure anti-node) while the

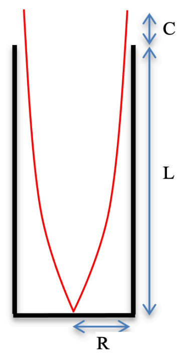

Figure 1. Standing wave in a tube.

displacement antinode (pressure node) is located a short distance beyond the open end of the tube.

While this is the theoretical model for a cylindrical tube, the bamboo tubes typically used to make flutes are not perfectly cylindrical, therefore might deviate from the theoretical model. Thus, the frequency of the resonant sound produced by the bamboo tubes as a function of tube length and radius were measured and compared to the idealized theoretical model, represented by PVC tubes.

Bamboo flutes typically have finger holes drilled at regular intervals along the tube. Having an open finger hole part way up the tube allows air to pass in and out at that point, which effectively makes that point a pressure node, a displacement antinode, and effectively makes that the end of the standing wave. Susan Wang (2009) showed that for a plastic recorder, the effective end correction at an open finger hole was not 0.66 R, as it is for the end of a cylindrical tube, but was approximately three times greater, due to the smaller size of the finger holes. Here, holes were drilled in the bamboo tubes to test whether the end correction behaves similarly to Wang's results for a plastic recorder.

2. METHODS

Four different lengths of bamboo tubes, 0.15, 0.20, 0.25, and 0.30 ± 0.01 m, measured from the external joint line seen between sections of the bamboo to the end of the tube were prepared. The radius of these tubes was kept fairly constant at 2.4 ± 0.2 cm. To test the effect of radius on sound frequency, four bamboo tubes of varying diameter were cut to a length of 0.15 ± 0.01 m. The inner radius of the tubes ranged from 1.90 to 2.95 ± 0.05 cm. Finally, to determine the effect of the position of a hole drilled in the tube, five tubes of radius 2.4 ± 0.2 cm and length 0.30 ± 0.001 mm had 8 mm diameter holes drilled at locations ranging from 0.050 to 0.250 ± 0.0002 m from the closed end of the tube. A set of tubes with dimensions in ranges similar to the bamboo tubes was made from PVC pipe.

Each of the tubes described above was suspended on a string, so it was free to resonate. The tube was then tapped with a metal rod on its open edge with a constant force. The resonant sound it made when tapped was recorded, then analysed with sound analysis software "Audacity" to determine the frequency. Three trials were recorded for each tube. The temperature was maintained at 26 ± 1 °C for all trials. A diagram of the experimental setup is shown in Figure 2.

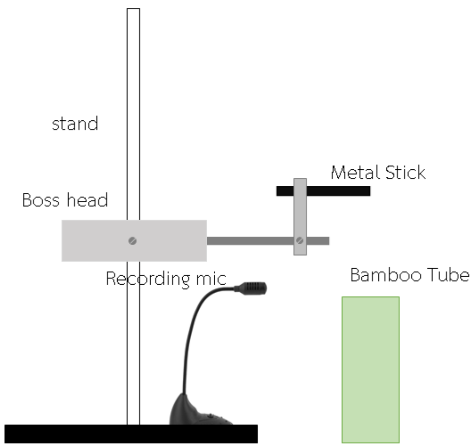

Figure 2. Experimental apparatus setup.

3. RESULTS AND DISCUSSION

The period of the sound produced by both the bamboo and PVC tubes varied linearly with the length of the tube, as seen in Figure 3. The slopes of the linear fits for the bamboo and PVC were, 11.4 ± 0.35 ms/m and 11.2 ± 0.27 ms/m, respectively, which is equal to the value predicted by the theoretical model (Equation 1) of 11.7 ± 0.3 within uncertainties. The value for the bamboo tubes was lower than the PVC, but still just within uncertainty. This shows that the natural variations in the internal diameter of the bamboo tube over its length caused no significant deviation from the theoretically predicted behaviour of a cylindrical tube.

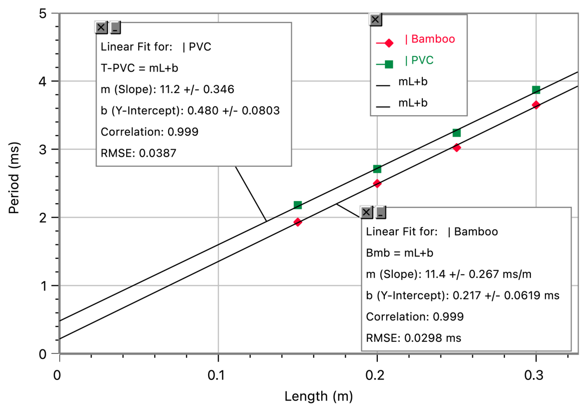

Figure 3. The length of the tubes and the period of the resonant sound produced.

The value for the y-intercept of the graphs, from Equations 1 and 2, depends on the radius of the tubes. The y-intercept of the bamboo and PVC fits both match the theoretical predicted value within uncertainties. It must be noted that the fact that the range of lengths tested, and the large distance that the fit was extrapolated, led to fairly large uncertainties, so not much weight should be placed on the agreement with theory here.

Looking at Figure 4, the period of the sound produced is linearly related to the radius of the four tubes of equal length, both for the bamboo and PVC pipes. However, the slope of the two fits is very different, and the quality of the fit for the bamboo tubes is very low, indicating the different radius bamboo tubes behaved very differently. From Equations 1 and 2, the slope of the fit can be used to calculate the proportionality constant in Equation 2 (0.66 ± 0.02 (Boelkes, 2011)).

The slope of the PVC fit gives a value of 0.68, which matches the model within uncertainties. The slope of the bamboo fit is much lower, and gives a constant of 1.8, which is almost double the accepted value. The largest radius bamboo tube produces a sound period similar to the matching PVC tube, but the narrower bamboo tubes increasingly deviate from the PVC results. It is possible that the internal structure of narrow bamboo tubes is different from larger radius tubes, and thus changes the behaviour of the resonating standing wave formed in the tube. This produces an end correction which is much longer than that predicted for a cylindrical tube of that radius. More research into standing wave formation in narrow bamboo tubes is needed to understand this result.

Since bamboo tubes are typically used to make flutes, the effect of the finger holes on the frequency of the sound produced was studied. Wang showed that, for a recorder, the finger holes effectively behaved as the displacement antinodes (pressure nodes) of the standing wave, albeit with significantly longer end corrections. Looking at Figure 5, it is clear that this is not how the tubes in this investigation behaved. Wang showed that the end correction was the same for each of the finger holes, and about three times longer than the end correction at the end of the recorder.

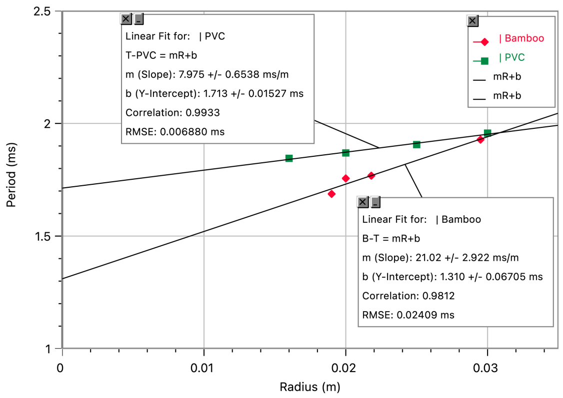

Figure 4. The radius of the tubes and the period of the resonant sound produced.

Here, as the hole moves closer to the base, the effective end correction of the standing wave increases dramatically. While the end correction for the 0.30 m hole position (just the 0.30 m long tube with no hole) is 0.035 m, which is in agreement with Equation 2, when the hole is drilled half way down the tube, at 0.15 m, the end correction is 0.14 m, meaning that the effective location of the displacement antinode is just 1 cm inside the end of the tube. When the hole is 0.05 m from the base, the effective location of the antinode has moved down only 4 cm, to 5 cm inside the end of the tube. Clearly, the holes are not acting as pressure nodes, as they did for Wang's recorder. While more research is needed, it is likely that this is due to the relative sizes of the holes in the two cases. The finger holes in Wang's recorder were approximately one third the diameter of the tube, but here, the finger holes were only one sixth the diameter of the tubes. Very small holes likely restrict air flow to the point where the holes do not act as pressure nodes, but only have a slight influence on the formation of the standing wave. More research is needed to determine how the relative size and location of a hole in a tube affects the formation of the standing wave.

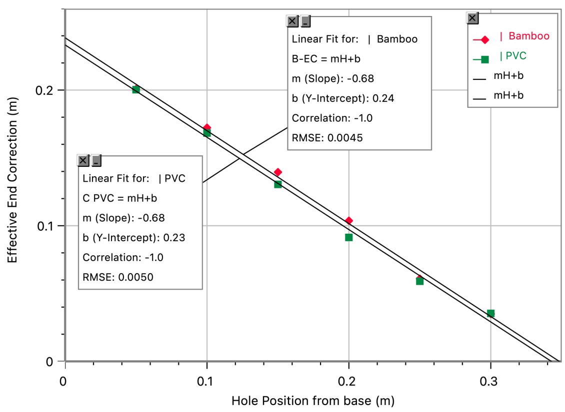

Figure 5. The distance of the drilled hole from the closed end of the tube and the period of the resonant sound produced. Note that the 0.30 m data shows the period for a tube with no hole.

4. CONCLUSION

Bamboo tubes, even though they are not perfectly regular cylinders with flat ends, have been shown to closely follow the theoretical model for the formation of resonant standing waves in cylindrical tubes. However, it was shown that holes drilled in the tube cause the standing wave behaviour to deviate significantly from the theoretical model. More research is needed to determine the effect of hole size on standing wave formation.

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