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GEOMETRICAL MODELING AND SPECTRAL ANALYSIS OF A CONCH SHELL TRUMPET

Lisa R. Taylor and M.G. Prasad
Noise and Vibration Control Laboratory
Department of Mechanical Engineering
Stevens Institute of Technology
Hoboken, NJ USA 07030

R.B. Bhat
Mechanical Engineering Department
Concordia University
Montreal, Quebec
Canada H3G 1M8

ABSTRACT

The clear and hauntingly beautiful sound of a conch shell trumpet was an integral part of daily life in many societies, where it was used for communication and in religious rituals. The sound spectrum and duct geometry of a conch shell trumpet is examined in this study to reveal the characteristics that allow its sound to propagate over large distances and give the conch its memorable tone quality.

The fundamental frequency of a *Turbinella Pyrum* was sounded and its spectrum measured in an anechoic chamber. Spectral analysis shows a strong fundamental frequency and five overtones at integer multiples that form a smoothly decreasing envelope. The placement of the harmonics and their relative amplitudes suggest the conch shell cavity has a duct profile similar to an exponential horn such as a French Horn.

X-ray tomography was used to reveal the shape and size of the duct cross-section at every half-turn, as well as its corresponding location with respect to the longitudinal axis. This information was used to approximate the duct profile as it would appear if the conch were unwrapped. The results reveal that most of the cavity has an almost conical profile, and that there is a large exponential flare at the termination.

INTRODUCTION

Conch shells have been used for centuries as a type of trumpet and became an integral part of daily life for many groups of people [1]. It was the first form of war trumpet and hunting horn. In New Guinea it is used for communication, and there are standard calls for alarm, a successful hunt, and other important events. It is also credited with some supernatural powers, and was used in Western Bohemia to ward off storms. In India the conch shell trumpet is sounded during religious rituals in temples and homes.

The sound quality of the conch trumpet is clear and hauntingly beautiful. The tones produced can be heard at great distances, and the shells are portable as well as abundant on certain shores. Thus it is not surprising that so many uses were found for the shell. A study of the spectral content and cavity geometry of a conch shell trumpet was undertaken to reveal the characteristics that allow it to project so far in open air and give the conch its distinctive sound. The autospectrum of a conch shell trumpet sounded in an anechoic chamber was measured and analyzed. Also, the geometrical profile of the spiral duct formed by the shell cavity was approximated using information obtained from x-ray tomography pictures. These results are compared and are presented herein.

SPECTRAL ANALYSIS OF A CONCH SHELL TRUMPET

The pointed tip of a conch is cut off to open the cavity, and it is played by blowing into that end through vibrating lips. When the frequency of lip vibration matches a resonance frequency of the shell cavity, a clear tone is produced. By adjusting lip tension and air speed, different frequencies can be produced by skilled players, as on any brass wind instrument. The spectrum of sound produced on an end-blown Indian conch shell trumpet was studied by Bhat [2,3]. A photograph of this particular type of conch, a *Turbinella Pyrum*, is shown in Figure 1.

The autospectrum of a conch trumpet sounded in an anechoic chamber is shown is Figure 2. Clear peaks at integer multiples of the fundamental resonance frequency are seen in this figure, and the resonance peaks form a smoothly decreasing envelope. Six harmonics can be distinguished, and the fundamental frequency of 436 Hz is dominant. The placement of the harmonics and their relative amplitude, as well as the clarity of tone and ability to project suggest that the shell cavity has an exponential profile. In order to find out if this was true, the cavity geometry was examined using x-ray tomography.

GEOMETRICAL MODEL OF A CONCH SHELL CAVITY

The three-dimensional nature of the cavity geometry along with its irregular cross-section makes prediction of conch trumpet harmonics a difficult task. The results of spectral analysis suggest that a one-dimensional model is valid despite the non-symmetrical nature of the duct cross-section, as indicated in a previous study by Bhat [3]. The model developed here uses an approximate duct length based on an average radius, and a cross-section with different major and minor axes.

The rigid walls of the conch shell are excellent for the production of sound, but they impede geometrical measurements of the cavity. X-ray tomography was used to reveal the cavity geometry of the *Turbinella Pyrum* that was used for spectral analysis. A view of the shell sectioned through the longitudinal axis is shown in Figure 3. This figure was used to find the location of the cross-sectional area center points in terms of angular location θ, radius r and height z. These points were projected onto the rθ plane (where z=0) and an Archimedes spiral was fit to the data, as shown in Figure 4. An Archimedes spiral has the form $r = k\theta$, where k is a constant, but in this case a constant could be used only for piecewise sections of the spiral. Appropriate constants were found for each section, and a sixth-order polynomial fit was used to find k as a function of θ. Measurements from Figure 3 were then used to approximate the height z as a function of r at every half-turn of the spiral. The results are shown in Figure 5.

Once the height and radius are known as a function of angle, it is possible to determine the length of the spiral by summing the results of a piecewise calculation:

$$dL_{arc} = \sqrt{dx^2 + dy^2 + dz^2} \tag{1}$$

where $dx = r\cos(d\theta)$, $dy = r\sin(d\theta)$, and $dz = dz(r)$. The size of the differential arc length is controlled by dθ, and the total length was calculated using increasingly smaller angles until the length converged satisfactorily. The approximate total duct length was calculated to be 51 cm, which is very close to a rough estimate of the length found by wrapping a string along the outside spiral of the shell and then measuring its length.

The harmonic series that can be produced on any open-ended duct can be determined using the well-known relation [4]:

$$f_n = \frac{nc}{2L'} \qquad n = 1,2,3... \tag{2}$$

where n refers to the harmonic number, c is the speed of sound in air, and L' is the acoustic or effective length of the horn. The effective length can be calculated as [4]:

$$L' = L_{physical} + 0.6\,(r_{throat} + r_{mouth}) \tag{3}$$

where r is the radius of an unflanged open end. The presence of the player's lips eliminates the need for an end correction at the throat. In addition, it is assumed that the standing wave is reflected back from a point somewhere inside the final flare, as in a French horn bell mouth, so that the physical length would actually be longer than the acoustic length. Therefore no end correction was used to alter the tube length in this analysis.

By placing cross-sectional measurements extracted from Figure 3 at corresponding points along the length of the duct as calculated above, it was possible to approximate the cavity profile as it would be if the conch spiral were straightened out. The results are presented in Figures 6 and 7, which illustrate cavity profiles for the major (vertical) axis and the minor (horizontal) axis, respectively. Both figures reveal an almost conical profile over most of the cavity length, and Figure 7 shows the exponential flare that forms the mouth of the major axis. This is similar to brass wind instruments, which have conical portions in the leadpipe and after the valve section, and terminate in an exponentially flaring bell mouth [5].

It is seen from Figure 6 that the cavity flare increases suddenly at about 39 cm. Equation (2) was used to calculate the fundamental frequency for a 39-cm duct, and the result is $f_1 = 440$ Hz, which is very close to the fundamental frequency measured in the anechoic chamber. This supports the assumption that the standing wave is reflected back from a location near the beginning of the final flare.

CONCLUSIONS

The autospectrum of a conch shell trumpet sounded at its fundamental frequency reveals clear peaks at integer multiples of the fundamental. The fundamental frequency is dominant, and 5 overtones are clearly distinguishable, providing the conch with its characteristic sound. The overtones are relatively "in tune" with the fundamental, the spectral envelope decreases smoothly with increasing frequency, and the autospectrum has no extraneous peaks, indicating that the shell cavity geometry might resemble the geometry of a brass wind instrument. This was found to be true after an approximate model of the cavity geometry was created using measurements from x-ray tomography pictures of the shell interior.

ACKNOWLEDGMENTS

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REFERENCES

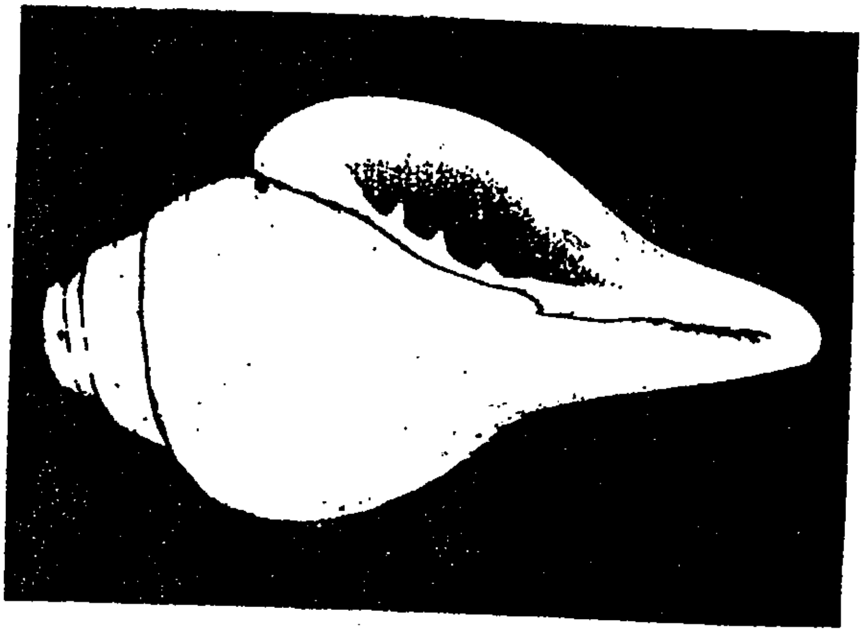
[1] Baines, Anthony. Brass Instruments: Their History and Development. Faber & Faber, London, 1980.

[2] Bhat, R.B. "Acoustics of Conch Shells." *Journal of Sound and Vibration*, 157(1), 1992, 190-191.

[3] Bhat, R.B. "Studies On The Cavity Geometry and Sound Characteristics Of A Conch Shell," Proceedings of the National Symposium on Acoustics, December 12-14, Madras, India.

[4] Kinsler, L.E and A.R. Frey, Fundamentals of Acoustics, 3rd Edition, Wiley, New York, 1982.

[5] Rossing, Thomas D. The Science of Sound. Addison-Wesley, Reading, Massachusetts, 1982.



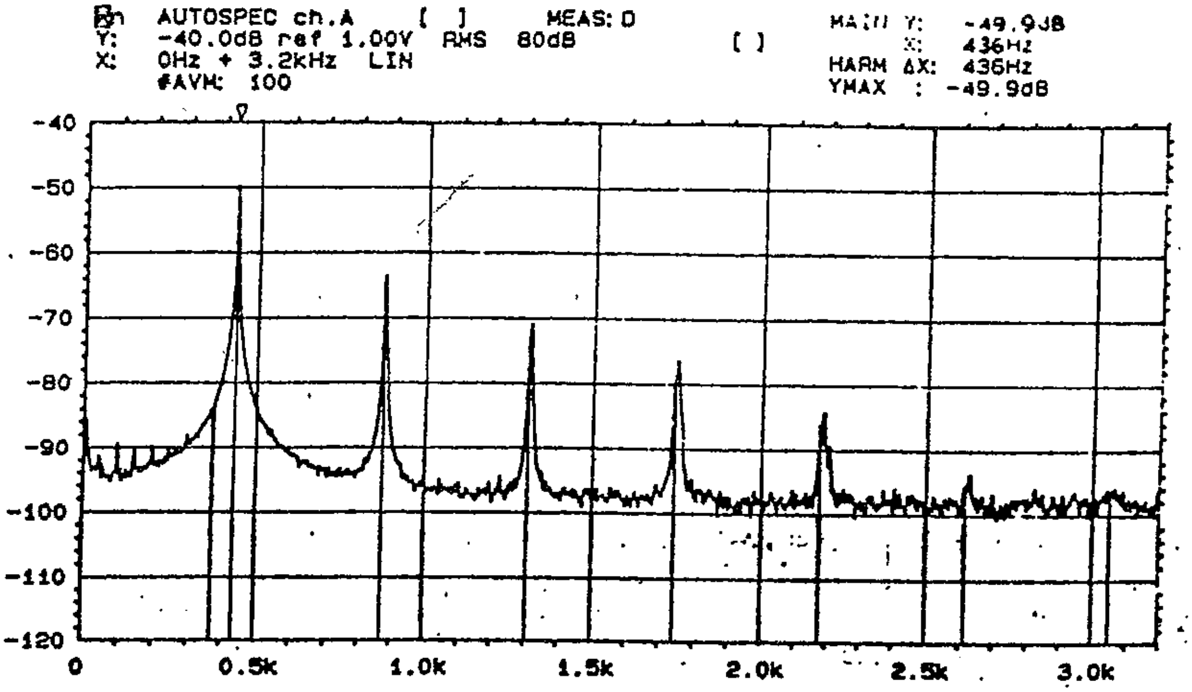


Figure 2. Sound spectrum of conch shell trumpet

Figure 3. X-ray tomography picture of conch longitudinal section.

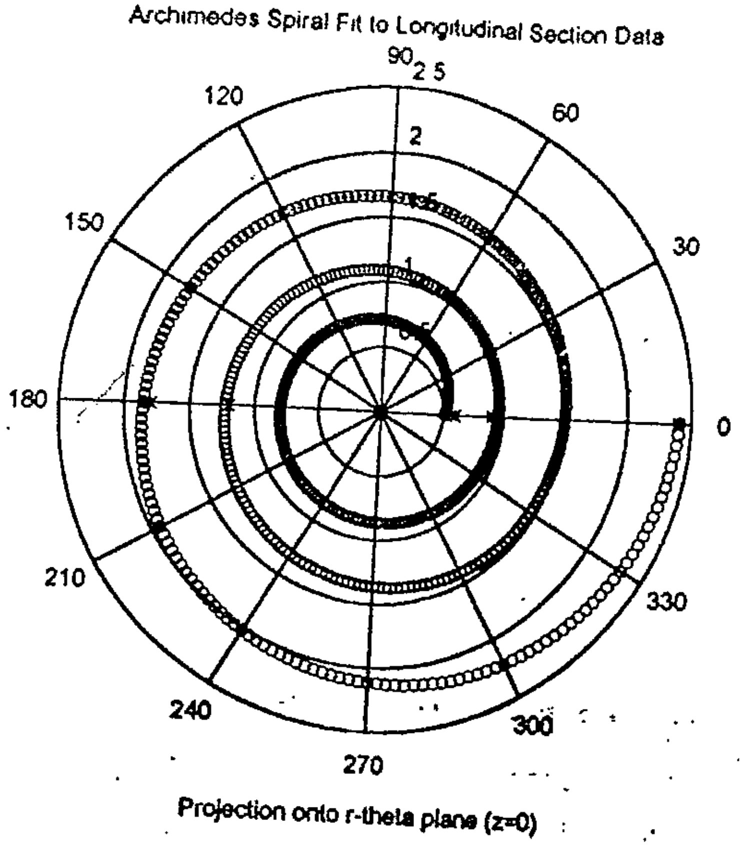


Figure 4. Archimedes spiral fit to longitudinal section data.

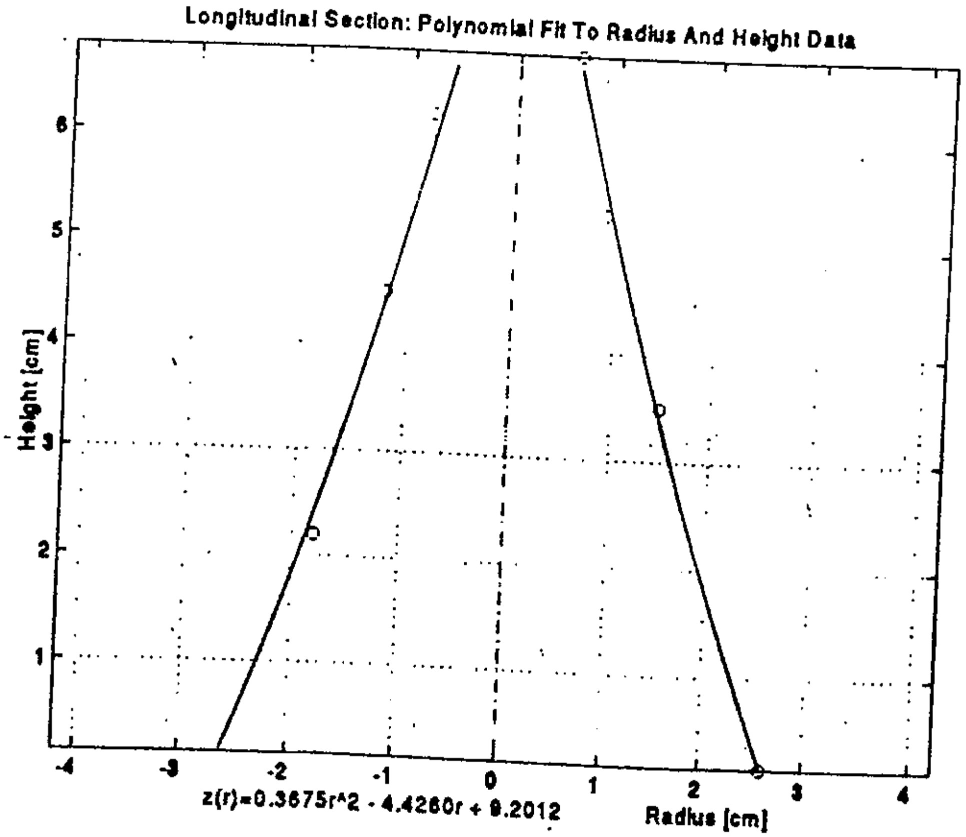


Figure 5. Determination of cross-sectional area center point height as a function of radius.

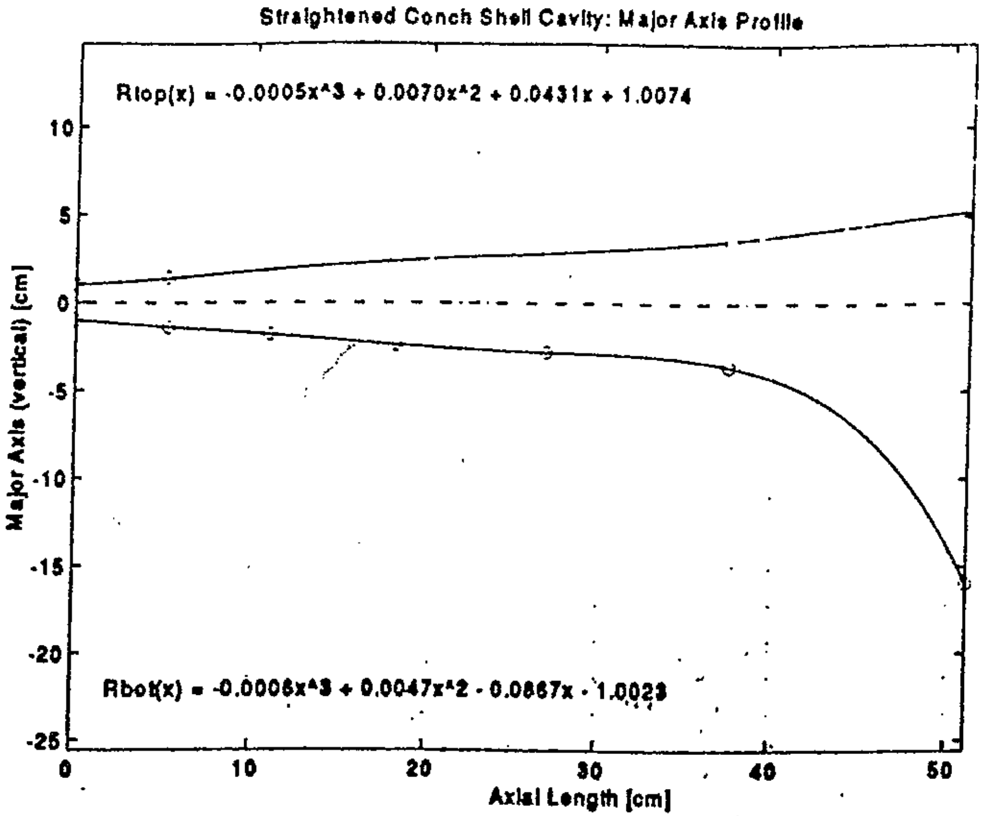


Figure 6. Straightened conch cavity profile, major axis.

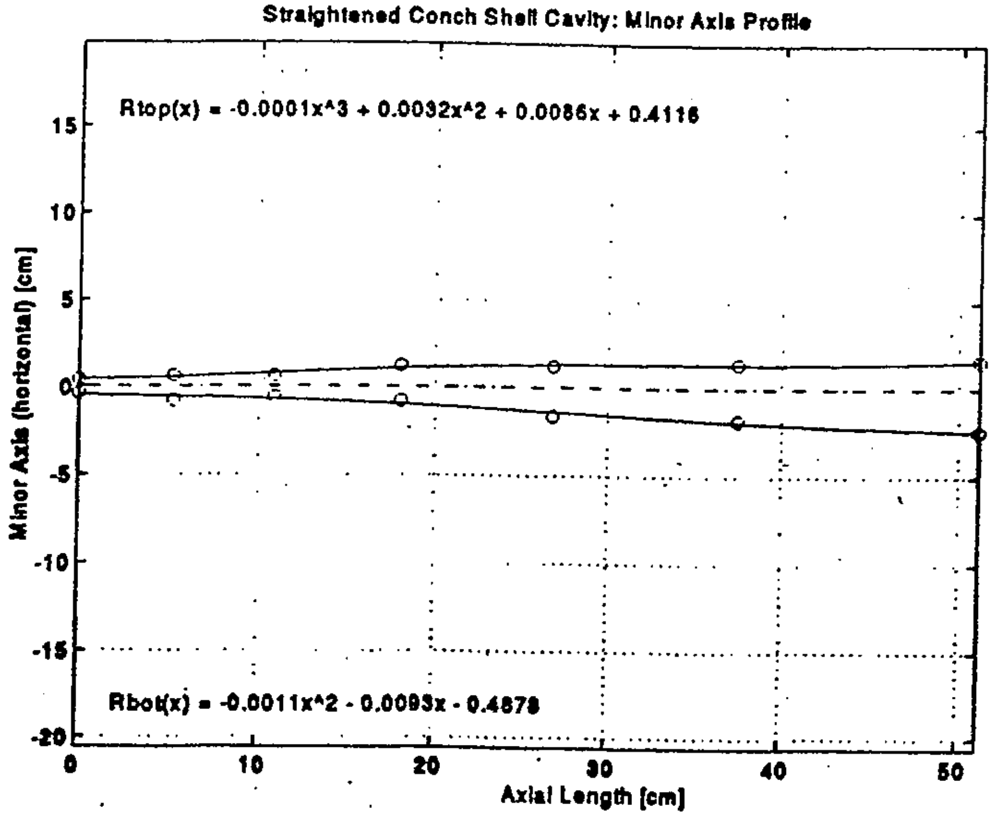


Figure 7. Straightened conch cavity profile, minor axis.