Spectrum analysis and directivity pattern of a transducer-driven Conch shell

Rasoul Morteza Pouraghdam *[1] **and Rama B. Bhat** †[1]
[1]Department of Mechanical and Industrial Engineering, Concordia University, Montreal, Quebec, Canada H3G 1M8

1 Introduction

Conch shells were and are still being used in different cultures around the world, such as in India, Greece and Japan. They served as fog warning devices, but also were used for coded communication purposes, to signify auspicious occasions and as a musical instrument, solo or as part of an ensemble. In this paper, we conduct a geometric analysis of the conch shell spiral cavity with the help of X-ray tomography scans and by approaches used in past literature. Moreover we study the directivity pattern of the conch shell in two excitation cases : 1. Loudspeaker 2. Electro-pneumatic transducer (EPT). Finally we examine the sound spectra in both previous excitation cases, as well as for lip-excitation.

2 Experimental Study

2.1 Geometrical Analysis

It is a difficult task to come up with a single geometry that matches all conch shell spiral cavities. Taylor, Prasad and Bhat [1] obtained X-ray tomography scans of a *Turbinella Pyrum* and showed that the shell's cavity approximates a conical spiral growing around a central stem with a cross-section area varying in both axial and transverse directions. Rath and Naik [2] found the geometry of a Nautilus shell to be a golden spiral, and discovered Fibonacci patterns inside a conch shell with the proper parameter selection. In our sample, we took X-ray tomography scans of a Turbinella Pyrum conch shell. Our measurements showed that none of the shell spiral geometries resembled a golden spiral. We also followed the same measurement procedure done by Rath and Naik and found Fibonacci patterns in our conch shell sample (table 1). We finally applied the same measurement approach done by Bhat [3] in order to find the equivalent acoustical straight tube to a given conch shell spiral cavity. We found a 55 cm conical tube to approximate our Turbinella Pyrum shell inner cavity. The resonances of a 55 cm conical tube and the lip-driven Turbinella Pyrum matched with minimal deviations. The result for the Turbinella Pyrum is displayed in table 2 (tagged as estimation).

Distance between points	Green Points	Pink Points
1 & 2	23 cm	12 cm
3 & 4	40 cm	22 cm
5 & 6	63 cm	34 cm

Table 1: The Fibonacci pattern is clearly present with the correct selection of parameters, as originally demonstrated by Rath and Naik.

*. r_morte@encs.concordia.ca
†. rama.bhat@concordia.ca

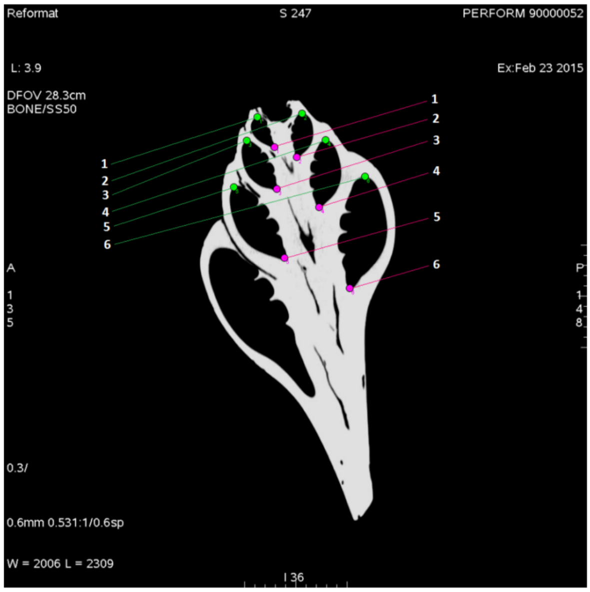

Figure 1: X-ray scan of our Turbinella Pyrum with selection points.

2.2 Spectrum Analysis

Taylor, Prasad and Bhat [1] also carried out a spectrum analysis of a conch shell. They found that when the shell is excited by lip-vibration, the sound spectrum contains harmonics that decrease smoothly in magnitude. Their results confirmed Bhat's [3] earlier findings. A skilled brass player could generate different notes by exciting different frequencies of the shell's cavity with the proper lip tension adjustment. This has been clearly displayed by the famous American trombonist Steve Turre who is also a conch shell virtuoso.

The sound spectrum of our lip-excited conch shell also displayed a fundamental frequency and several harmonics. Moreover, we measured the spectra in two other excitation cases as well. All of the measurements were done in an anechoic chamber and the results are presented in table 2.

Loudspeaker Sine Sweep Measurement

The sine sweep measurement was done by attaching a small loudspeaker to the throat of the conch shell. We set the frequency span to 100 - 2000 Hz with a time span of 1 second. Figure 2 shows the spectrum of the loudspeaker-driven Turbinella Pyrum.

The output spectra of the conch shell displayed harmonic resonances of a fundamental frequency, but slightly shifted which is acceptable as the shell's geometry is not perfect. The results verify that the shells are approximately wrapped conical tubes around a central stem, since it is a known fact that resonances inside a conical tube are harmonics of a fundamental mode.

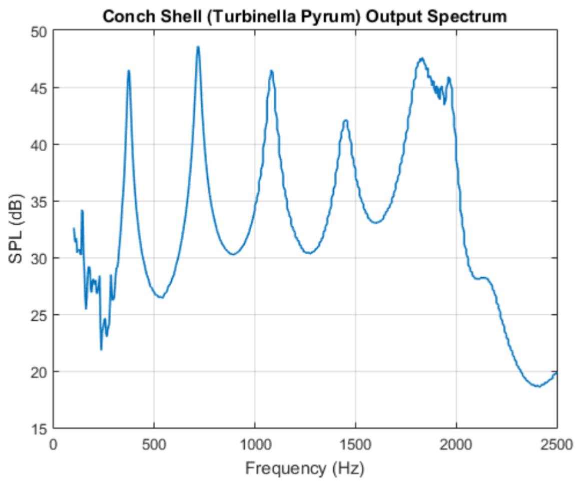

Figure 2: The Turbinella Pyrum resonances at 372, 716, 1080, 1450 and 1830 Hz

Electro-Pneumatic Transducer (EPT)

In this setup, the Turbinella Pyrum was driven by an EPT operating at 52 Hz. This was an attempt to see how the shell would respond to an excitation different than a sine sweep, and how closely it simulates lip-excitation. The output spectrum displayed $3k + 4$ multiples of the driver frequency (52 Hz) where $k = 0, 1, 2, ...$ and although a clear pattern is found, not much can be deduced due to the non-linear nature of the excitation.

Loudspeaker	EPT	Lip-vibration	Estimation
372	52	315	312
716	208	626	624
1.08K	364	944	936
1.45K	520	1.26K	1.25K
1.83K	676	1.57K	1.56K

Table 2: Resonance modes of the Turbinella Pyrum in different excitation cases (in Hertz). The estimated resonance frequencies correspond to the theoretical resonances of an equivalent conical (straight) tube to the shell's spiral cavity.

2.3 Directivity-Pattern

We carried out directivity measurements of the loudspeaker and EPT-driven Turbinella Pyrum in both horizontal and vertical alignments. The measurements were done in an anechoic chamber where the shell was mounted on a tripod, positioned at the center of the room. The loudspeaker was glued to the throat of the shell and a microphone positioned in front of the mouth of the shell at a distance of 1.35 m was used to capture the output.

The loudspeaker was driven at a given frequency and the shell was rotated at 60° interval about both its longitudinal and transverse axes to find the 2-D 360° directivity pattern in both vertical and horizontal alignments of the shell. The same configuration was used for the EPT-driven shell.

Based on our results, the shell radiates sound uniformly in space at frequencies near the shell's cavity resonance. It is also seen that the shell's alignment makes negligible difference.

Degree	LS-H	LS-V	EPT-H	EPT-V
0	73.7	73.9	55.1	55.1
60	73.1	72.8	53.4	53.5
120	73.1	72.2	53.0	52.5
180	73.6	72.8	53.9	53.0
240	74.6	73.6	55.2	54.3
300	74.5	73.6	53.9	53.2

Table 3: The captured output magnitude (in dB) for the loudspeaker (LS) and EPT excitations at 310 Hz in both horizontal (H) and vertical (V) alignments.

3 Conclusions

In this study we confirmed that by using X-ray scans of a conch shell, the spiral inner cavity could be approximated by a straight conical tube, originally suggested by Bhat [1,2]. We also carried out sine sweep measurement of the conch shell and found the resonance modes to fall in integer multiples of a fundamental frequency with minimal deviation. The lip-driven shells display perfect harmonics and only some of the harmonics are excited when driven by an Electro-pneumatic transducer (EPT). Finally we carried out directivity measurements of a conch shell in both vertical and horizontal alignments, excited by a loudspeaker and an EPT. The results indicated that the shell is essentially an omnidirectional source when excited near its cavity resonance frequency.

Acknowledgments

We would like to highly thank Chetas Shah and Pratik Desai for having carried out the directivity and the Electro-pneumatic transducer spectrum measurements in the anechoic chamber.

References

[1] M.G. Prasad, L.R. Taylor and R.B. Bhat. Geometrical modeling and spectral analysis of a conch shell trumpet. *Third International Congress on Air And Structure-Borne Sound And Vibration*, June 1994.

[2] S.K. Rath and P.C. Naik. Fibonacci structure in conch shell. *Current Science*, 88(4) :555–557, February 2005.

[3] R.B. Bhat. Acoustics of conch shells. *Journal of Sound and Vibration*, 157(1) :190–191, 1992.