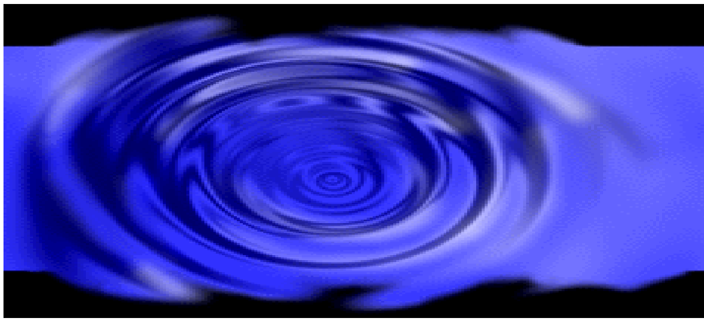


Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing

January 2004 Newsletter

Dominus Vobiscum

We are continually exposed to sounds from a plethora of sources. Some of the sounds are unwanted noise. Other sounds are pleasing music.

Beverage bottles, crystal glassware, and other household objects can be used as improvised musical instruments. These objects are also very useful for teaching students about sound vibration principles.

This month’s newsletter presents some acoustic experiments using these items. The resulting sounds were recorded on a Nicolet Vision data acquisition system. I use this system to measure pyrotechnic shock data from rocket vehicle tests.

The same experiments, however, could be readily performed using a computer sound card. A student could thus repeat the tests for a science project. I would be happy to provide guidance to any teachers or students who are interested.

Sincerely,

Tom Irvine

Tom Irvine
Email: tomirvine@aol.com

Feature Articles

Crystal Glass Singing page 2

Beverage Bottles as Helmholtz Resonators
Page 6

Figure 1.

Crystal Glass Singing

By Tom Irvine

Introduction

A crystal glass emits a high-pitch tone as a finger-tip rubs its rim. This effect is a well-known demonstration of sound and vibration.

Galileo Galilei (1564-1642) wrote about this subject in *Two New Sciences,* published in 1638. He also wrote about musical instruments and octaves in this same book.

Benjamin Franklin (1706-1790) had a keen interest in music. He invented a musical instrument called an “armonica” using a set of tuned wine glasses. Franklin wrote "Of all my inventions, the glass armonica has given me the greatest personal satisfaction."

Mozart, Beethoven, and other composers even wrote music for this instrument.

Molecular Structure

Glass is an amorphous solid that lacks crystalline order.

Common glass is made by melting a mixture of quartz sand (silicon dioxide), soda (sodium oxide), and lime (calcium oxide). The quartz forms the basic structure of the glass. The soda makes it much easier to melt and work with. The soda also makes the glass weaker and more temperature sensitive. The lime prevents the soda-rich glass from dissolving in water.

Common glassware is relatively soft with high internal friction. It thus emits a dull sound when struck.

In contrast, crystal glass has lead oxide, which makes the glass easier to melt while maintaining strength. As a result, crystal is hard with little internal friction. These properties give crystal its unique acoustical response.

Mechanism

Crystal glass singing in response to finger-tip rubbing is often described as resonance by science references. Many of these sources use resonance to characterize the excitation of a natural frequency by any means whatsoever. This is a common but imprecise usage of this term.

A true resonant response occurs when the excitation frequency coincides with the natural frequency.

The finger-tip motion around the rim of the glass lacks such a frequency, however.

Rather the mechanism is slip-stick excitation due to frictional effects between the finger and the glass.

The frictional effect is characterized as “dry damping.” The damping force decreases as the velocity increases.

On a submicroscopic scale, the glass molecules along the rim initially follow the motion of finger-tip. The frictional force is rather high during this phase because there is very little relative velocity between the finger and the glass molecules. The molecules are thus stretched from their rest position.

Eventually, elastic forces within the glass cause the rim molecules to snap back to their rest position, except that inertia causes the molecules to overshoot this mark. During this phase, the rim molecules are traveling in the opposite direction as the finger. The relative velocity is high, and the frictional forces are low.

After the overshoot, the elastic forces then attempt to bring the molecules back to the rest position. The cycle is then repeated.

This process is a “self-excited” vibration response, rather then a resonant response. It is due to the imbalance in frictional forces with respect to the relative motion between the finger and the glass molecules.

The glass vibration generates an audible tone as a result, since the surrounding air molecules vibrate at the same frequency as the glass. This frequency is called the natural frequency of the glass. The glass has a number of natural frequencies. The first is called the fundamental frequency.

A further explanation of self-excited vibration is given in: Den Hartog, Mechanical Vibrations, Dover, New York, 1985.

Test Procedure

I performed an experiment using a Mikasa leaded crystal wine goblet, identical to the one shown in Figure 1. The goblet had a diameter of 2.75 inch at the opening.

A wet finger-tip was rubbed around the rim. The resulting tone was recorded using a Radio Shack sound level meter with an integral microphone.

The analog signal from the microphone was recorded by a Nicolet Vision data acquisition system. Two tests were performed.

Empty Crystal Glass

The glass was empty for the first test. A time history segment is shown in Figure 2 for this case. The corresponding spectral function is shown in Figure 3. The fundamental frequency is 677 Hz, with a slight harmonic at 1354 Hz. The harmonic is one octave higher than the fundamental frequency. The resulting tone has a musical note between E and F.

Half-Full Crystal Glass

The glass was filled halfway with water for the second test. A time history segment is shown in Figure 4 for this case. The corresponding spectral function is shown in Figure 5. The fundamental frequency is 650 Hz, with a harmonic at 1300 Hz. This is nearly an E note on the musical scale.

The addition of water lowered the fundamental frequency as expected. The decrease was only 4%, however. Note that the water increases the effective mass of the crystal, thus lowering the frequency.

Furthermore, the harmonic was more prominent for the half-full glass than for the empty glass.

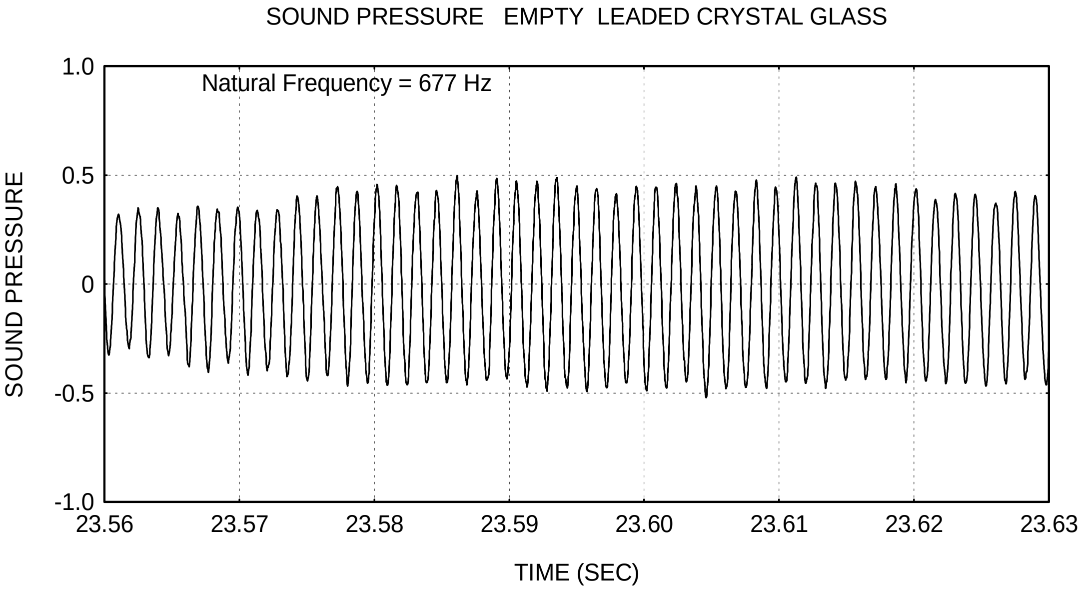


Figure 2.

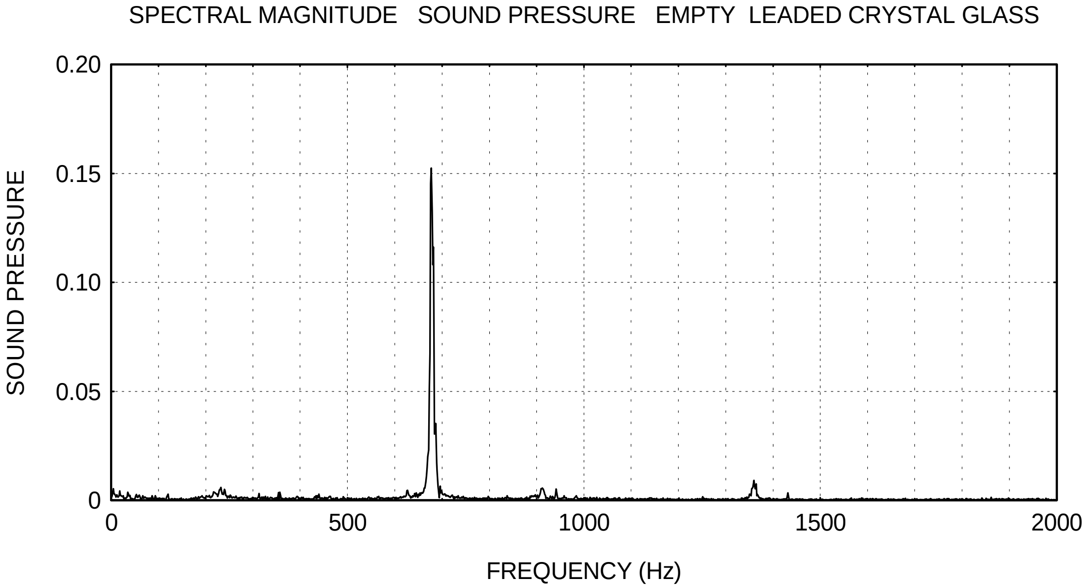


Figure 3.

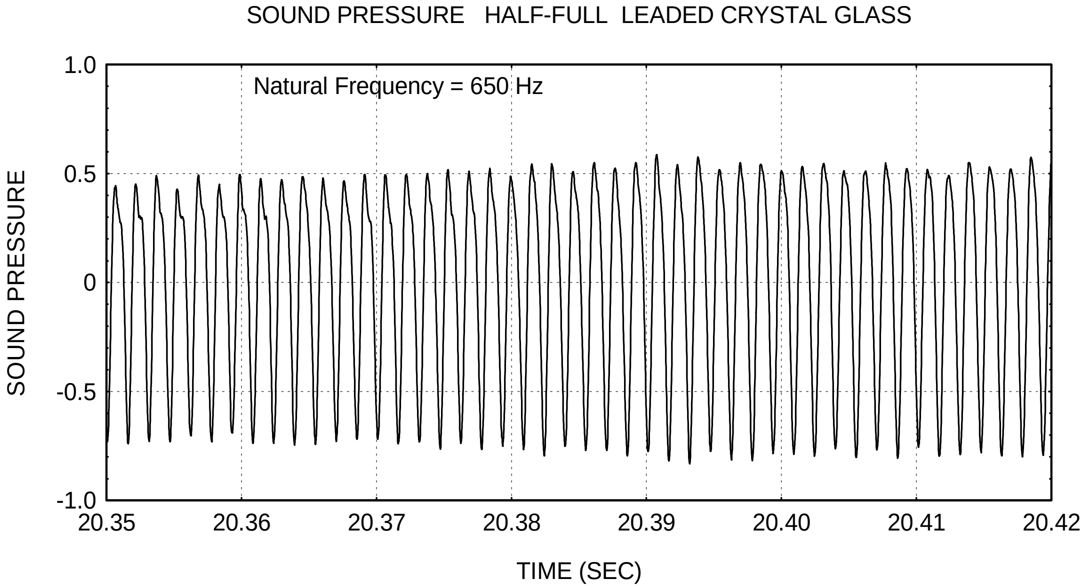


Figure 4.

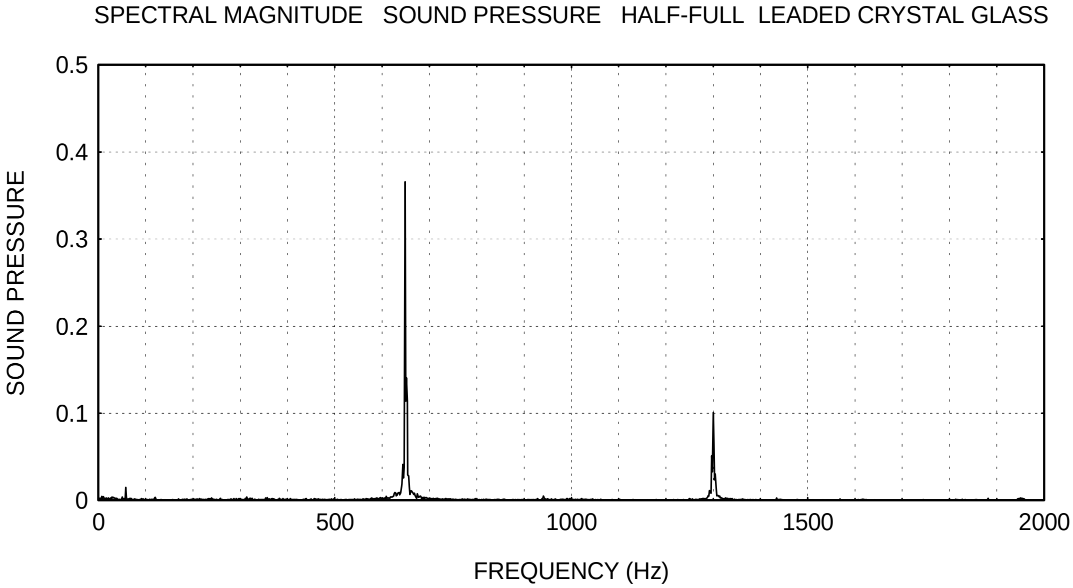


Figure 5.

Beverage Bottles as Helmholtz Resonators

by Tom Irvine

Introduction

A Helmholtz resonator is a volume of air which is enclosed in a container with at least one opening. It is also called a cavity resonator.

Perhaps the simplest example is a pop bottle. There are many other types. Some examples are:

1. A hollow sphere with a narrow neck
2. A large rectangular box or cylinder with a perforated cover
3. Air in the body of a guitar
4. A vented loudspeaker

Natural Frequency Formula

The air in the bottle's neck acts as a mass. The air in the volume acts as a spring. The Helmholtz resonator thus behaves as a mechanical spring-mass system.

Consider a bottle excited by a steady-state air jet. As the air in the neck moves inward, the pressure in the bottle rises and pushes the air in the neck back out. The air mass overshoots the rest position. As a result, a slight vacuum is created inside the bottle, which pulls the air mass into the cavity. The air mass again overshoots its rest position. The cycle repeats itself.

The resulting oscillation is an example of simple harmonic motion, since it occurs at a single frequency.

The natural frequency f_n in a Helmholtz resonator such as a bottle or sphere is given by

$$f_n = \frac{c}{2\pi}\sqrt{\frac{A}{L_e V}} \qquad (1)$$

$$L_e = L + 1.5\,r \qquad (2)$$

where

C	is speed of sound in the fluid or gas
A	is the cross-sectional area of the neck
V	is the volume of the chamber
r	is the radius of the neck
L	is the length of the neck
L_e	is the effective length of the neck

The effective length is longer than the actual length due to "radiation-mass loading."

Speed of Sound

The speed of sound in air is approximately c = 1125 ft/sec, or 13,500 in/sec.

Excitation Method

The natural frequency can be excited by blowing across the opening as shown in Figure 1.

In addition, the transient response can be excited by sealing the opening with the palm of the hand and then suddenly releasing the palm. This method could allow the loss factor to be calculated from the resulting pressure decay.

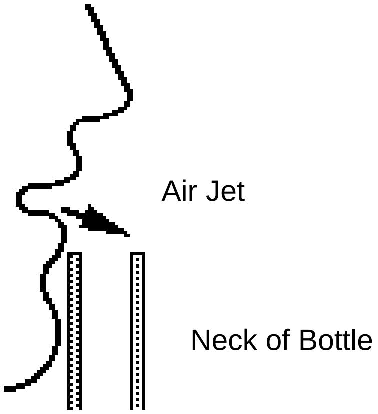


Figure 1. Excitation of the Helmholtz Resonance

(Image courtesy of The University of New South Wales, Australia)

Tests

Four bottles were tested, using the blowing method in Figure 1. Again, the data was recorded using a Radio Shack sound level meter and a Nicolet Vision data acquisition system.

Each bottle opening had an inside diameter of 0.875 inch, with an area of 0.60 inch^2.

The calculated natural frequency for each bottle is shown in Table 1.

The test results are compared with the theoretical frequency in Table 2. In each case, the measured frequency was slightly lower than the calculated frequency.

Sprite (2 liter)

The time history for the Sprite bottle is shown in Figure 2. The fundamental frequency is 106 Hz.

The corresponding spectral function is shown in Figure 3. The energy near zero Hz is due to noise. The fundamental frequency appears at 106 Hz. Harmonics appear at integer multiplies, although the amplitude of each is relatively small.

Minute Maid Lemonade (20 fl oz)

The time history for the Minute Maid bottle is shown in Figure 4. The fundamental frequency is 185 Hz. The spectral function is shown in Figure 5. The response is a pure tone with no appreciable harmonics or beat frequencies.

Arrowhead Spring Water (0.5 liter)

The time history for the 0.5 liter water bottle is shown in Figure 6. The fundamental frequency is 209 Hz.

The spectral function is shown in Figure 5. A small harmonic peak occurs one octave higher.

Arrowhead Spring Water (8 fl oz)

The time history for the 8 fl oz water bottle is shown in Figure 8. The fundamental frequency is 304 Hz.

The spectral function is shown in Figure 8.

Table 1. Calculated Helmholtz Frequency

Bottle	Volume (Liters)	Volume (inch^3)	L (in)	r (in)	Le (in)	fn (Hz)	Nearest Musical Note
Arrowhead Spring Water (8 fl oz)	0.237	14.5	1.0	0.44	1.66	342	F
Arrowhead Spring Water	0.5	30.5	1.0	0.44	1.66	236	A#
Minute Maid Lemonade (20 fl oz)	0.591	36.1	1.2	0.44	1.86	203	G#
Sprite	2.	122.1	1.2	0.44	1.86	110	A

Table 2. Helmholtz Frequency Comparison

Bottle	Calculated fn (Hz)	Measured fn (Hz)	Error
Arrowhead Spring Water	342	304	12.5%
Arrowhead Spring Water	236	209	12.9%
Minute Maid Lemonade	203	185	9.7%
Sprite	110	106	3.8%

The error is with respect to the measured value.

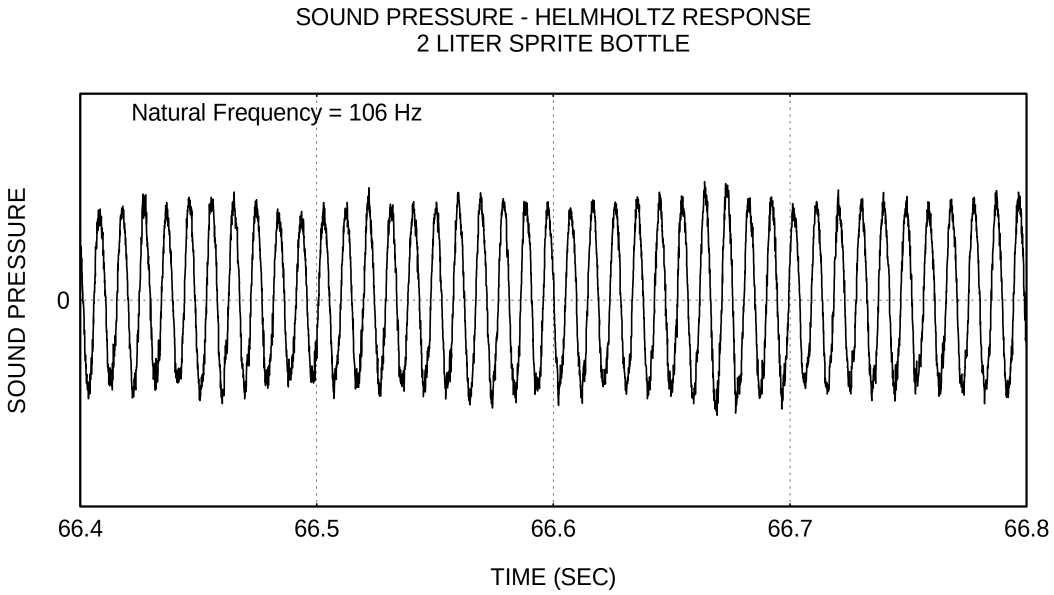


Figure 2.

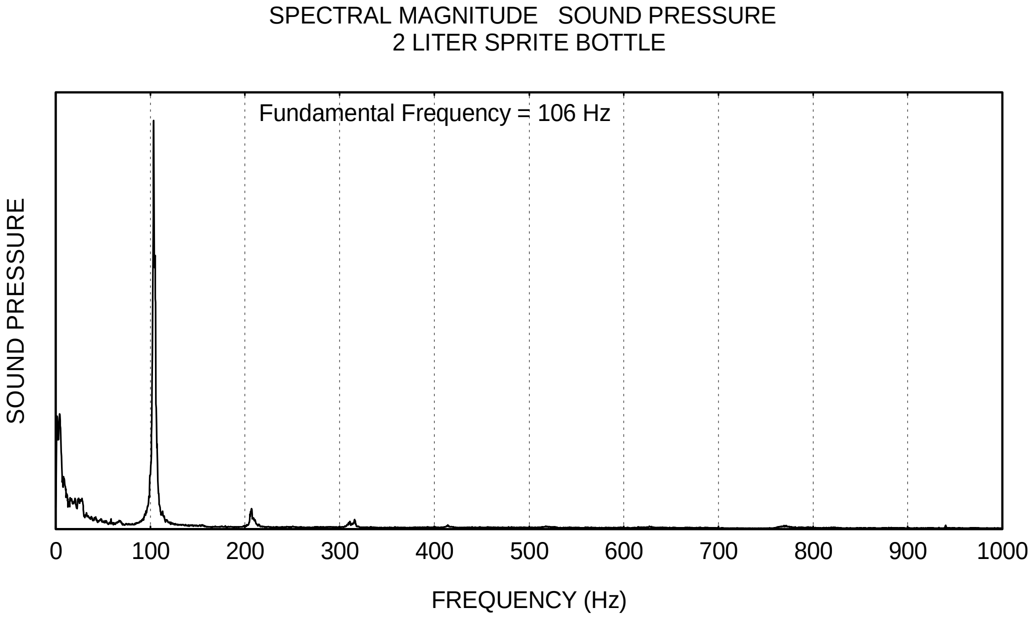


Figure 3.

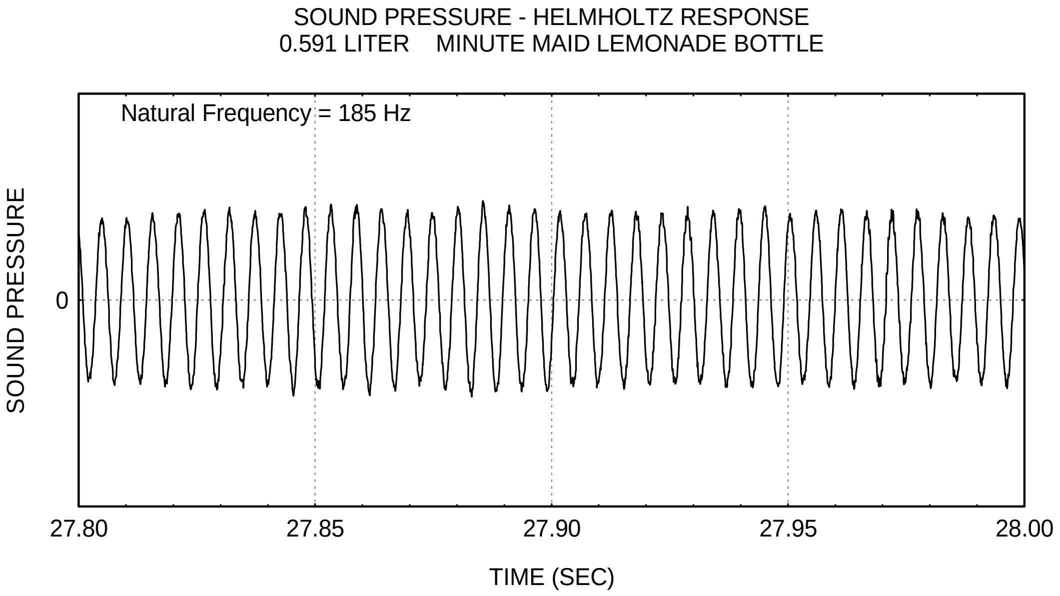


Figure 4.

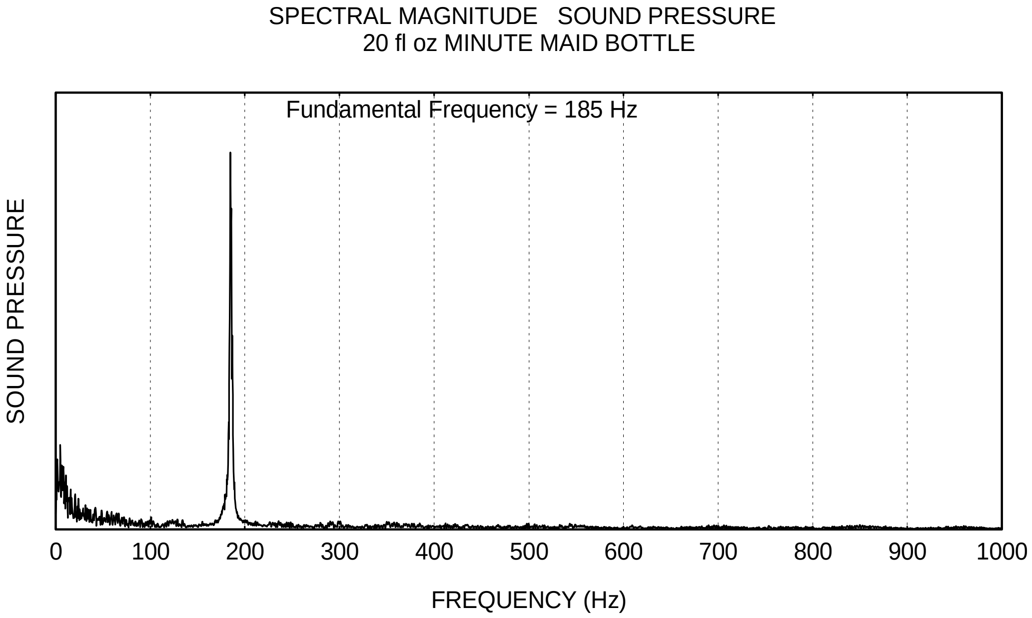


Figure 5.

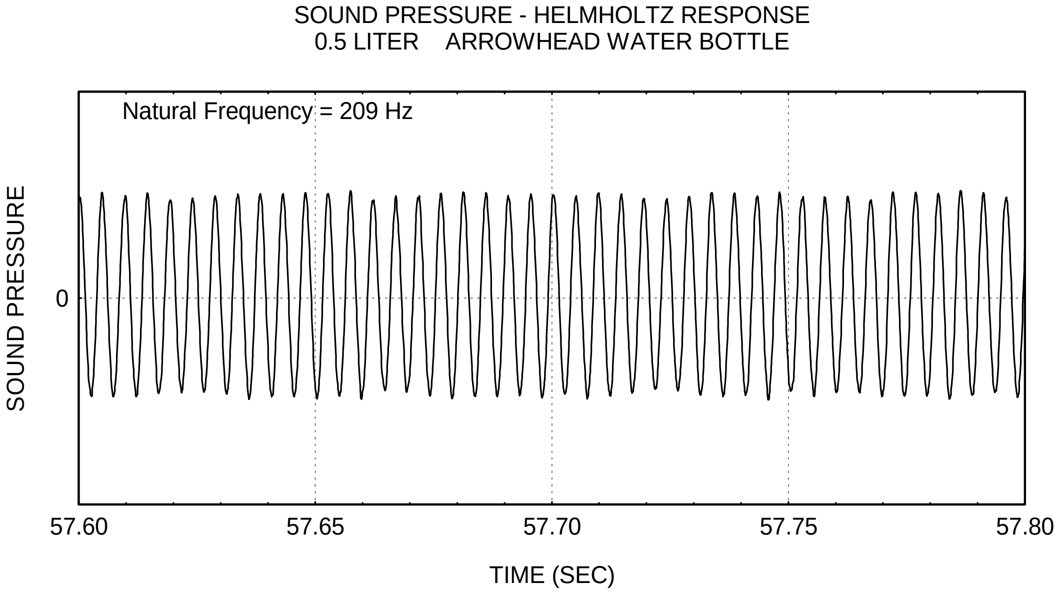


Figure 6.

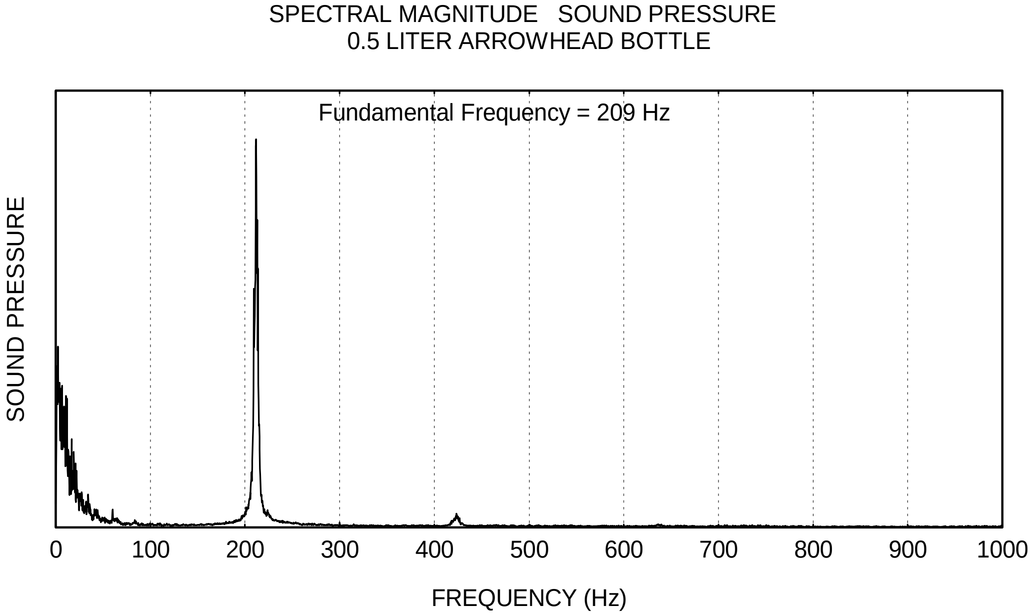


Figure 7.

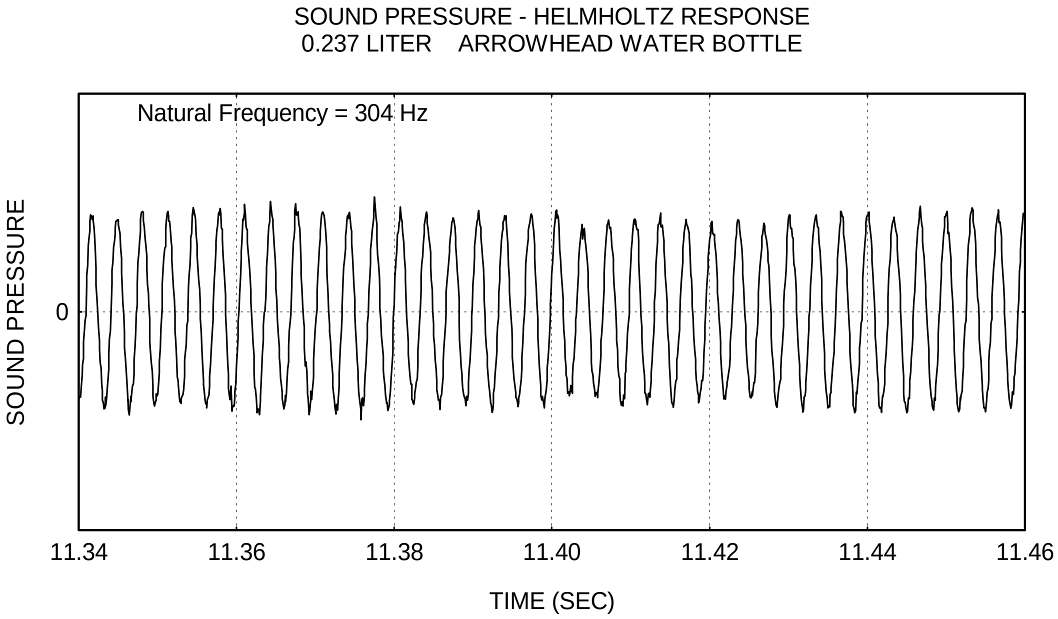


Figure 8.

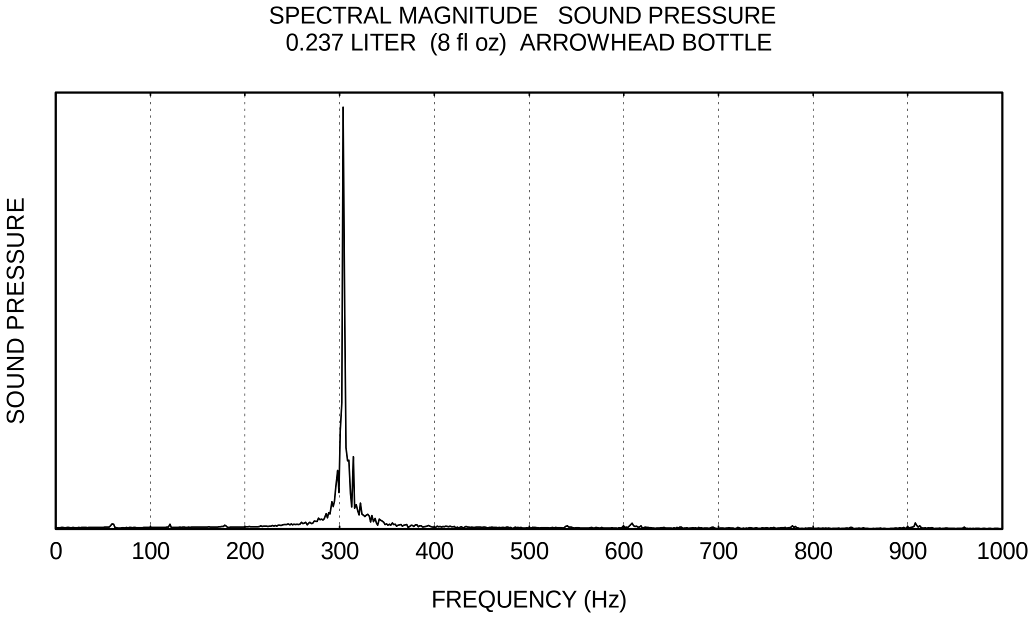
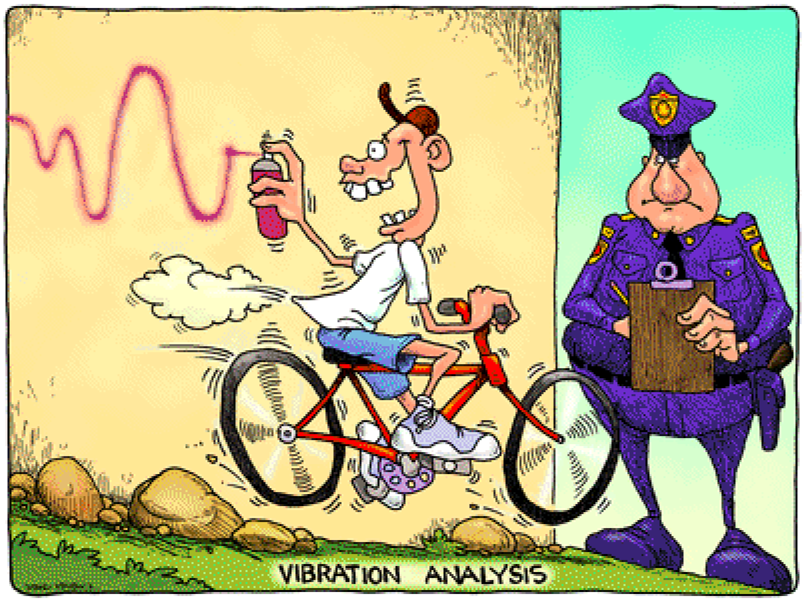


Figure 9.



Courtesy of UCSB and R. Kruback