It's An Open & Shut Musical Pipe And That's About the Shape of It

BY ROGER GOODMAN

In the last issue we explored the exciting world of beer bottle music. This article continues the road to understanding a little more about wind instruments and begins with a question: Why does the clarinet sound a full octave lower than the flute even though they are both about the same length? To begin to get to the bottom of this mystery, let's quickly review the last issue's topic about resonance and standing waves (see the Archives at *www.folkworks.org* Vol. 4 No. 5 page 4).

To summarize what was covered in the last issue, when you blow over a bottle, the column of air inside the bottle is excited, thus producing a state of resonance. Resonance is characterized by the existence of a standing or stationary wave. Standing waves have regularly re-occurring locations called nodes where the sound wave's amplitude remains at zero and, therefore, does not move. (If you can overlook a little misspelling, you can remember that **NODES** are points of **NO-DES**placement). Half way between each node there are locations of maximum displacement called anti-nodes.

As it turns out, playing an orchestral wind instrument is just a more sophisticated way of blowing over the mouth of a bottle. Blowing into the instrument excites the column of air and causes it to resonate.

Most wind instruments can be visualized as cylindrical pipes that can be divided into two groups defined by their boundary conditions. Boundary conditions refer to what happens at the ends of the tube. Cylindrical tubes can be open pipes (both ends open) or closed pipes (one end closed). All orchestral wind instruments react as open pipes except for the instruments in the clarinet family that react acoustically as closed pipes.

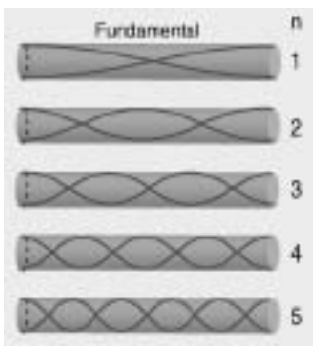

Figure 1. Open Pipe (Flute)

OPEN PIPES

The flute is a good example of an open cylindrical pipe (open to the outside air on both sides). Since the open ends of a pipe do not obstruct air movement, nodes (nodes = **NO-DES**placement) cannot form there. Instead, anti-nodes will occupy these openings. With anti-nodes at each end of the tube, the standing wave, by definition, says that there must be a node midway between them (see **Figure 1**, n=1). This is the fundamental or lowest vibrational mode of the instrument. Note that the pipe contains only half of a complete cycle or sine wave. So the wavelength is actually twice the length of the pipe. By opening successive finger holes, the flautist can shorten the effective length of the pipe and produce successively higher pitches. That's what makes it possible to play a scale.

However, the capability of the flute is much greater than a single scale. The flautist extends the range by over-blowing to kick the instrument into the next higher register. Over-blowing is a technique where the flautist increases the rate of airflow. This, in turn, pushes the instrument toward a higher pitch. But the instrument can only resonate at pitches that place an anti-node at the openings of the pipe. In the next available resonant mode (see **Figure 1**, n=2) the pipe will contain a complete sine wave or cycle. This means that the new wavelength is half of the fundamental wavelength, so the frequency or pitch is doubled. With that, the mode is an octave above the fundamental. While in this mode (register) the fingering pattern can again be applied to produce the next scale.

The next register up (**Figure 1**, n=3) contains 1½ full cycles, which places it at an octave and a fifth above the fundamental. The next register above that (**Figure 1**, n=4) fits two complete cycles into the pipe making it two octaves above the fundamental frequency.

CLOSED PIPES

As mentioned above, the instruments of the clarinet family respond acoustically as closed pipes (open to the outside air at the bell, but closed by the player's mouth at the other end). There must be a node at the closed end where the air movement is obstructed (remember **NODES** = **NO-DES**placement) and an anti-node at the open end. As shown in **Figure 2**, there is only room for one quarter of a wavelength within the closed pipe instead of the one half of a wavelength that fit into the open pipe. This means that the fundamental of the clarinet sounds an octave lower than the fundamental of the flute even though they are about the same length (and that's the answer to our initial mystery question!).

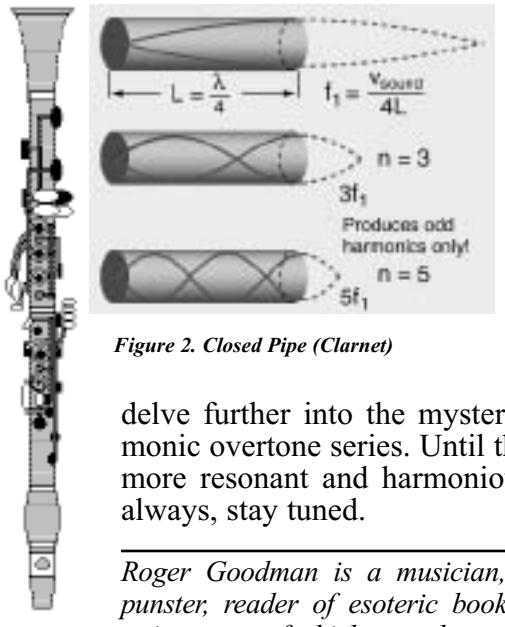

Figure 2. Closed Pipe (Clarnet)

The next register up still has to have a node at the closed end and an anti-node at the open end. You can see (from **Figure 2**, n=3) that only three quarters of a wavelength fits into the pipe for the fundamental mode. The next register above that follows from the next available anti-node (**Figure 2**, n=5) and allows one and one quarter wavelengths to fit within the pipe.

By now you might be wondering about the **values of n** from **Figures 1** and **2**. In the next installment of FolkWorks you will see that these **values of n** represent the **harmonic overtones** that are built upon the fundamental. As we observed above, the flute, because it is an open pipe, can resonate all of the harmonics (n = 1, 2, 3 …) while the clarinet, since it acts as a closed pipe, can only resonate the odd numbered harmonics (n = 1, 3, 5 …). Adding up the sine waves for just the odd numbered harmonics results in a wave form that is moving from the smooth sine wave towards an edgy square wave. This is what gives the clarinet its characteristically hollow and throaty sound.

The next article will examine the harmonics of stringed instruments and show that they are rather similar to those of an open pipe. We will also delve further into the mysteries of the harmonic overtone series. Until then strive for a more resonant and harmonious life and, as always, stay tuned.

Roger Goodman is a musician, mathematician, punster, reader of esoteric books and sometime writer, none of which pays the mortgage. For that, he is a computer network guy for a law firm. He has been part of the Los Angeles old-time & contradance music community for over thirty years. While not a dancer, he does play fiddle, guitar, harmonica, mandolin, banjo & spoons. Roger has a penchant for trivia and obscura and sometimes tries to explain how the clock works when asked only for the time. He lives with his wife, Monika White, in Santa Monica.
