The clay pot... that sings

Among the oldest of musical instruments, ocarinas seem like near cousins of the recorder, until you understand the very different physics at play

by Ray and Lee Dessy

ANITA FENG

WHAT SOUNDS LIKE A RECORDER, looks like an egg, a goose or flying saucer, is made of raku-fired clay or wood, makes music like some cicadas or crickets, and is at the heart of Nintendo's most famous computer game? It's the ocarina. This article examines its history, fabrication, playing characteristics, and use in recorder consorts. We'll see how ocarinas differ from recorders and explore their different shapes.

An early hitchiker's guide

Ocarina-type musical instruments probably date back to 10,000 BCE. If you put your thumbs together, cup your hands, and blow, it is easy to guess where the idea came from. Spherical Chinese *Xun* instruments appeared as early as 7,000 years ago, and examples of ancient Egyptian globular flutes exist. Small whistle-based terra-cotta figures of birds and other animals were known in India 6,000 years ago. The earliest pre-Columbian clay instruments are found on the coast of present-day Ecuador and date from 2,000 BCE. Aztec and Mayan zoomorphic hollow flute figures of armadillos, birds, and reptiles are known.

Typically single chambered, these latter instruments were often tuned to a non-Western scale and used in solo and ensemble playing for both ritual and pleasure. Some played only a few notes, but one archaeological marvel could play an impressive 17 notes (x-rays show that it has three chambers).

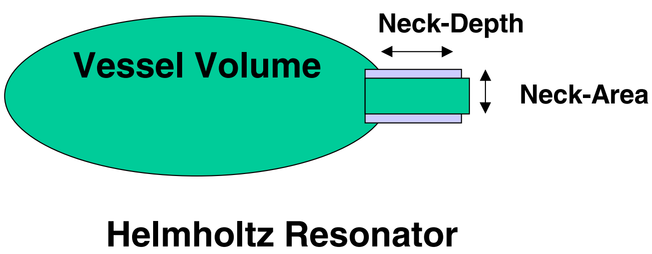
A 1988 Science Section article in *The New York Times* quoted a number of academics on the significance of ocarinas (Source 1). "People often think of these objects as playthings," said UCLA's Sue De-Vale. "That's wrong." Sometimes "they've been written off as another small artifact," said Rutgers' Norman Hammond. But discoveries at Pacbitun (Belize), Guatemala, Honduras, Columbia, and Peru included double, triple, and even quadruple instruments, which could produce more than one note at a time. The ease with which clay could be rolled, pinched, pierced, and cut allowed these cultures to advance musically at a time when Europe was playing with simple flutes. Samuel Marti, a Mexican anthropologist, said, "There can be no doubt that pre-Columbian music reached a level of development comparable, perhaps superior, to the contemporary cultures of Europe." One early Mayan ocarina, dating from 500-600 BCE, was advanced enough to play the first five notes of a diatonic scale. Studies on Colombian instruments show that many had similar tuning systems, allowing them to play in harmony. Dale Olsen of Florida State University said, "The care that went into making these instruments suggests that they were more than diversions or toys."

Best of times, worst of times

Ocarinas were brought to Europe in 1527 after the Spanish conquest. When Cortez sent a group of Aztec dancers and musicians to perform for the court of Emperor Charles V at Valladolid, the *altoplano* bird dancers moved in synchronicity with fippled pottery ocarinas.

One story tells of a Roman baker who used his oven to make low-fire copies as toys and novelty items. The ovoid body

Figure 1: Ocarinas may be thought of as Helmholtz Resonators.



$$f = (sound\_speed / 2pi)\sqrt{(neck\_area)/(neck\_depth * vessel\_volume)}$$

Figure 2: The plane of the fipple's window is made tangential to the body of the ocarina.

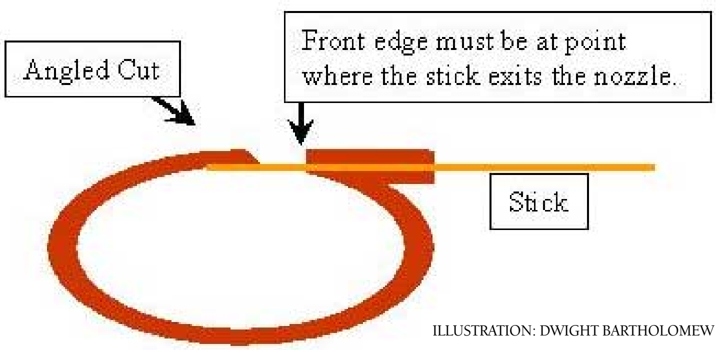
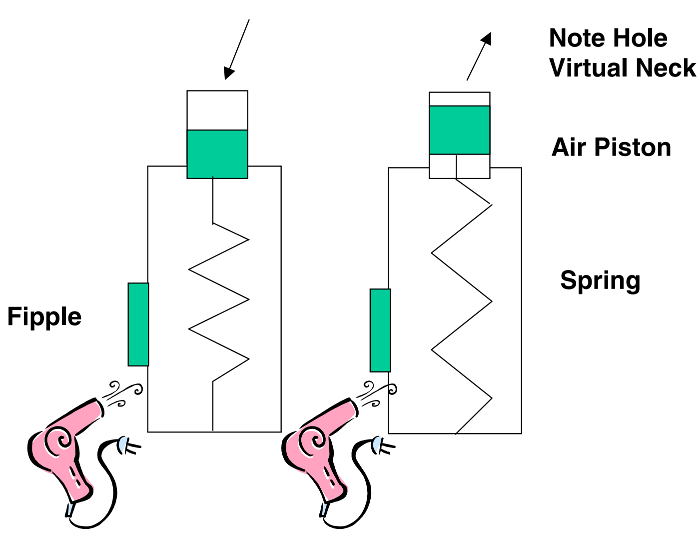


ILLUSTRATION: DWIGHT BARTHOLOMEW

Figure 3: The air in the vessel of the ocarina acts like a spring, moving the air in the tone-holes in and out as if they were pistons in a car engine.



and short stubby fipple neck led to the word "ocarina," meaning "little goose" in the Emilian Italian dialect.

The ocarina was slowly "modernized," and in the mid-1800s Italian craftsmen produced instruments that played a complete scale. This was an era when the demand for inexpensive musical instruments increased dramatically. It was the time for ocarinas and harmonicas. People were happy and prosperous. In the 1860s the economic growth rate in the North "German" area was 8 to10 percent annually, thanks to free trade, new rail systems, the industrial revolution, and Bismark's luck. The Kingdom of Italy was formed in 1861. In the 1860s, Giuseppe Donati set up his first ocarina workshop in Budrio, then Bologne, and finally Milan. In 1870, two ex-apprentices, Ercole and Alberto Mezzetti, set up shop in Paris and London, respectively. In 1878, Cesare Vicinelli began making ocarinas near Budrio, and in 1920 he left his workshop to his assistant Guido Chiesa. Arrigo Mignani finally bought the workshop with its tools in 1964. Ocarina di Budrio is now a prominent firm complete with web site (Source 2).

Soldiers in World War I and II (remember the film *Stalag 17*?) kept up morale with molded plaster and Bakelite ocarinas, respectively, because they were compact and easy to play. All of these had the traditional goose or sweet-potato shape. The 1930s heard a new Broadway sound in *Girl Crazy* and *Anything Goes* from the "Sweet Potato Tooters." The "Italian Connection" of the ocarina made it natural to feature ocarinas in Ennio Morricone's film *The Good, The Bad, and the Ugly*. In Japan, Sohjiro's ocarina concerts and recordings generated a cult status, as we'll see when we look at the "Nintendo Connection" later.

The reshaping of the ocarina began with John Taylor of London, who made the first four-hole ocarinas in 1963. Imagine the four different-size holes as binary bits. How many combinations are there?—16. And here, we must pause to outline the difference between recorders and ocarinas.

Ocarinas from Venus, recorders from Mars

Recorders (*flûte à neuf trous*—with nine holes) play a fifteenth or more. They rely on the ability of opened holes to shorten the effective length of the bore. Four registers are passed through as the wavelength of the standing acoustic wave is shortened and the acoustic frequency correspondingly increased (wavelength equals speed-of-sound divided by frequency) (Source 3). The complex airflow moving from the windway over the labium develops a resonance condition with the standing wave in the bore, stabilizing the struck note. (Resonance describes things like pushing a swing to greater excursions by timing the push with the swing's motion.)

Ocarinas, on the other hand, may be thought of as Helmholtz Resonators. Named after Hermann von Helmholtz (1821-1894), a German physiologist and philosopher, Helmholtz Resonators were hollow spherical containers with a small open neck at one end. They were used to analyze complex musical tones. When the partial of a tone had the correct frequency, it would couple with the air in the sphere so that only this amplified partial could be heard by the listener (through an ear canal tube). Until electronic instruments became available, it was the only way the partials of musical tones could be analyzed. The frequency that the Resonator responds to is easily calculated (Figure 1).

What does this have to do with ocarinas? An ocarina is a hollow vessel like a Helmholtz Resonator, but with a built-in fipple assembly like a recorder. The plane of the fipple's window must be tangential to the body of the ocarina (Figure 2). When you blow into the fipple assembly with all holes closed, it creates an in/out air motion. This couples with the Helmholtz Resonator by pushing the air in the window into the vessel, which then responds by pushing the air back out. An alternating air pressure is created in the vessel's volume. This oscillation radiates the "*do*" note through the window of the ocarina.

The labium/window square-hole is very difficult to analyze, so let's play the ocarina with just one tone-hole open. The alternating pressure change, which is uniform throughout the vessel, affects the air in the open tone-hole (and window), moving it in and out, just like the piston in a car. The plug of air in the open hole has mass, which for a round hole is calculated simply as air-density times hole-area times hole-depth. The open hole (and the window) have become the new neck of a Helmholtz Resonator. The air in the vessel of the ocarina acts like a spring that is coupled with the air-piston in the virtual neck. Hang a weight on the end of a spring and pull it down, and then let go. The spring/weight oscillates, and internal friction losses will eventually slow the motion. If you could add energy periodically to the system, it would oscillate forever. If you keep blowing into the ocarina, it keeps sounding its note (Figure 3).

It may be difficult to imagine a tone-hole as a piston, but an open round hole in a thin-wall vessel acts as if it had a flange, ⌋ ⌊, on the inside and outside of the vessel, each with a height equal to the hole radius, making the "depth" of the tone-hole about equal to the hole diameter. As the mass of the piston air-plug pushes in, the air-spring in the vessel compresses and pushes it outward. As the air-piston pulls out, the air-spring stretches and pulls it back in. The bigger the vessel (a weaker spring), the lower the frequency of the sound. The bigger the tone-hole-area (a bigger, heavier piston), the higher the frequency. Try it with some old springs and weights. The fascinating part is that, for a given volume of air, the frequency is nearly *independent of the shape* of the vessel. Rather, it is nearly *proportional to the square-root of the sum of the diameters of the open holes* (see Figure 4 and Source 4).

Continued overleaf

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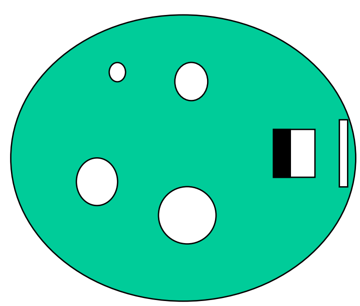
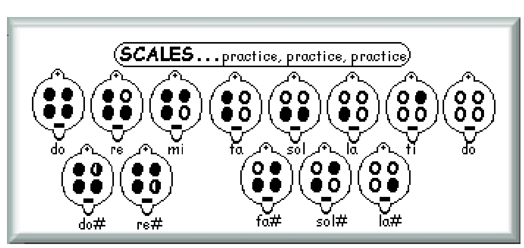
Figure 4: Pitch is a function of the summed sizes of all the open holes.



$$f = (c/2pi)\sqrt{((D1+D2+D3...)/V)}$$

$$Dn = diameter\_hole\#n$$

Figure 5: Producing a chromatic octave with a four-hole ocarina.



SANDI AND RICHARD SCHMIDT


DARRYN SONGBIRD

The good and the bad

Theoretically, a clever pottery maker could pierce the walls of a hollow, fipple equipped vessel with four different-size holes and make an instrument that produces sixteen different rather pure tones that are chromatically related. The holes can be almost anywhere that makes playing easy (Source 5).Their total open area is the important factor. John Taylor did just this, laying out a road that many have followed. Unfortunately, physics is always exact but often unkind. Using a little geometry and algebra, you can show that some of the finger combinations are going to sound a bit "off"; a chromatic octave is a more reasonable goal (Figure 5). If you add another hole, the good combinations will allow a ninth. Some think that a sixth hole makes accepted fingering patterns sound better. Other makers suggest shading the window will let you add one note at the bottom. Some makers add a small hole near the fipple entrance, and your lip is used to open and close it.

The beauty of the ocarina is that the sound frequency is not determined by the length of a bore, as in a recorder. Recorder basses are big, since the scaling is linear! If you want to halve the frequency, you must double the length. In ocarinas, the frequency is determined by the ratio of dimensions in the square-root term, so that bass instruments don't need to be quite as big, in comparison.

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Two questions become important at the extreme limits: 1) Is the instrument too small to accommodate big fingers, and will it produce enough sound? or 2) Is it too big for convenience, and will your finger pads cover the biggest holes? Between these extremes is a vast world for creativity. I have a five-hole clay ocarina in ~C5 that is 2.5 inches in diameter, about 1.5 inches thick, shaped like a flying saucer and decorated with a Kokopelli figure (see illustration). The windway entrance is on the rim (at the bottom of the illustration; the window and blade are on the backside together with the fifth hole), and it has four unequal diameter tone-holes on the top. It can be worn with a thong around the neck like a pendant.

Ten years that shook the world

When folk music was rediscovered in the '60s, an ocarina rebirth took place. Recently, artisans have produced a phantasmagoria of shapes and kiln colors, plus single, double, and triple ocarinas. Some of these are delights, while others may represent only "The Ugly" toys. We'll look at some of the best. Many web sites listed in the Sources offer sound bytes, so you can hear the bird sing.

Darryn Songbird (Source 6) makes a soprano alto-tenor-baritone-bass set in raku-fired unglazed clay. Clayz and Clay-Wood-Winds (Sources 5, 7) offer a glazed sopranino, soprano, alto, and tenor series. Often, the naming of the instruments is inconsistent with recorder practice, so it is best to ask. Clay has a tendency to shrink in the firing process, so it is also common to find instruments that are in tune with

Figure 6: Making an ocarina from clay.

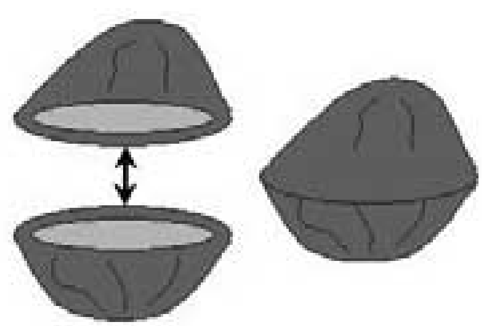
ILLUSTRATION: DWIGHT BARTHOLOMEW

themselves, and fully chromatic, but which are not tuned to a common scale. Alone, in the woods, on the street, or in your home, that doesn't matter. If you play with other instruments, it will, so it is best to request a concert pitch. Egg, arrowhead, ellipsoid and flying saucers shapes are available from a group associated with John Taylor (Source 8). The Budrio (Source 2) site displays the world of the "classical ocarina" from six-hole to ten-hole, covering four octaves in a presentation set of five instruments, or individual units.

Hind (Source 9) offers American walnut ocarinas with four, six, or eight holes, soprano, alto, tenor and bass, and double ocarinas pitched a fifth apart. Avant-garde ceramic artisans such as Susan Rawcliffe and Anita Feng craft an eclectic, exotic collection (Sources 10, 11). Ocarinas come with four to ten holes, diatonic or chromatic, covering from an octave to an eleventh+. The shapes challenge anyone's imagination.

More complicated instruments are available. Some have more than one chamber in the instrument. Play a duet with yourself. Tune the two chambers a little apart, and get a harmony similar to dual reeded harmonicas. Janie Rezner (Source 12) makes a triple ocarina whose two front chambers play a full scale, while the back chamber plays a two-note drone. The chambers come together at the top into a single divided mouthpiece, so the two front chambers can be played with or without the drone background.

DIY: Do it yourself

Making ceramic ocarinas is an art. There are two basic approaches. One uses a mold like a tennis ball to form the two halves of the shell from moist clay (see Figure 6 and Source 13). The two halves are joined by slip clay, and pinched together. The windway and vent are put in place using wooden tools, and then the holes created with plunge sticks. The slightly dried instruments are tuned, and then fired. Post-firing tuning is necessary because of shrinkage. The other technique uses a solid body of clay, in the approximate final shape (Source 14). It is cut apart by a string-cutter, and the interiors scooped out. The parts are reassembled, and then treated as described above. Some artisans use polychrome luster, white crackle glazes, seaweed, or other interesting things for decorative purposes during firing. In the best-playing instruments, the windway is tapered, the exit and the blade are positioned slightly

Some different shapes and sizes of ocarinas. Clockwise from upper right: small ceramic four-hole model by Robin Hodgkinson; an ocarina by Sandi and Richard Schmidt; classic model ocarinas by Kenji Ogawa.

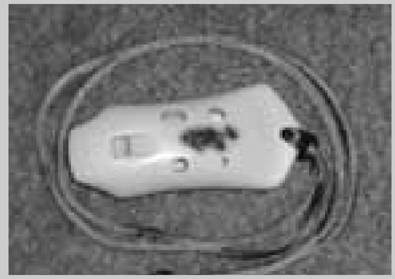

PHOTO: COULTER

KENJI OGAWA

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Sources for Further Study

1. *The New York Times*: Science Section March 29, 1988, p C-1; www.statnekov.com/peruwhistles/ nytimes.html
2. www.ocarina.it/
3. "Principles of Recorder Design Explained," *AR*, June 1992, pp. 7-14
4. www.phy.duke.edu/ ~dtl/36h4_sho.html
5. www.clayz.com
6. www.songbirdocarina.com
7. www.clay-wood-winds.com
8. www.ocarina.demon.co.uk
9. http://germanmarketplace.com/ hind.htm
10. http://artawakening.com/ soundworks/
11. www.scn.org/~bg599/ ocarinas.html
12. *Ceramics Monthly*, May 1999, p. 64
13. www.geocities.com/RainForest/ Canopy/2525/ whistles/ whistle.html; *Clay Whistles...the Voice of Clay*, J. Moniot (Whistle Press, 1990).
14. http://village.infoweb.ne.jp/ ~flute/egeioseisaku.htm
15. *Journal of Experimental Biology, 173*: 123-163 (1992); *International Journal of Insect Morphology* 22: 185-205 (1993)

differently from that of a recorder, and the window has an aspect ratio a little squarer than the recorder.

Cricket, cicadas, and Nintendo

With any musical instrument that has mass appeal, is easy to learn, and is not in the modern orchestral ensemble, there is always the caustic comment, "It isn't a serious instrument." For such ocarina critics there are serious works by Harrison, (*Canticle 3* for ocarina, guitar and percussion); Budaschkin, (*Domra Concerto* for accordion, ocarina, and mandolin); Ichiyanagi (*Concerto* for four recorders, two ocarinas); even moments in works by Janáček and Respighi.

But the ocarina has at least one trump card to play that recorders don't have. Nintendo's best-selling video game, *Legend of Zelda™: Ocarina of Time,* has generated money for Nintendo (more than 250 million copies), as well as recognition for artisans like Anita Feng. Perhaps ocarinas have another card. Biological studies on the sound-producing and sound-detecting organs in certain cicadas and crickets involve Helmholtz Resonators. In some Australian species, the male abdomen forms such a structure, using a large air sac as the cavity vessel, and the tympana as the neck of the resonator. In some antipodal crickets, a similar mechanism is involved. Within the same species, the maximum sensitivity of the female's ear, also a Helmholtz Resonator-tuned device, coincides with the carrier frequency of the male's call (Source 15). If it didn't, there'd be no little cicadas or crickets.

Sidelights: Thinking, Sounding, Playing

Thinking: The basic dissonance between the methods of scientist, artisan, and player is shown by an Internet exchange between David Peterson and Barry Jennings (John Taylor's associate) posted at www.ocarina.demon.co.uk/FAQacad.html.

PETERSON: I am a mathematician. I have a partially verified formula (for the four hole ocarina). The primary vagaries are the fipple impedance and equivalent depth of holes. Do you or John Taylor have any comment?

JENNINGS: (I am an instrument maker.) Your terms... are quite different—though we may refer to the same specifics. For instance you say "mass" whereas we think "volume." Can you [relate] the [volume] of an ocarina to pitch?

Sounding: At low sound levels, a Helmholtz Resonator can have a high resonance "quality" factor, Q. Think of Q as reflecting the range of frequencies that might easily excite resonance; HiQ = narrow range, LoQ = broad range. Q also reflects the ratio of the blowing-energy stored to the blowing-energy lost in the resonant system. This loss may be due to 1) wall-loss (think of air striking a wall and cooling off), 2) viscous-loss (think of syrup dripping, its layers shearing from the spout), 3) turbulence-loss (think of rushing white water), or 4) radiation-loss (think of what you hear). Typical modern flutes have Qs of 35-40. John Coltman, the flute acoustic expert, has made Helmholtz Resonators from plastic toilet float balls, milling various size holes in them. Wall loss is dependent on area/volume ratios, and may be ~10-15%. Small holes (~G3) at low sound levels have high viscous-losses (Q=26). At high sound levels, turbulence-losses become important (Q=11). With larger holes (~G4) at low sound levels, radiation-losses becomes appreciable (Q=45). At high sound levels, Q drops. Coltman has taken an irregular ocarina-like vessel flute in his collection, made by Martin Breton of Quebec, measuring ~2.5"x2.5"x2". With one open hole (~B4), the measured Q=16. [Q >5 is good]

Playing: Lower, broader Q values correlate with the ocarina's ability to strike a note with ease and shift frequencies with a change in breath pressure without "breaking" or losing resonance lock. "Bending" a note is simple, but getting out-of-tune is also made easier. Recorders tend to "break" if the shading, sliding, or rolling hole coverage is not smooth, and some holes are very sensitive. Ocarinas are more tolerant, and their frequencies shift up or down as the number or size of holes is changed by various shading, sliding, rolling, wiping, or multi-finger warble techniques. Smooth glissandos are possible. With higher notes, especially in elongated shapes, non-uniform pressures and inharmonicities result, and excessive losses develop. You can't fight physics and the scale ends. The recorder just "keeps on ticking."

Making recorders sweeter

We urge you to experiment. The musical instruments are not expensive and well-tuned ocarinas can be purchased from around $25 to $75. They combine well with recorders, since the purity of their own sound complements the reediness of many recorders. For old movie buffs, watch Frank Capra's *Meet John Doe*.

The recorder player will have little trouble adapting to the pendant five-hole ocarina, and the tonguing techniques used are identical. Although the resonance condition for a given note is a bit broader than a good recorder, and overblowing or underblowing will shift the frequency more than might be expected, the instrument returns in multiple kindnesses (see Sidelights). It does not "break" with too little or too much pressure and uses almost a constant breath pressure from one end of the scale to the other. Air movement in and out of the tone holes seems a bit more sensitive to the proximity of lazy fingers. It is therefore easier to do slides, and you can use the fifth hole to do a glissando fifth! It is a wonderful instrument for the blues and jazz. And if improvisation is new to you, the ocarina provides a wonderful companion that won't compromise your fingers' muscle memory for stricter, more rigid music. Perhaps these lines from Charlotte Smith's *Beachy Head (1807)* sum up the ocarina:

> Come, visitant, attach to my reed
>   your nest of clay,
> And let my ear your music catch.

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