Music From Oil Drums: The Acoustics of the Steel Pan

Over the past 50 years, the steel pan has evolved from a Caribbean folk instrument into a versatile and popular instrument, used worldwide in musical styles ranging from symphonic to calypso. Behind its rich sound lie some interesting acoustical properties.

Thomas D. Rossing, D. Scott Hampton, and Uwe J. Hansen

The steel pan—made from the end of an oil drum—is probably the most important new acoustical (that is, nonelectronic) musical instrument developed in the 20th century. In addition to being the foremost musical instrument in its home country, Trinidad and Tobago, the steel pan is becoming increasingly popular in North America and Europe. (See figure 1.) The modern family of steel pans now covers a five-octave range, and steel bands of today use them to perform calypso, jazz, and popular and classical music.

Steel pans originated on the island of Trinidad in the 1940s, partly because of a ban on tamboo bamboo bands, whose strong rhythms—created by striking the ground or other objects with bamboo sticks—had become a feature of the annual Carnival festivities. (Unfortunately, the large bamboo sticks were being used as weapons as well as musical instruments.) Not to be denied, the enterprising musicians turned to garbage cans, buckets, brake drums or whatever was available; the first steel drums were rhythmic rather than melodic.

The development of tuned steel drums took place in the years following the end of World War II, when the annual celebration of Carnival resumed with great enthusiasm. Thousands of 55-gallon oil drums left on the beach by the British navy provided ample raw material for experimentation.

Many claims have been made about the invention of the tuned steel pan. Undoubtedly, it resulted from a lot of trial and error on the part of musicians and of metalsmiths, such as Bertie Marshall, Anthony Williams and Ellie Mannette. It is still evolving.

Modern steel pans are known by various names, such as tenor or lead, double second, double tenor, guitar, cello, quadrophonics, and bass. (See figure 2.) The tenor pan has from 26 to 32 different notes, but each bass pan has only 3 or 4; hence the bass drummer plays on six pans in the manner of a timpanist. Different makers use different patterns for their pans, although there is a movement in Trinidad and Tobago to standardize designs.[1]

For the past 10 years, working closely with pan maker–tuner Clifford Alexis, who learned his trade in Trinidad and now codirects (with G. Allan O'Connor) the steel bands at Northern Illinois University, we have tried to understand the acoustics of steel pans. We have also tested steel pans tuned by Mannette, now at the University of West Virginia, and Felix Rohner, a maker–tuner in Bern, Switzerland.

THOMAS ROSSING *is a professor of physics at the Northern Illinois University, where* SCOTT HAMPTON *recently completed his studies for an MS in physics.* UWE J. HANSEN, *a professor of Physics at Indiana State University, has been a guest researcher at NIU on several occasions.*

Construction and tuning

The typical steel pan is constructed from a portion of an oil drum. The end of the drum is hammered into a shallow concave well, which forms the playing surface. The depth of the well varies from 4 inches in a bass pan to 7.5 inches in a tenor pan.[2] Part or all of the cylindrical portion of the drum is retained as the skirt, which acts as a baffle, acoustically separating the top and bottom of the playing surface to prevent cancellation of radiated sound; it also radiates considerable sound, itself. Skirt lengths vary from about 5 inches for the tenor to 18–27 inches for a cello pan. A bass pan retains the entire length of the original oil drum. Our experience has shown that the skirt of each pan has the length that gives it the best sound.

After the oil drum's end has been hammered into a shallow well, the playing surface is scribed and grooved with a punch to define the individual note areas. The tuner raises each note area up slightly and then works it up and down repeatedly to soften the metal. Next the pan is heated over a wood bonfire, which raises the pitch of each note and appears to harden at least the surface of the metal. The note areas are flattened and then tightened around the edges by rapid hammer work known as piening, which prepares the note areas for tuning.

The actual tuning process begins by lightly tapping the underside of the pan to create a small convex portion on the note area. Then, the grooves between the note areas on the playing surface are retightened with a small hammer, so that when the player strikes the note area, the vibrations will be restricted mainly to that note area. The fundamental frequency of a note area can be lowered a

STEEL PANS are being used to perform many different kinds of music. **a:** Pan player Liam Teague (left), codirector Clifford Alexis (right), both natives of Trinidad, and the other members of the NIU Steel Band perform calypso, jazz, and classical and popular music. **b:** With new appreciation of their versatility, the popularity of steel pans is increasing worldwide. Here the Northern Illinois University Steel Band plays during its 1992 tour of Taiwan. FIGURE 1

b

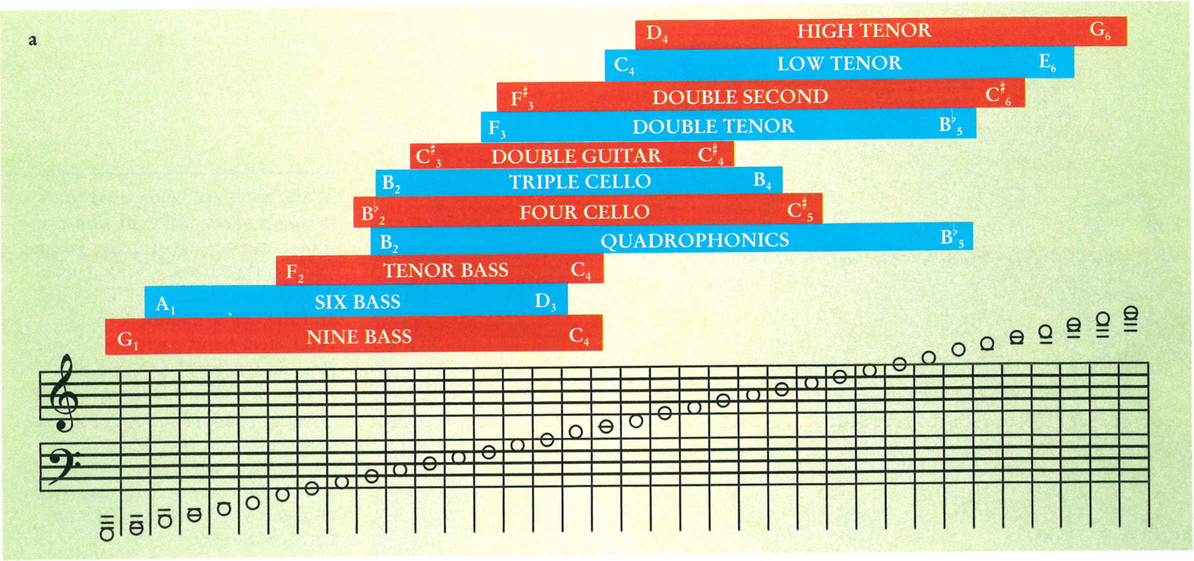
by glancing blows across the top of the area, while it can be raised by increasing the height at the center or by tapping down at the corners of the area.

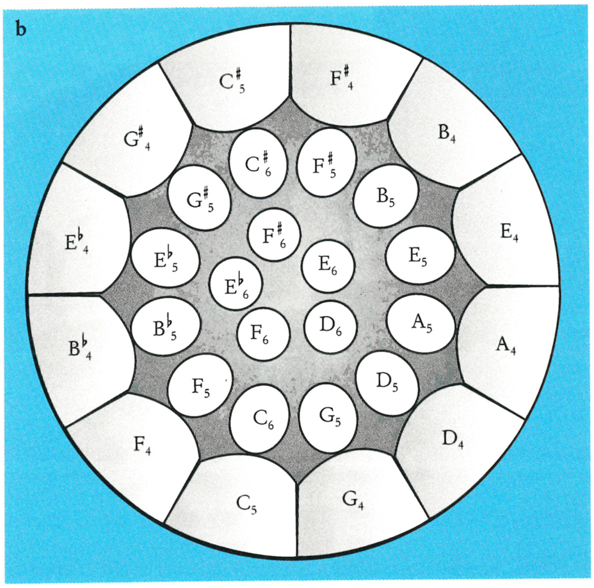
A skilled pan maker also tunes at least one overtone of each note area to a harmonic of the area's fundamental frequency (nearly always the octave). Whenever possible, a second overtone is tuned to the third or fourth harmonic, especially in the larger note areas, which have low fundamental frequencies. Tuning the third mode to a musical twelfth (third harmonic) gives the note a more more mellow tone, and tuning it to the double octave (fourth harmonic) gives it a bright tone. Tuning the harmonics is more difficult than tuning the fundamental frequency. In general, though, tapping the underside of the pan along or just outside a boundary of a note area that runs parallel to the nodal line for that mode will lower a harmonic, whereas tapping down or outward on the playing surface just inside this boundary will raise the harmonic frequency.[3,4] Figure 3 shows the regions of a note area where hammering causes the most significant change.

Spectra, vibration modes and coupling

Steel pans are played with homemade mallets, which vary in length from 8 inches (for single or double tenor pans) to 12 inches (bass pans). Mallets are usually made from ½-inch-diameter aluminum tubing or wooden dowels. The mallet tip is wrapped with strips of surgical rubber, or, in the case of a bass player's mallet, is covered with a firm sponge ball. The short contact time between the mallet and the note—lasting only 1–2 milliseconds for a tenor pan—allows for the fast repeated strokes and rapid arpeggios that characterize virtuoso performances on the steel pan.

Striking a note with a mallet produces a sound spectrum that is rich in harmonic overtones. Radiation from higher modes tuned harmonically by the tuner is





MODERN STEEL BANDS include pans that span five octaves. **a:** Distinctively named pans of a steel band, showing the musical ranges of the instruments (as colored bars). Note names are given in standard American notation, with A_4 having a frequency of 440 Hz. (Adapted from ref. 2.) **b:** For ease of playing as well as acoustical reasons, note areas on a typical tenor or lead pan are arranged in three rings, called circles of fifths (each note is a musical fifth above or below its neighbors). On one side of the pan are the notes corresponding to a piano's white notes; on the other are the black notes (sharps and flats). As shown, notes in the middle ring are one octave higher than the notes in the outer ring, and the notes in the innermost ring are yet another octave higher. FIGURE 2

only one source of these harmonic overtones. Two other physical mechanisms are:[5]

▷ Radiation from nearby notes whose frequencies are harmonically related to the struck note (sympathetic vibration);

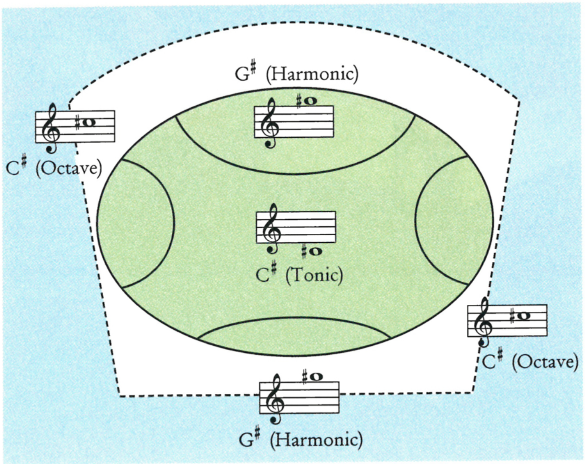
▷ Nonsinusoidal motion of the note area vibrating at its fundamental frequency.

Sound spectra from two notes on a double-second pan are shown in Figure 4.

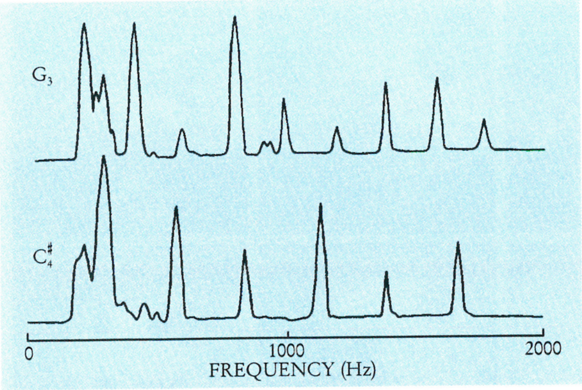
Modal shapes of various modes of vibration in three different $B^\flat$ note areas in a double-second pan are shown in figure 5; similar modes of vibration of note areas can be seen in the holographic interferograms in figure 6.

Striking the B_3 note in a steel pan excites both the B_4 and B_5 note areas nearby. The B_4 area in turn radiates a very strong second harmonic; damping the B_4 note produces a very noticeable change in the timbre of the B_3 note.

The mechanical coupling between notes, which is nonlinear in character, can be studied using holographic



$C^\sharp$ NOTE AREA showing regions where the pan tuner's hammering causes the most significant change. Tuning is usually done in the ellipse (green), and the lines extending inward from the sides of the ellipse show where tuning is done for the second ($C^\sharp$) and third ($G^\sharp$) harmonics. (Adapted from ref. 4.) FIGURE 3



SOUND SPECTRA of two notes on a double-second pan. Note the large number of harmonics. (Adapted from ref. 6.) FIGURE 4

interferometry by driving one of the notes at its fundamental frequency as well as the frequencies of its first and second harmonics.[7] (See figure 6.) In general, as the drive amplitude is increased, more and more note areas are excited, until at amplitudes typical of a performance almost the entire drum vibrates and radiates sound. If the driving frequency is a harmonic of the fundamental frequency of the note area, nearby note areas that are harmonically related to the fundamental are more highly excited.

Damping the entire pan except the struck note area with sandbags all but eliminates radiation from other note areas. Even so, we have observed harmonic partials up to the tenth harmonic in the sound spectra of such damped steel pans.[8] These harmonics appear to result from inharmonic motion of the vibrating note area, mainly at its fundamental frequency. We are not aware of a theoretical description that accurately predicts the amplitude of higher harmonics, although Neville Fletcher[9] has estimated the amplitude dependence of the second and third harmonics of a quasispherical cap shell with a fixed edge. The irregular shapes of the pan's note areas and the variable boundary conditions would be expected to enhance the nonlinear generation of harmonics.

Note shapes

The note areas in the various pans differ rather widely in shape: some are nearly trapezoidal, some are circular and some are oval. A good starting point for modeling them might be shallow rectangular shells with length L, width W, thickness h and radii of curvature R_L and R_S along the length and width, respectively. Such shells have been studied analytically.[10] This model allows for a wide variety of surface contours and exhibits several interesting features when applied to steel pan notes. Nodal patterns observed in many notes resemble those of rectangular plates and shells, as well as those of elliptical plates of small eccentricity.[11]

The frequency expression derived for such rectangular shells is

$$\omega_{m,n} = \frac{u}{R_S}\left(\frac{(1-\nu^2)(R\alpha^2+\beta^2)^2 + k(\alpha^2+\beta^2)^4}{(\alpha^2+\beta^2)^2}\right)^{1/2}$$

where $R = R_S/R_L$, E is Young's modulus, ν is Poisson's ratio, $k = 0.083(h/R_S)^2$ and

$$u = \left(\frac{E}{p(1-\nu^2)}\right)^{1/2}, \quad \alpha = \frac{\pi R_S(2m-1)}{W}, \quad \beta = \frac{\pi R_S(2n-1)}{L}.$$

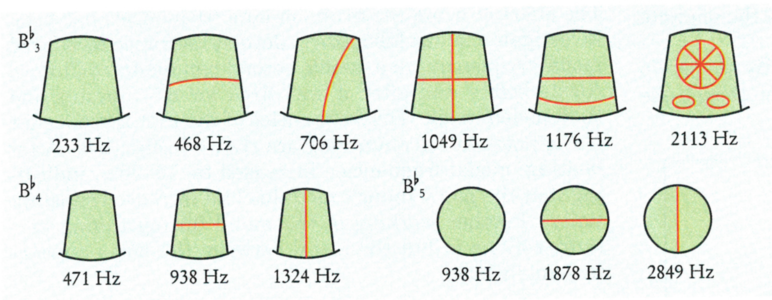
The indices m and n allow only for modes that are symmetric about the shell center. However, because the conditions at nodes are the same as at the edges, simple geometric rescaling can recover mode frequencies corresponding to any modes of interest.

Using the above equation, a computer program was written in an attempt to answer the following question: For the model shell with physical dimensions and thickness approximating steel pan note areas, is there a surface topography for which the resonance frequencies form a harmonic series? A total of 143 520 physical configurations were tested for various mode hierarchies. The computer models considered aspect ratio L/S in the range $1 \leq L/S \leq 2.5$, thickness $h = 0.77$ millimeters, and radii of curvature R_S and R_L between 2.5 and 25 times the length of the rectangle's short side.

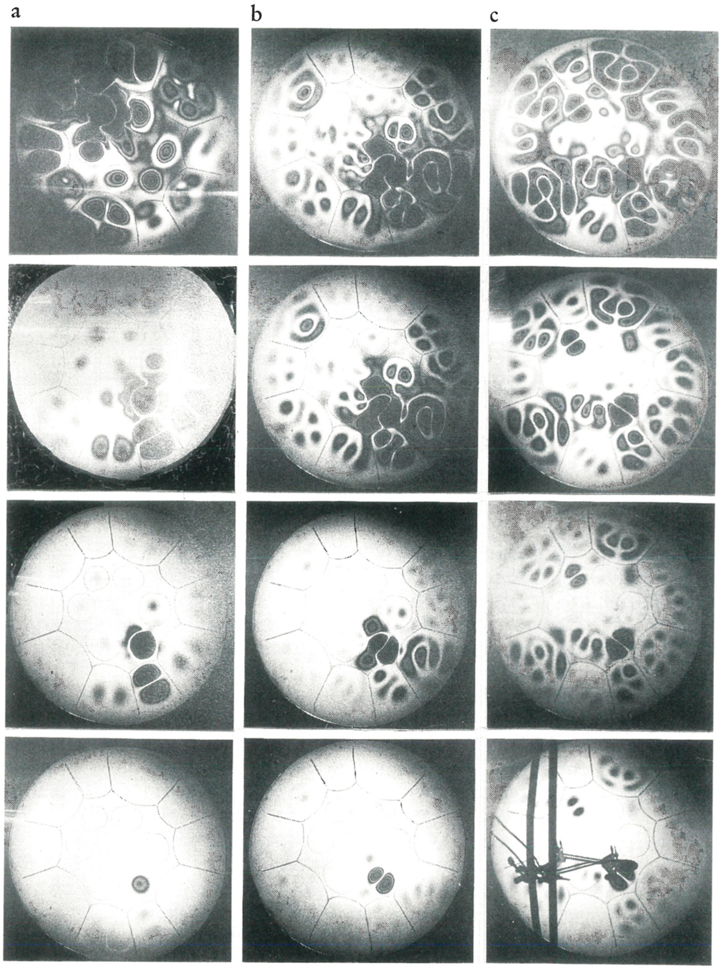
About 1.2% of the configurations tested produced a second harmonic (1,0) mode. About 4% of those that produced a second harmonic also produced a third-harmonic (0,1) mode; about 9% of them produced a fourth-harmonic (2,0) mode. In most of the harmonic cases, the profile parameter R was negative, and the curvature magnitude parameter R_S/S was small (less than 10). For given boundary dimensions and mode indices (l,s), there exists some surface profile (R value), in which the mode frequencies given for a shallow rectangular shell become the same as those of a flat rectangular plate with simply supported (hinged) edges. Under these conditions, the frequency is most sensitive to changes in curvature.[12]

We have also examined the relation between the fundamental frequency of a note area and its size in various pan types, ranging from the tenor (lead) pan to bass pans. (See figure 7.) For a representative number of note sizes, we have observed a scaling law that can be written as $L = Kf^{-2/3}$, where L is the longest dimension of the note area and f is the fundamental frequency.

The wavelength of bending waves is approximately twice the length of the note area; multiplying the wavelength by the frequency gives the speed of bending waves. These speeds range from 68 to 199 meters per second in the set of pans studied. This range is well below the speed of sound in air. Thus, all the notes are vibrating well below



MODAL SHAPES observed in three different B♭ notes in a double-second pan. In all three notes the two modes having a single nodal diameter have been tuned to the second and third harmonics of the fundamental note. In the B♭3 and B♭4 notes, both located in the outer ring of notes, the mode with the nodal line parallel to the circumference of the pan supplies the second harmonic, and the mode with its node along the diameter of the pan is tuned to the third harmonic; in the B♭5 note in the inner ring, however, the opposite is true. (Adapted from ref. 7.) FIGURE 5



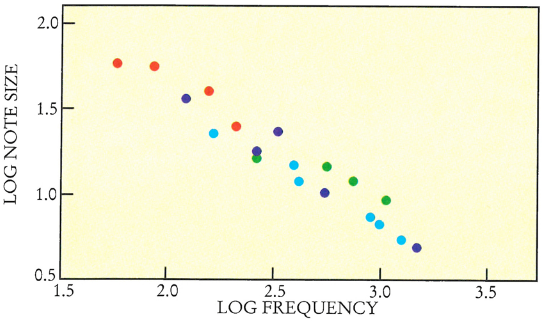
HOLOGRAPHIC INTERFEROGRAMS show the motion of a double-second pan when the G_5 note area is driven at various frequencies (left to right) and at increasing amplitudes (bottom to top). **a:** When driven at the fundamental frequency (815 Hz), the G_5 note also excites the second (octave) mode of the G_4 note area (radially outward from G_5) and the third mode of the C_4 note area (clockwise from G_4). Further amplitude increases excite additional notes until, at typical performance amplitudes, almost the entire drum vibrates and radiates sound. **b:** When driven at its second resonance frequency (1605 Hz), a node forms parallel to the circumference of the drum. **c:** When driven at the third resonance frequency (1878 Hz), which is not a harmonic of the fundamental, the excited modes are less localized. (From ref. 7.) FIGURE 6

their coincidence frequency (the frequency at which the speed of bending waves equals the speed of sound in air), which suggests relatively weak radiation of sound. However, although direct radiation from the note area may be fairly weak, sound is radiated by the entire instrument, so that the radiated sound is fairly strong.

Role of the skirt

Although measuring the total amount of sound radiated by the skirts is difficult, we have compared the vibrational spectra and amplitudes of the skirt with those of struck notes. Using accelerometers attached to the pans, we found that, in a tenor pan, the vibrational amplitude of the skirt on the side nearest the struck note averaged 19 ± 9 dB less than the note amplitude (averaging over all the notes), while it was 23 ± 11 dB less than the average note amplitude on the side of the drum opposite the note. In a double-second pan, the corresponding differences in amplitude averaged 27 ± 12 dB on the same side and 37 ± 14 dB on the opposite side. In a cello pan the differences were 41 ± 10 dB when the skirt accelerometer was on the same side as the note and 46 ± 13 with it on the opposite side; in the bass pan it was 40 ± 8 dB on the same side and 41 ± 8 on the opposite side.[13]

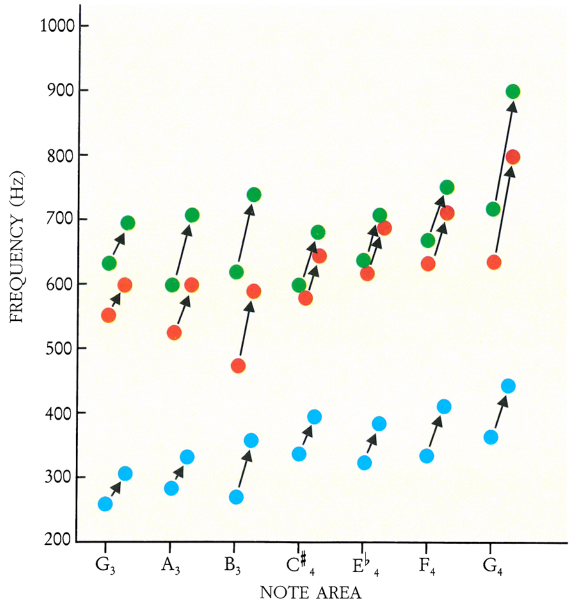
Whether the note was played loudly or softly seemed to make no significant difference in the data. Even though the area of the skirt is considerably greater than that of the note area, the large differences in acceleration level (corresponding to vibration amplitude ratios ranging from about 10:1 to 200:1) suggest that radiation from the skirt does not contribute a lot to the sound level. However, the vibrational spectrum of the skirt is sufficiently different from that of the note area to influence the timbre of the pan.



SIZE OF THE NOTE-AREA L (as measured by the area's longest dimension) is related to fundamental frequency, f, in steel pans by the relation $L = Kf^{-2/3}$. The relation holds for a variety of steel pans, including tenor (green), double second (blue), cello (purple) and tenor bass and bass (red). FIGURE 7

Effect of firing the drum

The effect of firing the drum on note frequencies has been investigated in our laboratory. Jerome Defrance measured modal frequencies in a double-second pan made by Clifford Alexis before and after it was fired for 6.5 minutes and then cooled in air. The frequencies of the first three modes of the notes in the outer ring are shown in figure 8. After heating, modal frequencies increased by 10–30%, indicating that the pan's Young's modulus had increased substantially. Further working of the metal during tuning partially softens it, but the metal between the notes appears to remain hard.



FIRING A STEEL PAN raises the frequencies of its modes, as shown when one looks at the first (blue), second (red) and third (green) modes of the note areas in a double-second pan before and after firing (indicated by the arrow). FIGURE 8

Some pan makers prefer to use "sandwich" hardening: the surface is hardened by nitrating it, that is, by heating it either in a nitrating bath or in a nitrogen atmosphere.[14] The aim is to keep a flexible core for ease in tuning but to create a hard surface that resists mechanical deformation when the drum is played.

References

1. K. Roach, *The Imperatives for Standardization,* Trinidad and Tobago Bureau of Standards, Tunapuna (1992).
2. L. Pichary, *Results of the Steel Pan Survey 90,* Trinidad and Tobago Bureau of Standards, Tunapuna (1990).
3. C. Alexis, E. Mannette, personal communication.
4. U. J. Hansen, T. D. Rossing, E. Mannette, K. George, MRS Bull. **20**(3), 44 (1995).
5. N. H. Fletcher, T. D. Rossing, *The Physics of Musical Instruments,* Springer-Verlag, New York (1991). See chap. 20.
6. T. D. Rossing, D. S. Hampton, J. Boverman, "Acoustics of Caribbean Steel Drums," paper presented at 112th meeting of ASA (1986).
7. D. S. Hampton, C. Alexis, T. D. Rossing, "Note coupling in Caribbean steel drums," paper presented at 115th meeting of ASA (1987).
8. K. K. Leung, T. D. Rossing, "Sound spectra of Caribbean steel drums," paper presented at Joint Annual Meeting of APS and AAPT, Arlington, Va. (1988).
9. N. H. Fletcher, J. Acoust. Soc. Am. **78**, 2069 (1985).
10. A. W. Leissa, *Vibrations of Plates,* NASA, Washington, DC (1969).
11. M. D. Waller, *Chladni Figures: A Study in Symmetry,* Bell, London (1961).
12. D. S. Hampton, "Investigation of the Vibrational Modes of Steel Drums by Holographic Interferometry," MS thesis, Northern Illinois U., De Kalb (1995).
13. T. D. Rossing, D. S. Hampton, U. J. Hanson, "Acoustics of Steelpans," paper presented at 130th meeting of ASA (1995).
14. F. Rohner, "Empirical Steel Pan Development: Materials, Shapes and Musical Concerns," paper presented at International Converence on Advanced Materials, Cancun, Mexico (1995). ■