DESIGNING AND MAKING A CEREMONIAL DINNER GONG

Neville Fletcher
Research School of Physical Sciences and Engineering
Australian National University, Canberra 0200
neville.fletcher@anu.edu.au

ABSTRACT. The acoustic and aesthetic design of a ceremonial dinner gong for the fiftieth anniversary of University House at the Australian National University is described. The gong is made from polished stainless steel with a walnut frame constructed from the same timber used in building the Great Hall, and the shape of the frame echoes the slightly sloping walls of the Hall in which it will be housed and used.

1. INTRODUCTION

The Australian National University in Canberra was established in 1947 as the first and only purely post-graduate University in Australia, offering only PhD degrees at a time when these were offered by no other Australian University. In 1960 it amalgamated with the Canberra University College, then part of the University of Melbourne, to form the current Australian National University, which offers degrees at all levels, though the Research Schools of the original ANU still maintain something of a separate existence within the whole and cater only for graduate students.

In 1954 there was established, within the original ANU, a residential College for students and staff with the title of University House, and in March 2004 this institution celebrated its fiftieth anniversary. In the tradition of University Colleges in England, University House has always been a meeting place for students and senior members of the academic staff, and a feature of this collegiate life has been the formal dinners held each week in the Great Hall. This hall is notable for its architectural simplicity and subtlety, and also for the grand panelled painting covering the wall behind High Table, painted by renowned Australian artist Leonard French. To celebrate this anniversary, University House commissioned the design and construction of a ceremonial dinner gong to rest on High Table on formal occasions and to punctuate the procedures. The design and construction of this gong was delegated to the workshops of the Research School of Physical Sciences and Engineering (R.S.Phys.S.E.) in the University, and this note describes the steps taken to complete this honorific task.

2. ACOUSTIC DESIGN

A ceremonial dinner gong is a work of both acoustic and visual art and, while the two necessarily interact, they are also largely separate. In the first place, the sound expected of a dinner gong is not well defined. Provided it is pleasant and impressive, the sound is taken to characterise the particular gong. There are, however, certain acoustic principles that can guide the design in order that the resulting sound may be characterised as "pleasant and impressive".

The first design decision is the overall sound balance. In this, a gong is generally intermediate in sound between a bell, with well-defined tonal qualities, and a cymbal with an abundance of high and closely spaced vibrational modes. A bell achieves its tonal quality by being cast to a highly curved shape with very thick walls, so that wall stiffness dominates the behaviour and makes it almost completely linear. Under these conditions, the lower mode frequencies are well separated and clearly defined, and the bell-maker spends much effort in tuning their relative frequencies to near-harmonic ratios. At the other end of the scale, a cymbal is nearly flat and has free edges. When struck close to the edge with a hard stick, as is usual, many higher modes with nodal diameters are excited and the sound is "shimmering" rather than tonal. To add complication, the thinness of the cymbal means that vibrational amplitudes can be large relative to the thickness of the metal from which it is made, so that there is considerable nonlinear interaction, giving rise to sum and difference frequencies and to energy transfer between modes. All this contributes to the bright and incisive sound.

A gong sound lies between these two extremes, and can vary widely from one design to another. The metal sheet from which the gong is constructed is thicker than that of a cymbal but thinner than that of a bell, and the edge of a gong is almost invariably turned down to stiffen it against high-frequency modes with nodal diameters. In addition, a gong is usually struck with a padded hammer so that the impact is spread over an appreciable area, thus inhibiting the excitation of very high-frequency modes.

There is another feature of the sound to consider, and that is its evolution through time. The sound of a bell simply decays away, with higher partials decaying faster than those of lower frequency. A cymbal, on the other hand, tends to transfer energy from lower to higher modes because of vibrational nonlinearity, and it almost appears that the audible sound level increases momentarily before decaying. Gongs can be built to behave in either way. Large, thin, nearly flat gongs such as the Chinese tam-tam, the profile of which is

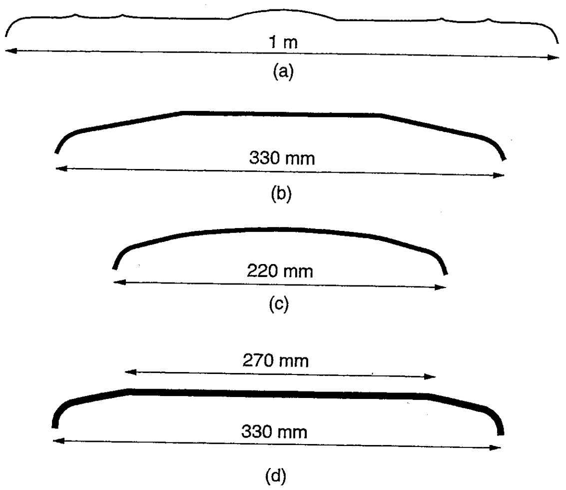

Figure 1. Profiles of (a) a Chinese tam-tam, (b) a downward-gliding opera gong, (c) an upward-gliding opera gong, (d) the gong constructed for University House. (Drawings are not to scale.)

shown in Fig. 1(a), can be nearly a metre across and not much more than 2mm in metal thickness, with a small central dome, a turned-down edge, and rings of hammered bumps. It is struck in the centre by a large and softly padded hammer, and actually behaves most impressively in this way, with the sound building up from a low-pitched boom to a shimmering rush over a period as long as two seconds.[1] The huge gong at the beginning of J. Arthur Rank films from the 1950s is a contrived example, though in this case it is not the real sound of the gong that we hear but rather an "artistic impression" constructed by the percussion section of a large English orchestra.

There is another feature of gongs made from metal of intermediate thickness and fairly flat shape that should be noted. If the gong surface is flat, under no initial tension, and essentially clamped round the edges by the turned-down lip of the gong shape as in Fig. 1 (b), then vibrational motion, as imparted by a hammer blow near the centre, will stretch the metal radially and introduce tension that tends to return the surface to a flat shape. This amplitude-dependent restoring force, which varies as the cube of the displacement, is in addition to the linear restoring force due to metal stiffness, so that the total restoring force F for a central displacement x looks like

$$F(x) \approx AEd^3a^{-4}x + BEda^{-4}x^3$$

where E is the Young's modulus of the plate material, d is its thickness, a is the gong diameter, and A and B are positive constants of order unity that depend upon the mode involved. The first term refers to bending stiffness and the second to displacement-induced tension. This means that the vibration frequency at large amplitude will be higher than that at small amplitude, so that the pitch of the gong will begin a little high and glide back towards its nominal value as the vibration decays, a sound that is striking in Chinese operas [2], but not very pleasant in a dinner gong. From the form of $F(x)$, such behaviour becomes noticeable once the amplitude of the vibration becomes comparable with the thickness of the metal from which the gong is made.

There is another Chinese gong that exhibits the opposite effect. If the metal is thin and the gong is very slightly domed to a height about equal to the metal thickness as in Fig. 1 (c), then the vibration frequency actually falls when the amplitude of the oscillation becomes comparable with the height of the dome. The physical analysis is rather more complicated [2], and derives from the fact that, in the absence of plate stiffness, the dome has two positions of stable equilibrium, normal and inverted, with an unstable equilibrium for a flat configuration in between. The sound of such a gong glides upwards as the sound decays, and this makes a dramatic contrast to the sound of the downward-gliding gong. Again, however, this effect is not appropriate for a dinner gong.

It turns out that there are two possible solutions that will maintain the gong pitch nearly level during the decay of the sound. One is to make the gong from rather thick metal so that the vibrational amplitude is always less than the metal thickness and the gong behaves almost in the same way as a bell. The second is to make the gong with a domed shape and to ensure that the height of the dome is much greater than the greatest vibrational amplitude that will be achieved. Other features of the sound, such as overtone pitches, also depend upon the metal thickness and shell shape, so that there are many things to be considered, and the design ultimately depends upon tradition and upon subjective judgment.

In developing the gong design for University House, the second of these approaches was initially tried, the dome height being about 10 mm, and this worked quite well. In the final design of Fig. 1 (d), however, the first approach was used because of the availability of appropriately thick sheet metal. There is another difference between the outcomes in the two cases, assuming that the gong diameter remains constant, and that is the effect on perceived pitch. The first solution, using thinner metal, leads to a lower pitch than the second, though the dome curvature tends to work against this.

The other acoustic adjustment that can be made is a little more subtle. If the gong is struck near its centre with a soft hammer, then several vibrational modes are excited and the listener will notice at least the lowest two of these, with the perceived pitch being determined largely by the frequency of the second mode, as in bells. It is important that the relation between the pitches of the first and second modes is heard as pleasant, which usually means a simple integer ratio between the frequencies. In our first experimental model, with slightly domed metal about 1.4 mm in thickness, the initial pitch relationship was not good, so this was modified by incising a series of deep rings into the metal at a distance about one-quarter of the radius from the centre. These incisions, being made near a node of the second mode but closer to an antinode of the first mode, shifted their relative frequencies to a much more pleasant relationship. For reasons of visual appeal and material availability, however, the gong was ultimately made from polished stainless steel sheet 2 mm in thickness and, because of the much greater stiffness, doming was no longer necessary. It turned out, also, that the frequency relation between the lower modes was initially pleasant, so that the incised-ring adjustment was no longer required. This feature, however, imparted a very striking and appropriate visual

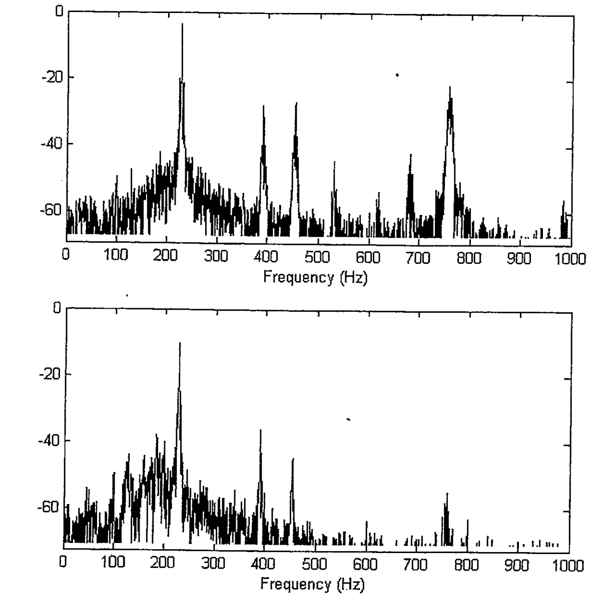

Figure 2. Relative sound pressure level spectra in dB about 1s after the strike (upper curve) and about 6s after the strike (lower curve).

appearance, and was retained for this reason in the form of lightly etched circles.

When the spectrum of the gong sound, excited by a central blow from the soft hammer, is examined, it is notable that it evolves significantly over a time of about 2 seconds. The bright initial sound has a pronounced fundamental at 226 Hz accompanied by a series of approximately evenly spaced upper partials, as shown in the upper panel of Fig. 2. Unfortunately there was no opportunity to examine the associated vibrational modes in detail, so that only a few general remarks can be made. The geometry of the gong is also too complex for a simple analysis to be helpful, though a finite-element analysis would give some insight. Where axially symmetric modes are concerned, the downturned rim of the gong acts simply as a small added mass and effectively the gong diameter a little with an essentially free condition on the extended boundary. For modes with nodal diameters, however, the rim is elastically stiff in the tangential direction, so that the edge of the gong is essentially clamped. Matters are then further complicated by the 30 mm sloped edge to the main gong plate.

The frequencies and relative frequencies of the modes are given in Table 1. If a mode with m nodal circles and n nodal diameters is represented by the notation (m,n), then approximate calculations suggest that the fundamental peak at 226 Hz is the (1,0) mode and that at 758 Hz the (2,0) mode, both being strongly excited by the central impact of the soft striker. The prominent second mode at 388 Hz is probably the antisymmetrical (1,1) mode excited by slight asymmetry in the strike. The strong modes at 454 and 682 Hz are puzzling in that they are almost exact integer multiples of the fundamental frequency. An intriguing possibility is that these are the result of nonlinearity and the abrupt change in slope of the gong surface towards its outer edge.[3]

The sound decay of the gong is a two-stage process. For the first two seconds or so, the decay rate is about 3 dB/s, while for the remaining time it is only about 1 dB/s, the faster initial decay being associated with the more rapid attenuation of the upper partials in the sound. The actual sound spectrum at two times after striking is shown in Fig. 2. The upper panel gives the spectrum about one second after the strike, while the lower panel is about six seconds after the strike. Clearly the upper partials decay much more rapidly than the fundamental.

The several harmonically related partials, indicated with an asterisk, define the subjective pitch of the gong, while the strong inharmonic partial with frequency ratio near 1.7 relative to the fundamental probably contributes largely to the slightly bell-like sound. As in carillon bells, the perceived pitch is more nearly that of the third partial at 454 Hz rather than that of the fundamental. The fact that there are several strong inharmonic partials in the initial strike note does not lead to a discordant sound, since these are well-spaced pure tones, and discords arise from rapid beating between the overtones of complex tones.[4]

Table 1. Prominent partials in the sound

Frequency (Hz)	226	388	454	530	618	682	758
Frequency ratio	1.0*	1.72	2.01*	2.35	2.73	3.02*	3.35
Harmonic ratio	1 : 1	—	2 : 1	—	—	3 : 1	—

3. VISUAL DESIGN

Visual design is a rather more subtle matter than acoustic design in this case. Gongs are traditionally usually made from brass or bronze that has been cast or hammered to shape, depending upon its thickness. This results in a mottled surface appearance and, in addition, these metals rapidly tarnish to a rather undistinguished patina. In contrast, a material such as stainless steel will retain its original surface appearance for a very long time without further attention. For this reason, and since the University House authorities had asked for an engraved crest on the gong, it was decided to make it from highly polished stainless steel sheet and to create a surface pattern by a mixture of etching and abrasion. The availability of appropriate sheet material of 2 mm thickness and the desirability having a flat surface for visual reasons also led to the adoption of the second acoustic design alternative. The final visual appearance of the gong incorporated the University House crest on a polished background, centred and surrounded by circles, further surrounded by broad area roughened by abrasion with fine glass beads, and then a final ring with concentric abrasion produced by fine emery paper.

A gong is not, however, simply the metal vibrating element, but involves also the means by which this element is supported. The design adopted recognised the geometry of the University House Great hall architecture, and in particular the gently sloping walls, and these are echoed in the shape of the walnut timber frame in which the metal gong is mounted.

Figure 3. The completed ceremonial gong, seen against the great panelled painting decorating the end wall of the Great Hall of University House. The design and construction team (L to R) comprised Tony Barling, Stephen Holgate, Steve Brooks, Neville Fletcher, and Ron Cruikshank, (absent: Anthony Mackey and Tony Cullen) all from R.S.Phys.S.E. at ANU. (Photograph by Tim Wetherell)

The mounting of the gong within the wooden frame is unobtrusive and simply requires, from an acoustic point of view, that it does not interfere with the vibration of the gong. The mount therefore consists of two loops of nylon cord passing through small holes in the gong rim and supported by hooks screwed into the wooden frame.

The completed gong, together with members of the design and construction team, is shown in the photograph of Fig. 3. The shape of the wooden frame is clearly seen to match that of the Great Hall, while the surface decoration of the metal gong shows up the University House crest to perfection.

4. CONSTRUCTION

The gong was constructed, as mentioned before, from 2 mm stainless steel sheet, polished on one side. To create the necessary profile with smoothly down-turned edges, a wooden disc about 30 cm in diameter and 20 mm thick was made that was a replica of the required inside shape. This was fixed in the spindle of an appropriately large lathe and the circular steel plate was clamped against it using a steel disk to prevent slippage and to protect the surface of the central area that was later to be decorated with the University House crest. The steel was then spun against the wooden template using a lubricant and a polished bronze forming tool to give a narrow sloping band and then a smoothly turned-down edge as shown in Fig. 1(d). The engraved design was produced externally by a screen printing type process, the design then being etched into the surface using an acid solution.

The timber frame was made in the School's carpentry shop. We were very fortunate in being able to secure some thick walnut planks that were left over from the original building of the Great Hall, and these were both symbolically appropriate and also an excellent match to various exposed timbers and furnishings in the Hall. The shape of the frame, as seen in Fig. 3, echoes the profile of the Great Hall, and is so constructed that the gong can be easily carried using the hand-grip at the top of the frame. The gong is supported in the frame by a light flexible cord passing through two holes in the gong rim and secured to two hooks in the frame. The striker for the gong was made from the same walnut as the frame, and the head from ironbark as a bobbin with a high-density foam layer wrapped with woven glass fibre fabric to give a narrow cylinder about 60 mm in diameter. It sits on two supports at the rear of the frame.

5. CONCLUSION

The ceremonial gong is the gift of Ms Pauline Griffin, Honorary Fellow and former Pro-Chancellor of the University, and was formally presented to University House at a commemorative dinner on March 31, 2004. It will repose in a specially built cabinet near the High Table, to be used on formal occasions, both in the Hall and elsewhere within University House. The team from the Research School workshop is proud to have been associated with its design and construction.

ACKNOWLEDGMENTS

It is a pleasure to recognise the contributions of Ron Cruikshank, Stephen Holgate and Tony Barling (metalwork), of Steve Brooks and Anthony Mackey (woodwork), and of Tony Cullen (striker). Stephen Moore, from UNSW@ADFA, assisted with the spectral analysis.

REFERENCES

1. K.A. Legge and N.H. Fletcher "Nonlinearity, chaos, and the sound of shallow gongs" *J. Acoust. Soc. Am.* **86,** 2439–2443 (1989)
2. N.H. Fletcher "Nonlinear frequency shifts in quasispherical-cap shells: Pitch glide in Chinese gongs" *J. Acoust. Soc. Am.* **78,** 2069–73 (1985)
3. K.A. Legge and N.H. Fletcher "Nonlinear mode coupling in symmetrically kinked bars" *J. Sound Vibr.* **118,** 23–34 (1987)
4. W.A. Sethares *Tuning, Timbre, Spectrum, Scale* (Springer-Verlag, London 1998)