WHY DO BELL PLATES RING?

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Abstract: Bell plates are polygonal plates which, when held in the hand and struck with a beater, produce an initial transient followed by a sustained, pure tone. The presence of the sustained tone depends sensitively on the shape. This paper addresses the question: why does a particular shape ring so well, while slightly different shapes do not? We show that, in the standard ringing shape, the nodal lines of one of the lowest modes of vibration fuse in the handle to produce a region that exerts neither vibrational force nor torque on the hand, and therefore does not transfer vibrational energy to the hand.

1. INTRODUCTION

Bell plates are new musical instruments that are played in much the same way as handbells, but are much cheaper. They are also lighter and so easier to hold when played with two in each hand, a style in which the axes of the bells or plates in the same hand are at right angles, so that they can be shaken independently or together by rotation about an appropriate axis. They have a pleasant, slightly bell-like sound and are becoming popular as an alternative to hand bells as a group musical activity in schools. A bell plate consists of a flat metal polygonal plate with a handle attached (Fig. 1). When struck in the middle with a hard rubber beater, it produces a very short, bell-like transient followed by a long, pure tone. Monsma [1], Rupil [2] and Hogg et al [3] have studied the sounds produced. Monsma measured relations between size and pitch.

The performance of the bell plate depends strongly on its shape. In general, even modest changes in the proportions produce a plate that, to put it colloquially, 'goes clunk' when struck, i.e. it produces a short, non-harmonic transient and no sustained tone. However, there is a family of possible ringing shapes: as b:a increases, c:b must be decreased. We have posted sets of photographs and sound files [5] on the web to demonstrate the dependence of the sound on the shape, as well as other features. Two sonagrams are shown in Fig. 2. Note that both plates have a strong initial transient but that, while the plate with the standard shape has a strong, sustained pure tone throughout the two second period displayed, the analogous resonance of the plate of altered shape decays strongly over the first 0.2 second.

It is difficult to describe the feeling of pleasant surprise and wonder that this produces when one first experiments with such plates. Why is it that this plate rings so beautifully while another just goes 'clunk'? The purpose of this paper is to answer that question.

Metals have low intrinsic elastic losses, so one would expect metal plates of almost any shape to ring if struck without the influence of gravity and therefore without supports. In contrast, holding the plate in the hand provides a mechanism whereby mechanical energy from the plate vibrations is rapidly lost in the hand holding it. It is helpful at

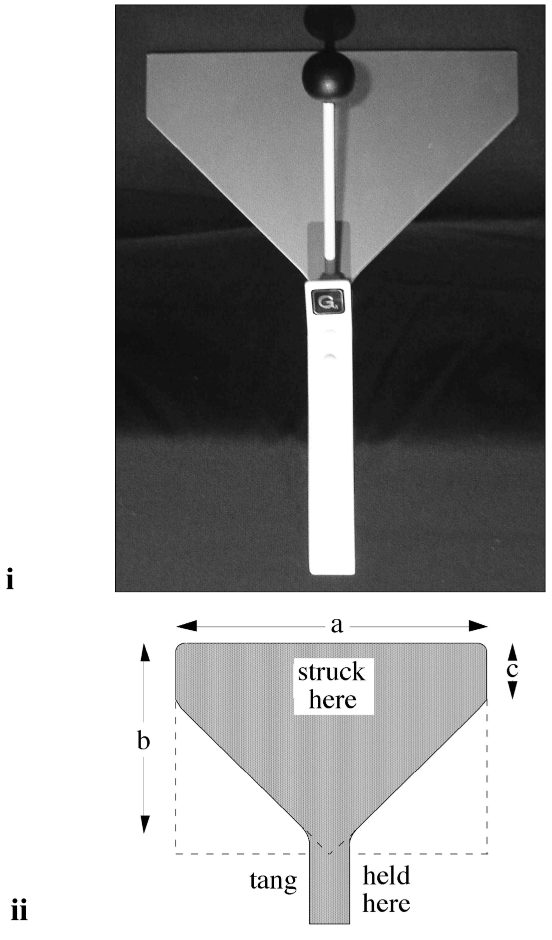

Fig. 1. (i) A photograph of a commercial instrument (Belleplates, Ashford, UK) that plays the note G4. (ii) The standard geometry of a typical bell plate. The dimensions a:b are typically in the ratio 1.5 to 1.6 while the ratio a:c is approximately 6 or 7 (table of shapes given in [2]). The size and shape of the tang is not important for the musical sound and is therefore chosen for the convenience of the player—a constant 20.2 mm width and 45 mm length. In commercial instruments, all corners are rounded, but this is not important to the sound. For playing, a hand strap and the mounting for a clapper are attached to the tang. Other pitches can readily be made: for thin plates, the resonant frequencies are approximately proportional to the thickness and inversely proportional to the square root of linear dimension [4].

this stage to consider a simpler example. A glockenspiel bar is usually mounted on two supports that are positioned below the bar at nodes of the lowest mode of vibration (See Fig. 3). When the bar is thus supported and when struck somewhere near the middle, it rings audibly for many seconds. The nodes do not move, so no oscillatory force is exerted on the supports. If one holds it at a point that is not a node of one of the low modes, it makes a short transient sound, but there is no sustained ring. Another way of describing this is to say that the deformation shown in Fig. 3(ii) displaces the centre of mass, requiring oscillating forces at the supports, while that in Fig. 3(i) does not.

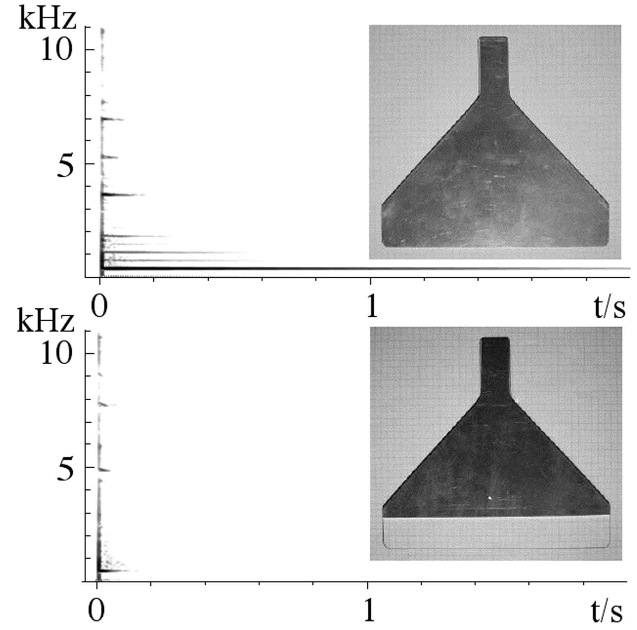

Fig. 2. Sonagrams (amplitude in a logarithmic grey scale vs time and frequency) for a standard shaped bell plate (top) and for the same plate after a 25 mm strip was guillotined from the long edge. The insets show photographs of the plates. Both were struck with a soft rubber mallet. These are among the sound files on the web [5].

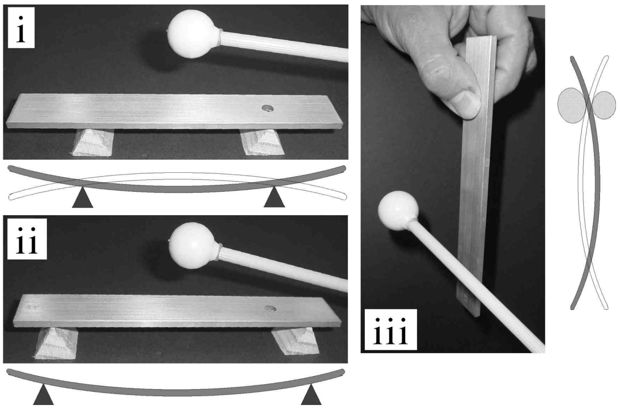

Fig. 3. How must one hold a glockenspiel bar so that it rings? The supports must be at the nodes of a low frequency mode: (i) rings at the fundamental and (ii) does not. Further, the supports must allow rotation at the node: (i) rings well and (iii) rings poorly.

Supporting the bar at a node is a necessary condition, but there is a further condition: the supports must have very small size along the direction in the bar at right angles to a nodal line. The supports of a glockenspiel or xylophone are narrow in the direction along the bar. They therefore allow local rotational motion of the bar, so no torques are exerted on the support. In contrast, human fingers have larger width so, even if one holds the bar 'at' a node (Fig. 3(iii)), one's fingers impede the rotation about the node and so the oscillatory torques extract vibrational energy. To return to bell plates, obviously the tang of the bell plate must be a node, but what is it about this node that allows it to be held in the hand without damping the ringing mode? In this study, the shapes of the nodes of plates of various geometries were studied by the Chladni method to answer this question.

2. MATERIALS AND METHODS

Two sets of plates with a range of geometries were cut from aluminium sheet. One set had thickness 1.5 mm and the others were 1.0 mm thick. The latter gave lower frequencies and larger amplitude that made them easier to study with Chladni patterns. The thinner plates were sprayed with a thin coat of black paint on one side. (The thicker plates have higher frequency and are used for the sound files in our web site [5].) For Chladni patterns, the plates were excited electromechanically. They were supported on three or four posts, each topped by a dome-shaped pad of sponge rubber, whose position could be varied. The masses of the plates ranged from 50 to 100 g. Two small rare earth magnets (total mass 1.3 g) were placed near the striking point on opposite sides, so that they held themselves in place without the need for glue. An air-cored coil was placed coaxially with the magnets and driven by a sinusoidal current of variable frequency. Fine sand was sprinkled on the plate and the frequency of the coil was varied until the desired mode was excited. A microphone was positioned several millimetres above the plate and, in some experiments, scanned at 5 x 10 mm grid points across the surface of the plate to measure the relative amplitude of the vibration. When the frequency was adjusted to obtain maximum amplitude, the posts were moved to coincide with the nodes and the coil was retuned. The frequency was readjusted, if necessary, and this process was iterated until the post positions exactly coincided with the nodes. The distribution of the sand was then photographed.

3. RESULTS AND DISCUSSION

Before we discuss the results, we remind the reader of the lowest mode of vibration of a simple rectangular plate, which is sketched in Fig. 4. This is called the (2,0) mode, the numbers enumerating the nodes in the two perpendicular directions. In this mode, the nodes are slightly curved lines across the plate, roughly parallel to the short sides. In a Chladni pattern, particles accumulate at the nodal lines, where there is no motion. Note that nodal lines separate regions that are 180° out of phase.

A bell plate may be considered as a rectangle with two corners removed and a tang added. What happens to the nodal lines when we remove two corners? Fig. 4 shows the Chladni patterns of three steps in the 'evolution' from a rectangular plate to a bell plate. On the long side from which the corners have been removed, the nodal lines are, not surprisingly, closer together. In the bell plate shape, these two nodes meet near the edge of the rectangular part of the plate and form an extended node in the tang. Figure 5(v) shows the nodal lines on a shape qualitatively similar to a bell plate, but wider (higher *a:b* and *a:c* ratios, in the nomenclature of Fig. 1.). In this case, the two nodal lines meet and fuse inside the rectangular area, so that the tang is no longer a node. When held at the tang, this plate will not produce a sustained ring: it is a 'clunk plate'.

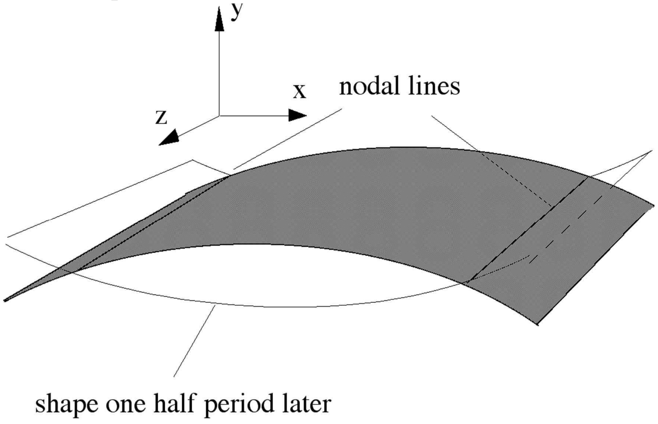

Fig. 4. A sketch of the lowest mode of a rectangular plate, and coordinate axes to which we refer later.

A horizontal section at mid-height through the plates shown in Fig. 5 (i-v) would give a shape *y(x)* much like that of the glockenspiel bar in Fig. 2. The central region of the plate is in antiphase to the right and left hand edges, and so at the two nodal lines the plate displacement *y* is zero, but its slope *dy/dx* has opposite sign at the two nodes (Figs 3,4).

What happens when two nodal lines join, as they do in Fig. 5(iv)? When the two lines join, the displacement *y* is zero, but the slope *dy/dx* is zero too! This is important when one holds a plate. Consider what happens when one supports a plate with the fingers at a single nodal line (Fig. 3(iii)): although the average displacement across the support is zero, there is local rotation and therefore loss of energy via the torques. When two nodal lines join (Figs 5(iv) and (v)), there is no rotation, and no torque in the *z* direction is applied to the support. At such a position, one can hold the plate with a support of small, finite width and extract negligible energy from vibration, to a first order approximation in the width of the support. This recommends it as a good place for the handle, as bell plate makers have found empirically. Note that, in Fig. 5(iv), the region where sand has accumulated extends part way along the tang but not all the way to the end. The electromechanical excitation does produce vibration at the end of the tang so an extended handle must remove some vibrational energy here[1]. Because the end of the tang is narrow, however, and its motion small, the force that accelerates it in this circumstance is small. A similar force applied to a handle and hand would therefore lose relatively little energy. Holding the plate by the plate end of the tang and by the part where it joins the body makes no noticeable difference to the decay time.

In addition to the mode shown in Fig. 5(iv), the bell plate has several other modes, which do not produce a node in the

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[1] This observation may be of interest to the manufacturer of the plate: a small increase in the decay time of the fundamental ring tone might be obtained by fixing the tang to the handle only along part of its length.

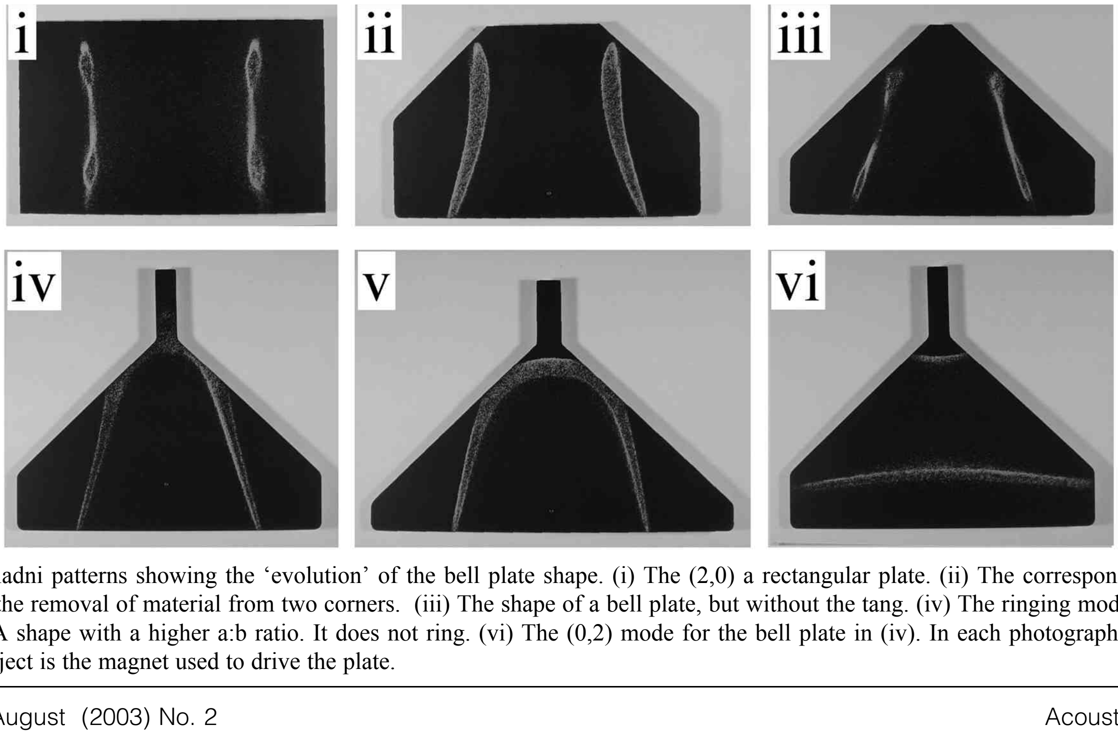

Fig. 5. Chladni patterns showing the 'evolution' of the bell plate shape. (i) The (2,0) a rectangular plate. (ii) The corresponding mode following the removal of material from two corners. (iii) The shape of a bell plate, but without the tang. (iv) The ringing mode on a bell plate. (v) A shape with a higher a:b ratio. It does not ring. (vi) The (0,2) mode for the bell plate in (iv). In each photograph, the small circular object is the magnet used to drive the plate.

tang. One of these, the (0,2) mode, is shown in Fig. 5(vi). These modes do not have a sustained ring, although those that do not have a node at the position at which it is struck presumably all contribute to the strike transient. In the plates we measured, the pitch of the (0,2) mode is approximately one tone lower than that of the ringing mode. One bell plate was made with a hole drilled at the intersection of nodal lines of these two modes. Suspended on a thread passed through this hole, the plate may be struck to produce both notes simultaneously. (It is also possible to produce the two notes by holding the plate at this point with thumb and forefinger, but with this support the ring time is much reduced. Examples are given in sound files [5].)

Finite element analyses of the bell plate were conducted using Strand 7. These gave shapes similar to those indicated by the Chladni patterns and microphone scans, and frequencies that differed by a few percent. These are described in detail by Lavan [6].

4. CONCLUSION

One of the lowest modes of a bell plate, the ringing mode, has nodal lines that curve and fuse at the region where the tang and handle are attached. Vibration in this mode exerts no force and no torque upon the hand holding it, and so this mode has a sustained ring. Other modes do not have such a node and contribute only to the initial strike transient. The nodal line fusion is a function of the specific geometry, so plates with only slight different geometry may not ring at all.

REFERENCES

1. B. Monsma, *The Characteristics of Bell Plates*, (Undergraduate thesis, University of Technology, Sydney 1993).
2. C. Rupil, *Analysis of Belleplate Vibration* (Undergraduate thesis, University of Technology, Sydney 1994).
3. S. Hogg, A. Fischer-Cripps, B. Monsma and C. Rupil. "A study of the acoustical quality of bell plates". Proc. 4th Intl Congress of Sound and Vibration, St. Petersburg (1996).
4. N.H. Fletcher and T.D. Rossing, *The Physics of Musical Instruments*. (Springer-Verlag, New York, NY 1998), pp 461–548.
5. J.Wolfe and J.Tann. "The Acoustics of Bell Plates", a web resource at www.phys.unsw.edu.au/~jw/bellplates.html (2003).
6. D. Lavan, *Vibrational Characteristics of Bell Plates* (MSc thesis, University of Technology, Sydney 2002).