BRANCHED DUCTS AND THE DIDJERIDUO

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ABSTRACT. Branched ducts can produce a range of resonances and antiresonances, which may be varied by changing the termination condition. One example of the use of such branching is the forked didjeridu or didjeriduo, an unusual instrument occasionally made when a forked section of a tree is suitably eaten by termites. A single player may select the mouthpiece, then produce changes in pitch and timbre, either by adjusting lip tension to select different bore resonances, or by using the heel of his hand to close the other mouthpiece. It is even possible for two players to play the same instrument simultaneously. Here we present detailed measurements of the acoustic input impedance of a forked didjeridu and employ numerical modelling to explain the major features. The modelling gives insights into the behaviour of branched ducts in general.

1. INTRODUCTION

The didjeridu (or didgeridoo) is a musical instrument originally developed by the indigenous peoples of Northern Australia, where its tribal names include the yidaki, yiragi and mago. It is basically a wooden tube with a central bore that is largely produced by termites eating out the interior of small eucalypt trees [1]. The instrument usually plays only a single note at a frequency close to the lowest resonance, although overblowing at the second (and occasionally third) resonance is used for a musical accent [2-4]. The musical interest comes from striking variations in timbre, including the rhythmic contrasts between the sounds produced during inhalation (during which air from the cheeks is expelled into the instrument) and exhalation: a technique called 'circular breathing' that allows continuous sound.

Unlike other wind instruments, the didjeridu bore lacks a significant restriction at the mouthpiece and consequently an unusually strong coupling can exist between the waves in the bore and the player's vocal tract. This allows a skilled player to modify the spectral envelope of the output sound by varying the resonances of his vocal tract [5-7]. The central bore is highly irregular and somewhat flared, both of which features are important to the performance quality of the instrument [8].

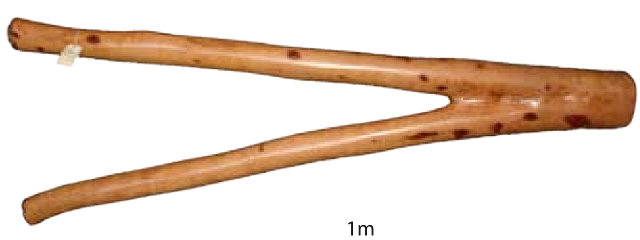

Figure 1. The forked didjeridu measured in this study. Tube A is at the top and has an identifying label attached.

Occasionally, a forked section of a tree is suitably eaten by termites. This allows the manufacture of a 'forked didjeridu' or 'didjeriduo' with a branched bore and two available mouthpieces as shown in Fig. 1. This can be played normally by a single player with the other mouthpiece left open, or closed with the heel of his hand to produce changes in pitch and timbre.

The second branch, whether open or closed, adds new resonances which have musical implications: adding one or more extra resonance(s) in the lowest range may give the instrument two or three pedal notes, instead of one. Extra resonances or antiresonances in the higher range, especially in the range 1-2 kHz, can influence the musical performance in a subtle but more important way. It is in this range that the variable, strong formants or enhanced frequency bands are produced by the variations in the player's vocal tract. We have recently shown that properties of the instrument's resonances in this frequency range are among the most important determinants of the perceived quality of an instrument [8].

Some forked dijeridus may be played simultaneously by two players – for novelty value rather than intrinsic musical interest. Generally this requires that the two bores are joined in the output half of the instrument. If the bores are joined too close to the mouthpieces, it can be difficult for each player to maintain stable lip vibration whilst the bore immediately outside his lips is pressurised by the other player.

In this paper, we present detailed measurements of the acoustic input impedance of a forked didjeridu and demonstrate that numerical modelling can explain the major features.

2. MATERIALS AND METHODS

The instrument used was made available from the collection of the Didjshop (www.didjshop.com). The input impedance Z_{IN}, i.e. the impedance at each mouthpiece, was measured as a function of frequency f for each instrument as described in detail elsewhere [8,9]. The overall quality of this instrument was assessed by 6 players giving an average score of 6.1/10 (see [8] for more details, including the relation between subjective quality and physical properties of an instrument). This assessment might have been influenced by the higher sound level at the player's ear when the second tube was open.

3. NUMERICAL MODELLING

A simple one–dimensional model composed of three cylindrical elements was used (see Fig. 2). The bore of an instrument made by termites in the traditional manner is, of course, very much more complicated. The various impedances were calculated in the standard manner (e.g. see [10]). Radiation impedances were included when appropriate. The values used to approximate the dimensions for this forked didjeridu were; L_A = 0.93 m, L_B = 0.88 m, L_C = 0.17 m, $d_A = d_B$ = 0.025 m, d_C = 0.05 m.

4. RESULTS AND DISCUSSION

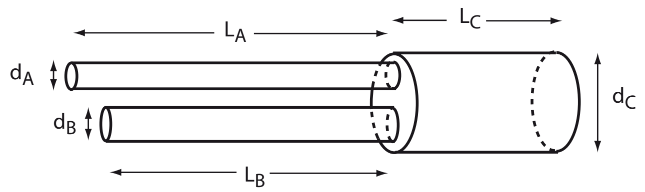

Figure 2. Schematic diagram used for the numerical model of the forked didjeridu measured in this study. Although the diameter d_C is greater than $d_A + d_B$ in this sketch, this is not necessarily true in the model.

Acoustic impedance spectra.

The acoustic impedance spectra, $Z_{IN}(f)$ are shown in Fig. 3, measured for the four possible playing configurations (A or B used as mouthpiece, and in each case with the other port closed or open). As might be expected, the impedance spectra are rather more complicated than those of simple didjeridus [8]. We consider the low frequency behaviour first.

All four configurations display the strong fundamental resonance of frequency f_1 required to set up a stable, low frequency oscillation in conjunction with the lips (see Fig. 4 with an expanded scale at low frequencies). However, an interesting feature is a splitting of each of the low frequency maxima into a doublet when the other mouthpiece is closed. Figure 4 indicates it is possible to play notes corresponding to each of these adjacent maxima, but we found the lower frequency note to be stronger and easier to play. In each of the four possible configurations, it was possible to play the higher resonance at frequency f_2, where the ratio $2.83 < f_2/f_1 < 2.93$.

We now turn to the critical range 1-2 kHz. In this range, the resonances of a skilled player's vocal tract can attenuate the radiated power over certain frequency ranges. The remaining frequency bands or formants give the instrument characteristic timbres, and it is the variation of these formants over time that is one of the most important elements of idiomatic performance.

The resonances of the tract give rise to peaks in acoustical impedance that are typically one to several MPa s m^{-3} [5,6]. In another study [8], we showed that the most important single determinant of the subjective judgment of instrument quality was the value of Z_{IN} in the frequency range 1 to 2 kHz, with low maximum values associated with high quality instruments. This is readily understood: if the instrument's resonances in this frequency range are too strong, the player is less able to manipulate the spectral envelope with his own resonances.

This instrument could be blown at either tube A or tube B, but tube A was chosen by the Didjshop as the normal mouthpiece. Figure 3 shows that tube A has the lowest values of Z_{IN} in the frequency range 1 to 2 kHz, particularly when the other tube is open (tube A blown and tube B open). When tube B is closed (tube A blown and tube B closed), there is an increase in the maxima in the 1 to 2 kHz frequency range. This would be expected to alter the timbre of the sound, and to reduce the influence of the player's vocal tract. A similar increase of Z_{IN} is apparent when tube B is blown and tube A is changed from open to closed.

Inspection of these curves suggests that the low value of Z_{IN} in Fig. 3 for tubes A and B open is due to cancellation of standing waves. Could the open second branch thereby be turning a mediocre instrument into one of higher quality? To consider this possibility, we conducted some numerical modelling.

Numerical modelling

The model used in Fig. 2 very substantially underestimates the complex bore of a traditional instrument. However, it explains qualitatively the $Z_{IN}(f)$ of this didjeridu, and some features of branched ducts in general.

We start by defining $Z_D(f)$ as the input impedance for tube A if the extra tube (in this case tube B) were absent or blocked off at the junction. This configuration would correspond approximately to a conventional didjeridu.

When tube B is present, it introduces an additional impedance Z_B in parallel with Z_C, the impedance of tube C from the junction to the external radiation field. We define Z_P as the parallel combination of Z_B in parallel with Z_C. The impedance Z_C is less than Z_B at low frequencies and, because ducts in parallel add admittances rather than impedances, the only features of tube B that will appear in Z_P correspond to the minima in Z_B (see Fig. 5). The effect of these minima is to produce additional, small maxima in Z_{IN}.

If the end of tube B is open, Z_B will be roughly similar to Z_D, providing that L_B is not too different from $L_A + L_C$, and consequently their minima will occur at similar frequencies. These minima in Z_B will produce minima in Z_P that in turn produce maxima in Z_{IN} around the frequencies where minima would occur in the absence of tube B.

Figure 5 shows that, if the end of tube B is closed, Z_B is almost the inverse of Z_B when open (it is not exactly the inverse because there is also a radiation impedance present when the tube is open). In this case, minima in Z_B occur at frequencies that correspond approximately to the maxima in Z_D. They will thus produce minima in Z_P that in turn produce maxima in Z_{IN} around the frequencies where maxima would occur in the absence of tube B. This will effectively produce notches in the maxima of Z_D producing the pairs of adjacent maxima.

The frequency dependence of Z_{IN} is a complicated function

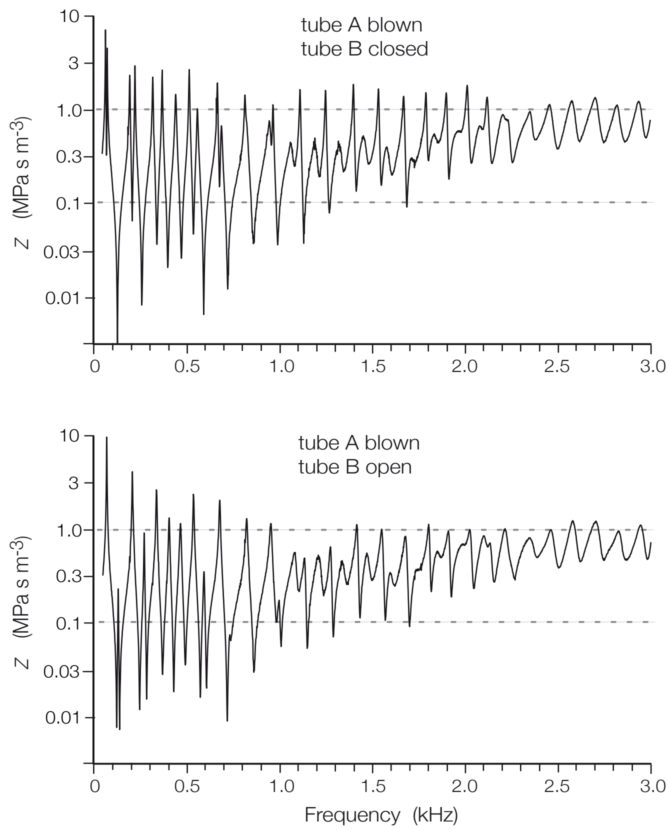

Figure 3. The measured acoustic input impedance Z_{IN} as a function of frequency plotted on a semi-logarithmic scale for the 4 possible input configurations of the forked didjeridu shown in Fig. 1.

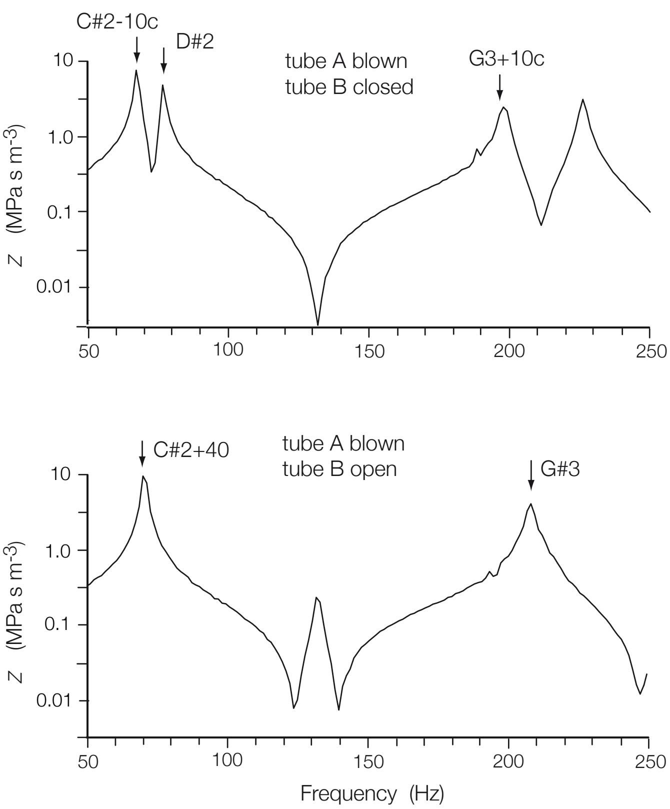

Figure 4. The measured acoustic impedance spectral data of Fig. 3 shown on an expanded scale for low frequencies. The vertical arrows indicate the frequencies of the musical notes played on the instrument by one of the investigators.

of the exact geometry of the forked didjeridu, particularly at high frequencies. This is because the frequency dependent load produced by tube B will have a greater effect, at a given frequency, when there is a pressure maximum at the junction, and this will depend upon the location of the junction. It is thus possible that, under some circumstances, the addition of a parallel duct could reduce the magnitude of several sequential impedance peaks.

The sound produced by two players.

To a first approximation, a duct closed by a player's lips behaves acoustically like a closed end. So Fig. 4 shows that the impedance peaks available for playing regimes are somewhat similar for the two players.

A notable feature of the sound produced the didjeridu is the very wide range of heterodyne components produced when a single player vocalises during playing. Thus if the didjeridu plays a note at frequency f while the player vocalises at a frequency g, the non linearities present can produce frequency components at frequencies given by $nf \pm mg$, where m and n are integers, e.g. see Fig 11 of Tarnopolsky *et al*., 2006 [6]. Even without vocalisation, two players using pairs of the impedance peaks shown in Fig. 4 can produce similar sets of heterodyne components. Two of the investigators found this possible, but somewhat difficult to control. The possible frequency components if two players play and vocalise simultaneously at four different frequencies are bewildering.

5. CONCLUSIONS

The additional mouthpiece on a forked didjeridu can allow a

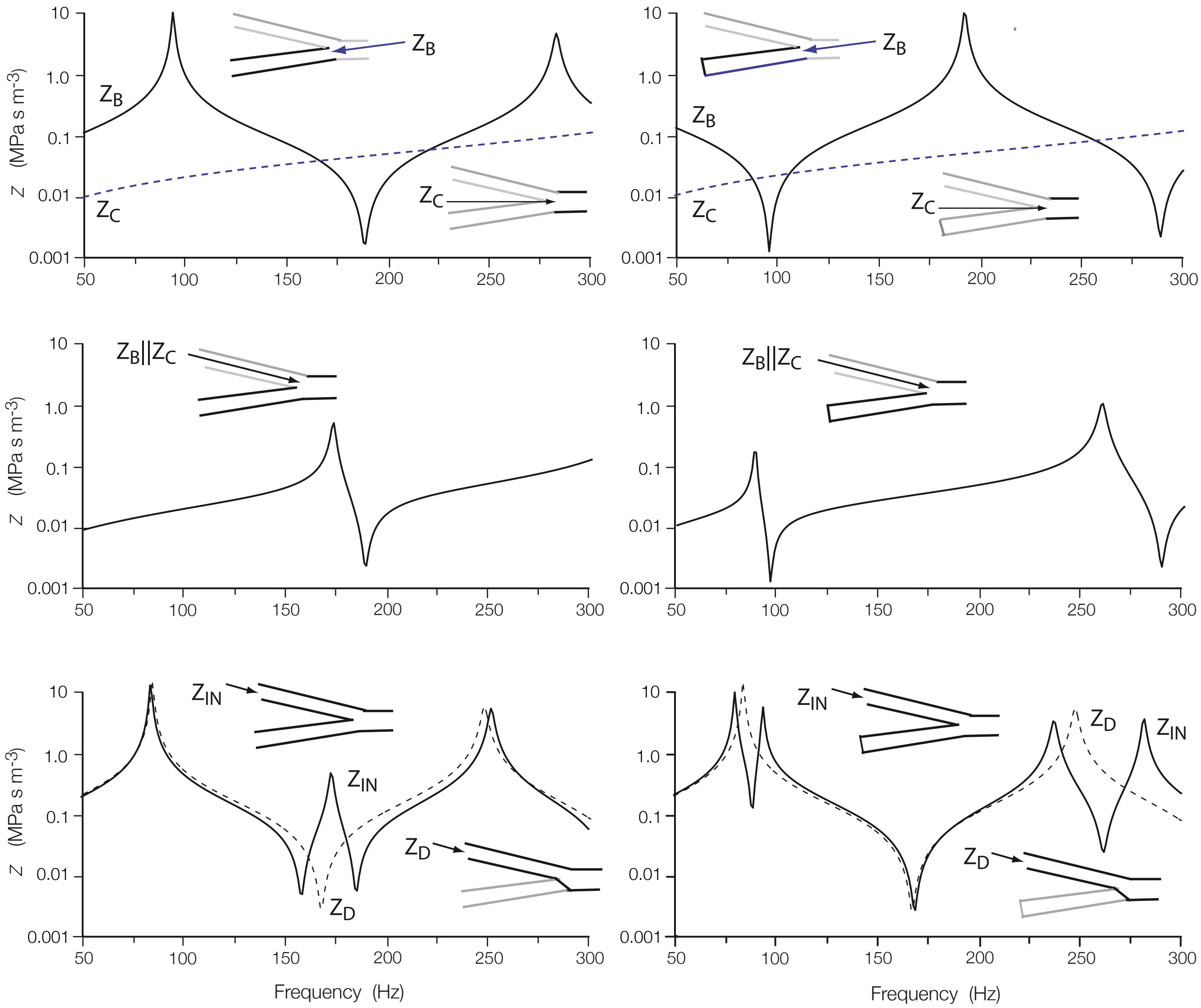

Figure 5. The calculated acoustic impedance of elements of the model shown in Fig. 2. The left and right hand curves were calculated with the end of tube B open or closed respectively. The continuous curves on the upper figures show the impedance Z_B of tube B alone as seen from the junction, whereas the dashed curves show the impedance Z_C of tube C alone as seen from the junction. The middle figures show the impedance Z_P presented at the junction by tube B and tube C in parallel. The lower curves show the input impedance Z_{IN} of the instrument when played at tube A. The dashed line on the lower curves shows the input impedance Z_D if tube B were blocked off at the junction.

player to produce changes in pitch and timbre by using the heel of his hand to close it. These effects can be explained by the use of a simple numerical model. Under propitious conditions, the extra tube may improve the playing qualities, which suggests the possibility of 'tuning' the length of one side tube to improve the quality of an instrument.

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