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Acoustical and musical properties of the Deskford carnyx reconstruction

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In 1992 a multidisciplinary team including the musicologist John Purser, the archaeologist Fraser Hunter, the silversmith John Creed and the musician John Kenny undertook a reconstruction of the carnyx, a Celtic brass instrument characterised by a bell in the form of a boar's head. The reconstruction was based on a fragment of a carnyx which was discovered in the early nineteenth century buried on farm land near Deskford in north-east Scotland. Since only the head of the Deskford carnyx has survived, decisions on the length and bore profile of the tube and the nature and orientation of the mouthpiece were guided by images of the carnyx on vessels and coins from the early part of the Christian era, and by acoustical considerations based on calculations and measurements on a prototype. In 2004 excavations at Tintignac in France revealed a collection of bronze tubing including parts of several carnyxes. The present paper reviews the acoustical and musical behaviour of the Deskford reconstruction, and reconsiders the decisions taken in 1992 in the light of the new information from Tintignac and the extensive performing experience of John Kenny over the last eighteen years.

1 Introduction

'Carnyx' is the name given by the Romans to a lip-excited wind instrument widely used by the Celtic inhabitants of Northern Europe around 2000 years ago. The most striking feature of the instrument is the bell section in the form of a boar's head. Although images of the carnyx appear on coins and vessels from the period, no complete carnyx has survived to the present time. The instrument described in this paper is a reconstruction based primarily on a fragment discovered at Deskford in the North of Scotland in 1816, now in the National Museum of Scotland in Edinburgh.

The reconstruction project was a collaboration between the musicologist John Purser, the archaeologist Fraser Hunter, the silversmith John Creed, and the musician John Kenny [1]. Since only the head had survived, decisions about the length and bore profile of the main tubing of the instrument were based largely on evidence from iconography, notably the depiction of three carnyx players on the Gundestrup cauldron. The team also sought advice from the Musical Acoustics Laboratory at the University of Edinburgh, and input impedance measurements were carried out on a prototype in 1992 [2]. The final design was completed in 1993. John Kenny found the instrument to offer rich musical properties, and some years later commissioned John Creed to produce a second reconstruction with essentially the same bore profile. The original reconstruction is now on display in the National Museum of Scotland. The second reconstruction, which has been extensively played and recorded by John Kenny, is the subject of the studies reported here.

In 2004 an archaeological dig at Tintignac in France uncovered a cache of metal objects including parts of several carnyxes. It has recently proved possible to assemble from reconstructions of these parts a complete instrument, which is the subject of another paper at this conference [3]. This exciting development provides a stimulus for a reconsideration of the decisions made in reconstructing the Deskford carnyx. Quite apart from the historical and archaeological interest in the carnyx, the experience of John Kenny in over eighteen years of playing the instrument, writing music for it and commissioning works by other composers has confirmed his view that the Deskford reconstruction is a wind instrument with a unique presence and voice. The present study attempts to relate scientific measurements of the acoustical properties of this instrument to specific aspects of its musical behaviour.

Figure 1: The Deskford carnyx reconstruction, sounded by an artificial mouth in the Musical Acoustics Laboratory at the University of Edinburgh.

2 Bore profile of Deskford carnyx reconstruction

The length of the reconstruction from the mouthpiece to the point at which the tube enters the head is just over 1.6 m. In the original prototype most of the main bore was cylindrical. To improve the harmonicity of the acoustical resonances it was suggested that this bore was made conical; practical considerations led to the compromise that the main tube expanded slightly in a series of steps, as shown in Figure 3. Various designs of mouthpiece were constructed. Playing experience led John Kenny to choose a design with a minimal bore constriction ('throat'); the bore profile in Figure 3 includes this mouthpiece.

Physical measurements of the bore of the completed instrument were complemented by a bore reconstruction using Acoustic Pulse Reflectometry (APR), shown in Figure 4. For this measurement the mouthpiece section was removed and replaced by a cylindrical connector 60 mm

Figure 2: Detail of the Deskford carnyx reconstruction, showing the head and throat.

shorter. The interior of the head is a complex structure with a moveable jaw and a large sprung wooden tongue (see Figure 2). From the APR curve it can be deduced that the terminating impedance presented to the internal air column by the head is similar to that of a rapidly flaring bell.

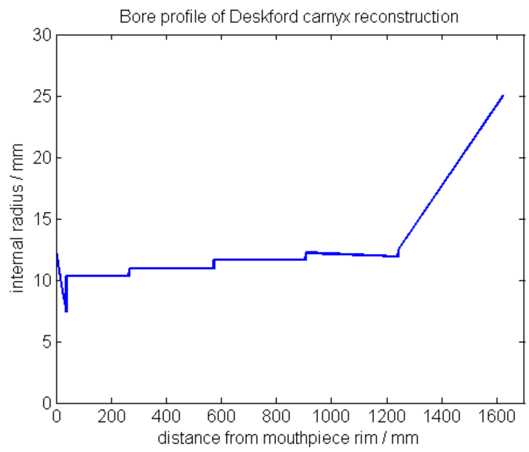

Figure 3: Measured internal bore profile of carnyx reconstruction, from integral mouthpiece to junction with head.

3 Input impedance and transfer function of carnyx

The input impedance of the instrument, measured using the BIAS apparatus [4], is shown in Figure 5. Three features of this curve which have implications for musical performance can be noted. Firstly, the frequencies of impedance peaks 1 to 5 are clearly not harmonically related. Secondly, the unusual design of mouthpiece means that the boosting of impedance peak amplitudes around peak 5, commonly seen in the impedance curves for cup mouthpiece instruments, is very weak in this case. Thirdly, at least 30 peaks can be distinguished, suggesting that the cutoff frequency is around 2500 Hz, around three times that of a tenor trombone.

The extent to which the resonance frequencies deviate

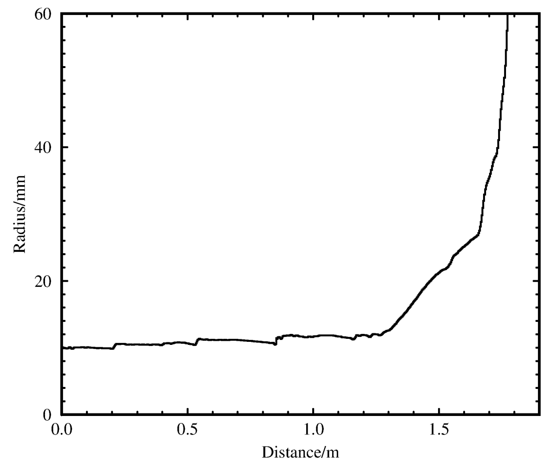

Figure 4: Internal bore profile of carnyx, reconstructed using acoustics pulse reflectometry.

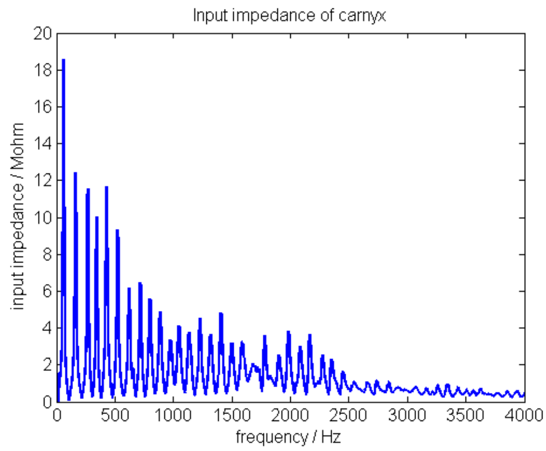

Figure 5: Input impedance of carnyx reconstruction.

from a harmonic series is illustrated by the plot of Equivalent Cone Length (ECL) [5] in Figure 6. While the fourth and fifth resonances correspond to those of a perfect cone of length 2.0 m, the first resonance is that of an equivalent cone of length 2.85 m. A strongly mode-locked regime of oscillation can occur between modes which lie close to a vertical line on the ECL plot; clearly an oscillation based on the first or second mode frequency will not satisfy this criterion.

The frequency dependence of the radiation efficiency of the instrument was investigated by measuring the transfer function T, defined as

$$T = p(out)_{rms}/p(in)_{rms} \quad (1)$$

with $p(in)$ the acoustic pressure of a sine wave at the mouthpiece entrance and $p(out)$ the acoustic pressure in the radiated sound field, measured at a point 50 cm from the hinge of the fully open jaw and directly in front of the opening. The measurement was carried out in an anechoic chamber. The frequency of the input sine wave was ramped from 50 Hz to 5000 Hz with an amplitude sufficiently low that effects of nonlinear propagation were insignificant. The result is shown in Figure 7.

Below 1500Hz the minima of the transfer function are close to the maxima in the input impedance. For an open

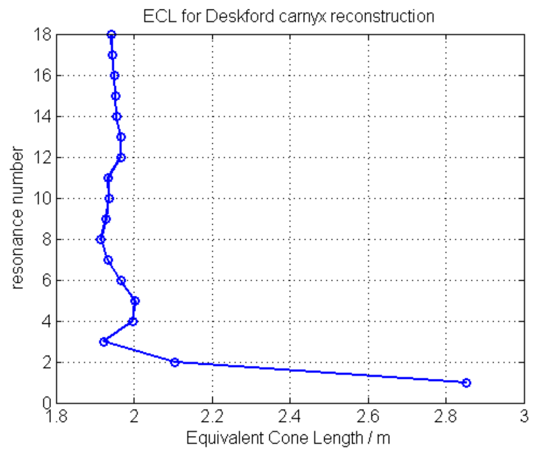

Figure 6: Equivalent Cone Length for carnyx reconstruction.

trombone bell the overall shape of the transfer function is a rise from low frequency to the bell cutoff frequency, above which the function is broadly constant. In contrast, the transfer function for the carnyx shows a deep minimum around 1500 H, with two strong peaks between 2000 Hz and 3000 Hz. It appears that the mouth shape and tongue are performing an acoustic function similar to that of a trombone mute.

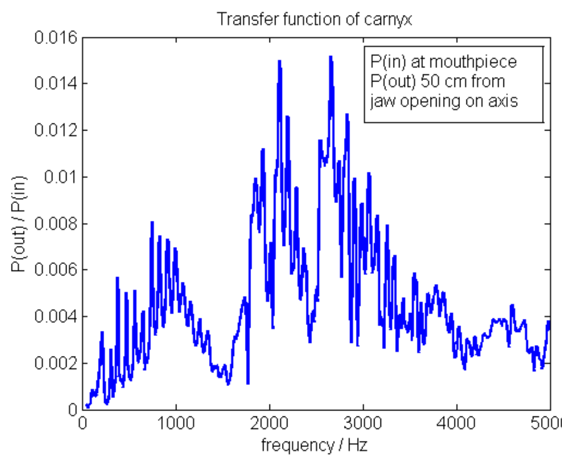

Figure 7: Transfer function of carnyx reconstruction, measured from mouthpiece entrance to a point 50 cm in front of the jaw opening on the head, as a function of frequency.

4 Playing frequencies

A recording was made of John Kenny playing what he considered to be the natural notes of the instrument. The playing frequencies and pitches of some of these notes are shown in Table 1.

Two particularly strong played notes were at pitches E3 + 49 cents (described in the following discussion as E3) and C4 + 29 cents (described as C4). Frequency spectra of these notes were calculated. The spectrum of E3 is shown in Figure 8, superimposed on the input impedance curve. It is evident that the fundamental frequency of the played note is slightly higher in pitch than the second resonance peak, while the second and third harmonics are below the fourth and sixth resonance peaks respectively. This could account for the

Table 1: Playing frequencies and pitches.

Frequency (Hz)	Pitch
39	D#1 + 5 cents
77	D#2 - 18 cents
169.5	E3 + 49 cents
266	C4 + 29 cents
526	C5 +9 cents
623	D#5 + 2 cents
696	F5 - 6 cents

relative weakness of the upper harmonics, implying that the lip behaviour is outward striking. A similar comparison of played spectrum and input impedance is given in Figure 9 for the played note C4. The frequency match between harmonics and resonance peaks is much better in this case, and the upper harmonics much stronger.

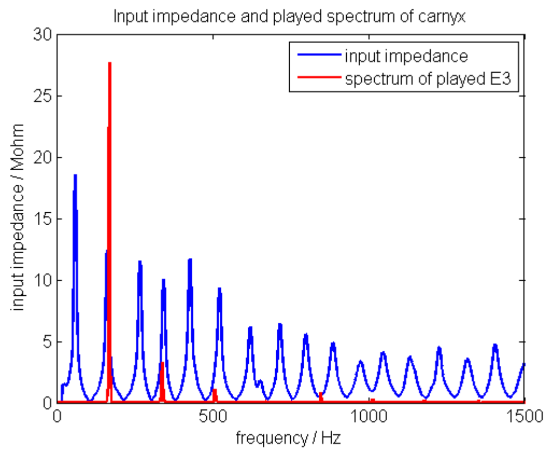

Figure 8: Input impedance curve with superimposed frequency spectrum from played E3

Another way to visualise the relationship between played notes and the input impedance curve is shown in Figure 10. The Equivalent Fundamental Pitch (EFP) for resonance number n with frequency f_n is

$$EFP = (1200/\log 2)\log(f_n/nf_r) \quad (2)$$

where f_r is an arbitrarily chosen reference frequency. In Figure 10 f_r = 87.31 Hz, corresponding to the pitch F2. The EFP then shows the pitch interval in cents between the n^{th} resonance peak and the n^{th} harmonic of F2. A perfectly harmonic set of frequencies lies on a vertical line, whose horizontal position shows the deviation from F2 of the fundamental of the set.

This display can also illustrate the possibilities for playing notes based on a mode with $n > 1$. Figure 10 also includes the harmonic frequencies for the note E3 (based on the second resonance) and C4 (based on the third resonance). This shows, for example, that the played E3 is nearly 70

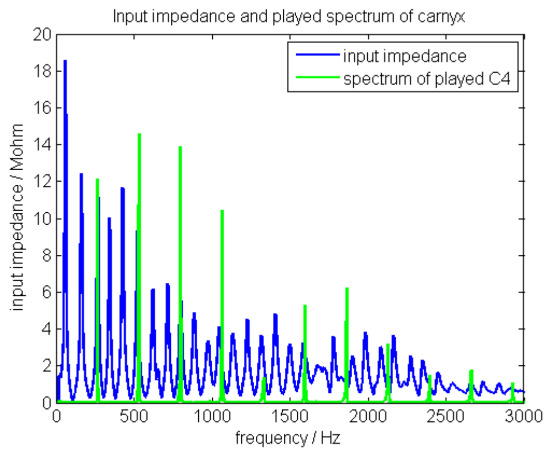

Figure 9: Input impedance curve with superimposed frequency spectrum from played C4

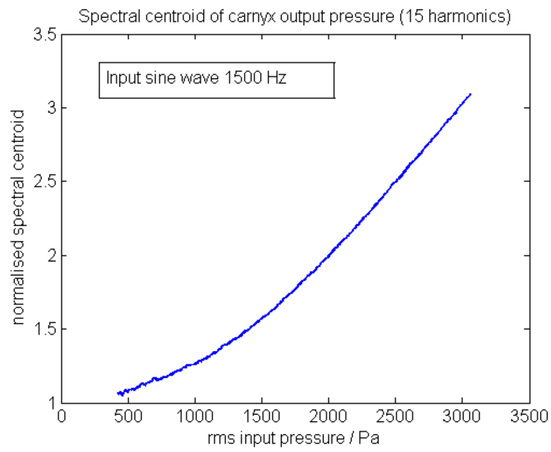

Figure 11: Spectral centroid of radiated sound, with input sinusoid at 1500 Hz, as a function of rms input pressure.

cents higher than the pitch corresponding to the second resonance frequency, while the played C4 is 11 cents below the pitch of the third resonance.

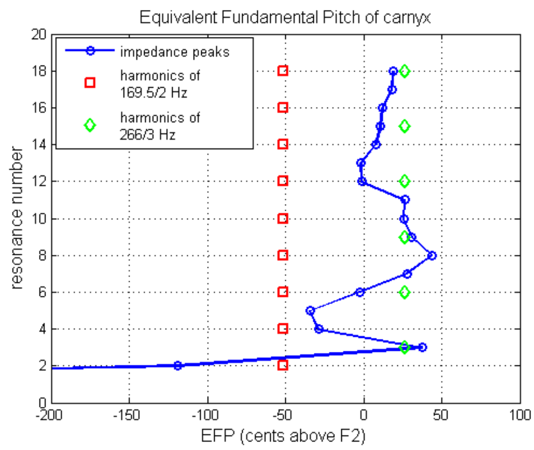

Figure 10: Equivalent Fundamental Pitch for carnyx with superimposed harmonics of played notes E3 and C4

5 Brassiness potential of the carnyx

John Kenny has demonstrated that the reconstructed Deskford carnyx can readily generate the characteristic 'brassy' timbre arising from nonlinear distortion in the propagation of sound within the instrument. To examine this effect, a setup similar to that used in measuring the transfer function was used. A sine wave of frequency 1500 Hz was injected into the mouthpiece of the instrument, and the spectral centroid of the sound radiated from the open mouth was calculated as a function of the input pressure. The experiment was again carried out in an anechoic chamber.

The spectral enrichment with increasing input pressure illustrated in Figure 11 is similar to that found in narrow bore trombones [6]. The brassiness potential parameter, calculated from the bore profile of the instrument, is $B = 0.69$, which is also a typical value for instruments of the trombone family.

6 Conclusion

Most of the natural notes of the Deskford carnyx reconstruction identified by John Kenny can be readily understood in terms of the measured input impedance, since each is fairly close to one of the input impedance maxima of the instrument. The lowest two notes, D#1 (39 Hz) and D#2 (77 Hz), are more difficult to understand. There is no resonance close to either of these frequencies. It is possible that each has the character of a pedal note, with the second harmonic of D#2 and the fourth harmonic of D#1 being supported by the resonance at 163 Hz. This hypothesis is consistent with the fact that D#1 is a weaker note than D#2.

In describing the musical playing properties of the Deskford carnyx reconstruction, John Kenny has emphasised the very large dynamic range which is possible on the instrument, ranging from the quietest pianissimo to a brassy fortissimo. The fact that very loud playing is possible is consistent with the wide bore of the instrument, which results in a high transfer function to the radiated sound field, and with the relatively efficient radiation of sound in the perceptually important frequency range around 3 kHz. The brassiness potential parameter is also fairly large, encouraging the generation of high frequency components which are efficiently radiated.

Comparisons of the Deskford carnyx reconstruction with the reconstruction based on the Tintignac discovery has only recently become possible. One interesting issue is the design of the mouthpiece: it is reassuring to find that the mouthpiece which is an integral part of one of the Tintignac pieces is very similar in its internal profile to the mouthpiece selected for the Deskford instrument, with almost no throat. The Tintignac instrument has a more sharply tapering conical bore than the Deskford reconstruction, resulting in a set of resonances significantly closer to a harmonic series [3].

Whether the Deskford carnyx reconstruction is a close approximation to the 2000 year old original instrument is a question unlikely to be answered. Further investigation of the Tintignac horde may shed further light on the nature of instruments of this type, although it should be borne in mind that the carnyx was apparently made and played over a period of several centuries, and no doubt existed in various different forms during that time. Reconstruction projects inevitably involve some speculation, but as John Kenny and other musicians have demonstrated they can result in instruments capable of playing a valuable role in the musical culture of the present day.

Acknowledgments

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7 References

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