Acoustical study of the Carnyx of Tintignac

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The carnyx is an instrument which was used by Celtic peoples in various parts of Europe around 2000 years ago. In September 2004 an excavation at Tintignac (Naves, Corrèze district of France) revealed a buried horde of bronze instruments, including a lot of parts of several different carnyxes. Some of the parts have been put together to make an almost complete carnyx which has been exposed in Paris in 2012. In 2011, a brass copy of this carnyx has been made by Jean Boisserie. This paper discusses some acoustical aspects of the carnyx brass copy, and presents measurements made on it. The measurements are mainly input impedance, vibrations measurements, and playing frequencies estimations. The question of the bore profile and its influence on the resonance frequencies inharmonicity are particularly discussed. In order to minimize the inharmonicity, it is suggested that the carnyx should be slightly extended. A specificity of the Tintignac carnyx is the presence of thin large ears on its head, their possible influence on the radiated sound is discussed.

1 Introduction

In 2004 an excavation at Tintignac (Naves, Corrèze district of France) revealed a buried horde of bronze instruments, including a lot of parts of several different carnyxes. Some of the parts have been put together to make an almost complete carnyx. In 2011, a brass copy of this carnyx has been made. The aim of the present work is to investigate the copy on the acoustic point of view in order to obtain information on the sounding characteristics of the instrument. Incidentally, our measurements can be used as a validation of the reconstruction the carnyx.

After the description of Tintignac site and the excavation (Section 2), the paper discusses some acoustical aspects of the carnyx brass copy, and presents measurements made on it. The measurements are mainly input impedance, resonance and playing frequencies in Section 3. The question of the bore profile and its influence on the resonance frequencies inharmonicity is discussed Section 4. A specificity of the Tintignac carnyx is the presence of thin large ears on its head, their possible influence on the radiated sound is discussed Section 5.

2 The Carnyx of Tintignac

2.1 The site of Tintignac

The Gallic tribe of Lemovices occupied, at least the last two centuries BC, an area covering the north-west of the Massif Central, in the approximate location of the Limousin region. The habitat there was essentially rural and sparse, despite the existence of some cities open or protected behind walls. At the heart of the department of Corrèze, in Tintignac (Naves city) an important sanctuary [1, 2] was dedicated to public meetings and religious ceremonies of some of the Gallic tribe (Figure 1). Animal sacrifices, libations (wine imported from Italy mainly) and large banquets of sharing and communion between men and gods were carried out. The Gallic sanctuary was indicated by a wooden fence (which archaeologists have found the foundation trench, wood having disappeared) enclosing a square space of about 24 m square. On this sacred platform a small wooden building (temple?) had been built whose imprint remained in the form of postholes. In the northeast corner of the platform, a small pit quite extraordinary was unearthed in 2004. Despite its small size (1.10 m square of 0.30 m deep), it contained nearly 500 fragments of iron and bronze objects. Among these objects, some are extremely rare if not unique, archaeologically speaking, in the Celtic world (roughly the Europe area nowadays). This has given to the archaeological site an international interest.

Figure 1: Photograph of excavations at the site of Tintignac.

In the surface of the pit offensive weapons such as blades and sheaths of iron sword and spear were accumulated. The defensive equipment were represented by metal parts of shield, bronze disks that may have served as body armor, and ten helmets, some of them having a quite surprising morphology. One of them, in particular, took the form of a swan. All these weapons bear traces of blows probably dealt voluntarily as part of a ritual mutilation well known among the Gauls in the funeral or religious contexts. Parts of harness were also taken from this pit by archaeologists, as well as a pot made of sheet iron and bronze assemblies. Several bronze sheets are clearly portions of body, paws or heads of animals including a horse. These metal animals were probably cult statues exhibited in the space of the sanctuary. Finally, in the bottom of the pit, fragments of seven great trumpets were identified. These trumpets called Carnyx, were mainly known previously by representations on monuments or coins. As tall a man, they were ended by a bell showing an animal's mouth wide open, usually that of a wild boar. The presence of large bronze plate ears, tree leaves-shaped, originally set on the bell, is a previously unpublished observation.

2.2 Carnyx parts

To date, worldwide, only two elements found by archaeologists, have been interpreted as Carnyx bells. One in Mathay Mandeure (Doubs, France), a site of a Gallic sanctuary. The other, in Scottish bog of Deskford. However, in light of recent discoveries, the interpretation of the last can be seriously questioned, especially because it was not accompanied by any other piece of instrument. Portions of straight tubes and plate-shaped leaves were, however, associated with the bell Mandeure. Other fragments of tubes have been found previously in England and Germany, and large ears in Germany and Switzerland (La Tene), which, however, had not found a satisfactory

interpretation. Recently, other fragments of tubes, always straight, associated with an ear and mouth were found, coming from Sanzano (Italy) in the 1950s. The fragments of Carnyx known to date, except those of Tintignac, boil down to a score of fragments spread across Western Europe.

The gallic trumpets are also known by many illustrations, both on Gallo-Roman monuments, as on coins Gallic or of the cesarean period, or on the Gundestrup cauldron discovered in a bog in Denmark. On buildings or coins after the Conquest, the Carnyx is most often associated with a warrior trophy erected in memory of a victory. The trophy consists of elements taken from the enemy (tunics, flags, weapons ...) and arranged strictly on top of a mast, where prisoners, namely the Gauls, are attached. To such an extend that the Carnyx will become, for Caesar and the first Roman emperors, the symbol of the Gallic nation defeated. However, only the representation of the Gundestrup cauldron shows the instrument in use. On one of its inner sheet metal three characters seem to follow a procession of armed and helmeted infantry with one hand holding a Carnyx upright. They blow in the mouth by raising the head and by advancing the lower jaw. From this representation some researchers and amateurs have imagined that the beginning of the instrument was curved. If this picture may indeed be the subject of discussion, all the others, on which the mouth is visible, clearly show a straight tube at the beginning of the Carnyx.

In the pit of Tintignac, these trumpets, long over 1.80 m, had been deliberately broken or partially dismantled before being put down the pit. Among the seven Carnyx bells, six were representing a boar head and one a snake head. Among the former, two were molded and have small ears. Four consist of sheets of bronze brazed together and endowed with big ears in which the sound could propagate. All in all, 5.35 m of linear tube, one mouth and six ears were extracted (Figure 2). No instrument was complete. We do not know what happened with the missing parts ...

Figure 2: Photographic elements of Carnyx in their grave at Tintignac.

2.3 The Carnyx reconstituted and its copy

A Carnyx was reconstituted from the parts found in the pit of Tintignac (Figure 3), especially the most important. Thus, the bell and all the curved portion of the tube were found in one piece coming obviously from the same instrument. The beginning of the tube has been reconstructed from different original parts. However, the decreasing diameter of the tube and the similarity of rings, connecting portions between the two instruments, leave well imagine that they belong to the same Carnyx. The section sandwiched between the base of the tube and the mouth was found more away in the pit. The mouthpiece was isolated and disconnected from any tube. To propose the reconstruction of a coherent instrument, a copy of the mouthpiece has been used. Finally, a pair of ears has been restored. It turned out that it was perfectly adapted to the bell chosen for reconstitution.

The only uncertainties therefore concern the connection between the mouthpiece and the first tube, the precise distance between the two large tube portions between which a piece is missing and the shape of the anterior superior portion of the ridge which was totally destroyed on the original. During a long time, for ergonomic reasons, it was thought that the mouthpiece was curved, and it led to many curved reconstructions. However, no archaeological discovery has ever demonstrated the existence of curved tube in Carnyx. In addition, all representations, except the one of the Gundestrup cauldron, show straight mouthpieces. In approaching the acoustics, archaeologists wanted to characterize and hear that famous impressive sound described by Polybius and Diodorus of Sicily. The influence on the sound of a potentially curved mouth or the acoustic role played by ears were among the open questions.

Figure 3: Photograph of Carnyx reconstituted (center), its mouthpiece (top left) and its head with ears (bottom left), the Carnyx copy (right).

The desire of archaeologists was to obtain a copy closest to the model, both in terms of material than of dimensions. If these have been met to the millimeter, it is not the same for the alloy used. Indeed, at the request of Jean Boisserie, for greater ease of manufacture and use of techniques he masters, this first copy was made from sheet brass (copper and zinc) and non-bronze (copper and tin). In addition, the sheet used is a little thicker (0.8 mm) than the original ones (0.4 to 0.6 mm), which tends to slightly increase the weight of the instrument: the reconstruction (3 kg compared to 2 kg for the original), is probably a little less easy to handle (Figure 3).

3 Resonance and playing frequencies of the carnyx copy

3.1 Input impedance measurement

For the input impedance and resonance frequency measurements, a set-up developed jointly by CTTM (Centre de Transfert de Technologie du Mans, 20 rue Thale`s de Milet, 72000 Le Mans, France) and LAUM is used [3].

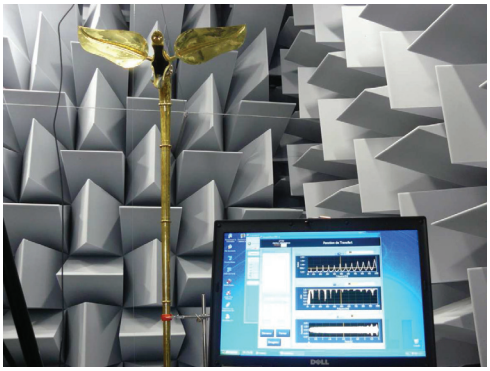

Figure 4: Input impedance measurement set-up in an anechoic chamber.

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The measurement set-up (Figure 4) allows the determination of the resonance frequencies from the input impedance curves (Figure 5). This is displayed by way of representation of the "Equivalent Cone Length (ECL)". The value E*CL(N)* is associated with the N^{th} resonant frequency F_N via the following relationship:

$$CEL(N) = \frac{c}{2F_N / N} . \qquad (1)$$

The set of resonance frequencies is quite far from a conventional harmonic set. An harmonic set of resonance frequencies would be represented by a straight vertical line in Figure 5. Note that the closest modern brass instrument is an alto saxhorn where the set of resonance frequencies (except the first and the second one) is more harmonic (Figure 5).

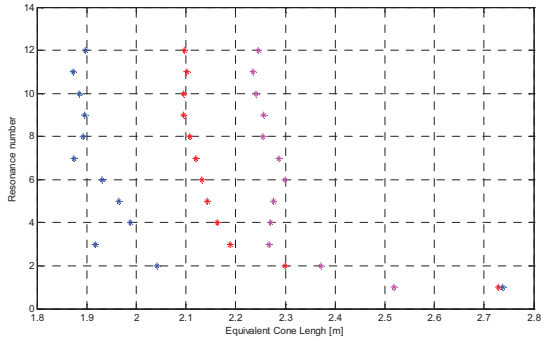

Figure 5: Equivalent cone length [m] corresponding to the first twelve resonances of the Tintignac carnyx copy (red), of the Dexford reconstructed carnyx (blue) adapted from [4] (data courtesy of M.Campbell), and of a modern alto saxhorn (cyan).

The ears of the carnyx are connected to the head. There is no significant influence on the input impedance. If the ears are closed, no effect is visible. There is only a small artifact around 400 Hz consequence of a vibro-acoustic coupling [5] which is smoothed if the ears are blocked. The effect of the vibrating ears is discussed further on (Section 5).

3.2 Playing frequencies

Consequently to the inharmonic set of resonance frequencies, the playing frequencies are organised in the same kind of inharmonic set. Furthermore the Carnyx is not easy to play, and not as powerfull as a modern brass instrument. By practicing more and more the Carnyx, one get significant progress in terms of exploration of range, volume and tone color. The Carnyx being mainly conical, it is very difficult to get brassy sounds [6]

The Carnyx of Tintignac being reconstituted from separate pieces, it is not excluded that a part is missing! In the following section we discussed the implication of an added part from the acoustic point of view.

4 The Carnyx bore revisited. Toward a longer Carnyx ?

As written in Section 2.3, uncertainties concern the connection between the mouthpiece and the first tube, the precise distance between the two large tube portions between which a piece is missing and the shape of the anterior superior portion of the ridge which was totally destroyed on the original. Then it can be useful to estimate the acoustic consequence of an extra length.

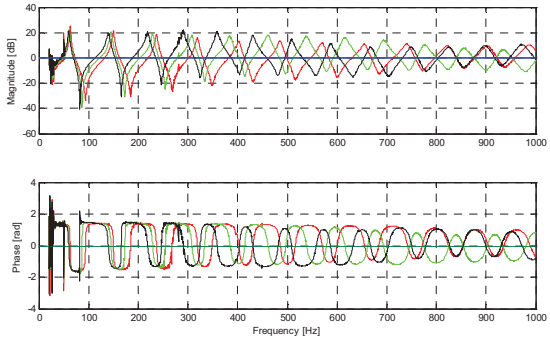

Figure 6: Measured impedance (magnitude and phase as a function of frequency) of the Tintignac carnyx copy (red), and with a calculated extension of 10 cm (green) and of 20 cm (black).

It is possible to extend the instrument with a cylindrical portion of length L by calculation from the measured impedance. Two cases (L = 10 cm and L = 20 cm) are presented in Figure 6.

Obviously the extension of carnyx lowers the overall tone of the instrument, and modifies the inharmonicity. This is shown in Figure 7 by way of representation of the "Equivalent Cone Length (ECL)". A perfect harmonicity would correspond to a vertical line in Figure 7. We can observe that an extension of 10 cm promotes good harmonicity, and an exaggerated extension (20 cm) degrades again harmonicity resonances.

This result suggests that a piece of tube is missing in the copy. Indeed, the main part of the carnyx is strictly conical which is acoustically justified only if the cone is almost complete. The Carnyx is not a primitive instrument and it would be surprising that the playability, which is related to

the harmonicity of the resonance frequencies, would not have been optimized.

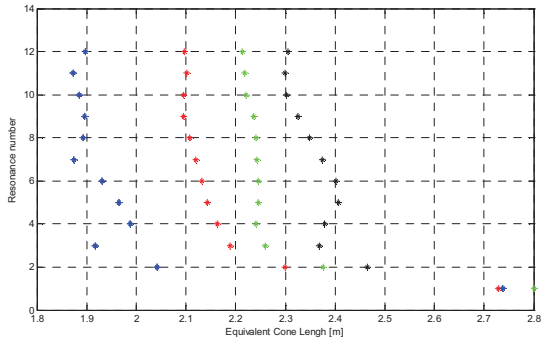

Figure 7: Equivalent cone length [m] corresponding to the first twelve resonances of the Tintignac carnyx copy (red), 10 cm extended (green), 20 cm extended (black), and of the Dexford reconstructed carnyx (blue) adapted from [4] (data courtesy of M.Campbell).

5 The vibrating ears

The ears have a small effect on Z (Section 3.1) due to a light vibro-acoustic coupling phenomenon, but not enough to have marked consequences on the ease of playing and the sound radiated. Connection of the ears to the main tube has no significant effect sound either. The presence of open connection might be the result of ease of mechanical assembly?

However, the ears vibrate significantly and audibly. At the end of the note played, the acoustic transient is much shorter than the transient due to the vibration source (consequence of the low structural damping of mechanical modes of the ears). At the end of the note played a "mechanical reverberation" can clearly be heard. This reverberation can be cancelled completely by blocking the ears.

It might be pointed out that, the ear are thicker on the copy (0.8mm instead of 0.4-0.6mm). So one can wonder if the ear vibrations on the Carnyx were not so large that it might affect clearly the sound of the Carnyx

6 Conclusion

A brass copy of a Carnyx discovered in Tintignac (France, 2004) has been analysed by doing input impedance measurements, and playing frequencies estimations. The Carnyx is almost conical, and then it is very difficult to get brassy sounds. The closest modern brass instrument is an alto saxhorn. The set of resonance frequencies is quite far from a conventional harmonic set.

Because the Carnyx of Tintignac was reconstituted from separate pieces, it is not excluded that a part is missing. Resonances frequencies analysis suggests. That a piece of tubing of about 10 cm at the input of the Carnyx is probably missing.

A specificity of the Tintignac Carnyx is the presence of thin large ears on its head. The ears have a small effect on impedance due to a light vibro-acoustic coupling phenomenon, but not enough to have marked consequences on the ease of playing and on the sound radiated. Connection of the ears to the main tube has no significant effect sound either. But the ears vibrate significantly and audibly at the end of the note played. As the thickness of the ears are significantly larger on the copy than on the original instrument the question of weather the ears vibrations might a significant effect on the sound produced by the Carnyx remains open.

A second copy is being manufactured. It is made of bronze like the original ones. It is planned to include a cylindrical portion just after the mouthpiece. Then the assumption of a longer Carnyx will be tested experimentally.

Acknowledgments

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