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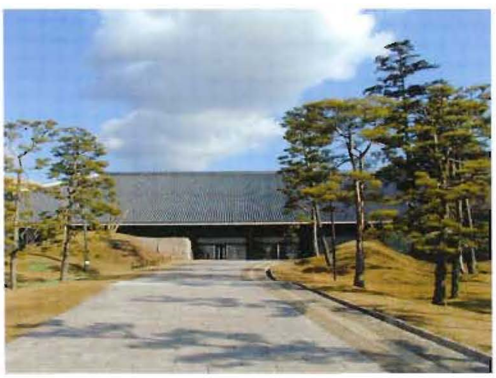
Planting the Grains and Harvesting the Ears



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The Acoustic Context of Oxus Trumpets

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Abstract

The Oxus river (modern Amu Darya) flows near the border of northern Afghanistan and southern Turkmenistan-Uzbekistan. Local excavations have produced numerous examples of trumpets dated 2200 — 1700 BCE. They are the earliest known extant trumpets, and their design is unlike any other. Their legacy seems to survive in Zoroastrian texts composed some centuries after Oxus trumpets had disappeared. These mention trumpets that had been used to communicate with animals.

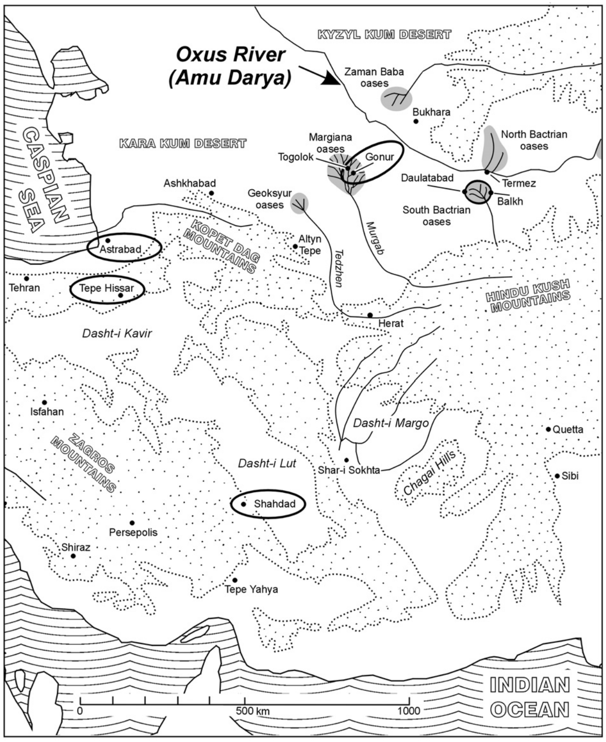

Figure 1. Oval areas mark sites where Oxus trumpets have been found. Oxus regions are shaded.

This is consistent with the acoustical properties: measurement on reproductions, calculations on analogous electric-circuit elements, and spectra of played trumpets show that Oxus trumpets give tones near 1 kHz which are similar to deer calls. Hunters still mimic the sound to call the male deer. From an acoustical point, the novelty of the design concerns the short length, the shape of body and the mouthpiece. The latter facilitate the production of high-pitched sounds.

1. Introduction

A fragmentary terracotta plaque from 2500 BCE depicts a 50-cm long, slightly conical, object protruding from the mouth of a Mesopotamian man. It may be the first documented trumpet, but it is only a single instant. Three

Figure 2. Face trumpet made of gold elaborately sculpted into three bison heads.

hundred years later, extant trumpets suddenly turn up in great numbers in the Oxus region 1500 km to the NE, principally at the Margiana and Bactria oases, but also in more southerly places marked with ellipses in Fig. 1. Many were illicitly excavated in the 1970s. Most were made of silver, but a few of gold and bronze. Some were objects with high artistic merits, e.g., the gold trumpet Decorated with bison faces with inserted horns of silver (Fig. 2). Such trumpets eventually spread south into Iran, but disappear by 1700 BCE. Trumpet history then has a hiatus of 400 years until the appearance of Tutankhamun's instruments.

Recently, the complete corpus of about 50 Oxus trumpets was described and analyzed from an archaeological point of view [1]. Four distinct shapes were recognized: bulb trumpets (Fig. 3A), face trumpets (3B), plain exponential trumpets (3C) and plain conical trumpets (3D), each type with many members: 18, 9, 6, and 10 respectively. Face trumpets often exhibit more

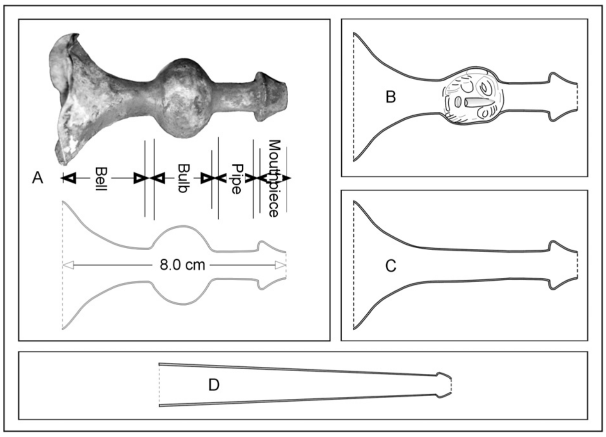

Figure 3. Four types of Oxus trumpets.

than one face, e.g., the bison trumpet has three. There are big differences between types, but the members within each differ little. The types may fit a logical sequence: plain trumpets may eventually have acquired quasi-spherical bulbs located midway between the bell and mouth piece; in time, the bulb may have been elaborated into faces. Yet, the archaeological dating is too imprecise to support such a sequence within the period 2200 – 1700 BCE.

What made the four types so successful that many copies were made during 2200 – 1700 BCE? Did each type have distinct and useful acoustical properties? As I discussed a year ago [1], there is archaeological and textual evidence that the trumpets had been used in hunting. Zoroastrian text composed a few centuries after the trumpets existed indicate that they had been used to gather animals at an earlier 'golden age'. I now like to study their acoustics and learn if the trumpets can, indeed, make sounds appropriate for animals. Today there is a hunting method ("stalk hunting") where the hunter silently sneaks up on the male animal and produces sounds that attract the animal's attention. In Germany (*Pirsch* or *Puersch* hunt) the hunter relies on special "game calls" or on his voice suitably modified by external means (hands, funnels, etc.). The most attractive large prey in the ancient Oxus region was the deer. Male deer are easily attracted by the sound of a female deer in heat. Can Oxus trumpets imitate female deer calls? Does the trumpet's shape affect its ability to do so? I will (1) analyze sound produced by trumpeters, (2) compare them with sounds of deer, and (3) analyze the relevant acoustical properties of the four types of trumpets (experiment and theory). Since the shapes (especially the bulb trumpet's) differ radically from modern trumpets, the results are novel.

All Oxus trumpets are short, and their fundamental frequency corresponds to a high pitch near c''', two octaves above middle-c. On modern trumpets such a high note would demand very high lip tensions, but the mouthpieces of Oxus trumpets are shaped to cut down the mass of the vibrating lips. This circumstance lessens tensions. The acoustical match between the short length of the trumpet and the shape of the mouth piece indicates a purposeful design 4,000 years ago.

2. Trumpet response

One likes to know the output Sound Pressure Level (SPL) in front of the bell when the mouthpiece receives a constant input SPL. The level is a function of frequency, and a rough estimate of the peaks is given by the formula for open-closed pipes: $f_n = c\ (2n+1)/4L$ [where L is the length of the trumpet and n is an integer]. Known Oxus trumpets are between 7 and 12 cm long. For this study I made all replicas 8 cm long which lead to f_n being approximately (2n+1) kHz.

But we need to measure real trumpets, and I chose a small dynamic earphone (Sony MDR-ED238) as sound pressure source. The magnitude of its SPL was not precisely controlled, but the trumpets have tiny air columns which exert similar small loads on the transducer, i.e., the condition is close to those for the piezo-electric transducer described in [2]. The earphone output was not constant across the chosen frequency range. The system response was obtained by comparing the measured output of a cylindrical open-closed tube with results calculated using an analog electrical network (see below).

The earphone was collimated by a 3-mm hole that fit entirely inside each mouthpiece. The rest of the earphone was enclosed in an acoustically damped metal box that largely eliminated external radiation; the trumpets were pulled tightly against the box. A small microphone with 1-mm entrance diameter (Knowles BL-1785) was placed near the exit. The earphone was fed by a VCO (HP 3311A) controlled by an AD/DA unit (DT9802) attached to a laptop. A program running Agilent's VEE OneLab swept the VCO, applied a FFT transform to the microphone signal, selected the correct peak, integrated its surface, subtracted the background, and plotted the response across a frequency range between 0.5 and 10 kHz. Replicas with trumpet-like shapes ("the models") were made by a glassblower.

The models have three distinct elements: tube, bulb, and bell. To see how the components affected the sound, I studied four systems: (1) a straight tube, (2) a tube with a central bulb, (3) a tube terminated by a bell, and (4) a tube with a central bulb and a bell at the end (the shapes are shown as inserts in Fig. 4, the measurements as gray lines). In the case of the cylindrical tube (Fig. 4, top), the

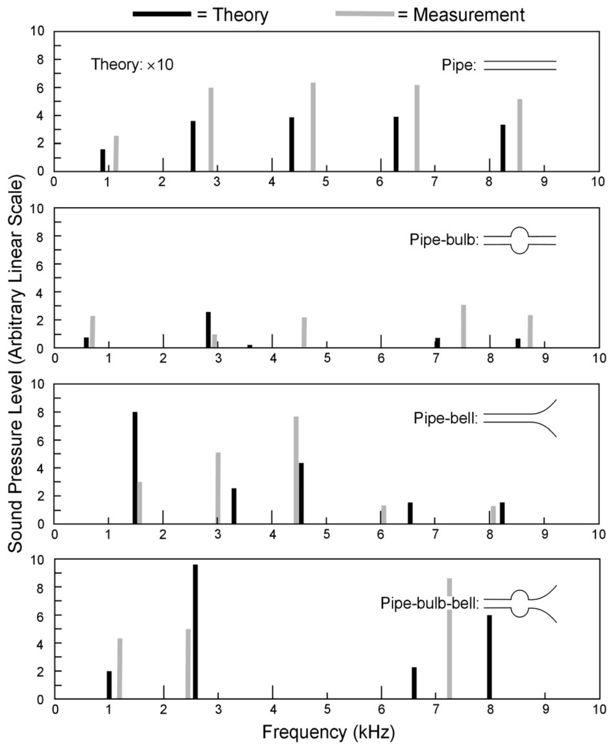

Figure 4. Sound radiation from four glass models resembling Oxus trumpets.

peaks fell close to predicted f_n values, and their amplitudes were used to calibrate the response of the equipment. Longer and shorted tubes supplemented the range of the calibration. On the next more complex system, the tube–bulb, the fundamental is lowered in frequency (by 40%), but on the "tube–bell" system the fundamental is raised (50%). In the latter case, the system behaves much like an open-open (but shorter) tube [3], here f_n = 1.5n. On the full system, the tube–bulb–bell, the fundamental moved 15% above that of the open–closed tube. The acoustical effects of bulb and bell nearly cancel.

To learn if this behavior can easily be calculated, I used an analog electrical network to find the SPL at the model exit. Surprisingly, the shape and dimension of our tube–bulb–bell model are nearly identical to that of burrows built by crickets [4]. Fletcher has considered that system, and I followed his approach [5] and [6] (in the latter reference all signs in eq. B.8 should be changed – as confirmed by Fletcher on July 3, 2001). However, I closed the entrance to the tube nearly completely and injected the source through a narrow channel (d = diameter = 0.002 mm). The microphone was put at the model's exit. As Fletcher [4] did, I substituted a large-diameter cylinder for the spherical bulb. The parts defined in Fig. 3 had the following dimensions (in mm). Bell: L = 31, d = 43 and 11, front and back respectively; Bulb: L = 23, d = 28; Tube + mouthpiece: L = 33, d = 10.

Calculated and measured frequencies of the tube are in good agreement across the full range of measurements (Fig. 4, black lines). This is particularly striking for all lowest-frequency-peaks. In the case of the tube–bell model, the effective length of the tube is shortened and it behaves like an open-open pipe. With tube, bulb, and bell present, the two lowest peaks are back in roughly the same position as on the plain pipe of the same length, but there is now a wide gap between 2.5 and 7 kHz and large peaks above that range. On the whole, peak heights are increased by the presence of bells. Although the relative heights of peaks are predicted less well, one can confidently calculate the position of the lowest resonances for any of the models.

3. Mouthpiece

When the first extant Oxus trumpets came to light 1841 and others followed in the early 1930s, archaeologists were puzzled. The objects were shaped like trumpets much smaller than any known playable trumpets, and some thought it merely a miniature funerary offering in lieu of a (playable) larger trumpet. But no larger trumpets were ever found at these sites, and we now accept them as true trumpets because (1) reproductions are playable — albeit the sound cannot be used in modern musical contexts (they produce only single notes at high pitch), and (2) their mouthpieces are consistently designed to facilitate the production of such high pitches. Figure 5 illustrates the unconventional design of the mouthpieces. Whereas modern ones expand toward the lips, the Oxus variety are truncated cones that contract toward the lips. Modern mouthpieces encircle most of the lips in the vertical direction. Oxus mouthpieces, on the other hand, are wedged between the front-ends of the lips and leave only a small sliver at the back-ends free to vibrate. Its mass of the vibrating part is much smaller than the full lip used on modern trumpets, and it should more easily allow high frequencies. Although lips are amenable to analysis, the limited space here only allows this qualitative observation.

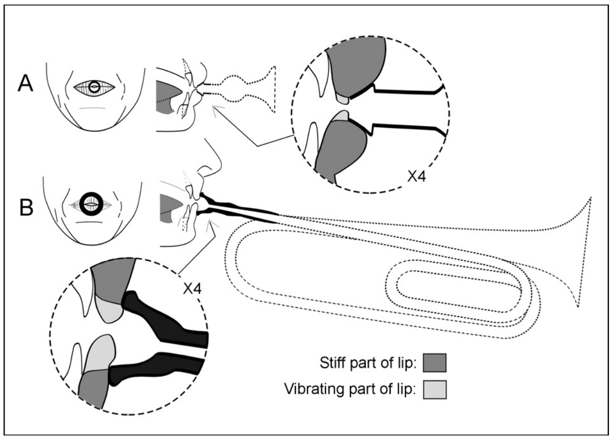

Figure 5. Comparison of mouthpieces on Oxus and modern trumpets. All are drawn to the same scale, except the encircled areas, each magnified four times.

4. Comparing sounds of bulb trumpets and deer calls

A Zoroastian text, probably going back to 1000 BCE, mentions trumpets used to call animals. The sounds obtainable on our replicas have fundamentals in the 1 - 1.5 kHz range, a range similar to those of mating calls emitted by female deer. The Fallow deer has a very weak fundamental near 450 Hz, but the harmonics above 900 Hz are clear (Fig. 6). The sound of the Roe deer has a

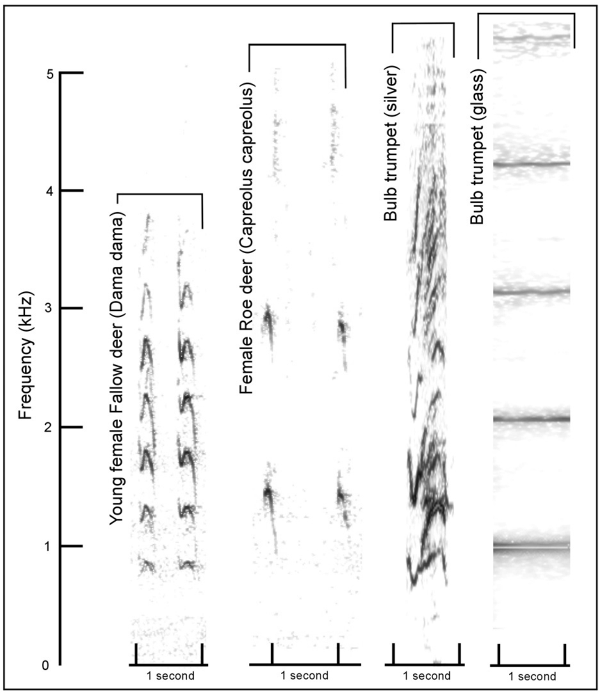

Figure 6. Spectrograms of two kinds of deer and two bulb trumpets.

fundamental near 1.5 kHz and a prominent harmonic at 3 kHz. In both cases, the pitch rises and falls in a characteristic manner during the length of the utterance, about 250 ms. One of my bulb trumpets (a replica made of silver) emits harmonic sounds with a fundamental near 1 kHz and is capable of similar sliding pitches, although the sound in Fig. 6 was played for too long (600 ms). With some practice, the bulb trumpet could probably mimic calls of the female Fallow deer.

Long and steady sounds could also be played on bulb trumpets. On another replica made of glass, the fundamental had a frequency of 1.09 kHz. There was also a prominent harmonic near 8 kHz, just as Fig 4 (bottom) makes us expect. The presence of such a steady tone shows the instrument as a true trumpet.

Since Oxus trumpets can mimic animal (deer) sounds, they could, presumably, also attract animals. On the other hand, the trumpets were not used in a musical context — at least not in the sense we now define such terms.

Acknowledgments

I am grateful to two trumpeters, D. Smithers (glass trumpet) and J. Schween (silver trumpet) whose techniques were flexible enough to permit Oxus trumpets to sound after 4,000 years. It is worth noting that another highly trained trumpeter failed to make a single sound. His polished technique, which had never let him down during 40 years of solo and orchestra playing, was inconsistent with the mouthpiece and high pitch.

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