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# *Ziphius cavirostris* bio inspired acoustic antenna. Finite element analysis and experimental validation

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ABSTRACT

One way to amplify an incoming signal is to design a receiver that couples with the signal frequency. In this study a resonant system made of a belt, one part exposed to the incoming signal and the other part inserted in a protected cavity is investigated. The cavity is shaped like a tapered horn in order to obtain maximum amplification at the horn tip. A finite element model based on displacement fields for the acoustic fluid and the belt is developed. The moving surfaces are coupled in such a way that the coupled stiffness and mass matrices are symmetric. Different resulting coupling modes are analysed. A prototype is constructed in order to verify the numerical results. The experimental and numerical results agree to within 6%. The desired amplification inside the cavity is obtained and the time exposure necessary to reach a stationary wave inside the cavity is measured. The design is a simplified, bio inspired, representation of a *Ziphius cavirostris* lower jaw bone and its surrounding fat cavity.



## 1. Introduction

Odontocetes, which are marine mammals, like dolphins and orcas are well known because of their ability to use echo localization to find their prey. The literature includes many surveys on how their echolocalization system is supposed to work [1,2]. A complete computational model of another odontocete, the *Ziphius cavirostris*, was presented by Cranford [3,4].

The lower maxilla of a *Z. cavirostris* is a fine bone, made of a material that resembles ebony and is shaped like a tuning fork. Suppose that this animal emits a sound when it finds food; the sound propagates in the water. The sound may reach its prey, usually a squid, which has the same density of water [5]. Part of the sound bounces back and, after diverging, returns to its source. It then, following the accepted mechanism [1,2], traverses the animal's cheek and goes into the fat cavity before finally reaching the cochlea. Of course the animal may already have a highly tuned hearing system, but our interest lies in the amplification of the sound. Specifically, how does the arrangement of the shapes and materials found in the lower jaw system could produce amplification? There are many well-known acoustical shapes in the maxilla-fat cavity assembly that merit analysis.

This study identifies acoustical shapes, components, and the expected effects. Their combination is used to produce a tuned resonant assembly and they are analysed using an ad hoc finite element model rendered in 2-D for simplicity. The model retains the features most worthy of investigation. The model uses a displacement based 3-node element developed in [6,7] that is coupled with a thin beam.

A prototype is constructed and its frequency response in the band of 1500–4000 Hz is obtained. The experimental frequencies are identified with the numerical model. The instrumentation available in our laboratory allow sound propagation in air to be measured, thus the FE model is developed using air as the acoustic medium.

In short, shape and components are used to develop an acoustic antenna.

## 2. The natural shapes

On observing the lower maxilla of a *Z. cavirostris*, three distinct parts can be identified: a peak, a cup and a plate, see Fig. 1.

By cutting the peak into slices, the internal details appear. The peak is a flexible curved plate made of compact bone covering a tube of porous bone. The porous bone is traversed by a central conduct, Fig. 2. The diameter of the conduct increases exponentially from the tip to the other end, like a horn. The plate continues to

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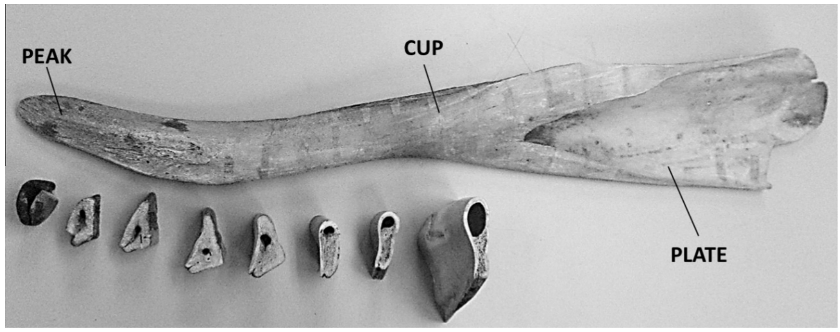


**Fig. 1.** Lower jaw and sliced jaw. The so-called cup is the slice at the bottom-right.

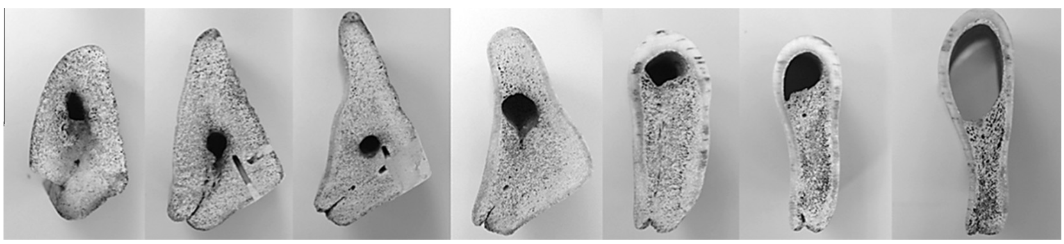

**Fig. 2.** Peak slices from left to right. Notice how the cover plate appears in the third image and continues covering the whole section.

the back, covering the conduct and the porous part, leaving uncovered the side where the teeth were supposed to be (the *Z. cavirostris* does not have teeth). The plate thickness increases up to 2 mm in our specimen and the duct moves from the central position to one side. In the part we call the cup, the central hole increases its size and the porous material moves to one side. The shell that forms the cup is solid, with thickness between 1 and 1.5 mm.

The side of the cup facing outwards continues to the end of the bone, forming a slightly curved plate folded at the centre. The peak is covered by a thin layer of fat. The cup and the plate are immersed in a cavity filled with liquid fat. In Fig. 3(a) a ventral view of a *Z. cavirostris* skull and lower maxillary bones is shown. A diagram of the fat cavity and a schematic sagittal cut of the maxilla are added over it.

*2.1. Hypothetical behaviour*

A hypothesis on how this assembly functions follows:

(a) The sound wave reaches the peak through a thin layer of fat, causing it to vibrate over the porous elastic bed.

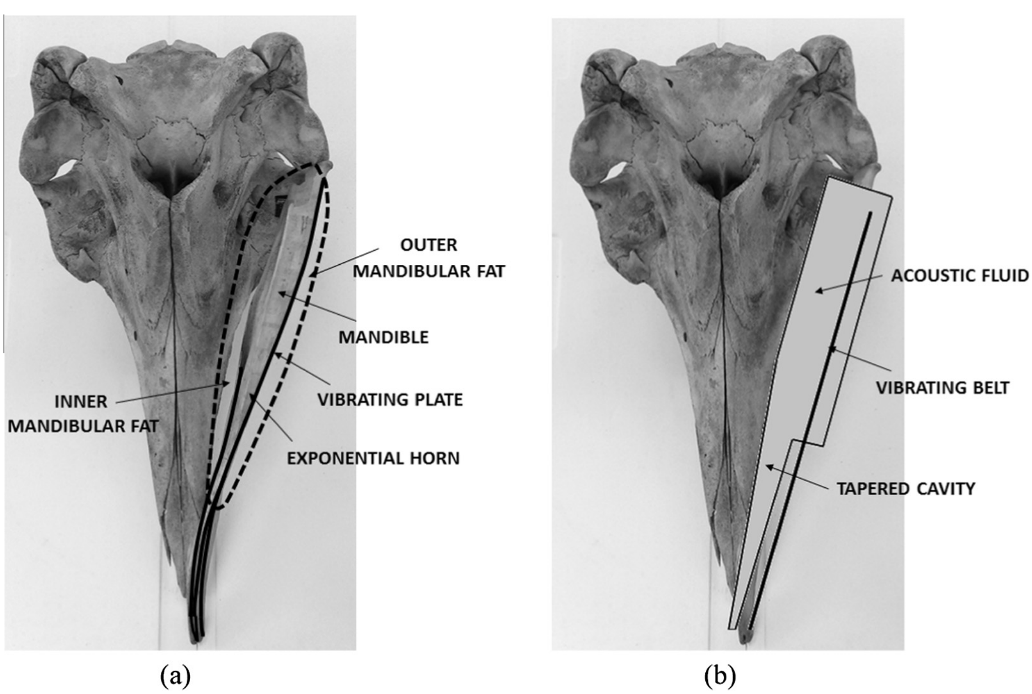


**Fig. 3.** Ventral view of *Ziphius cavirostris* skull with only the left lower maxilla. (a) Diagram of the fat cavity and a schematic sagittal cut of the maxilla. (b) A simplified 2D acoustic cavity model.