An experimental study of the acoustic radiation of a concert harp using Nearfield Acoustic Holography

Nicolas Dauchez, Jean-Hugh Thomas, François Gautier, Jean-Claude Pascal
Laboratoire d'Acoustique de l'Université du Maine, UMR CNRS 6613, Avenue Olivier Messiaen, 72085 Le Mans cedex 9, France, Email: Nicolas.Dauchez@univ-lemans.fr

Introduction

Stringed musical instruments generally comprise many couplings and consequently their acoustic radiation can be quite complex. In the case of instruments such as the guitar and the violin, the acoustic radiation has been extensively investigated [1,2], but there are relatively few studies related to the harp [3], despite the fact that it works in a similar way. The harp is composed of a tapered, stiffened, roughly trapezoidal thin plate, called the soundboard (see Fig. 1). The soundboard is fixed on a thick cone shaped cavity, called the soundbox, and is excited by strings attached from the central line of the soundboard to the string arm. Several holes are designed on the soundbox to permit access to the back of the soundboard for string mounting.

The aim of this study is to provide a description of the acoustic radiation of a concert harp, allowing to identify the main acoustical sources and to validate analytical and numerical models which will be developed in the future. Acoustic radiation is studied using planar nearfield acoustic holography (NAH) [4].

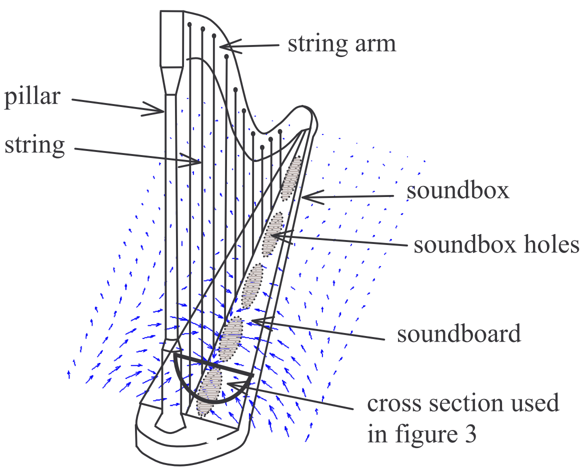


Figure 1: Intensity vectors retro-propagated on the soundboard of the harp at 168 Hz.

Experimental procedure

The aim of NAH is to reconstruct the acoustic pressure and velocity fields at the source plane from pressure measurements made close to the source plane. Then acoustic intensity vectors can be computed (see figure 1). The acoustic pressure fields were measured from two planes in the nearfield of the soundboard and the soundbox holes of the harp while a stationary mechanical excitation was placed at one string location: a shaker connected on the central line of the soundboard by a stinger allowed to generate a broad spectrum of spatial wavenumbers. The scan was conducted in an automated point-by-point fashion using a single microphone. The complex pressure was restored from the phase relations between the acoustic acquired signals and the excitation signal. Two areas were scanned. First, the pressure was measured 3.5 cm from the soundboard plane on a rectangular grid of 16×22 points covering half of the soundboard plane. The step size in both directions and for the two experiments was 5 cm. The points of the other side are deduced by symmetry with respect to the string plane providing an overall scan dimension of 1.5×1.05 m. The second measurement plane was also rectangular. The pressure was acquired 2 cm from the soundbox holes on a grid of 16×32 points extended by symmetry to 32×32 points as for the soundboard measurements.

Experimental results

Calculations of acoustic power radiated by the soundbox and the holes allow us to quantify their relative importance (see Fig. 2). We will focus on the first frequency range [150-220 Hz] where the radiation through the holes is the most important. Acoustic power radiated by the holes reaches local maxima for *f*=168 Hz and for *f*=184 Hz.

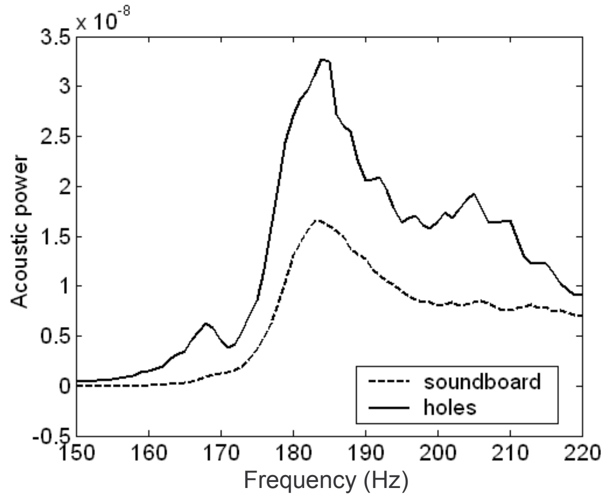
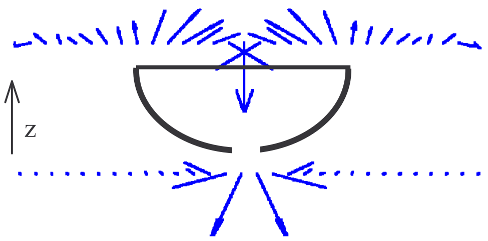


Figure 2: Acoustic power radiated by the soundboard surface and by the soundbox holes.

It is suggested that these maxima correspond to the two resonances of an elastic Helmholtz resonator. Such a model is commonly used to describe the behaviour of the guitar, which is similar to a bass-reflex enclosure in the low frequency range [5, 6]. In a more general way, it has been shown that in the low frequency range, the radiation pattern of a string instrument having a sound hole in its shell is that of a dipole [7]. Such a result can be obtained using a multipole expansion of sound field outside a sphere that encloses the source. In such a configuration, a two degrees of freedom model can be used to describe the oscillators representing the first top-plate resonance and the Helmholtz air resonance. The two mechanical oscillators are acting like acoustic flow sources and are leading individually to monopole acoustic radiation.

In the case of the harp, definition of the equivalent elastic Helmholtz resonator is not so easy as in the case of the guitar due to the presence of several holes. The analysis of the intensity field in the low frequency range (see Fig. 1) suggest that the first monopole would be located on the bottom part of the soundboard, and the second one on the area of the holes 1-2. The variations of the intensity vector distributions observed between Fig. 3(a) and 3(b) show that the relative magnitude and phase of these two sources depend on frequency in a similar way that could be observed for an elastic Helmholtz resonator.

(a)



(b)

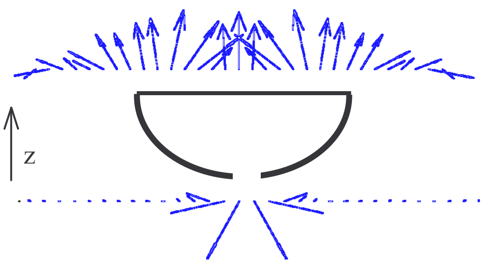


Figure 3: Details of the intensity vectors distribution on the cross section defined on figure 1 for the given frequencies : 168 Hz (a) and 184 Hz (b).

On Fig. 3-a corresponding to f=168 Hz, the intensity vectors on the soundboard have high amplitudes and are mainly oriented towards the instrument (in the ingoing normal direction, denoted by $-z$). On the surface of the soundbox holes, intensity vectors are oriented in the $-z$ direction, which is the outgoing normal direction. These two orientations show that the instrument is radiating like two equivalent monopoles having different acoustic flows (amplitude and phase). Such a configuration is observed for frequency values between 160 Hz and 177 Hz.

On Fig. 3-b corresponding to f=184 Hz, the same configuration as the previous one is shown: in this case, the acoustic intensity vectors on the soundboard have high amplitudes but are oriented in the outgoing direction ($+z$). The relative amplitude and phase between the two equivalent monopoles have changed in comparison with the configuration for f=168 Hz.

Conclusion

The acoustic radiation of a concert harp was investigated using planar nearfield acoustic holography (NAH). Comparison of the acoustic radiated power of the soundbox holes and the soundboard shows that soundbox holes radiation is the most important in the low frequency range [150-220 Hz]. Two radiation maxima are observed. It is suggested that acoustic radiation can be described by two equivalent monopole sources which relative amplitudes and phases can be determined by a two degrees of freedom system describing the harp as an equivalent elastic Helmholtz resonator. Analysis of the spatial distributions of intensity vectors suggests that the equivalent monopole would be placed at the bottom part of the instrument.

This approach has been successfully used to describe the behaviour of the guitar in the low frequency range. Its application to the harp is not straight forward because of the presence of several holes and will be the purpose of following works.

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