FREQUENCY AND DYNAMICS ANALYSIS OF BASS TONE OF CAJON BOX DRUM

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Abstract: The paper deals with the resonance of cuboid enclosed air mass with circular hole and sounding board of cajon box drum. Experimental cajon drum has internal dimensions of 260×280×470 mm, sounding board is made of thin 3-ply plywood and resonance hole has diameter about 120 mm. When playing cajon box drum, the sounding board is striking by hand about midway between center of sounding board and top edge and therefore is excited mainly (0,0) mode of rectangular plate with clamped edges. Frequency of this mode varies around 110 Hz and it is the strongest sound of instrument. Experimental instrument was excited by falling silicone ball to about midway between center and edge of sounding board. The diameter of resonance hole was enlarged for each experiment from 70 to 170 mm by steps of 10 mm. The sound pressure level (SPL) of excited instrument was measured by sound level meter BK2218 using octave filter BK1613, set to 125 Hz. The sound was recorded through the 24bit/96kHz recording system to the computer for frequency analysis. There is an assumption of Helmholtz resonance uprising. Objective of this measurement is to prove or disprove this phenomenon in case of cajon box drum.

1 Introduction

Cajon is a kind of box drum comming from both Peru and Cuba and has arisen as substitution for African drums. The wooden boxes for fruits, fishes and food was used by slaves, because playing drums was prohibited. In seventies of 19th century famous flamenco guitarist Paco de Lucia from Spain bring two pieces of cajon drum from Peru to Spain and since this time it is used in flamenco music. Standard contemporary flamenco cajon has dimensions of about 30x30x50cm, it is made of plywood and has additional strings, that touches the sounding board from inside and makes the sound brighter. On the back side is situated the resonance hole of diameter about 12 cm as shown on Fig. 1. Cajon player is sitting on the instrument and is striking the sounding board by palms and fingers. Sounds of flamenco cajon are similar to sounds of basic drum set (bass drum, snare drum, hi-hat) and sound character depends of place of stroke. Striking by palm near the center of sounding board (about one-third of height) causes strong bass sound and striking by fingers to the top edge of sounding board causes bright sound similar to snare drum.

This experiment is focused on influence of resonance hole diameter to intensity and timbre of bass tone of cajon drum.

Figure 1. Cajon box drum’s back board with resonance hole.

2 Theoretical background

Cajon is on principle similar to speakerbox construction. There is enclosed air with vibrating membrane and resonance hole (so-called bassreflex). Whole system works like Helmholtz
resonator, which frequency depends on air mass volume, bassreflex tube’s diameter and length. The resonance frequency of vibration is given by formula:

\[ f_R = \frac{c}{2\pi} \sqrt{\frac{S}{Vl}} \quad [\text{Hz}] \quad (1) \]

where \( c \) is speed of sound in air, \( S \) is surface of resonance hole \((\pi R^2)\), \( V \) is volume of air mass and \( l \) is length of resonator’s neck [2]. The natural frequency of neckless Helmholtz resonator with a large face is expressed as:

\[ f_R = \frac{c}{8} \sqrt{\frac{3R}{V}} \quad [\text{Hz}] \quad (2) \]

where \( R \) is radius of resonance hole [1],[5],[7]. The sounding board of cajon resonates at frequencies of normal modes of rectangular plate with clamped edges [4]. The stronger mode of 3mm, 3ply cajon sounding board of plywood is \((0,0)\) mode and it’s frequency varies around 100 Hz [3]. In the case of drums, the West African djembe drum works as Helmholtz resonator [6].

3 Materials and methods

The corpus of cajon drum is made of birch plywood with dimensions of 47 x 28 x 28 cm has thickness of sides, bottom and top of 10mm, back board with resonance hole has thickness of 5mm. Sounding board was made of cherry 3mm-3ply plywood. Sounding board and back board were removable and were mounted on corpus by screws. Cajon was situated on solid supports and sounding board was excited by falling silicone ball (70mm). Resonance hole diameter was increased from 70mm to 160mm in 13 steps by wood milling machine. For every diameter was measured 10 values of SPL by Sound Level Meter Brüel&Kjær type 2218 through Octave Filter BK1613 set to 125 Hz (Fig.2a). Sound level meter was set to IMPULSE mode. Every sound was recorded by Wavelab software through 24bit/96kHz external sound card for FFT (Fast Fourier Transformation) frequency analysis.

![Figure 2. a) Sound level meter Brüel&Kjær type 2218 with Octave Filter BK1613 set to 125 Hz
b) Frequency response of unidirectional condenser microphone SHURE SM81 used for frequency analysis. Low frequency response was switched to 18dB/oct rolloff (red encircled) [8]
Microphone Shure SM81 was used for recording sounds. It is a high-quality unidirectional condenser microphone designed for studio recording, broadcasting and sound reinforcement. Its wide frequency response, low noise characteristics, and low RF susceptibility have made it a standard for applications involving acoustic instruments [8]. Frequency response of this microphone is shown on Fig. 2b. Scheme of measuring system and measuring process is shown on Fig. 3.

![Figure 3. a) Scheme of measuring system – cajon drum excited by silicone ball b) Measuring process](image)

### 4 Results

Calculated diameter of resonance hole of experimental cajon as Helmholtz resonator can be obtained by formula (2). There was necessary to find out the resonance frequency of sounding board’s mode (0,0) on experimental cajon with original back board (medium diameter - 129mm). This was measured by modal analysis with harmonic excitation. Sounding board was excited by system of generator, amplifier and speaker and the resonance frequency of (0,0) mode was 131,5 Hz. Process of modal analysis is shown in Fig. 4.

![Figure 4. Modal analysis of sounding board of cajon with original back board (diameter 129mm). Frequency of modes was obtained: a) (0,0) 131,5 Hz b) (2,0) 303 Hz c) (1,2) 373Hz.](image)
Optimal diameter of resonance hole for this sounding board can be obtained from formula (2) and it is 181mm. Oops, I expected less.

Results of dynamic analysis are shown in Fig. 5. Increasing resonance hole diameter causes almost linear rising of SPL. There is no significance maximum of SPL for calculated diameter cause there is no this diameter in Fig. 5. Average value of Standard Deviation is 0.968 and it is shown as vertical abscissae in Fig. 5. Because the experiment was not finished yet for calculated diameter 181mm, there is no possible to verify the formula (2) currency for this type of Helmholz resonator. Another way to verify the formula currency is to repeat the experiment with another (thinner or another material constant) sounding board, which will have lower frequency of (0,0) mode (about 110Hz). Then the sounding board will have smaller equivalent diameter of resonant hole.

![Graph showing influence of diameter on sound pressure level](image)

**Figure 5.** Influence of the diameter of resonance hole on the sound pressure level of excited experimental cajon

FFT frequency analysis of some recordings of experiment are shown in Fig. 6. There are three important peaks in low frequency spectrum from about 60 Hz to about 400 Hz. When increasing diameter, frequency of the first peak rises from 63 Hz to 94 Hz with it and the intensity of this peak rises too. On the other hand, the intensity of second peak seems to be almost constant and the frequency of it rises not so radically – seems to be almost constant too. The third peak seems to be constant in frequency and intensity. Therefore could be supposed, that the first peak represents Helmholz resonator’s frequency and second peak represent resonant frequency of (0,0) mode of sounding board.
Figure 6. FFT frequency analysis of experimental cajon with different diameters of resonance hole: a) 74mm b) 125mm c) 160mm. Three curves represent FFT in various times after incidence of silicone ball: dashed curve – attack, red curve – decay and black curve – sustain.
FFT frequency analysis of experimental cajon without back board is shown on Fig. 7. In this case the sounding board was open to the environment from both sides and there is no enclosing air affected the resonance frequencies of various modes. Therefore this type of construction cannot be consider as Helmholz resonator. There are three peaks in low frequency spectrum that should represent some of normal modes of rectangular plate with clamped edges.

5 Conclusions

1. Increasing resonance hole diameter causes almost linear rising of SPL, but cajon without back board has lower intensity than maximal measured diameters (SPL150 > SPLwithout). This means that maximum SPL can be found on interval of diameters from 150mm to about 220mm.

2. For (0,0) mode frequency of sounding board (131,5 Hz) was calculated diameter of 181mm. For this diameter was not carried-out measurements, because calculations was done after experiments. To finish experiment should be the material of sounding board changed or decreased the thickness of original sounding board to lower the resonance frequency of (0,0) mode.

3. When increasing diameter, frequency of the first peak rises from 63 Hz to 94 Hz with it and the intensity of this peak rises too. On the other hand, the intensity and frequencies of second and third peak seems to be almost constant. Therefore could be supposed, that the first peak represents Helmholz resonator’s frequency , second peak represent resonant frequency of (0,0) mode of sounding board and next peaks means some of modes (2,0) or (1,2) as obtained from modal analysis shown in Fig. 3.

4. It should be possible to prove the phenomenon of Helmholz resonance in cajon box drum, but there are necessary another measurements and experiments.
References


