CHAPTER 6

ACOUSTICS OF CHENDA

6.1 INTRODUCTION

This chapter focuses on acoustic testing of carbon fibre composite and the traditional wooden Chenda. Quantitative and qualitative evaluations of Chenda were carried out in order to understand the suitability of composite manufacturing.

6.2 ACOUSTIC TESTING

The experimental set up and data capture methods are explained in section 3.3. The manufactured composite shell and the traditional wooden drum shell were compared when a common drum head was used on the two shells. The skin was first tested on the composite shell and then on the wooden shell. To avoid any bias in the results caused by different tensions applied to the skin, the tuning of the instrument was monitored when replacing the skin and it was carefully adjusted to create the same frequency of first skin mode on both shells (at 342 Hz). Evaluations were carried out for a broad frequency range running from about 100 Hz to about 5000 Hz. The same adjustable tension chord system was used on both shells.

The manufactured composite shell was tested against a traditional wooden drum shell, when a common drum head (both batter and resonant) was used on the two bodies. The wooden shell and the drum heads were supplied by Mr Girish Marar, professional Chenda player. It is likely that the
tension of the skin was slightly different for the two situations as the
general geometry of the wooden and the composite bodies were not quite the same.
The wooden body had a slightly smaller diameter and was slightly ovalized
due to cold conditions in Canada. Further, the length of composite shell is
slightly less (1 cm) than that of the wooden one. The skin was tensioned on
the composite body for more than a week so there were chances that the skin
was deformed and adjusted itself with the exact profile of the edge of the
composite body, with a more uniformly distributed tension (this is indeed
desirable to happen before an instrument is ready to be played). The situation
could however be different for the case of the wooden body in which the skin
was assembled on the instrument during the test. To eliminate such biases and
also to check the repeatability of the experiment, after the second set of
measurements on the wooden body the skin was placed back on the composite
body and was re-tested. The actual acoustic test setup is shown in Figure 6.1

![Image of test setup]

Figure 6.1 Actual test set up

In each of the three cases the sound radiativity was measured. Radiativity is computed by dividing the radiated sound pressure by the excitation force in the frequency domain. An impulse hammer with a plastic
tip (PCB Model 086C01) was used to apply the force (in the form of an impulse) while a microphone (Bruel&Kjaer Type 4228) was recording the hit sound. Compared with metal and rubber tipped impulse hammers, the one with plastic tip is more preferred as the sound produced is similar to that of an actual wooden stick. The two synchronous recordings were then used to calculate the Frequency Response Function (FRF). The microphone was placed at the distance of 120 cm from the skin pointing normal toward the centre of the skin.

The drum was hung with free-free conditions to avoid any disturbance from boundaries. An average of five measurements in frequency domain was applied to cancel the effect of random environmental noises. This procedure was repeated for 23 points marked concentrically on the skin Figure 6.2. Multiple points were used to give flexibility to later select any point that does not fall on the nodal line of any modes of the skin in the frequency range of interest.

![Figure 6.2 Stroke locations on drum head](image)

Extracting the mode shapes was the aim of this study, although they should not be far from the ones predicted by simple theoretical modes of an ideal membrane (Gough 2007), or the ones reported in the literature for other
membrane-type percussion instruments (Rossing 1992). Further, the sound produced by using the actual drum stick on both shells was also tested. Actual notes were played by Mr. Bruno Pacquet, professional Chenda player. The frequency responses functions for both the cases were compared.

6.3 RESULTS AND DISCUSSION ON ACOUSTICS OF CHENDA

To summarize and evaluate different cases, three radiativity plots were made for the same point selected on the skin when the skin was stretched on the composite shell, the wooden shell, and the composite again.

6.3.1 Frequency Response Evaluation

The frequency spectra of the three above-mentioned cases were compared up to the frequency of 1800 Hz. Figure 6.3 shows the frequency spectra plot. The general trend of all graphs is quite similar, and as was expected the frequency of the first mode perfectly matched for all three cases. The two repetitions of the same experiment on the composite shell showed a slight difference. The major source could be the fact that the edge of the body does not touch the exact same circle on the skin, which may lead (among other consequences) to a different position of the excitation point relative to the body edge. The composite body behaves slightly different than the traditional wooden body that we tested. The most significant differences are illustrated in Figure 6.3. The first and most obvious difference is the significantly higher frequency of the second mode for the wooden body (575 Hz vs. 480 Hz). The major reason for this disagreement might be the relatively smaller diameter of the wooden body and the fact that all mode frequencies of a stretched membrane do not scale proportionally when its tension changes.
Figure 6.3 Frequency spectra: Radiativity of the carbon fibre Chenda, first repetition (Solid red line), the composite Chenda, second repetition (dashed green line) and the traditional wooden Chenda (dashed-dotted blue line). Black upward arrows show the areas of systematic dissimilarity between the wooden and composite shell.
Two other important differences between the wooden and the composite shells are relatively stronger frequency response of the wooden body as compared to both repetitions of the carbon fibre body for the frequency ranges between 1200 Hz and 1400 Hz and again from 1650 Hz to 1750 Hz. The audible consequences of the dissimilarities mentioned in the two above-mentioned paragraphs would be a higher perceived pitch and a brighter tone for the wooden body respectively. This assumption was in agreement with our listening tests performed during the experiments. It is worth mentioning that the differences were still well within the range of variability of two traditionally-made instruments and the sound and feel of the composite Chenda was indistinguishable from a regular one.

Figure 6.4  Frequency response of wooden (blue) and composite Chenda (red) when hit by stick

Figure 6.4 shows two samples of FRF wooden and carbon fibre Chenda hit by the wooden stick. The stick hit does, to a good extent, represent an ideal impulse; so at lower frequencies (say up to 1 KHz) the FFT of the recorded sound looks like the measured FRF, and above that frequency, although the
relative amplitude of the peaks might be different, their frequencies should stay the same.

Figure 6.5  Mode shapes of composite Chenda by modal analysis
Figure 6.5 shows the 3D mode shapes obtained for composite Chenda by modal analysis. Further the modal frequencies of composite and wooden Chenda were compared with that of an ideal membrane, as discussed in section 2.5.3. The results showed that at higher frequencies the behaviour of wooden Chenda is similar to that of ideal membrane. However, for composite Chenda a slight deviation within 10% is observed. The frequency of the skin modes are really following the frequency of an ideal flexible membrane with fixed boundary condition (Russel 2011) perturbed a bit by its coupling to the shell, air cavity, and to the back membrane through the air cavity. The first three modes should be theoretically $f_0$, $1.593f_0$, and $2.135f_0$; where $f_0$ is the fundamental frequency. By comparing it with the wooden and composite instruments it was observed that the second modes varies by quite a bit (because of the slight oval shape of the shell) which may allow to set it to $1.5f_0$ if desired, but the third mode is a bit more robust at above $2.1f_0$ which is sufficiently far from $2f_0$ not to be considered a harmonic from a psychoacoustics point-of-view. Table 6.1 shows the comparison of modal frequency of wooden and composite Chenda.

Table 6.1 Assignment of peaks on sound pressure spectra to vibrational modes of membrane

<table>
<thead>
<tr>
<th>Chenda</th>
<th>Mode No. and description(m,n)</th>
<th>Frequency (Hz) (by impact hammer)</th>
<th>$f_i/f_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>1(0,1)</td>
<td>$f_1$=342</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2(1,1)</td>
<td>$f_2$=480</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>3(0,2)</td>
<td>$f_3$=741</td>
<td>2.17</td>
</tr>
<tr>
<td></td>
<td>4(1,2)</td>
<td>$f_4$=842</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>5(0,3)</td>
<td>$f_5$=978</td>
<td>2.85</td>
</tr>
<tr>
<td>Wooden</td>
<td>1(0,1)</td>
<td>$f_1$=342</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2(1,1)</td>
<td>$f_2$=560</td>
<td>1.64</td>
</tr>
<tr>
<td></td>
<td>3(0,2)</td>
<td>$f_3$=700</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>4(1,2)</td>
<td>$f_4$=875</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>5(0,3)</td>
<td>$f_5$=900</td>
<td>2.63</td>
</tr>
</tbody>
</table>
Also note that the perceived pitch of \([f_0, 1.5f_0, \text{ and } 2f_0]\) would be 0.5\(f_0\) with a missing fundamental, but to produce such an effect, many more harmonics than first three frequencies are needed.

### 6.3.2 Comparison of Q factor

Another important factor to compare two instruments, particularly two percussion ones, is the damping factor for individual modes and its trend over frequencies. It was aimed to mimic the damping properties of the wooden body in our composite body so it was desired in our experiments to see a similar damping behaviour for the common skin when placed on the two bodies. Single mode fitting procedure was performed over the frequency range of our interest (below 1800 Hz) on the radiativity data. The quality factor (Q-factor) of each mode (its centre frequency divided by the half-power bandwidth) can be seen in Figure 6.6. To make the cases easier to compare a linear trend line was fitted to each set of measurements, which is also shown in Figure 6.6.

As was expected for a complex system with broadly different physics (rigid wood, flexible membrane, and the enclosed air), the Q-factors cover a wide range of values from 20 to 400. The very low values of the Q-factor are most likely corresponding to the longitudinal sloshing modes of the air within the enclosed cavity. In general, the damping trends for the two repetitions of the composite Chenda were steeper than the trend for the traditional wooden instrument, with all damping trends rising with frequency. The average value of the damping, however, was relatively close for different cases with the average of around 150. This again confirms that the two bodies would make comparable instruments if a similar skin with a close tension is placed on them.
Figure 6.6  Damping trend as a function of the frequency for composite Chenda, first repetition (Solid red line, instances with red triangles), the composite Chenda, second repetition (dashed green line, instances with green squares) and the traditional wooden Chenda (dashed dotted blue line, instances with blue circles)
6.3.3 Summary of Acoustic Testing

This chapter has shown the influence of shell material on the sound characteristics of Chenda. The biggest effect that the body can make on the sound of a Chenda is by affecting its damping properties (as long as the diameter is the same and the tension is set to match the first frequency unchanged), and it is shown here that the trend and the value of damping for the sandwich composite and the wooden instrument is quiet similar. It is also shown that the CF1 and CF2 are repetitions made on the same body and the degree of their difference by no means represents the level of variability that we may get among a pool of “different” instruments.