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Measurement-based comparison of marimba bar modal behaviour

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Abstract

A marimba bar's modal behaviour is governed by the shape of its 'undercut'. Manufacturers typically shape these undercuts to tune up to three modes for specified frequencies. With only three or fewer partials to tune, numerous bar geometries may yield the desired results. Different manufacturers will employ different techniques to arrive at suitable bar geometries. This diversity in tuning approaches, coupled with the natural variability of wood, results in a multitude of undercut shapes. Two bars may produce the same musical note despite plainly visible differences in undercut geometry.

This work uses experimental modal analysis to investigate the variability of marimba bar modal behaviour. Measurements are performed on numerous bars of the same note. Geometric data, including overall dimensions and mass, are recorded for each bar. Several manufacturers are represented in the resulting data set, including Yamaha, Musser and Marimba One.

Variability of the tuned and untuned modal frequencies are of primary interest. Untuned torsional modes may compromise bar performance if their frequencies are near those of the tuned modes. The proximity of these untuned mode frequencies to those of the tuned modes is therefore also investigated. Results are presented comparing bar performance both between brands and within a brand.

Keywords: Marimba, Modal Analysis, Experimental Measurements

1 INTRODUCTION

Marimba bars are tuned by removing material from the underside of the bar to affect its modal behaviour. The resulting *cutaway* or *undercut* is typically shaped to tune up to three modes of vibration. Each of the tuned modes is a flexural mode in a vertical plane. It is common for the first three flexural modes to be tuned to the frequency ratios $(1:4:10)$. The fundamental mode is tuned to the bar's designated musical note. The second flexural mode is tuned two octaves above the fundamental. The third vertical flexural mode is tuned roughly three octaves and a major third above the fundamental.

For some notes, the frequencies of untuned torsional modes may be close to those of the tuned modes. Depending on the difference in frequency, these untuned modes may affect the bar's timbre in a negative way. Marimba manufacturers have described the challenge these untuned modes can present [1].

With only three vibrational modes to tune, any number of cutaway geometries may produce the desired frequency ratios. As a result, bar geometries vary considerably. Different manufacturers may employ different tuning strategies to attempt to tune flexural modes while separating the frequencies of untuned modes. Within a brand, bars of a lower quality designation may have different geometries than those of higher quality, the tuning of which warrant more effort. In fact, it is not uncommon to find visibly apparent geometry variations between adjacent bars on a single instrument.

This work investigates the variability of marimba bar geometry through measurements. Bars of the note F♯3 were taken from a variety of instruments for investigation. Experimental modal measurements were performed on each bar. Outer bar dimensions were also recorded. At the time of writing, efforts are underway to produce 3D scans of select bars.

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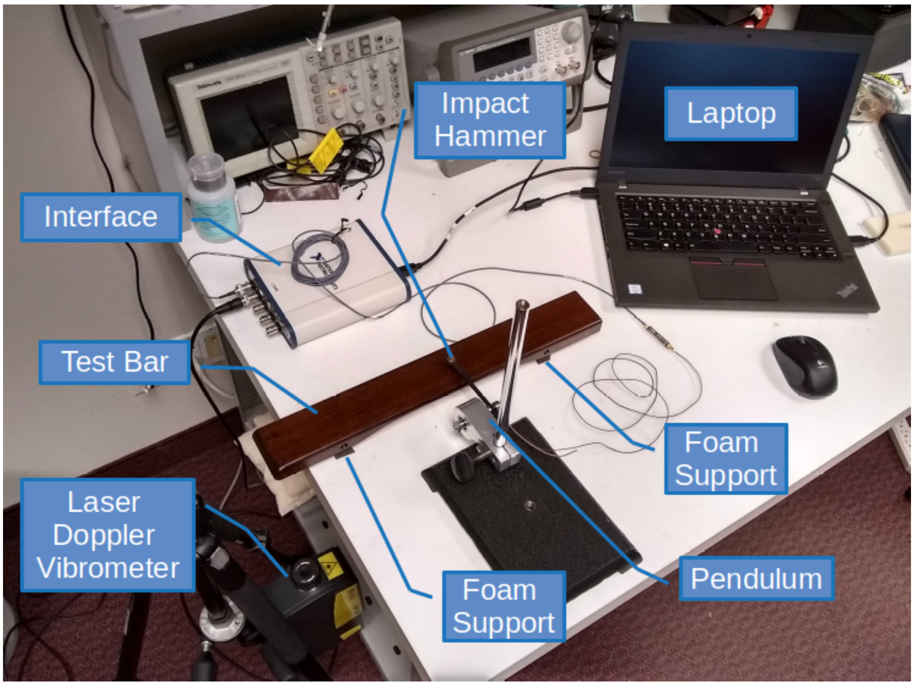


Figure 1. Experimental modal analysis measurement setup.

2 MEASUREMENT PROCEDURE

Bars on a marimba are supported by a cord passing through two holes bored through the bar. These holes are positioned near the nodes of the fundamental mode. During experimental modal measurements, the bar under test was supported on small foam blocks positioned below the bar's bored holes. This approach served to mimic the support conditions of a marimba while ensuring unrestrained bar movement. Each bar was excited using a Brüel & Kjær Type 8203 Impact Hammer. Responses were measured with a Polytec PDV-100 Laser Doppler Vibrometer (LDV).

The LDV was positioned to measure movement on the bar's bottom surface, near a corner. Strike locations were laid out in a grid on the bar's playing surface. Each location was excited using the impact hammer. Three responses were recorded for each point. At the time of writing, it is under consideration to include excitation locations on the sides of some bars, similar to previous work on marimba bar modal analysis [2].

Mode shapes and frequencies were estimated from the measured data using the Complex Mode Indication Function (CMIF) [3]. The modal frequencies presented herein are taken directly from peaks in the CMIF. At the time of writing, it is contemplated to further refine these values by fitting parameterized models to the data.

3 BAR GEOMETRY

Figure 2a gives a view of the F♯3 bar taken from an Adams 5.0-octave marimba. Notable in this geometry is the large asymmetric portion of material removed from the cutaway. This cut nearly intersects the bored holes for the supporting cord. Also notable, though more difficult to see, is a portion of material removed from the flat portion of the bar at the right end, just beyond the stamped letters "MA". These modifications appear to be part of retuning work performed some time after the bar was purchased.

Figure 2b shows the F♯3 bar taken from a Yamaha 4.5-octave marimba. The geometry of this bar is notably symmetric compared to others in the measured set (particularly that of the Adams bar in Figure 2a). It is interesting to contrast the Yamaha bar in Figure 2b to a second Yamaha bar shown in Figure 2c. These bars have essentially the same width and length, though the bar in Figure 2c has slightly thicker ends. The cutaway portion of the bar from Figure 2c is noticeably longer, ending near the cord support holes.

Table 1 provides measured dimensions for the bars assessed at the time of writing. As shown in the table, bar widths and end thicknesses are generally consistent, with the exception of the much older Premier bar. More variation is observable in the bar lengths, with the longest bar a full 50 mm longer than the shortest bar.

(a) Adams 5.0-octave marimba

(b) Yamaha 4.5-octave marimba

(c) Yamaha 5.0-octave marimba

Figure 2. Cutaways of F♯3 bars from the instruments indicated. Note that the bar in (a) appears to have been retuned since its initial manufacture.

Table 1. Measured bar dimensions.

Brand	**Instrument Size (octaves)**	**Length (mm)**	**Width (mm)**	**End Thickness (mm)**	**Mass (g)**
Adams	5.0	404	58	24	366
Marimba One	5.0	416	57	24	418
Musser	4.3	373	56	25	336
Premier	4.0	397	51	26	331
Yamaha	4.0	423	57	22	382
	4.5	423	58	22	390
	5.0	422	57	24	447

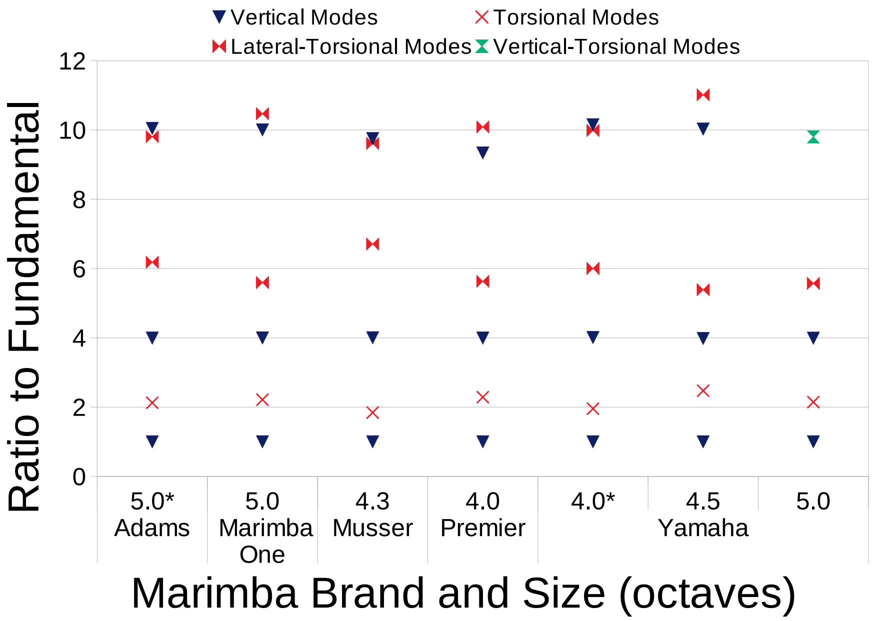


Figure 3. Modal frequency ratios of measured bars. *Indicated bars have been retuned one or more times since purchase.

4 MEASUREMENT RESULTS

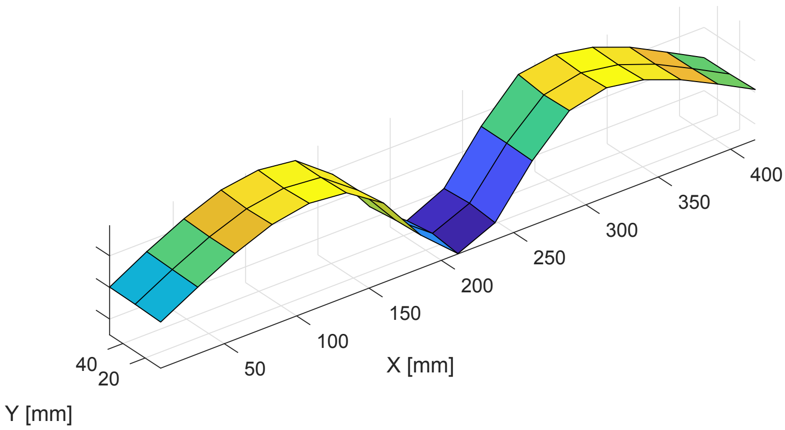
Figure 3 displays the experimentally measured modal frequencies of the various bars as ratios of each bar's fundamental mode. The first tuned overtone of all bars is consistently very near the target frequency ratio of 4, two octaves above the fundamental. The second tuned overtone, with a target frequency ratio near 10 shows greater variability between bars. Differences in frequency between the second tuned overtone and the nearest untuned mode varies considerably from bar to bar, even within the same brand. In terms of achieving the desired tuning ratios and separating untuned modes, the F♯3 bar from the Yamaha 4.5-octave marimba is the clear winner from the bars measured at the time of writing.

Removing material from only the bottom of the bar to create the cutaway results in a coupling between lateral and torsional deformations. With the exception of the first torsional mode, lateral and torsional deformations are observed in modes of either type. These two modes types are thus combined into a single lateral-torsional category in Figure 3.

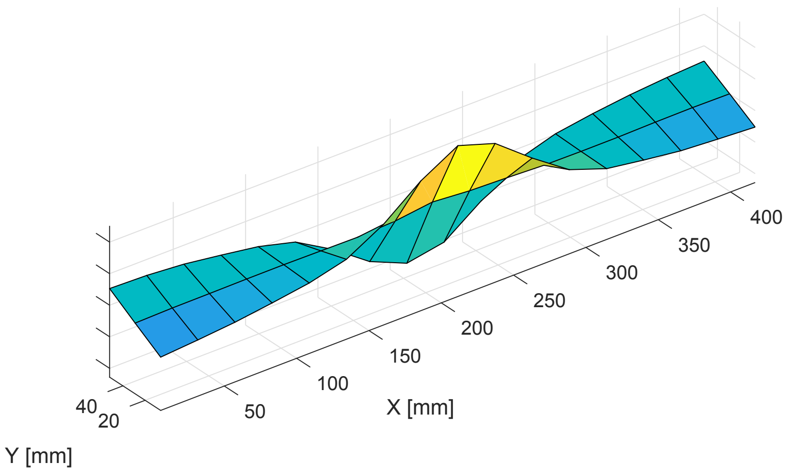
By contrast, the lone vertical-torsional mode appears to be produced from two degenerate modes. The third vertical mode of the Yamaha 5.0-octave marimba bar is so close in frequency to a lateral-torsional mode that the CMIF analysis yields a single mode. The shape of this single mode, shown in Figure 4c, is recognizable as a combination of the third vertical mode (e.g. Figure 4a) and nearby lateral-torsional mode (e.g. Figure 4b) observed in other bars.

5 SUMMARY

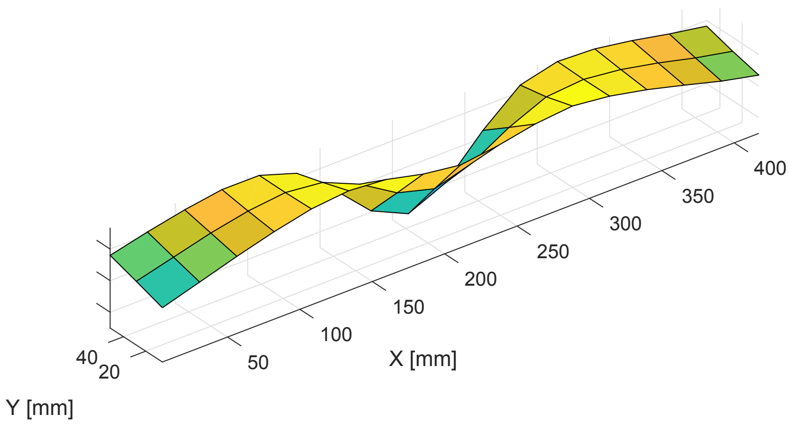
At the time of writing, experimental modal analysis has been performed on seven F♯3 marimba bars, with additional bar measurements planned. The following features of the current measured bar set are notable in their variability:



(a) Yamaha 4.5-octave marimba, mode shape 5



(b) Yamaha 4.5-octave marimba, mode shape 6



(c) Yamaha 5.0-octave marimba, mode shape 5

Figure 4. Measured mode shapes (vertical component only) of F♯3 marimba bars. Instruments and mode shape numbers as indicated.

- Bar mass and length
- Cutaway geometry
- Ratio of second tuned overtone frequency to fundamental
- Frequency spacing of second tuned overtone and nearest untuned mode

For the F♯3 bar from the Yamaha 5.0-octave marimba, the Complex Mode Indication Function (CMIF) produced a single mode at a frequency around ten times that of the fundamental. For all other bars, the CMIF indicated two modes around the same frequency ratio. The mode shape of this single mode (Figure 4c) appears to be a combination of the two modes (Figures 4a and 4b) near the same frequency ratio for other bars. At the time of writing, further investigation with additional measurement points is contemplated to separate this single mode.

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