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Short notes

THE EFFECT OF TOP SOUNDBOARD THICKNESS ON VIOLIN MODAL PARAMETERS

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ABSTRACT

This study investigates the impact of top soundboard thickness on the modal parameters of violins. By analysing variations in plate thickness, the research explores how these changes influence modal frequencies, damping characteristics, and overall acoustic properties. Findings indicate that increased thickness results in lower modal frequencies and better damping, which may affect sound quality. The study references established research on violin acoustics and discusses the structural implications of varying plate thicknesses, particularly concerning the effects of string tension. These insights contribute to a deeper understanding of violin construction and offer potential guidelines for optimising instrument design to achieve desired tonal qualities.

KEYWORDS: Violin top plate, thickness, modal analysis, violin acoustics.

INTRODUCTION

Bowed string instruments such as the violin employ metal-wound strings whose interaction with the wooden instrument body excites vibrations primarily governed by the instrument's physical and structural properties. In violins, acoustic performance is strongly influenced by tone wood anisotropy, density, elastic moduli, internal damping, and the thickness distribution of the resonance plates, which together control modal frequencies and vibration efficiency (Guercini & Ceccarelli 2020). Quantitative evaluation of these effects is commonly performed using modal analysis, a method that identifies natural vibration modes, resonance frequencies, damping, mass, and dynamic stiffness coefficients of a structure (Liss & Żółtowski 2014).

Although modal analysis is widely applied in mechanical and civil engineering (Avitabile 2001; Fu & He 2001; Schwarz & Richardson 1999), it has also become an established experimental tool for characterising the vibrational behaviour of wooden musical instruments. Three principal approaches to modal analysis are distinguished: experimental, operational, and theoretical. Experimental modal analysis uses controlled excitation and measured responses, while operational modal analysis extracts modal parameters under normal operating conditions. Theoretical approaches rely on mathematical or numerical models but are often limited in practice by the complexity of heterogeneous, anisotropic wood and assembled structures.

Early vibration studies relied on nodal-line visualisation using Chladni figures (Chladni 1830; Gough 2007; Tuan et al. 2015), later applied to violin plates by Ghelmeziu & Beldie (1969). Subsequent research adopted a modal framework, recognising that sound radiation depends on time-dependent mode shapes and their transformation during vibration (Jansson & Molin 1989; Molin & Jansson 1989). Since the first experimental modal analysis of violins (Marshall 1985), numerous studies have examined modal behaviour in violins (Bissinger 2003; Pyrkosz & Van Karsen 2013; Skrodzka et al. 2009; Skrodzka et al. 2013, 2014), guitars (Elie et al. 2012; Torres & Boullosa 2009), cellos (Fouilhe et al. 2011; Fouilhé & Houssay 2014), and tonewood specimens (Mania et al. 2015,2017; Mania & Skrodzka 2020).

Despite this body of work, systematic studies of the influence of resonance-plate thickness on the modal parameters of complete violins remain limited (Meinel 1948; Skrodzka et al. 2009), with even fewer investigations focusing on isolated plate-thickness effects. Therefore, this study aims to quantify the impact of violin resonance-plate thickness on modal parameters, with emphasis on the material-dependent vibrational response of wood.

MATERIALS AND METHODS

Materials

For the modal analysis study required to determine the desired vibration modes of selected top plates, four spruce plates with similar density and, as much as possible, identical shapes were made. Narrow-grained spruce wood with a visibly higher proportion of latewood was selected, seasoned for seven years, and cut from logs into standard violin wedges. Once glued, these wedges were expected to create a mirror-image grain pattern. The wood needed the correct fibre arrangement, as natural deviations in fibre direction affect its elastic properties.

The study was conducted on *Picea abies* L. spruce wood sourced from the European Alps. An Italian company processed the logs into structural spruce wedges. The wedges had minimum dimensions of 280 mm in length, 180 mm in radial width, and 10–60 mm in tangential thickness, and they featured a straight grain pattern. After gluing and initial preparation, a template was applied to the plates, which was then used to cut the final shape of the top plate.

The template was created from precise dimensional data and photographs of an original 1:1-scale model. The selection of the specific model was driven purely by aesthetic considerations and a desire to work on an instrument from the classical Cremonese school - specifically, Antonio Stradivari's "Ward" violin from the year 1700. All plates were prepared according to the same template, with thicknesses of 2.5, 3.5, and 4 mm, respectively (Fig. 1).

a) *b)*

Fig. 1: a) Completed plates and sound box, b) measurement setup.

Methods

The modal analysis was conducted experimentally using a fixed response point and variable excitation points, allowing for a relatively quick determination of modal parameters. This means the accelerometer's mounting point remained unchanged throughout the study, while the hammer impact locations varied. The response signal and excitation force were sufficient to determine the transfer function. Fig. 1b illustrates the complete measurement setup.

The response point was chosen to avoid alignment with the system's symmetry or nodal lines. A total of 289 measurement points were placed on the violin plate at 14 mm intervals, except near the purfling and corners, as these areas do not vibrate due to their connection with the ribs and corner blocks. Each measurement point was struck with an impact hammer ten times to obtain an average value, and each plate was tested three times to eliminate accidental impacts and potential measurement errors.

The accelerometer was attached directly to the plate using slightly warmed beeswax. At the same time, the signal cable leading to the analyser was securely fixed to prevent unnecessary signal distortions caused by induced noise. The response point was measured using an NP-2910 accelerometer from Ono Sokki, weighing 2 g. This electromechanical transducer produces an output signal directly proportional to the acceleration it experiences. To ensure accurate measurements, the accelerometer's mass had to be kept to a minimum to avoid significantly loading the tested plate. It was established that the accelerometer should not exceed 1/10 of the object's mass. The excitation signal was generated by an impact hammer equipped with a built-in force transducer, providing a broad, flat frequency spectrum. A piezoelectric force transducer measured the magnitude of the excitation force applied to the system. Each measurement was monitored using the coherence function. Utilising these signals, the Frequency Response Functions (FRFs) were determined between all measuring points excited by the hammer and the fixed response point where acceleration was recorded. All FRFs were monitored using the coherence function, with 10 spectral averages applied.

RESULTS AND DISCUSSION

The modal analysis of the examined plates was conducted within a frequency range of 0 to 2500 Hz. The resolution was 3.125 Hz, and the Fast Fourier Transform (FFT) size was set to 2048. Only stable modes with damping below 10% were considered (Tab. 1). On average, four modes were identified for each plate and arranged in ascending order of frequency. As observed, the increase in absolute damping values is closely correlated with frequency; however, this does not directly translate into a percentage increase. Contrary to expectations, the damping percentage decreases with increasing frequency for all plates except the 3.5 mm-thick plate, which shows a relatively constant value. This explains why luthiers prefer a top plate thickness of approximately 3 mm.

Tab. 1: Modal frequencies and damping obtained from impact modal testing plates of different thicknesses (A, B, and C - symbols of varying thickness), d - a percentage of critical damping, D - a bandwidth of the modal peak.

Mode number	2.5 mm **(A)**	3.5 mm **(B)**	4.0 mm **(C)**	2.5 mm **(A)**	3.5 mm **(B)**	4.0 mm **(C)**	2.5 mm **(A)**	3.5 mm **(B)**	4.0 mm **(C)**
	f (Hz)			*d* (%)			*D* (Hz)		
1	260	232	145	9.93	11.92	22.69	25.93	27.83	33.81
2	860	1050	880	2.83	3.03	6.48	24.35	31.97	57.08
3	-	1440	1340	2.15	3.01	4.86	41.40	43.42	65.12
4	1930	1910	1770	-	2.81	2.34	-	53.64	41.28
5	-	2250	-	-	3.94	-	-	88.48	-

Interesting observations can be drawn from Tab. 1. Although some identified modes exhibit significant damping, they were included for comparative purposes. Most notably, it is possible to analyse the same modes - 1A, 1B, and 1C. While mode 1C deviates significantly in numerical values, its envelope shape remains similar. Additional modes such as 2A, 2C, 3A, 4B, 3B, and 3C are also distinguishable. Focusing on the first three modes, it can be observed that as the plate thickness increases, the damping percentage also rises.

While the increase in the top thickness is relatively small, between 2.5 mm and 3.5 mm, an additional 0.5 mm results in nearly a 100% increase in damping; another important aspect is that increasing the top plate's thickness causes this mode's emergence at lower frequencies. The 2A and 2C pair case is fascinating because, despite a significant 1.5 mm difference in plate thickness, their mode frequencies differ by only 20 Hz. However, their envelope shapes vary drastically. For the 2.5 mm thick plate, a well-defined B-1 mode is visible, whereas in the 4 mm thick plate, it becomes barely detectable. As in previous cases, the damping percentage increases, negatively affecting the plates' ability to transmit sound waves. The 3A and 4B pair exhibit a minor frequency difference of 20 Hz (decreasing with increasing plate thickness) and similar damping levels. This mode is most prominent in the 3.5 mm thick plate, where significant displacement along the plate's central axis is observed, with slightly smaller, symmetrically distributed displacements along the edges. Comparable to the first three modes, damping increases for the thicker plate. The final mode pairs, 3B and 3C, were not observed on the 2.5 mm thick plate. These modes exhibit pronounced plate deformations along the central

axis, particularly in the 3.5 mm-thick sample. Mode 3C in the thicker plate occurs at a frequency 100 Hz lower than in sample B. Additionally, as with all previous cases, damping increases by 1.85%.

Fig. 2 presents visualisations of the plate deflections for thicknesses of 2.5 mm, 3.5 mm, and 4.0 mm. For the thinnest plate, mode 2 is more symmetrical than the other two thicknesses, as both edges exhibit nearly identical displacements relative to the plate's central axis. In contrast, this symmetry is barely noticeable in mode 3, whereas mode 1 behaves very differently, primarily due to its significantly lower vibration frequency. In the 3.5 mm thick plate, modes 3 through 5 display similar shapes, with a distinct central region near the plate's glue line and slightly defined edges. Modes 1 and particularly mode 2, on the other hand, exhibit significant deflections at the widest sections of the plate while the upper sections remain relatively unchanged. This indicates a growing tendency for increased deflections in the lower portion of the plate and along its edges as frequency increases. Fig. 2 also presents the deflections of the 4 mm thick plate. As in previous cases, an increase in vibration frequency results in greater plate deformation. For modes 1 and 2, this asymmetry becomes particularly pronounced on the left side of the plate. However, mode 3 reveals significant displacements along the glue line and at the plate's edges. Despite exhibiting more significant deformations, mode 4 shows decreasing symmetry, especially in the upper part of the plate, where the violin neck is typically attached.

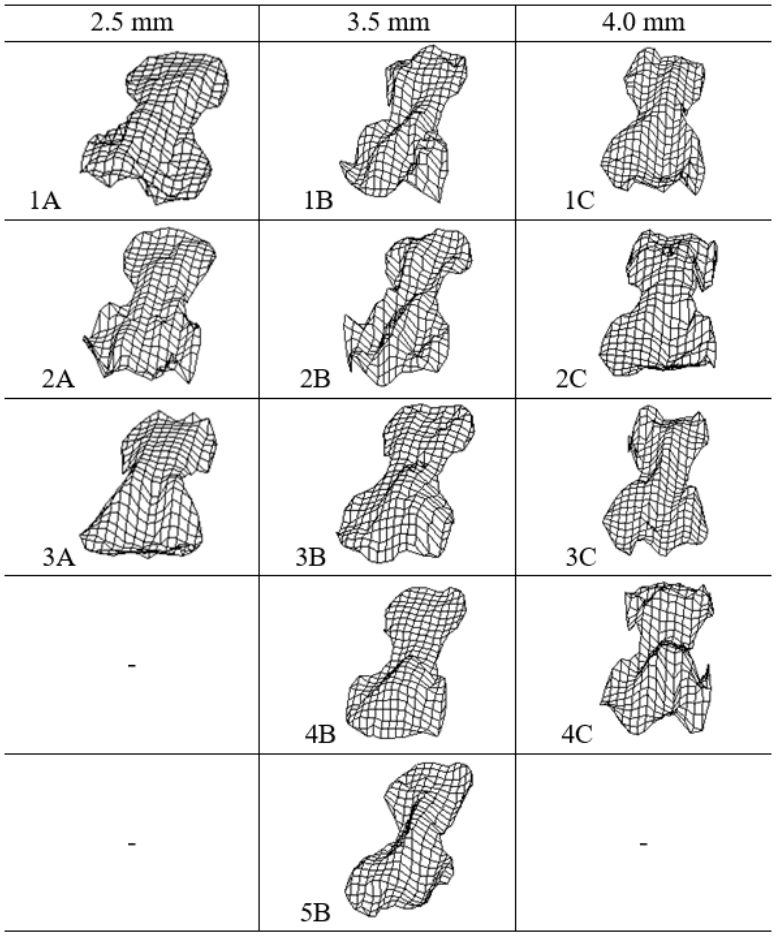

Fig. 2: Most characteristic vibration mode shapes of plates with different thicknesses.

All available data indicate that an increase in plate thickness results in the appearance of individual modes at lower frequencies, albeit with increased damping. This phenomenon suggests the potential to tune plates to achieve the desired characteristics for musicians. Moreover, as noted by Skrodzka (2016), the modes of isolated violin plates do not share significant standard features with the modes of complete instrument plates. Nevertheless, by shaping the modal envelopes and adjusting the frequencies of isolated plates, it is possible to influence the dynamic behaviour of the complete instrument.

However, the drastic increase in damping observed in the 4 mm plate is concerning. According to Bissinger's classification of violins into "good" and "bad" categories, even lower-quality instruments exhibited significantly lower damping values (Bissinger 2003). For instance, the damping for mode A0 (approximately 286 Hz) ranged between 2.4% and 2.7%. It is crucial to emphasise that the frequency differences between individual modes are relatively small, making it unlikely that these plates would significantly alter sound quality within specific frequency bands. Nevertheless, a more pronounced difference is observed at lower frequencies, suggesting a better-sounding instrument in this range.

Although a plate thickness of 2.5 mm may seem optimal for a complete instrument, it is structurally fragile and highly susceptible to deformation. The stresses induced by the strings' pressure on the bridge, along with the sound post's response, could distort the top plate, adversely affecting the violin's sound. Finally, as consistently stated by Molin and Jansson (1989) and Bissinger (2003), the effects of gradual variations in plate thickness become more apparent when considering the complete instrument.

CONCLUSIONS

Based on the obtained results, the following conclusions and statements can be formulated: *(1)* Increasing plate thickness shifts modal frequencies downward while simultaneously enhancing damping, which may impact the instrument's acoustic response. *(2)* The modes of isolated violin plates differ from those of complete instruments; however, shaping their modal envelopes and adjusting frequencies can influence the instrument’s overall dynamic behaviour. *(3)* Excessive plate thickness (e.g., 4 mm) results in a significant increase in damping, potentially degrading tonal quality. In contrast, thinner plates (e.g., 2.5 mm) exhibit favourable acoustic properties but are structurally unstable under string tension. *(4)* The most notable acoustic variations occur in the lower frequency range, suggesting that controlled plate thickness adjustments may optimise tonal characteristics.

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