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Comparison of alto saxophone reed fatigue between natural cane and synthetic reeds

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A study of alto saxophone reeds was conducted to evaluate and compare both natural cane and synthetic reed fatigue using a mechanical blowing system. Four different natural cane reed types and two different synthetic reed types were investigated, with manufacturer labeled reed strengths from 2.5 to 3. Three or four reeds of each type were "played" semi-continuously. Measurements of reed stiffness, blowing pressure, lip force, reed vibration velocity, acoustic pressure in the mouthpiece and sound measured near the saxophone bell were taken at the following times: 0, 0.25, 0.5, 1, 2, and 4 hours for the natural cane reeds and times of 0, 0.5, 1, 2, 4, 8 hours for the synthetic reeds (with a subset also measured at 16, 24 and 48 hours). Results showed clear trends in decreasing reed stiffness with playing duration. The stiffness of natural cane reeds decreased faster than for synthetic reeds, by a factor of 2–3 over a 4-hour playing epoch. Trends in sound quality were more difficult to quantify, as changes in mechanical player parameters necessary to keep the reeds oscillating as they fatigued over longer durations led to variations in reed vibrational regimes and control conditions.

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1. INTRODUCTION

Woodwind reeds are a critically important component of a woodwind instrument. While it is nearly guaranteed that a new musical instrument will be in good working condition and fully responsive to a player's actions, it is not uncommon that the reeds within a new box be quite different from one another, with some even failing to respond when attached to the instrument. Reeds are also well known to deteriorate over time, such that traditional cane reeds made from Arundo donax L may last only a few weeks when played regularly and allowed to completely dry after each use. Reeds made from synthetic materials have been available for several decades and are effective in addressing the consistency and decay problems, though there is no consensus on whether they respond as well (or better) than traditional cane reeds or how much longer they last compared to cane reeds.

A prior study [4] was conducted to investigate reed stiffness characterization techniques, using both point-stiffness and anatomical image analysis methods. That study included measurements and perceptual evaluation of a set of eight reeds that were regularly played by a professional musician over a 2.5 month duration. While several important observations and conclusions were found, it was not possible to precisely control the experimental conditions, simply because a human player was involved (despite the player making fairly regular and consistent notes about times played, temperature, etc...). A more controlled evaluation of reed stiffness would require the use of a mechanical player capable of replicating playing conditions to properly assess longevity in terms of stiffness decay and fatigue.

The present study was designed to evaluate the performance of both traditional cane and synthetic reeds under more precisely controlled conditions, in particular by making use of a mechanical blowing system instead of a human player. Four different natural cane reed types and two different synthetic reed types were used, within a range of manufacturer specified strengths from 2.5 to 3. Aspects of investigation included time-dependent stiffness and sound quality, which are two of the most important factors valued by players.

The remainder of this paper is organized as follows: Section 2 details the measurement requirements and setup. Section 3 provides information about the reeds selected for the study. Section 4 describes the experimental procedure conducted for each reed. Section 5 discusses the data analysis and results, while Section 6 provides suggestions for future research on this and related topics.

2. MECHANICAL PLAYER AND MEASUREMENT SETUP

Several custom systems to mechanically play a reed woodwind instrument have been detailed in the literature [1, 2, 3, 6]. The preliminary version of the system used for this study to measure the reed characteristics was described in [5]. A particularly unique aspect of this study was the desire to study reed fatigue when played semi-continuously over durations of up to 48 hours, with periodic assessments of reed and sound characteristics. This required a constant air supply, control of input "mouth" pressure, control of applied lip force, the ability to reliably and reasonably quickly measure experimental parameters such as blowing pressure and radiated sound pressure, and control of environmental factors.

Generally, the artificial player system designed for this study consisted of a piston pump, a pressure accumulator (pressure vessel), pressure regulator (manual pressure control), mouthbox assembly (artificial mouth, lip and mouthpiece coupling component) and an instrument (an alto saxophone in this case), in order of their placement in the air supply chain. The setup and experiments were located in an IAC Acoustics double-walled audiometric sound isolation booth (model 120act-3, 5.6 L x 3.2 W x 2.5 H), which with the doors closed, allowed the saxophone to be played continuously over hours-long durations without causing inordinate disturbance to individuals working in the vicinity. The $E\flat$ alto saxophone used for these experiments was sold under the brandname "SLADE.". Only a single written $C\sharp$ fingering (sounding frequency of ≈ 330 Hz, no keys depressed) was used in this study. The mouthpiece was a resin-molded copy of a Ronald Caravan mouthpiece, with a hole drilled in the side a few centimeters from the tip to allow internal pressure measurements.

A. AIR SUPPLY

The air supply for the system was provided by a piston pump (EcoPlus, Model #728459 and rated at 200 Watts, 225 L/min flowrate, 48 kPa or 6.96 psi maximum gauge pressure), as we did not have access to a continuous compressed air supply. This pump was found to be sufficient to blow an alto saxophone over a wide range of fingerings. One particular issue concerning the pump when used in a relatively small and confined space was heat buildup. First, we didn't want the pump to overheat and fail. Second, we wanted the air supply fed to the saxophone to have a relatively steady temperature. And finally, we wanted the room temperature to also remain relatively constant. In order to mitigate heat buildup, metal heat sinks were attached to the cooling fins of the pump. As well, the air tubing was connected to a section of metal pipe that was immersed in a large bucket of water. Finally, a fan was aimed at the pump during operation. Given the relatively small size of the room and the long durations of the experiments, the room temperature equalized to about 34–36 degrees Celsius within about 30 minutes.

Because we wanted to measure radiated sound from the saxophone at periodic intervals with the pump running, a passive damping structure made of open-celled foam was placed over the pump to attenuate the pump noise. To mitigate 60 Hz pump-induced flow oscillations in the air stream, a tuned muffler-like cavity (the pressure vessel) was incorporated in the air supply chain. Finally, a manual pressure regulator (Proximity Instruments, Series MPR Regulator, 150 PSIG Max supply, 0-5 PSIG output) was used to control the flow rate to the saxophone.

For the cane reeds, it was necessary to keep the reeds humidified. This was accomplished by connecting the air hose to two bubble humidifier bottles in series (after the pressure regulator). Bubblers in parallel were also tested but found to cause a significance pressure drop that would not support sustained reed oscillations. As well, a small reservoir of a saline-like (potassium sulfate) solution was placed inside the mouthbox and a thin paper towel was placed over the back end of the reeds (behind the lip-bar) such that the towel was partially submerged in the solution and would remain wet via a capillary effect.

B. MOUTHBOX AND ARTIFICIAL LIP

The mouthbox, with a volume of $\approx$ 30cm^3, was made from a combination of machined aluminum pieces, 3D-printed mouthpiece "mating" adapters, and plexiglass sections (to support LDV measurements, stiffness measurement alignment, and general monitoring of the system). The mouthbox is described in more detail in [5] and pictured in Fig. 1. A 3D printed adaptor allows the box to be used with a range of different mouthpiece sizes and types. The artificial lip or "lip-bar" is oriented vertically, with position controlled by a threaded screw mechanism from the top. The mouthpiece of the saxophone is rotated 180° from its normal playing condition, with the lip-bar being applied from above. The horizontal position of the lip-bar could also be controlled along the length of the reed via a slider mechanism at the top. A $\approx$ 5mm thick ethylene propylene diene monomer (EPDM) rubber material, sourced as rubber bands, was placed between the lip-bar and reed to simulate the human lip. This material is known to be resistant to environmental factors and was found to be minimally susceptible to creep with time. To allow reed vibration measurements using a laser doppler vibrometer (LDV), the sliding component of the lip-bar contains a small plexiglass window, positioned directly above the reed tip.

C. ACOUSTIC AND MECHANICAL PARAMETERS

Several different time-varying acoustic and mechanical parameters were measured during the experiments using a National Instruments USB-4431 signal acquisition card. The signals were recorded in MATLAB and included:

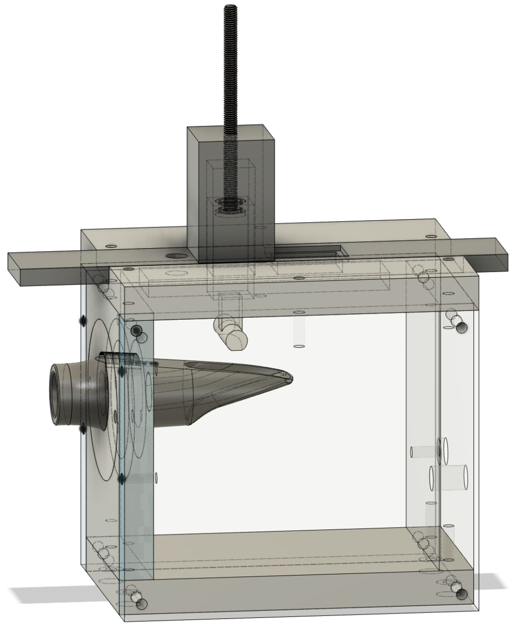

Figure 1: Mouthbox assembly.

- External sound pressure using a Shure SM57-LC microphone mounted on a stand and located about 10 centimeters from the bell of the saxophone;
- Internal mouthbox and mouthpiece pressures using Endevco 8510B-1 and 8507C-1 transducers, respectively, connected through an Endevco Model 136 DC amplifier;
- Reed tip velocity using a Polytec PDV-100 LDV;
- Lip force via both a load cell and a calibrated force sensing resistor (FSR).

Reed displacement was obtained from the LDV velocity signal by lowpass filtering (cutoff within 10% of the reed excitation frequency) and numerical integration. A calibration process, described in [5], was designed to verify the LDV results and assess any influence from the plexiglass plate.

Reed stiffness was assessed, with the pump off, indirectly by measuring reed deflection in response to a known weight. A digital dial indicator gauge was used to record the displacement with the weight placed on top of the dial. These displacements were also measured using a STIL Chromatic Confocal displacement sensor (resolution of 4.5 μm) based on displacement of the top of the dial. The measurements were made at the same position (centered about 5 mm from the tip) for all reeds. The variance of stiffness measures within each set of reeds of the same type was about 3% for cane reeds and about 1% for the synthetic reeds. While it was not necessary to remove or otherwise modify the saxophone setup while the reed stiffness measurements were made, it was necessary to remove the lip-bar structure during those measurements.

Static lip force was assessed during setup of the reed, before initiation of the pump, using the load cell signal and FSR. The load cell was built into the lip-bar mechanism and aligned vertically. It responded to increased compressive force applied via the “screw” mechanism that was outside the top of the box. The calibrated FSR was placed between the lip-bar and the EPDM artificial “lip” material.

3. SELECTED REEDS

The reeds tested included:

- 4 d'Addario Select Jazz, strength 3S
- 4 Rico Royal, strength 2.5
- 4 Vandoren, strength 3
- 4 Vandoren Java, strength 3
- 4 Légère Signature, strength 2.75
- 3 Légère Classic, strength 2.5

The first four reeds types are natural cane reeds (Arundo donax L), while the Légère reeds are synthetic.

4. EXPERIMENTAL PROCEDURE

All cane reed were measured at times of 0, 0.25, 0.5, 1, 2, and 4 hours. All synthetic reeds were measured at times of 0, 0.5, 1, 2, 4, 8 hours. All four Légère Signature reeds were also measured after 16 hours and one of those reeds was measured after 24 and 48 hours. The same procedure was used to setup each reed for testing. This involved:

- Positioning of the reed on the mouthpiece, insertion into the mouthpiece adaptor, securing of the reed with a small hose clamp on the mouthbox-side of the adaptor, insertion into the mouthbox, and an initial assessment of stiffness. If a cane reed, positioning of the humidifying paper towel over the back of the reed to keep it moist;
- Initiation of the pump and adjustment of the pressure regulator and the lip-bar position (both horizontal and vertical) to achieve a stable, good quality sound;
- Initial measurement of all signals mentioned in Sec. 2.C for a duration of 3 seconds.

At the end of a time increment, all time-varying signals were again measured before the pump was turned off. The lip-bar structure was removed from the top of the mouthbox and a static reed stiffness measurement was made. The lip-bar was then replaced, keeping the position unchanged, the pump was restarted, the playing parameters adjusted (if necessary) to achieve a stable sound, and all time-varying signals measured again. All reeds of the same model / type were measured consecutively, since they were generally the same geometry, thus requiring less modification of the setup than when switching between reeds of differing type. When changing reeds, the mouthpiece had to be loosened or removed from the mouthbox while remaining attached to the saxophone neck.

In an experiment of this type, parameter control is extremely important. For example, one would hope to apply the exact same mouthbox pressure and initial reed tip opening for all cases. For this system, it was not possible to accurately measure initial reed opening, so static lip pressure was used instead. While an attempt was made to keep the mouthbox pressure and lip pressure levels consistent for the duration of the test, it was found necessary to gradually adjust the parameters over the course of the experiment in order to achieve a stable oscillatory regime because the reed characteristics were changing, especially toward the latter stages of reed playing time when over-blowing became particularly prevalent in some reeds. As well, removal of the lip-bar structure when measuring stiffness may have resulted in some inaccuracy in resetting the lip pressure parameter.

5. DATA ANALYSIS AND RESULTS

A sample set of time-varying measurements is provided in Fig. 2. The oscillations seen in some of the reed displacement signals are attributable to 60 Hz fluctuations in the air supply.

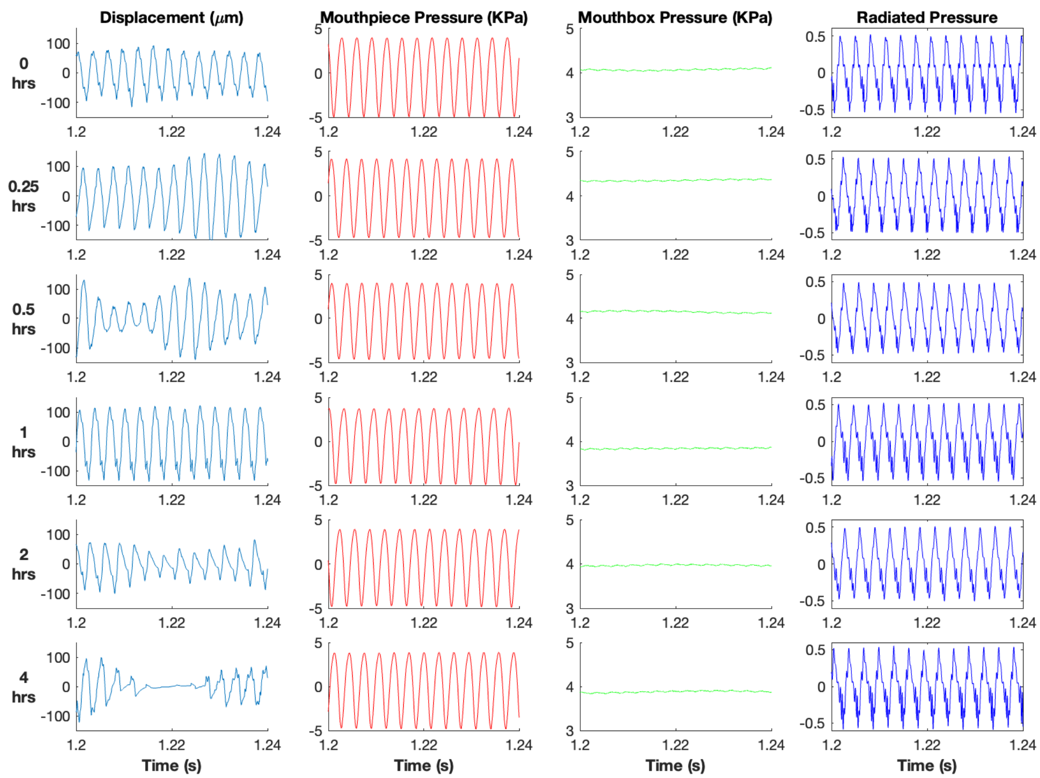

Figure 2: A sample set of measurements from one of the cane reeds at each measurement time.

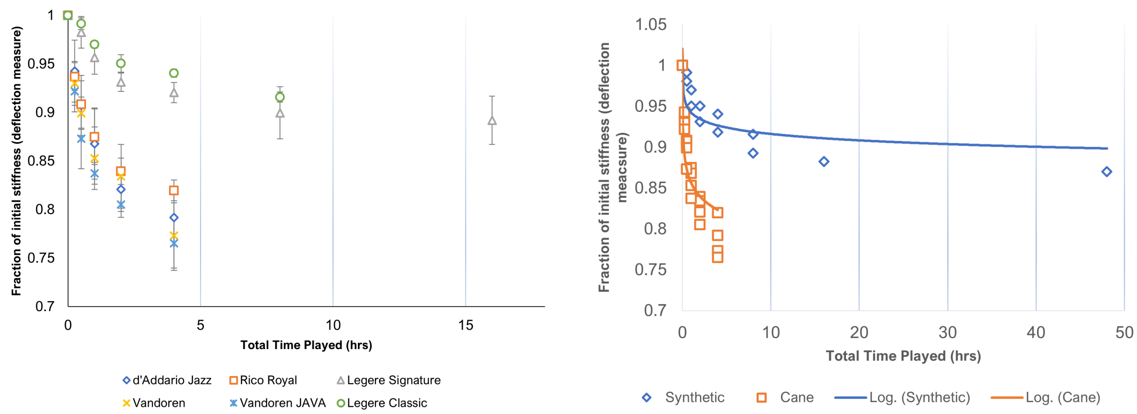

Figure 3: Reed stiffness (deflection) results for all reeds. Error bars are standard deviation across the reed sample of the corresponding reed type. The plot on the left is only to durations of 16 hours. The plot on the right includes a single measurement at 48 hours, as well as curves fit to all the synthetic (blue) and cane (red) reed stiffness results.

Averaged reed stiffness results (deflection measurements) for all reed types are shown in Fig. 3. The values are fractions of the initial deflection (i.e., 1 = deflection before playing was started). The error bars are standard deviation across the reed sample of the corresponding reed type. As seen in the plot on the right, there is a clear distinction between the cane reed types and the synthetic reeds, with the cane reed levels decreasing by a factor of more than two compared to the synthetic reeds. Within the cane reed types, the Rico Royal reed stiffnesses decreased less quickly than the Vandoren and Vandoren JAVA reeds. The Légère Classic reeds appear to decay slightly less quickly compared with the Légère Signature reeds.

Another interest in conducting this study was to see if there would be quantifiable changes in sound spectra or timbre over time as the reeds fatigued. Plots of averaged spectral magnitude (dB) envelopes for all reed types, averaged over all reeds for a given type, obtained at various playing intervals (up to four hours for cane reeds and eight or sixteen hours for the synthetic reeds) are shown in Fig. 4. It is difficult to discern a clear relationship between playing duration and spectral characteristics. The stiffness results (Fig. 3) indicate that the reeds are generally decreasing in stiffness the longer they are played. Thus, as reeds lose stiffness, they will deflect more easily and potentially beat more against the mouthpiece facing, thus likely producing more high-frequency energy in the sound. The results for the Rico Royal and d'Addario Jazz reeds in Fig. 4 show some trends that could support that behaviour but the results for the other four reed types are less clear. Some differences can be distinguished between different reed types but the primary focus of this study was on reed fatigue over playing duration, rather than differences between reed types. Attempts were made to distinguish beating versus non-beating oscillatory regimes in the data but that proved impossible to accurately identify.

6. DISCUSSION AND CONCLUSIONS

It is fairly clear from this and previous experiments [4] that natural cane reeds lose stiffness as they fatigue. Results from this study show that the Légère (synthetic) reeds demonstrate signficantly less loss of stiffness over time, which together with their more consistent playing behaviour and the fact that they do not need to be wet when played, may substantiate their higher cost (roughly 5–10 times more expensive). The spectral magnitude envelope results imply that there is no significant change in timbre over playing duration. However, it must be remembered that it was not always possible to keep the blowing and lip pressures constant over the duration of the experiment because the changing stiffness of the reeds required changes to those parameters in order to maintain stable oscillations. As reeds lose stiffness, they will tend to beat more and produce a brighter sound. With natural cane reeds, however, it is common that players will change reed settings as they fatigue through a combination of reed positioning (moving the reed tip toward or away from the mouthpiece tip) and geometry changes via sanding, scraping or tip trimming / cutting. Another, though likely less common, technique for prolonging natural cane reed stiffness and longevity is to keep them in a sealed container with a wet sponge, which not only reduces decay caused by repeated wetting and drying but also increases stiffness (at least initially) through water absorption. In order to minimize molding, the sponge is typically soaked in an alcohol solution and the container can be stored in a refrigerator. Thus, players can compensate to some extent for the results of the stiffness changes in natural cane reeds, while that is less possible with the synthetic reeds.

Some limitations of this study include the fact that the playing or control parameters could not be kept constant as the reeds lost stiffness and some inadvertent setup changes may have been introduced when removing and replacing the lip-bar mechanism (to perform the stiffness tests). As well, the cane reeds may have gradually decreased in wetness levels over the duration of the playing experiments, which may have contributed to a loss of stiffness. Also, the relatively high temperature (about 35 degrees Celsius) in the room may have changed the viscoelastic properties of the synthetic reeds and contributed to a slight decrease in their stiffnesses, though under normal playing conditions, a human lip is in contact with the reed and the normal human body temperature is around 37 degrees Celsius. Finally, there remains the issue of how synthetic reeds respond in comparison to cane reeds, as assessed by human performers, which we did not attempt to address in this study.

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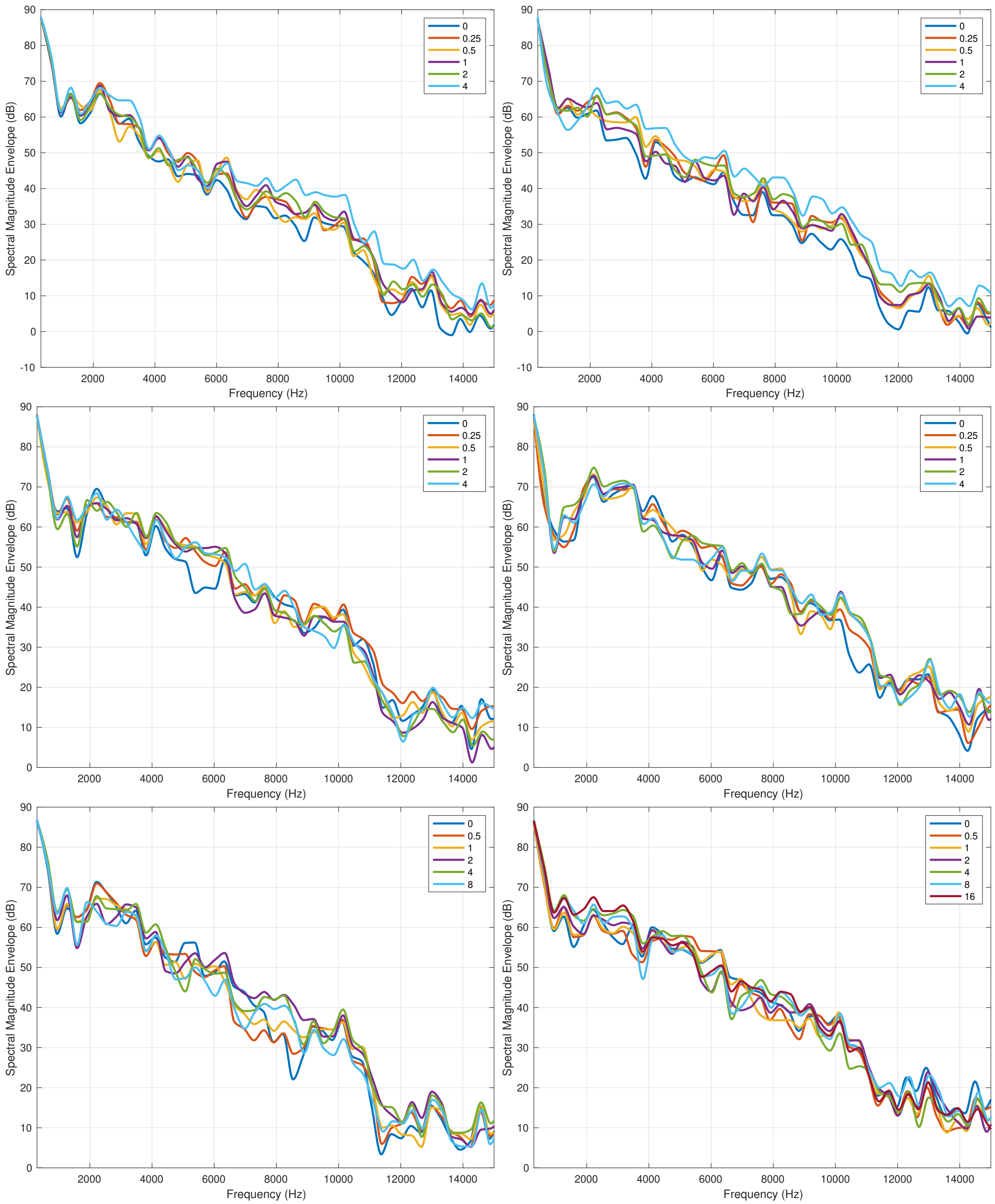

Figure 4: Averaged spectral magnitude envelopes for Rico Royal (upper left), d'Addario Jazz (upper right), Vandoren (middle left), Vandoren Java (middle right), Légère Classic (bottom left) and Légère Signature (bottom right) reeds played over the durations (in hours) listed in the legends.