

Effects of Time on the Sound Quality of Cane Oboe Reeds

An Interactive Qualifying Project Report
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

Zachary Everett Blais

Advisor:

Professor Satya Shivkumar

Date: **January 19, 2011**

Abstract

The purpose of this study is to address the longstanding disadvantages of the use of *Arundo donax* in the modern oboe reed. The first part of the study comprises a review paper detailing the history of *Arundo* in music and explaining the mechanical shortfalls of the material. The second part is an experimental paper wherein several reeds were analyzed to demonstrate the wear and degradation of *Arundo* during its use. Both papers have been submitted to the journal of the International Double Reed Society for publication. This study successfully demonstrated the changes in sound quality undergone by a cane reed when subjected to long-term use.

The results of this IQP have been compiled as two journal papers. Both papers have been submitted to ***The Double Reed***, the primary journal of the International Double Reed Society, for publication.

Table of Contents

Introduction	1
Objectives	3
Methodology.....	4
Article 1:“An Overview of the Rise of <i>Arundo donax</i> in Oboe Reeds”	5
I. History of <i>Arundo donax</i> :	6
II. Analysis of <i>Arundo donax</i> as a material:	9
III. Summary	13
IV. Acknowledgements	14
V. References	15
Article 2:“ Measurement and Deterioration of the Oboe Reed’s Sound Quality Over its Lifespan”	17
I. Introduction	18
II. Methodology.....	24
a. Materials	24
b. Procedure.....	25
c. Results	26
d. Discussion.....	31
III. Conclusions	35
IV. Acknowledgements	36
V. References	36
a. Literary	36
b. Audiography.....	36
Appendix I	37

Introduction

Arundo donax, or giant cane, has been used in music for millennia. Since the inception of the oboe and double reed instruments into musical ensembles, giant cane has been the almost-exclusive material used for creating both single and double reeds. Without these reeds, the instruments would not produce any sound. However, cane is a very poor material for use in the vibrating reed assembly because its fibrous nature causes it to weaken and fail after only a few hours of use. The material itself is also expensive, and this cost is compounded because it takes a great deal of experience in making reeds to produce them reliably. Overall, the reed suffers from several problems: fragility, inconsistency, and cost all adversely affect the material.

A serious effort to use different materials has only emerged within the past few decades. In the creation of single reeds synthetic materials have gained widespread acceptance and are used both at beginner and professional levels. However, similar efforts for creating synthetic double reeds have stalled, and the only products to be offered are generally considered vastly inferior to the cane reed.

This study aims to establish preliminary research in both the musical history of *Arundo donax* and in the mechanical disadvantages of its use. This research is performed with the intention of demonstrating the necessity of more reliable and cheaper materials in reed making. Furthermore, an experimental apparatus is detailed which is able to reliably and consistently record sound samples from oboe reeds. This experimental approach allows for quantitative definition of the oboe reed, whereas before only a qualitative description was possible. The experiment aims to be simple enough to allow continued work by the double-reed playing community at large, but also complete enough to allow significant results to be obtained from its duplication.

Both pieces of this study have been submitted for publication in The Double Reed, the quarterly journal of the International Double Reed Society, in order to reach a large audience of double-reed musicians. This audience is most likely both to be impacted by the research and to continue research in the field of alternative oboe reed creation.

Objectives

This work aims to complete the following objectives:

1. Establish preliminary research into the history and use of *Arundo donax* in creating oboe reeds
 - a. Catalog the general role of *Arundo donax* in music
 - b. Catalog the specific history of the oboe and its reeds
 - c. Analyze the reasons that *Arundo donax* has persisted as the primary material for reeds to the present day
 - d. Demonstrate the physical mechanisms that make *Arundo donax* non-ideal for use in reeds
2. Examine the theory behind the alteration of the oboe reed's sound over its playing life
 - a. Describe the acoustic theory invoked in sounding an instrument
 - b. Establish the presence of a unique sound spectrum for an instrument that is dependent on
 - i. The instrument being played
 - ii. The fundamental pitch being played
 - iii. (for oboe) The reed-maker's technique
 - iv. (for oboe) The age of the reed
3. Create a reproducible experimental approach to gathering consistent data
 - a. Devise a reliable setting for testing reeds with minimal environmental variation
 - b. Invent an apparatus that mimics the human player as accurately as possible, replicating
 - i. The lips and mouth of the player
 - ii. The air flow required to play
 - iii. The humidity and water saturation of the reed
 - c. Examine data from this apparatus and derive conclusions based on its results

Methodology

The purpose of this project was to analyze the modern oboe reed and establish a foundation upon which further improvements may be based. In order to accomplish this goal, both research and experiments were conducted in tandem.

The history of *Arundo donax*, both as a plant and as a component of music, was researched and catalogued from its origins in the Mediterranean region several thousand years ago up to today. In addition, the mechanical processes of fatigue, stress, and strain were applied to *Arundo* as a material in order to make suggestions on how to improve the reed.

An experiment was also devised which would allow physical measurement of the acoustic characteristics of oboe reeds under controlled conditions. As opposed to the theoretical considerations first applied, this experimental approach allowed for reeds to be analyzed directly and measured in a way that is directly applicable to musicians.

When combined, these two approaches allowed for experimental data to be backed up in a logical and approachable manner. Both reports were written for an audience of non-engineers, with straightforward explanations favored wherever possible. By doing this, those musicians who are interested in furthering the foundation established here will be able to do so even with minimal scientific background.

In order to disseminate these studies to the intended audience of double-reed musicians, Editor Dan Stolper of [The Double Reed](#), a quarterly journal by the International Double Reed Society, was contacted regarding publication. Both studies have been submitted as articles to the journal, with one focusing on historical and theoretical aspects and the other focusing on the experimental aspect. At the present time both articles are pending review for publication. Email correspondence with Mr. Stolper is included as Appendix I.

Article 1: “An Overview of the Rise of *Arundo donax* in Oboe Reeds”

Submitted to The Double Reed on May 17, 2010

An Overview of the Rise of *Arundo donax* in Oboe Reeds

Zachary Blais*

Department of Chemistry
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

A Bassoonist's dream, that "ONE REED", that non-descript entity which constitutes a reed with life, zeal, a resilience present only in a rubber band, life as long as an elephant.

A Reed that will NOT change with the very slightest temperature fluctuations.

The very act of playing you, Reed, is Destructive.

"But, WHAT CAN I SAY?"

-Michael Trentacosti, "WHAT CAN I SAY?"¹

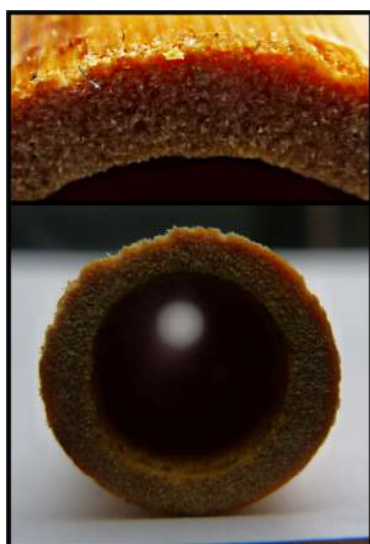


Figure 1: Two photographs of a typical dried *Arundo donax* cross section. [N.B. The upper image is sharpened to enhance detail.]

Giant cane has existed easily as far back as the writing of the Bible, where cane is mentioned frequently.² The plant itself is actually very common; in fact, some areas of New Zealand are so inundated with it that it is considered an “unwanted organism”.³ Giant cane is also known to have escaped cultivation in California, where it is reported to do damage to established species.⁴ Given its commonplace status, it may not be surprising that it has been so important in the history of Western music. (Its price, however, may be surprising, but we’ll save that for later.)

I. History of *Arundo donax*:

Initially, *Arundo donax* grew naturally near the Mediterranean Sea.⁵ The plant is noteworthy for its hardness, which Veselack attributes to silica (as in sand) in its bark; she notes that the plant will spark if struck with an axe. Giant cane is known to grow anywhere

* Zac Blais can be contacted by email at zblais@wpi.edu.

from 2 to 8 meters (roughly 6 to 26 feet) in height, with diameters of 1 to 4 centimeters (about ½ to 4 inches) giving finished reeds their distinctive curves. A smaller diameter yields a greater curvature of the finished cane, so smaller cane is generally used for something like an oboe reed while larger cane might be used for saxophone or clarinet reeds. (Figure 1: ⁶)

Arundo donax was utilized in early musical instruments as far back as five thousand years ago.² Perdue demonstrates that man used bone to create flutes in the Stone Age, and further suggests that “a much more satisfactory instrument could be fashioned from a tube of vegetable material.”² These cane flutes quickly evolved into the *pan pipe*, or *syrix*, which is simply a tuned set of these tubes placed in a row. While the common name “pan pipe” is derived from the instrument’s association with

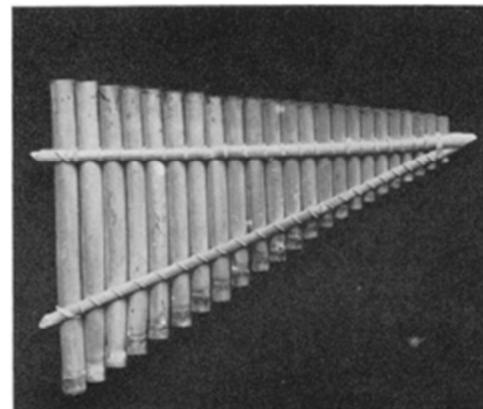


Figure 2: A modern pan pipe made from *Arundo donax* cane.



Figure 3: Two modern surnas. The one on the left is Turkish, and the one on the right is Syrian. Note the reeds, which are independent of the instrument.

the Greek god Pan—and so we know that these pipes were in use in ancient Greece, in approximately 300 BC—pan pipe expert Douglas Bishop states that syrinxes dating as far back as 4200 BC have been discovered in North America, some of these also being made of cane.⁷ (Figure 2: ²)

Soon, pipe crafters began to carve holes into the side of their pipes, removing the need for several pipes of different lengths. With the increased effort invested in these instruments it was no longer viable to produce a new instrument every time the mouthpiece failed, and so the replaceable reed soon followed.²

It should be noted at this point that although many primitive groups were able to discover the reed mechanism, further progress to an actual instrument was limited to only the Middle East, and specifically to Egypt and southwestern Asia. This coincides with the fact that, as noted earlier, *Arundo donax* was first found naturally near Egypt along the Mediterranean Sea. Perdue attributes this limitation of development to the fact that *donax* cane was the ideal material for producing reed instruments, based on its responsiveness and resilience to repeated soaking.² Indeed, it seems likely that the presence of *donax* cane was what propelled instrument development in these regions, as other areas with structurally similar plants (e.g. bamboo) were not able to independently develop double reed instruments.

Unfortunately, there is very little information on how musicians first discovered the mechanism of the double reed. The *surna*, which is generally considered to be the first European double reed instrument, is believed to have first surfaced around the eighth century.⁸ It did not use *donax* cane; rather, the material used was usually some sort of leaf or grass which was much thinner. The player could not use any sort of embouchure, as this would cause the thin material to stop vibrating altogether,

and so instead he would enclose the entire reed in his mouth. The instrument had a metal disk on its body, called the *pirouette*, and the player would place his lips on the disk to enclose the reed.⁹ (Figure 3:
¹⁰⁾

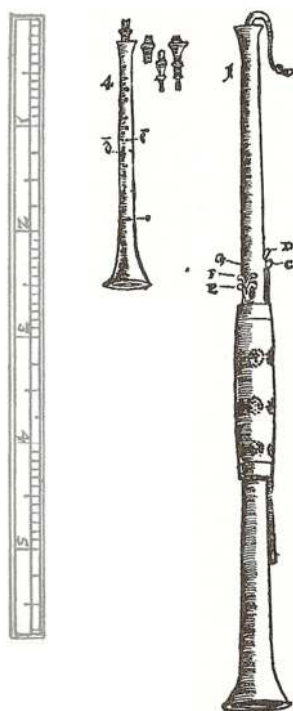


Figure 5: Comparison of a "standard" treble shawm (left) and a bass shawm (right), drawn to scale. The ruler to the far left measures feet.

The instrument that evolved from this, the *shawm*, came into existence during the twelfth and thirteenth centuries.⁹ The shawm was different in several ways from the *surna*; these differences included both a longer instrument body and a longer, narrower reed. In addition, for the first time the reed was made from *Arundo donax*, which was much harder than the grasses and leaves used before in the *surna*. This, coupled with a *pirouette* located closer to the base of the reed, allowed players to place their lips directly onto the base of the reed, giving them more control over the instrument's sound; in Figure 4¹¹, the *pirouette* is in the form of a wooden cup enclosing the reed.⁹ Baines notes that by the fifteenth century, the shawm was produced as a bass instrument, measuring six feet in length, as well as the more common tenor (shown in Figure 5⁸) and treble versions.⁸ In addition, a "small discant" version measuring less than two feet and a *great-bass shawm* measuring roughly ten feet both existed in the sixteenth century.

The shawm flourished for a few centuries, but was soon replaced by a new French invention: the oboe, first crafted by a group of Parisian instrument makers led by Jean Hotteterre. While the transition

from *surna* to oboe marked some important structural changes—the use of joints instead of a one-piece instrument, the inclusion of ornamentation to strengthen these joints, and the (initially) uneven internal bore⁸—probably the most important change was the removal of *pirouette* entirely, with the performer now using a full embouchure to control the reed.⁹ At first this embouchure was likely more vital than ever; the earliest reeds were about 30 millimeters longer and 3 millimeters wider than today's average reed, similar to the reed seen in Figure 7¹².⁹ This new instrument is believed to have debuted publicly in 1657, where it was extremely successful and immediately spread from France.⁸

The reeds used in the early oboe, as noted above, were drastically different in size; however, the material that was used is the same *Arundo donax* that musicians are so familiar with today (see Figure 6⁸). In an article on 18th century reedmaking from 1962, and acting on samples gathered before and after, Thomas Warner proposes that the change from this original larger size to the smaller modern size occurred around 1780.¹³ At the very latest, this change would have to have occurred by 1783, when Warner notes that

Oboe Reeds



1,2: English, c. 1780-1820
 3: French, c. 1870
 4: English, modern

Figure 4: Four oboe reeds, dating from the late 18th century to today, all made of *Arundo donax* cane.

Christophe Delusse had begun to make modern-style oboes, which would require modern-style reeds.^{13,8}

From this point forward, the development of the oboe is much more gradual. Ledet summarizes the instrument's changes in a few sentences by saying

Basically, over the years the oboe bore has become narrower, the reed has become controllable by the lips after being freed from the pirouette, and reeds have become narrower as the bore has gotten smaller. More keys have been added to facilitate technique and intonation. Heavier wood is used for the resonating body. Thanks to, in part, the principles of Boehm, Helmholtz, and the advancing science of acoustics, tone holes have undergone much development in spacing, size, and undercutting, which has helped intonation and response.⁹

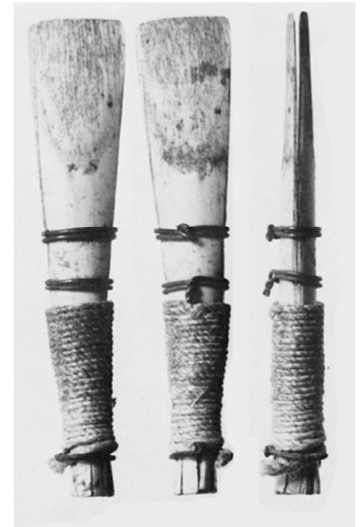


Figure 6: An 18th-century reed from a *bourdon*, an organ pipe similar in mechanics to the oboe. The reed itself is said to resemble that of the early oboe.

These changes have only brought about minor changes in the construction of the reed. Reed 3 in Figure 6, which was made circa 1870, utilizes the same style of scrape (i.e. V- instead of U-shaped) maintained to this day in France, with only the length of the scrape modified to compensate for changes in the instrument.⁸ Even with this difference, Reeds 3 and 4 are strikingly similar, and could plausibly be confused by a player who has not studied them carefully.

II. Analysis of *Arundo donax* as a material:

This brings us to today, an age where plastics and artificial materials reign. Having read this brief history, it can be seen that the cane that is so widespread today is not necessarily the best material for the job, but rather was the most usable material available to those who first started making instruments. The same material has been used all along—after all, why fix it if it isn't broken?—and for that reason it is used to this day.

However, ask any oboist today and he or she can almost certainly name something that is “broken” about the traditional oboe reed. At the end of December 2009, I conducted a survey of oboists in the Boston Musicians' Association, asking for their opinions on items such as the dimensions, material, lifespan, required embouchure, and required soaking of a reed. The survey also asked about the player's thoughts on artificial reeds, and asked the question, “If you could change one thing about the traditional oboe reed, what would it be? Why?”

This survey established that several aspects of the traditional cane reed are particularly troublesome:

1. Both with pre-processed cane and completed reeds, inconsistency is a significant problem. As any double reed player knows, slight changes in weather, humidity, and temperature can cause significant changes in the quality of a reed; and, as reedmakers

know, cane itself is a highly variable material because of its organic nature. A piece of cane taken from a pile is often just as likely to produce a good reed as it is to produce garbage, and it can be difficult to tell which will occur beforehand.

2. Reedmaking is a long and involved process, which makes inconsistency even more of a problem. A reed that will last only a handful of playing hours can take an hour just to be made, which is an enormous time commitment for oboists who do not perform for a living.
3. Even a good reed will be extremely fragile. All it takes to lose the best reed ever made is brushing it on a stand or chipping it on a tooth. It is also usually impossible to bring the reed back to a working state once this has happened, as many players know.
4. Reeds are extremely expensive. A professional who makes his or her own reeds gains a slight reprieve here, but students and casual players are forced to spend a fortune on reeds, which can be prohibitive.

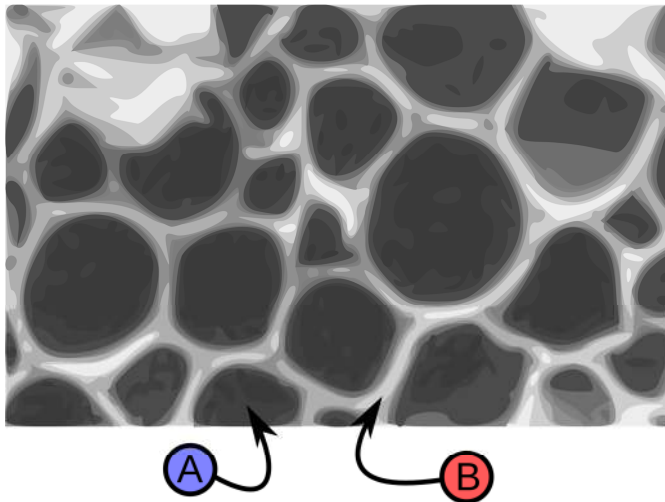


Figure 7: A vectorization of an *Arundo donax* cross section, looking down the length of the fibers. (A) is the fiber itself, and (B) is the weaker lignin holding each fiber together.

All of these problems are direct results of the fact that cane is a naturally-grown, organic product. Its structure, as seen in Figure 8¹⁴, is composed of many plant fibers held together with lignin, which acts as a glue of sorts. This configuration gives cane a much higher strength axially (that is, moving **with** the fiber) than equatorially (that is, moving **against** the fiber).

This difference in directional strength causes reeds to generally fail by cracking vertically down the reed. The internal forces holding each individual fiber together are larger than those holding separate fibers together, and so when the cane weakens enough to fail it does so by splitting the fibers apart. This weakening is a result of *fatigue*, which is a natural process in any part which goes through repetitive stresses.

To understand how fatigue comes about, it is necessary to know some basic information about how the oboe reed functions mechanically. When at rest, the oboe reed is just as it looks when held in the hand: the blades of the reed sit nicely on each other. When air begins to pass through the reed, air flows through the **inside** of the reed but not the outside. This fact sounds obvious, but is absolutely vital to buzzing on the reed. Because of this difference in pressure, caused by sitting air outside and flowing air inside, the blades of the reed will compress together. (This phenomenon is known as Bernoulli's Principle, and is the same principle that allows aircraft to lift off even though they are much heavier than the air around them.) The compressed blades decrease the opening size of the reed, which reduces air flow and **increases** the inside pressure.

At this point, the reed is closed, and the edges of the blades are acting like two compressed springs due to the hardness of the cane. This compression, combined with the now-higher internal pressure, causes the blades to fly open, nearly separating at their farthest. Now the wider opening increases air speed, decreasing internal pressure, and the blades act like stretched springs. This new tension drives the blades back to their normal state, but because they are already moving together they quickly become compressed once again.

While the blades are vibrating, the air pressure coming out of the staple is constantly changing. When the blades close the lower air flow causes a lower exiting air pressure, and when the blades open the higher air flow causes a higher exiting air pressure. This modulation of pressure is what the listener's ears sense when he or she hears the reed buzzing. If the reed is tuned to a perfect A of 440 Hz, the listener senses exactly 440 of these cycles every second.

These cycles, while they can produce beautiful music when put into the oboe, also do enormous amounts of damage to the reed. Every time the blades compress or stretch, very small cracks begin to form on the surface of the cane. These cracks are initially on the order of microns or smaller. (For those not accustomed to such a small measurement: in each millimeter, there are exactly one thousand microns. A human hair is about 100 microns wide, and an oboe reed measuring 72 millimeters is 72,000 micrometers long.) Each time the blade flexes, these cracks are pulled apart by tension in the surface of the cane, and so every cycle the reed generates will add a little more depth. As above, a reed playing at 440 Hz goes through 440 cycles every second of playing; a higher pitch will be at a higher frequency, and will require more cycles per second.

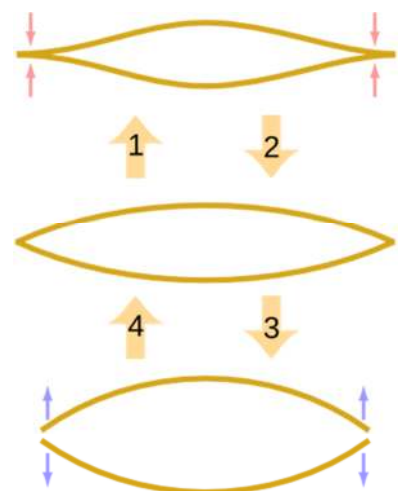


Figure 8: A diagram of the reed blades during vibration. Red arrows show compression and blue arrows show tension.

This gradual process of cracking is the cause of fatigue. After long enough, these cracks will weaken the structure of the blades, causing them to flatten and eventually stop sounding. If one were to continue to flex the blades after they stopped producing sound, the cracks would form more quickly between fibers—that is, lengthwise—than they would across fibers, and at some point the micro-cracks would likely join to cause a “catastrophic failure” where the cane splits visibly and permanently down the grain.

Going back to the fibrous nature of the plant, it can be seen that the difference in fiber and lignin strengths is also the cause of (1) above. When first preparing cane, it is impossible to tell whether or not the cane is strong enough to withstand playing for a long time. Because cane is grown naturally, it is expected that there will be a great deal of variations from piece to piece; like a fingerprint, no two canes should be identical. A particular cane tube could naturally be extremely poor for reedmaking, but the reedmaker himself or herself may not know it until he or she is unable to produce a working reed. This unreliability also exasperates (2), as all the effort expended in making this doomed reed will ultimately be for nothing, which is both a waste of time and a frustration for the reedmaker. The expenditure of effort, then, leads to (4); if a reedmaker is spending an hour of skilled labor on each reed,

and a significant number of reeds can't even be sold, it makes sense that reeds are so expensive. Add the fact that the highest quality cane often comes from France and must be shipped internationally to reedmakers, and the price only becomes steeper.

A plausible solution might be to replace the expensive *Arundo* cane with a cheaper material such as bamboo. Unfortunately, this is not a viable solution, and it is possible to compare several properties of these two materials to explain why. A brief definition of these parameters:

- **Stress** is the force being applied per unit area, similar to a tensile (or “negative”) pressure on the material. Here, it is measured in megapascals, or newtons per square millimeter. The higher the force that is applied to the cane, the higher the stress. (For comparison, the maximum stress before failure of a typical steel is about 700 MPa. LDPE, the plastic used to make grocery bags, tears at roughly 10 MPa.¹⁵)
- **Strain** is how much longer the material gets under a given stress. If a material is initially 100 millimeters long and is elongated to 110 millimeters, it is under a strain of 10%. Brittle materials such as glass cannot undergo high strain, but ductile materials like rubbers can.

These properties, when plotted against each other, give a picture of the physical properties of the material^{16, 17}:

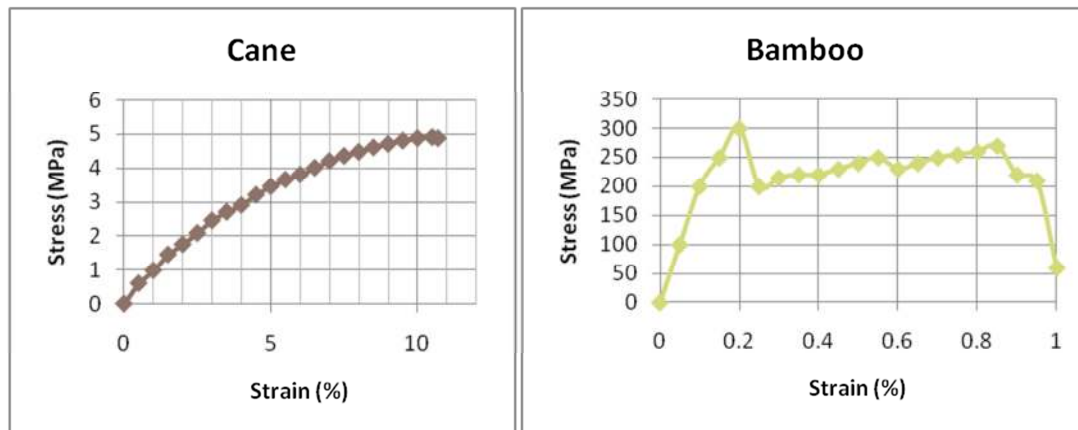


Figure 9: Stress-strain curves for cane and bamboo. Note the differing scales; if the curves were overlaid, the cane curve would be much longer and shorter than that of bamboo.

Several important things can be gathered from these plots:

- a. Note that the maximum stress, or **tensile strength**, of cane is only 5 MPa, while bamboo can withstand stress of up to 300 MPa. As stated in the definition of stress above, this gives bamboo a strength roughly half that of steel (which explains why it is often used for construction purposes). In contrast, cane only has a strength of 5 MPa, which makes it less resilient than a similarly-sized piece of LDPE plastic.

- b. Also note the maximum strain of each material. Bamboo has a maximum elongation of 1%, which makes it less ductile than most metallic alloys. On the other hand, cane can elongate by up to 11%.
- c. The curve for cane is largely straight, while the curve for bamboo is jagged. This shows that the cane material is likely to form a brittle, sudden fracture when it fails, while bamboo will fail partially at several points before separating fully. The implication of this difference is that there is a significant difference between the two materials' structures. Coupled with the greater tensile strength of bamboo over cane, this suggests that there is some sort of adhesion present in the bamboo structure holding it intact.

From these observations, it should be obvious that even though bamboo and *Arundo donax* may look similar at first glance, bamboo is simply too different to substitute for cane. Even if scraping bamboo into the correct shape and tying it into a reed is possible, it will be far too brittle to vibrate without cracking quickly. It seems, then, that the solution to many of the oboe reed's problems is to get rid of the variable nature of the starting material not by finding a natural replacement, but rather by using a new material chosen to match the properties of cane.

Some of the more prominent double reed companies have tackled the problem by producing synthetic reeds over the past several years. Unfortunately, they are generally panned by users due to their wildly differing characteristics from natural cane. One company, Légère Reeds, has successfully created a mass-produced **single reed** for the clarinet and saxophone made of specially-processed polypropylene (think yogurt cups). They boast an impressive roster of professionals from around the world using these reeds. However, they have been unable so far to create a satisfactory double reed; as they say themselves, "it is a lot harder than we originally thought it would be!"¹⁸

Instead of simply looking at reeds from the same viewpoint that we look at plastic toys or tools—that is, molding them into the correct shape and sending them on their way—we must look carefully at the characteristics of the materials we choose. New materials must be able to replicate the desirable qualities of cane—its flexibility and hardness, density, and acoustic properties, for example—while improving its weaknesses, such as its tendency to split easily. This may be as simple as finding what is needed in a catalog, or it may be as difficult as developing a new plastic resin with the correct properties.

III. Summary

Before pulling out the plastic catalogs, it is important to quantitatively measure the characteristics of the reed. Any oboist can tell you that the reed usually weakens after a few playing hours, but in order to solve the problem we need to take a closer look at the reason behind this. By taking samples from worn reeds and analyzing them under a high-powered microscope, it should be possible to examine fatigue patterns and see exactly which regions of the reed need to be strengthened. Knowing this puts a reedmaker in an excellent position to correct the problem: for example, if the heart of the reed is where the most damage occurs, then it may be possible to apply a particular processing

technique to, for example, add surface compression to the heart and prevent cracks from forming or enlarging.

As a way to determine the wear pattern of a reed over its playing life, I have proposed an experiment to be completed over this summer (2010). The experiment will call for an artificial mouth with material to mimic an oboist's lips, powered by an air compression pump to provide constant airflow. When operating, the mouth is intended to hold on to a reed and play it for several hours without stopping. This way, we can accurately measure the wear the reed is subjected to over its lifetime, and can further focus our efforts on strengthening those aspects of the reed. This research is similar to that of John Gillette, who examined the conditions under which a reed will perform (see [Some Measurements of Pitch and Air Pressure of Bassoon Reeds](#) in "The Double Reed" 2004 for more information).

Overall, the quantitative study of the reed at work is something that could easily be groundbreaking for the double reed player. There are mountains of anecdotal evidence for different problems with the traditional cane reed, but to date very little has been done to measure them accurately and apply these measurements to new approaches to the reed. The fact that Légère has been able to make a globally-acclaimed synthetic single reed out of such a readily available plastic is very promising, and is a very good sign that the same is possible with a double reed. If oboists are able to contribute to studies on the oboe reed—or even better, perform their own—it will provide a much-needed push toward an improved modern reed.

IV. Acknowledgements

This work was conducted as part of an undergraduate Interactive Qualifying Project, or IQP, necessary to fulfill the undergraduate degree requirements at WPI. As such, I wish to sincerely thank Prof. Satya Shivkumar and Mr. Joe Halko for their work as advisors on this paper.

V. References

1. TRENTACOSTI, Michael. WHAT CAN I SAY?. *The Double Reed*, 1978, vol. 1, no. 1 [cited 6 Mar 2010]. Available from <<http://www.idrs.org/publications/DR/DR1.1/what.html>> International Double Reed Society.
2. PERDUE, Robert E., Jr. Arundo Donax: Source of Musical Reeds and Industrial Cellulose. *Economic Botany*, Oct. - Dec., 1958, vol. 12, no. 4. pp. 368-404. ISSN 00130001.
3. Biosecurity New Zealand. *Giant Reed*. 20 Mar 2009, 2009 Available from:<<http://www.biosecurity.govt.nz/pests/giant-reed>>.
4. DIGIORGIO, Marguerite. Reeds as Weeds. *Science News*, 22 Feb, 1992, vol. 141, no. 8. pp. 127. ISSN 00368423.
5. VESELACK, Marilyn S. Arundo Donax: The Source of Natural Woodwind Reed. *The Double Reed*, 1979, vol. 2, no. 1 [cited 6 Mar 2010]. Available from <<http://www.idrs.org/publications/DR/DR2.1/arundo.html>> International Double Reed Society.
6. SNIECKUS, Kurt. *Cross Section of Arundo Donax*. , 2010 [cited 12 Apr 2010].
7. BISHOP, Douglas. *A Worldwide History of the Panflute*. , 2003 Available from:<<http://www.panflutejedi.com/pan-flute-history-main.html>>.
8. BAINES, Anthony. *Woodwind Instruments and their History*. 3rd ed. Mineola, NY: Dover Publications, 1991. ISBN 0486268853.
9. LEDET, David A. *Oboe Reed Styles: Theory and Practice*. Bloomington, IN: Indiana University Press, 1981. ISBN 0-253-37891-5.
10. BARDANT, Jean-Xavier. *Zournas*. Wikimedia, 2006 [cited 7 Apr 2010]. Available from <<http://en.wikipedia.org/wiki/File:Zournas.jpg>>.
11. LAZAR, Bill. *Shawm, Alto in G, Copy of Charles Collier*. , 2010 [cited 7 Apr 2010]. Available from <<http://www.lazarsearlymusic.com/Used-Instruments/images/Lazar/CollierCopyAltoShawm.jpg>>.
12. WOLDBYE, Ole. A Register of Early Reeds (GSJ XXX, p. 150). *The Galpin Society Journal*, May, 1978, vol. 31 [cited 19 Apr 2010]. pp. 144. Available from <<http://www.jstor.org/stable/841196>> JSTOR. ISSN 00720127.
13. WARNER, Thomas. Two Late Eighteenth-Century Instructions for Making Double Reeds. *The Galpin Society Journal*, 1962, vol. 15 [cited 14 Apr 2010]. pp. 25. Available from <<http://www.jstor.org/stable/842036?seq=4>> JSTOR.
14. FROST, Eberhard. *Arundo Donax Cross Section*. www.the-clarinets.net [cited 19 Apr 2010]. Available from <http://www.the-clarinets.net/images/arundo_schnitt_mikroskop.png>.

15. CALLISTER JR., William D. *Materials Science and Engineering: An Introduction*. 7th ed. New York, NY: John Wiley & Sons, Inc., 2007.
16. AMADA, Shigeyasu; and UNTAO, Sun. Fracture Properties of Bamboo. *Composites Part B: Engineering*, 2001, vol. 32, no. 5. pp. 451-459. Available from <http://www.sciencedirect.com/science/article/B6TWK-4372WGD-6/2/a8a24e2d612b5776145dfdab5c745682>>. ISSN 1359-8368.
17. SPECK, O.; and SPATZ, H. C. Mechanical Properties of the Rhizome of *Arundo Donax* L. *Plant Biology*, 2008, vol. 5, no. 6 [cited 29 Apr 2010]. pp. 661-661-669. Available from <http://www3.interscience.wiley.com/journal/120130826/abstract>> Wiley InterScience.
18. Légère Double Reeds Ltd. *Légère - Double Reeds*. , 2009. Available from:<<http://www.legere.com/index.php?page=double-reed>>.

Article 2:“ Measurement and Deterioration of the Oboe Reed’s Sound Quality Over its Lifespan”

Submitted to The Double Reed on January 10, 2011

Measurement and Deterioration of the Oboe Reed's Sound Quality Over its Lifespan

Zachary Blais¹

Department of Chemistry & Biochemistry
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

"[Playing the oboe] is a constant struggle, knowing you can only sound as good as your reed is."

-- Bobby Taylor (Principal Oboe, Nashville Symphony Orchestra)^[1]

I. Introduction

For as long as the modern oboe has existed, there have been frustrated oboists who must work with the fragile and expensive oboe reed. The material used in reeds, giant cane (*Arundo donax*), was chosen in the 17th century for its ability to produce the then-desired sound. However, for the 350 years since the instrument's inception, the material has remained virtually unchanged.

The stagnation of innovation in reed creation causes a serious problem for the modern oboist, as in reality giant cane is a very poor material for use in a vibrating assembly. Its fibrous nature causes the reed to weaken lengthwise when vibrated rapidly, causing it to fail within only a few playing hours. The inconsistent nature of cane only worsens the problem. Because it is a natural product (and because no synthetic alternative has been widely accepted), every piece of cane will have slightly different material properties. As a result of this inconsistency, reeds require extensive care, and professionally acceptable reeds are almost always handmade individually.

Material inconsistency is the primary cause of the oboe reed's most significant problems: fragility, unreliability, and cost (both in money and labor). One attempt to solve these problems is the use of synthetic materials, specifically plastics, in producing the reed. The use of artificial substitutes may solve the first problem—a plastic reed will generally be more durable than a cane reed. However, synthetic reeds are often more expensive than their cane counterparts. In addition, plastic reeds introduce a new problem in that many of them demonstrate a very low ability to control pitch while playing. Unreliability of tone, of course, is unacceptable for a professional musician and as a result synthetic reeds have not yet gained widespread acceptance.

¹ Zac Blais may be contacted at zblais@wpi.edu.

However, alternative materials should not be ruled out entirely. It is possible to examine the harmonic output of the traditional oboe reed to describe its sound mathematically. Harmonic analysis produces a “signature” for a desired sound which can be mimicked by different materials. If a reed from a particular material accurately matches that signature sound, then theoretically it will also match the desired sound when played through the oboe.

In a previous paper, both the historical origin and the mechanism of wear in the oboe reed were presented.^[2] It was indicated that reeds constructed from cane may not fulfill the ideal requirements necessary for optimum performance. The current contribution aims to present a specific apparatus for further, controlled testing of the effects of wear on the oboe reed. Before discussing the operational principles of this apparatus and presenting the results generated, an introduction to the basic principles of harmonic theory as they pertain to music in general is highlighted.

When a fundamental pitch is sounded, its **harmonics** are those frequencies that are also present in the instrument’s overall sound. For example, when an oboist plays his or her middle C, pitches at the intervals of perfect octave, perfect 14th (octave + perfect fifth), etc. can be heard. These frequencies are present in multiples of the fundamental pitch, indicating that if a pitch of 50Hz is sounded, possible harmonics will be located at 100Hz, 150Hz, 200Hz, and so on.^[3]

This linear definition of harmonics, by *adding* a constant for each increase, is distinctly different from the exponential definition of pitches, where a frequency is *multiplied* by two to reach the next octave. The physical consequence of these differing definitions is that as harmonic frequencies are added, the musical intervals between them become smaller. So, while the first two intervals are the pleasant-sounding perfect fifth and perfect fourth respectively, once the tenth harmonic is reached the intervals become dissonant major seconds or smaller. These more dissonant intervals effect a brighter sound. In contrast, when only the lower, larger intervals are present, a much rounder and smoother sound is created.

The desired sound quality, or **timbre**, is defined by the identities and ratios of the harmonics present when the sound is produced. As a demonstration, **Figure 1** contrasts an oboe and tuba playing the same note at the same volume.

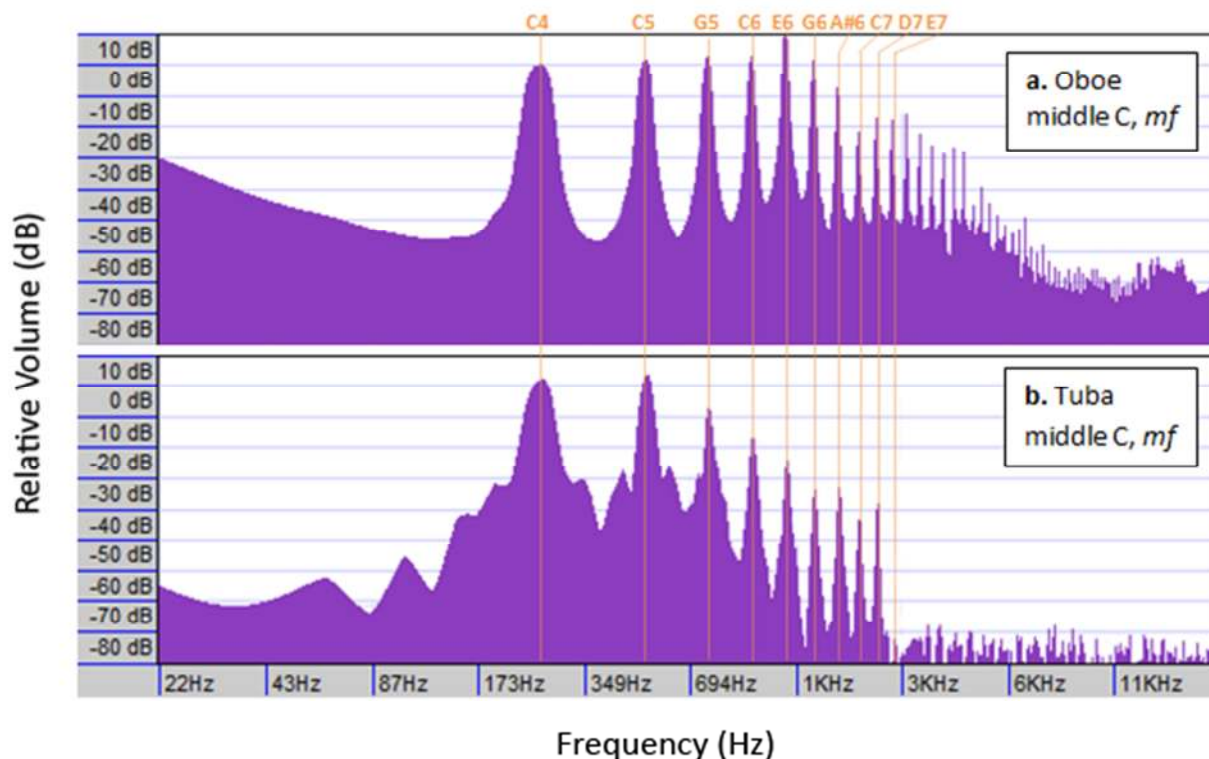


Figure 10: Spectra for oboe (a) and tuba (b) at *mezzo-forte* playing middle C. The first ten harmonics of middle C are emphasized and labelled in orange. (Adapted from references [6] and [7].)

The oboe spectrum (**1a**) shows a great number of peaks—perhaps more than 16 distinguishable ones—while the tuba spectrum (**1b**) drops off after only 9. As established earlier, the oboe has many more harmonics and therefore more clashes between harmonics. In contrast, the tuba has fewer of both. Because of the differences in harmonics, the oboe sound will be harsher and brighter while the tuba sound will be rounder and smoother.^[8]

It has been established previously that the upper harmonics are vital to the distinguishing sound of a particular instrument. One book by Barnes, *Practical Acoustics*^[4], states that:

When the fundamental is itself very high, the upper partials soon get beyond the limit of hearing, hence it is difficult or impossible to recognise the instrument in such cases...an extremely high note on a violin can hardly be distinguished at a distance from the same note on a [reed organ] pipe, and so on.

In other words, if the upper harmonics of an instrument are “removed” from the spectrum because they are at supersonic frequencies, the listener may perceive the instrument differently. Using similar reasoning, it can be established that by modifying the upper harmonics of an instrument’s sound (either physically or electronically), the overall timbre of the instrument can be changed.

The original oboe recording in **Figure 1a** can be altered by incorporating “invisible” harmonics to reduce the differing frequencies above D7 (about 2350 Hz). By muting the higher frequencies of the sound, the

recording loses a lot of its reed-like character and becomes darker, almost flute-like in tone. As demonstrated in **Figure 2**, if the spectrum of this new audio (**2a**) is compared to that of an alto flute playing the same note (**2b**), they are strikingly similar.^[8]

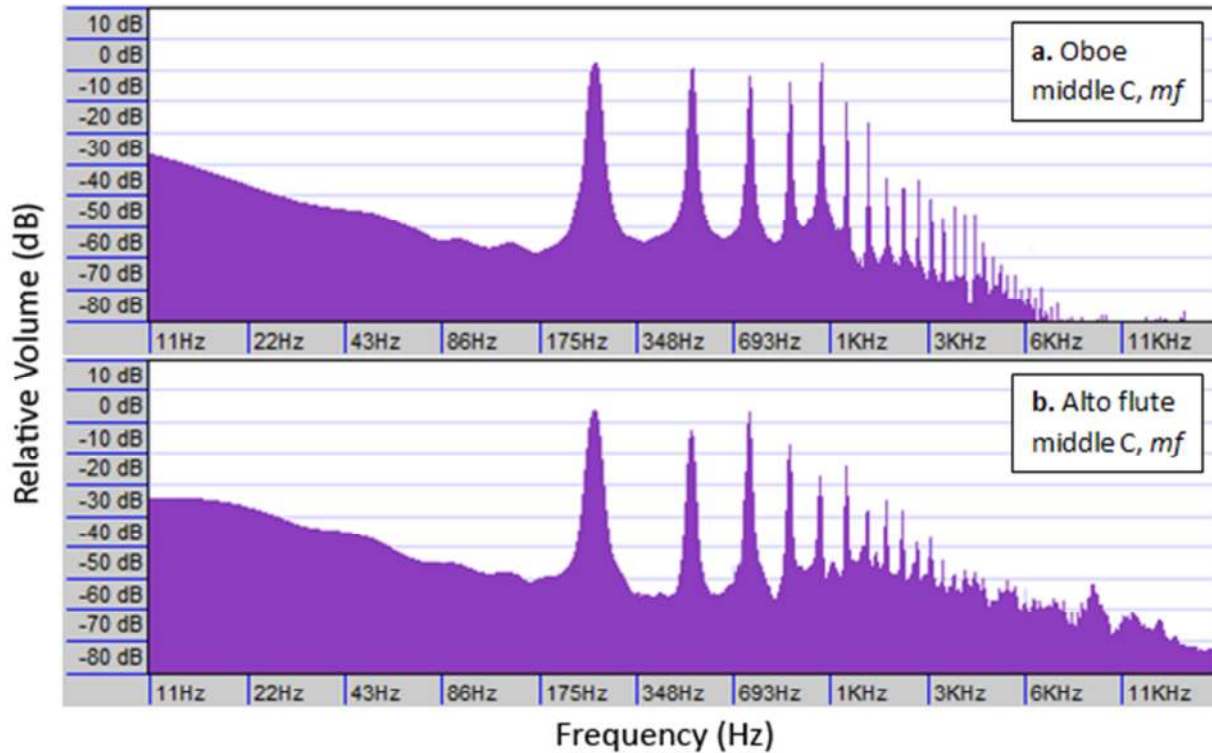


Figure 11: Spectra for oboe (a) and alto flute (b) at *mf* playing middle C. The spectra are plotted using a Hanning window and a logarithmic frequency axis. The oboe spectrum reflects changes made to minimize harmonics above 2350 Hz (D7). (Adapted from references [9], [10].)

The oboe spectrum (**2a**) still shows some traces of higher-frequency harmonics, which maintain a bit of reed-like sound. In comparison, the flute spectrum (**2b**) does not show those frequencies at all and as a result has no reed-like quality.

The same type of comparison can be made between different notes on the same instrument. Take, for example, the two spectra in **Figure 3**, which illustrate an oboe playing middle C and C6 (two octaves above).

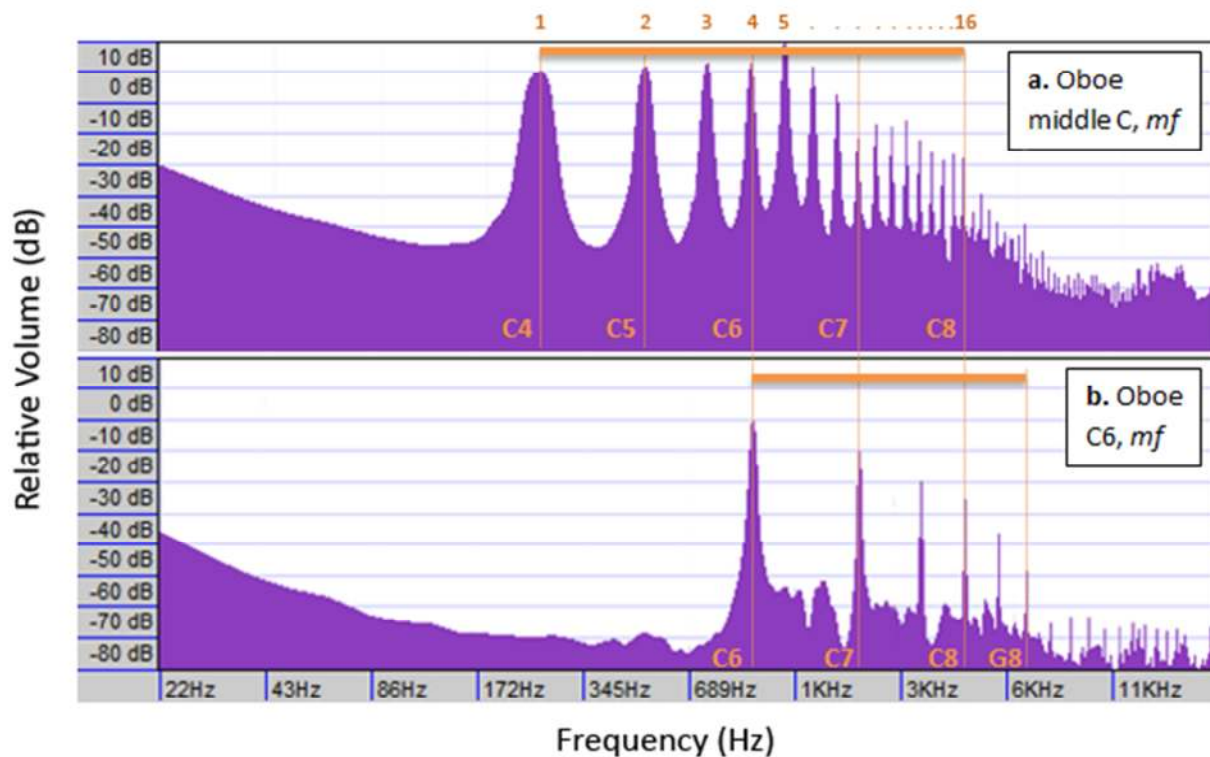


Figure 12: Spectra for an oboe playing middle C (top) and C6 (bottom). Octaves and G8 are emphasized and labeled in orange, with the range of harmonics labelled above. (Adapted from references [7], [10].)

Again, **Figure 3a** shows roughly 16 distinguishable harmonics covering four octaves from the fundamental tone of C4 up to C8 (the top pitch on an 88-key piano). The bottom spectrum, describing the pitch C6, shows just six distinct harmonics ranging only two-and-a-half octaves from C6 to G8, a fifth higher than C8. As a result of these differences, the lower pitch will sound relatively warm and full, while the higher pitch will seem more cutting and shrill.^[8]

The basic theory of harmonics can be applied to the benefit of the present discussion. Because the sound of an instrument is so intimately dependent on its harmonic makeup, it follows that by examining the sound's harmonic makeup a quantitative description of the sound can be obtained.

In reality, any experienced musician can relate that the timbre of any instrument can change based on many different conditions. A flute might sound different in dry conditions than in wet because sound can travel faster in water than in dry air. Humidity would thus allow more higher-frequency harmonics to reach the listener before decaying, yielding a fuller sound. The variability of timbre is accentuated for reed players because in addition to ambient conditions affecting tone, degradation of the reed will also change the sound. This degradation is even more of a problem for double reed players not only because there are two reeds breaking down instead of one, but also because the dimensions of the reed itself can often change based on the condition of the reed. (In other words, a single reed will remain roughly the same shape and size despite wear, while a double reed could open or close, or change in width.)

A reed that has deteriorated could change the harmonic output of the instrument in many different ways. In general, the reed is observed to produce a more subdued and monotonous sound over time. The gradual morphing of sound quality can be explained by natural phenomena and defined by changes in the spectrum of the reed.

As it is vibrated, cane tends to undergo fatigue due to constant cycling from compressive to tensile forces within the material.^[2] The reed is weakened by fatigue caused by the repeated cycling of these forces. While this fatigue is more severe along the fibers of the cane, it also acts to weaken the individual fibers. Once the cane fibers begin to weaken, much less energy in the form of air flow is needed to vibrate the blades. The decay of the material results in the reed blades tending not to separate as far as when the reed is new. Based on these physical phenomena, **the volume of the reed is expected to decrease over time.**

In addition, the oboe's sound qualitatively becomes less lively and more subtle, often being more easily lost in the rest of an ensemble. As demonstrated in **Figure 1**, darkening of sound could be caused by a loss of harmonics. Furthermore, this darkening of timbre is attributable to the loss of the smaller clashing intervals, which are found higher up in the harmonic series. So, **it is expected that the upper harmonics of the reed will disappear from the spectrum over time.**

As a hypothetical example, the original oboe/C4 spectrum above might be expected to change as in **Figure 4**. When the reed is new, it would produce the orange spectrum. As it ages, however, it is hypothesized that the spectrum would shrink to the purple form. This spectral reduction is characterized by a significant drop in volume throughout the entire spectrum and is much more severe past some threshold frequency—here, about 2500Hz—when the upper frequencies begin to drop off sharply.

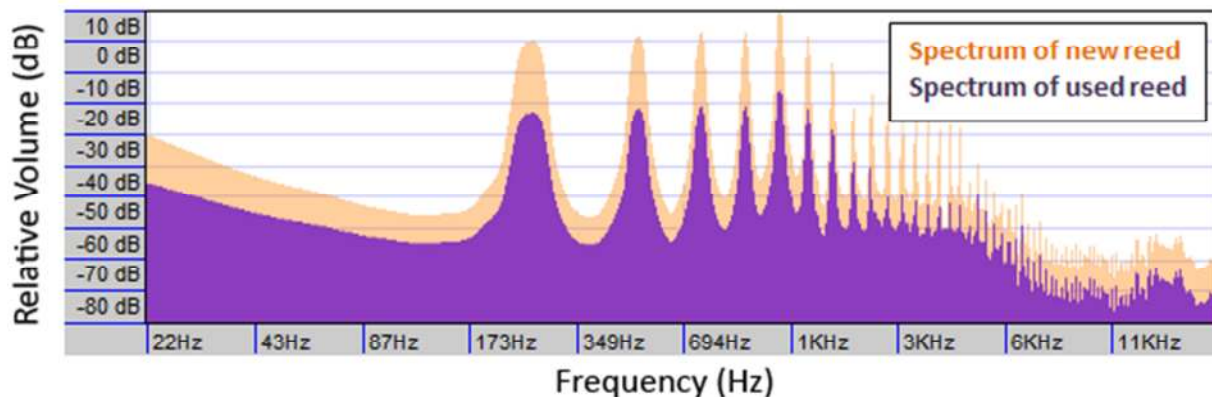


Figure 13: A theoretical modification of the oboe spectrum in Figure 10 based on the hypothesis presented. (Original spectrum adapted from reference [7].)

The mathematical projections established above have significant real-world application. If degradation of the oboe reed can be described precisely, then it will be possible to make much more pointed efforts in designing alternative reeds via differing materials, new designs, or a number of other methods.

II. Methodology

The purpose of this experiment is to quantify the anecdotal changes in reed character over its lifetime, as well as to observe the differences in timbre of several professionally made reeds. Observations will be made by recording these reeds in a controlled and consistent manner so as to remove as much variability as possible in testing. These analyses will make it possible to establish exactly how reed character changes over time and will explain the qualitative differences perceived by the musician.

a. Materials

Several pieces of specialized equipment were required for this experiment. The apparatus for reed testing was monitored using sensors from Phidgets, Inc. (Calgary, Alberta, Canada). Specifically, the parts required were a pressure sensor (part 1115), a precision temperature sensor (part 1124), and an interface kit (part 1018) to connect the sensors to a computer via a USB port. The sensors were pre-calibrated and provided values consistent with barometer and thermometer readings.

In order to keep a consistent embouchure between tests, an artificial mouth was created that mimicked that of a human player. To create an accurate simulation of the oboist's lips while playing, a proprietary vibration dampening gel was mounted between two small sheets of brass. The gel is sold under the name "Gel-Stuff Vibration Absorption Block" and was purchased online from Petra's Tech Shop (San Jose, CA). These sheets allowed the gel, which simulated lips, to compress the reed with arbitrary force as a human player is capable of doing. In an effort to avoid over-dampening the reed and producing an unnatural sound, the gel was shaped such that only a small amount of gel was actually in contact with the reed. A small amount of gel more accurately mimics the actual embouchure because when playing, only a small portion of each lip is in contact with the reed. This assembly, depicted in **Figure 5**, produced an accurate buzzing sound when tested with each reed.

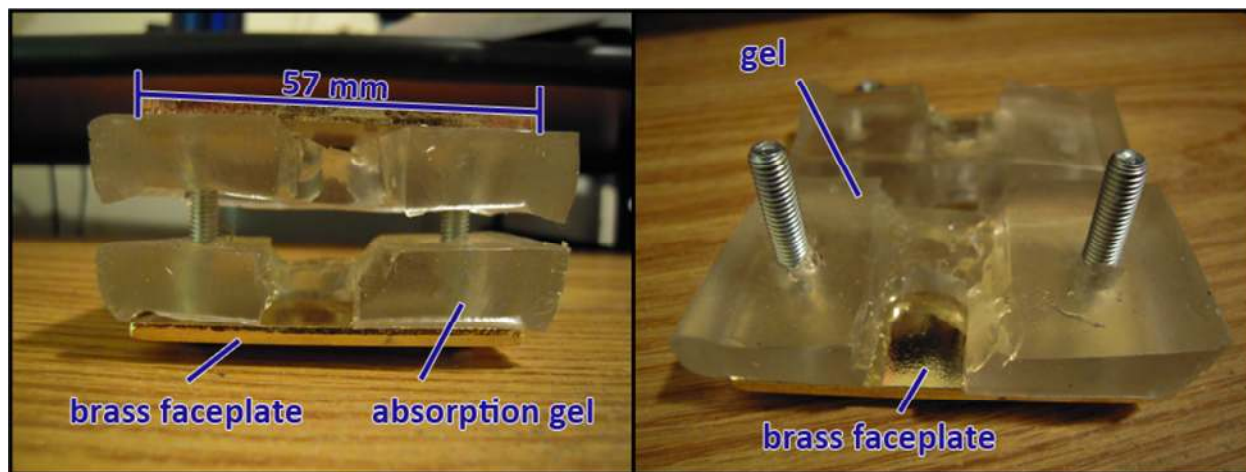


Figure 14: Two photographs of the exploded artificial embouchure.

The assembly casing, depicted in **Figure 6**, was made out of a small, hinged cedar box with a hole drilled to accept reeds and to hold the reed staple during testing. An adapter was added to the top to allow a half-foot piece of plastic tubing for air input. During tests the seam of the box was sealed with melted beeswax, which created a tight seal but was also easy to remove and replace when necessary.

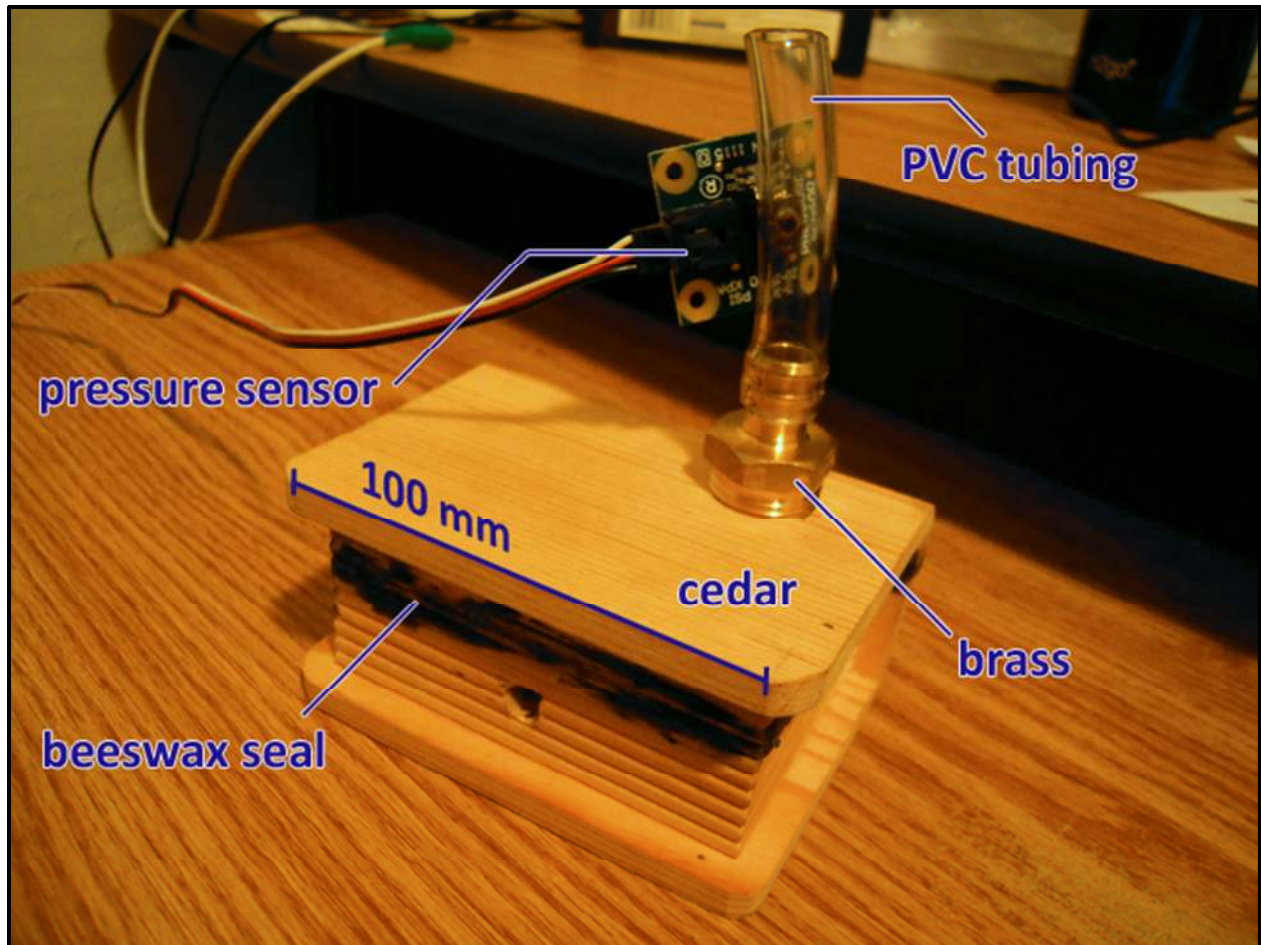


Figure 15: A photograph of the containing box assembly.

b. Procedure

Seven separate oboe reeds (labeled A through G) were purchased from six different local reed makers. Each reed was first soaked in room temperature tap water for 3 minutes and was then placed into the box assembly (Figure 6).

Each test was composed of two parts. Initially air was passed through the assembly at an increasing rate until the reed produced its buzzing sound. The required pressure for buzzing was recorded for each reed.

In the second part of the test, air was passed through the assembly for 2-3 seconds at the required buzzing pressure and recorded at a distance of 30 cm from the microphone. The playing pressure was not absolutely constant, but rather the minimum pressure was used for each reed. By choosing a “relatively constant” pressure for testing, fluctuations due to overblowing and changes in sound over the pressure range for each reed were negated.

c. Results

The pressures provided in **Table 1** were obtained for each test and indicate the required air pressure for buzzing. For a particular reed, using less than the indicated pressure would result in no appreciable sound output.

It should be noted that the reeds were tested in order of qualitative hardness. That is, the reed considered to be hardest was tested first, the second-hardest was tested second, and so on until the softest was tested at the end.

Table 1: Required air pressures for sounding on each test reed. Pressure values are precise to the nearest quarter-kilopascal (0.25 kPa). Reference values are provided at the bottom of the table.

Test	Required Pressure (kPa)
<i>A: Reed Maker 1</i>	109.5
<i>B: Reed Maker 2</i>	107.0
<i>C: Reed Maker 3</i>	108.0
<i>D: Reed Maker 4</i>	104.5
<i>E: Reed Maker 5</i>	104.5
<i>F: Reed Maker 6, new reed</i>	104.5
<i>G1: Reed Maker 6, "dying" reed, trial 1</i>	104.75
<i>G2: Reed Maker 6, "dying" reed, trial 2</i>	102.5
<i>Ambient pressure</i>	99.5
<i>Standard air pressure at sea level</i>	101.3

Before analyzing any spectra, it can be seen that **it generally takes more air pressure to play a harder reed than it does a soft one**. The difference in required air pressure is likely because a harder reed will, by definition, have a stiffer set of blades to be manipulated. The stiffer blades will require a greater amount of force to bend to the point that they touch, and once they have touched the reed will begin vibrating as expected and produce its tone. Using a variation of the Bernoulli Principle, it has been empirically established that

$$\boxed{-\Delta(v^2) \propto \Delta P} \propto |F|$$

That is, for a given change in force ($|F|$), a proportional amount of pressure reduction (ΔP) is needed. For a given reduction in pressure, the square of the air velocity ($\Delta(v^2)$) must grow by an equal amount. Therefore, the force required to bring the blades together via vacuum has a particular air velocity associated with it. Furthermore, the amount of air flowing through the reed per unit time (\dot{V}) is directly proportional to the velocity of the air (v):

$$\left[\frac{dV}{dt} = \dot{V} \right] \propto v$$

So, blowing harder into the reed will increase the pressure inside the player's mouth, but will actually reduce the pressure between the blades of the reed. This counterintuitive result is analogous to the physics behind creating lift in an airplane wing, wherein air passing quickly over the surface of the wing

tends to create a partial vacuum near the surface, drawing the wing up and creating lift. The same mechanic is in place here, but instead of just one surface moving, two are drawn toward each other.

Spectra A through G2 were obtained from each reed, and they show the relative magnitudes of each frequency of sound present. Peaks represent those frequencies that are present in the greatest proportion. For easy reference, the playing pressures presented in Table 1 are duplicated underneath each spectrum.

Note that the decibel [dB] scale is logarithmic. An increase of 10 decibels indicates a ten-fold multiplication of the volume level. So, a negative level does not represent a “negative volume”, but rather a very low one.

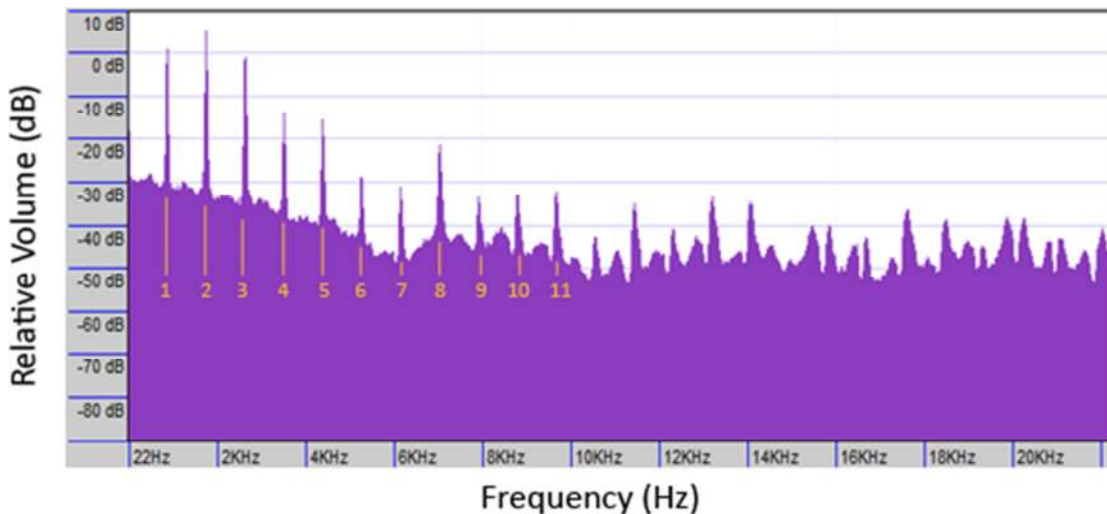


Figure 16: Spectrum from Reed A. (Required playing pressure = 109.50 kPa)

Reed A (**Figure 7**) exhibits 11 consistent peaks from 1 to 10 kHz, each spaced roughly 900 Hz apart. Above 10 kHz, peaks tend to be more sporadic and vary greatly in height.

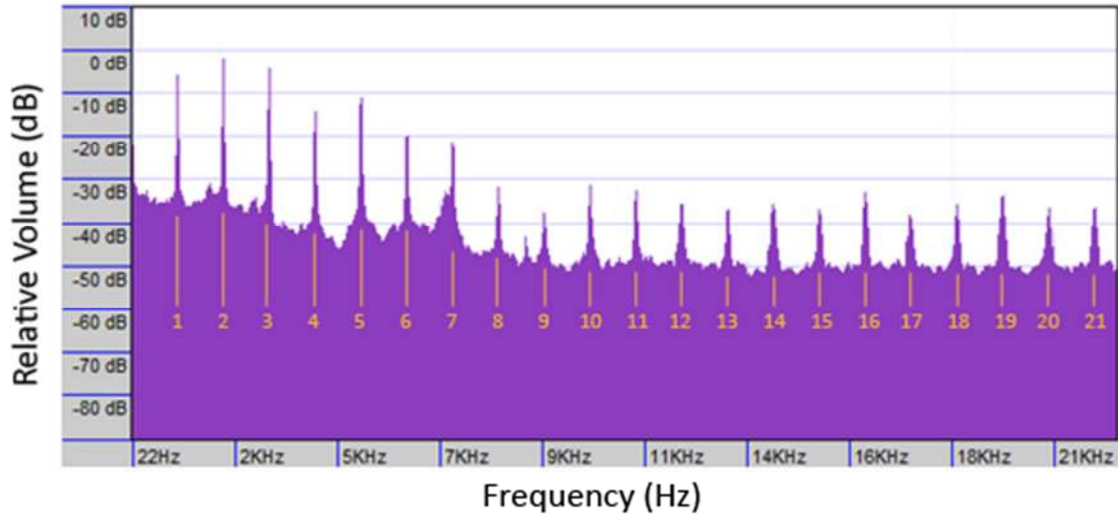


Figure 17: Spectrum from Reed B. (Required playing pressure = 107.00 kPa)

Reed B (**Figure 8**) exhibits 21 consistent peaks covering the entire spectrum of audible sound, each spaced roughly 1050 Hz apart. Only one noticeable consistency is visible at about 8.5 kHz (between peaks 8 and 9), but this minor peak is much smaller than those of the surrounding harmonics.

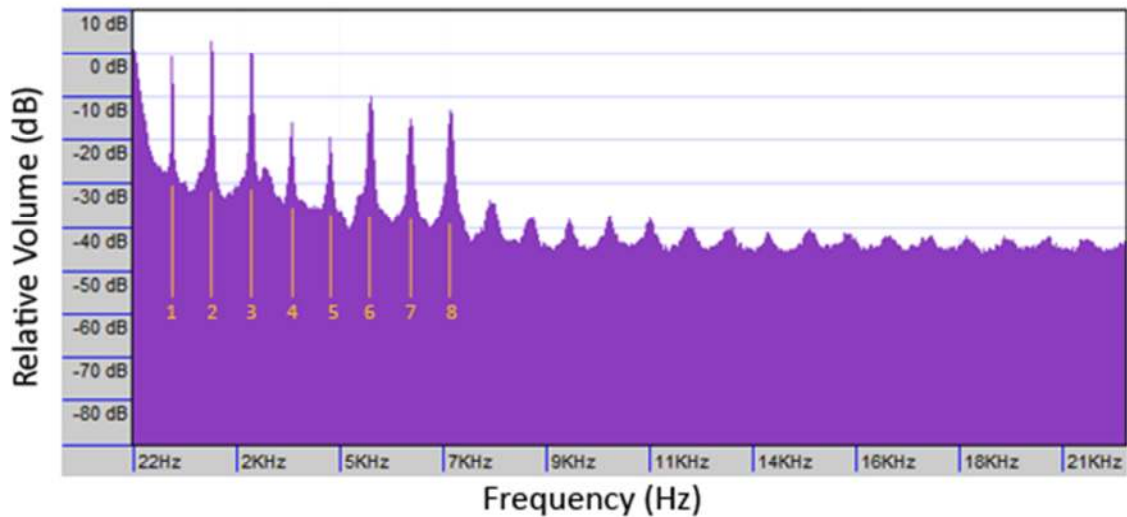


Figure 18: Spectrum from Reed C. (Required playing pressure = 108.00 kPa)

Reed C (**Figure 9**) exhibits 8 consistent peaks from 0.5 to 7 kHz, each spaced roughly 900 Hz apart. Above 7 kHz, additional harmonics drop off very quickly, with the first unlabeled peak nearly $\frac{1}{4}$ the height of the previous one.

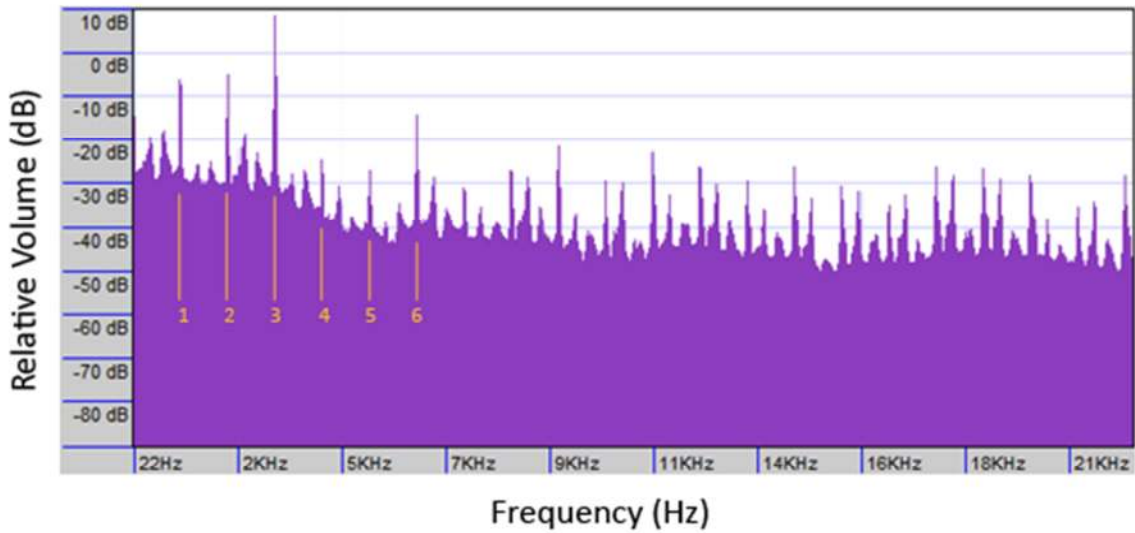


Figure 19: Spectrum from Reed D. (Required playing pressure = 104.50 kPa)

Reed D (**Figure 10**) exhibits only 3 apparently consistent peaks from 1 to 3 kHz, each spaced roughly 900 Hz apart. Peak 4 is significantly smaller than the first three peaks, and is only discernible from those surrounding it by the fact that it would theoretically be expected. Without advance knowledge it would be difficult to tell it from the surrounding noise. The peaks of Reed D (**Figure 10**), however, are not characteristic of external noise but rather are spaced very evenly and are likely an artifact of some acoustic phenomenon. A further analysis is included in the Discussion section.

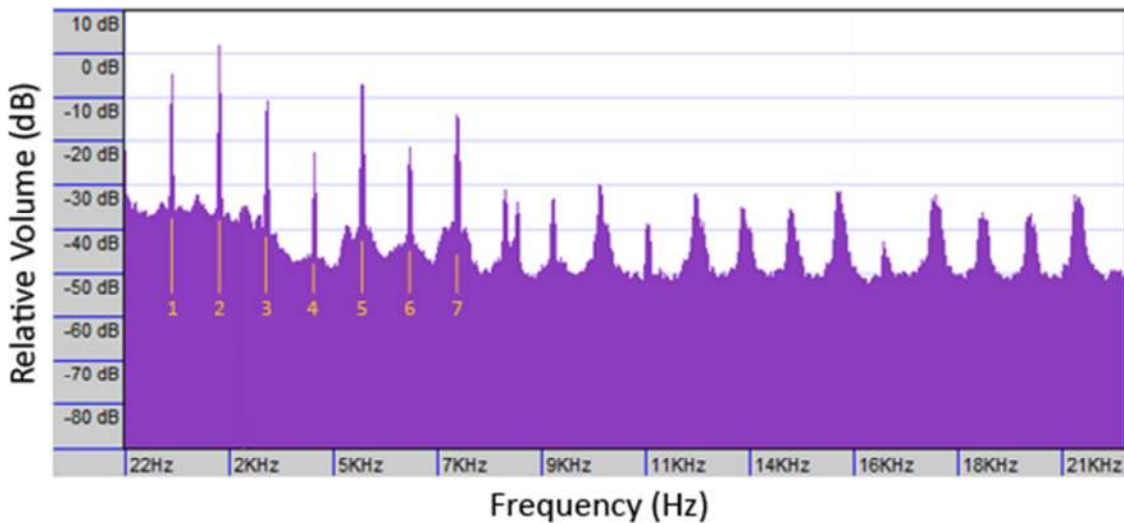


Figure 20: Spectrum from Reed E. (Required playing pressure = 104.50 kPa)

Reed E (**Figure 11**) exhibits 7 peaks from 1 to 7.5 kHz, each spaced roughly 1 kHz apart. At the frequency where the next peak would be estimated to occur, there are instead two potential peaks straddling this

“ideal” frequency. Past this point the higher frequencies are largely consistent, although there are a few peaks (notably at 11 and 16.5 kHz) which have been diminished.

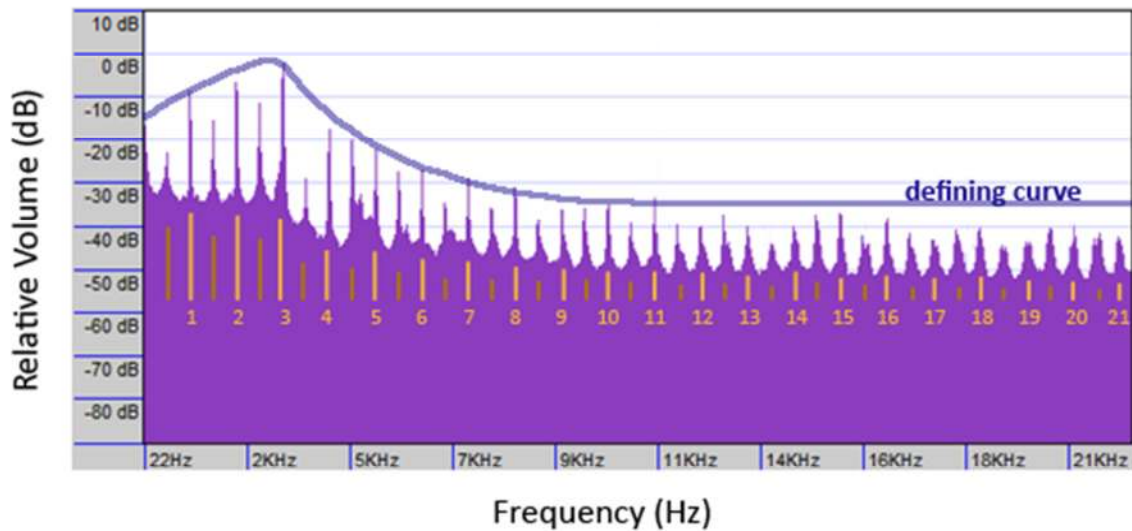


Figure 21: Spectrum from Reed F, a new reed. The blue line is the defining spectral shape for this reedmaker and is identical in Figures 12-14. (Required playing pressure = 104.50 kPa)

Reed F (**Figure 12**) is a departure from the patterns in previous spectra in that it demonstrates equivalent peaks between those that would be expected from the fundamental pitch played. While these doubly-packed peaks would normally be an excellent indication that the fundamental pitch was an octave lower, analysis at the time of recording confirmed that the crowded pitch was approximately 1 kHz (marked as peak 1 in **Figure 12**). The same phenomenon which affected Reed D is likely at work here as well, and will be addressed later.

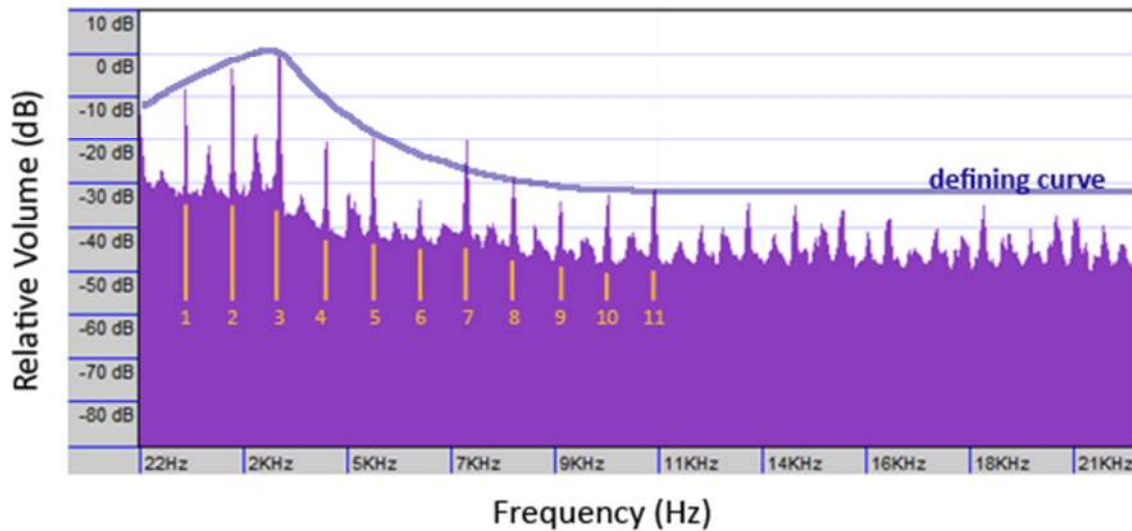


Figure 22: Spectrum for the first trial of Reed G, a “dying” reed. The blue line is the defining spectral shape for this reedmaker and is identical in Figures 12-14. (Required playing pressure = 104.75 kPa)

The first test of Reed G (**Figure 13**) exhibits 11 peaks from 1 to 11 kHz, each spaced roughly 1 kHz apart. Past 11 kHz it is not possible to discern predicted harmonics from those that are unexpected.

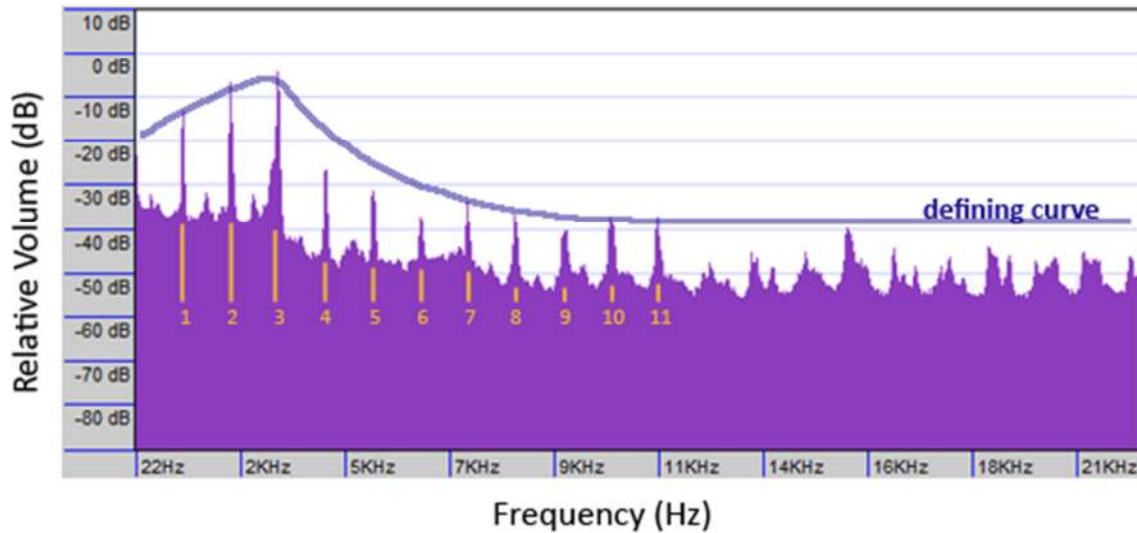


Figure 23: Spectrum for the second trial of Reed G, a “dying” reed. The blue line is the defining spectral shape for this reedmaker and is identical in Figures 12-14. (Required playing pressure = 102.50 kPa)

The second test of Reed G (**Figure 14**) once again exhibits 11 peaks from 1 to 11 kHz, each spaced roughly 1 kHz apart. At frequencies greater than 11 kHz the peaks collapse more rapidly than they had in the prior test, with only slight indications of the forecasted harmonics present.

d. Discussion

One notable characteristic, displayed prominently in Reeds D and F but also visible in most of the other reeds, is the presence of peak frequencies between theoretically predicted harmonics. The cause of these unexpected harmonics is likely to be constructive interference between the standard harmonics produced.

As explained in Section I, the harmonics of a fundamental pitch are located at integer multiples of its base frequency. A possible explanation for the observed “subharmonics” is interference, or the addition and subtraction of multiple waves. A wave of sound exhibiting a certain frequency will have a first harmonic which has exactly twice that frequency. The basic wave and its first harmonic can be depicted mathematically as two sine waves as in **Figure 15**.

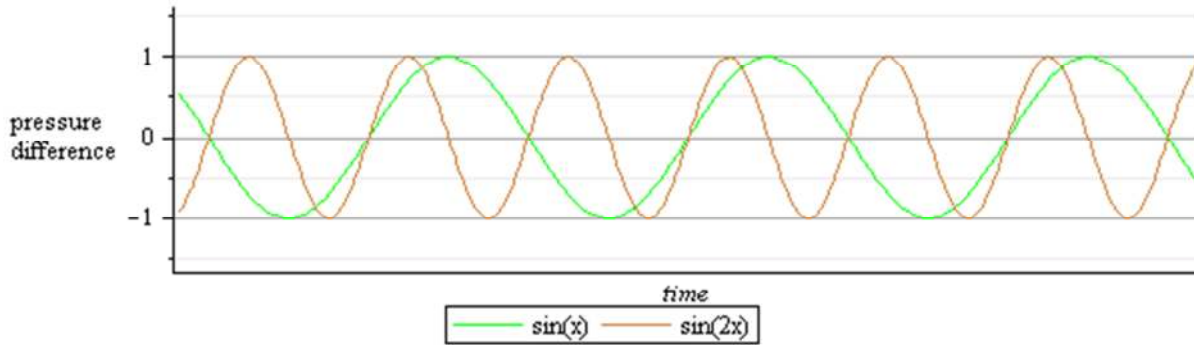


Figure 24: A qualitative graph showing two sine waves that are out of phase. The fundamental wave (green) corresponds to $y_1 = \sin(x)$, while the harmonic wave (gold) is represented by $y_2 = \sin(2x)$.

In the case of sound, each wave represents the relative air pressure at different points in time. Higher points in the wave represent higher pressure, while lower points represent lower pressure. Oscillating change in pressure is what the ear detects as sound.

Because each wave changes the air pressure, they can combine to produce different results. If, at a given point, both waves are at high pressure, then they will combine via **constructive interference** to cause an even higher total pressure. If one wave is at a high pressure and the other is at low pressure, the two will negate each other via **destructive interference** to approach normal air pressure.^[5] The addition and subtraction of these waves is illustrated mathematically in **Figure 16**.

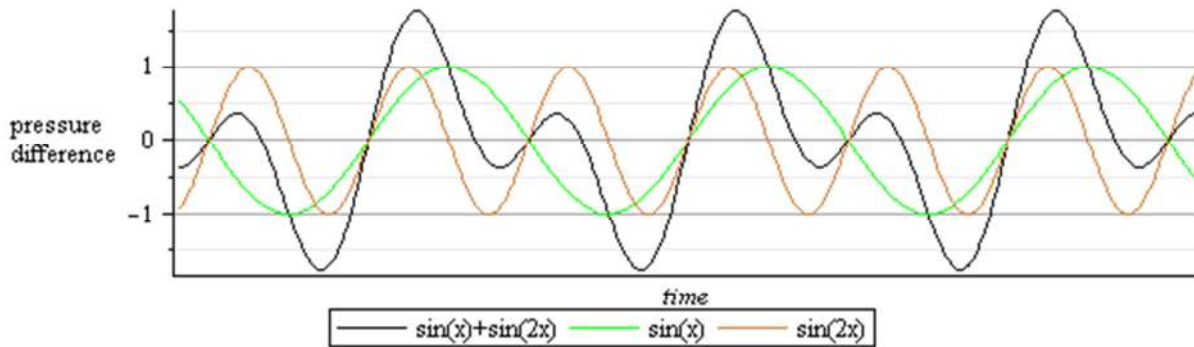


Figure 25: A qualitative graph showing two sine waves that are out of phase and their sum. The fundamental wave is displayed in green, the harmonic wave is displayed in gold, and the sum is displayed in black. Note the resultant pattern of a high pressure peak followed by a lower peak, comparable to the alternating pattern of harmonic peaks exhibited in **Figure 12**.

In the case of Reed D, where the *second* harmonic is much more prominent than the first harmonic, it may be more appropriate to apply the same logic using the wave with a tripled frequency as shown in **Figure 17**.

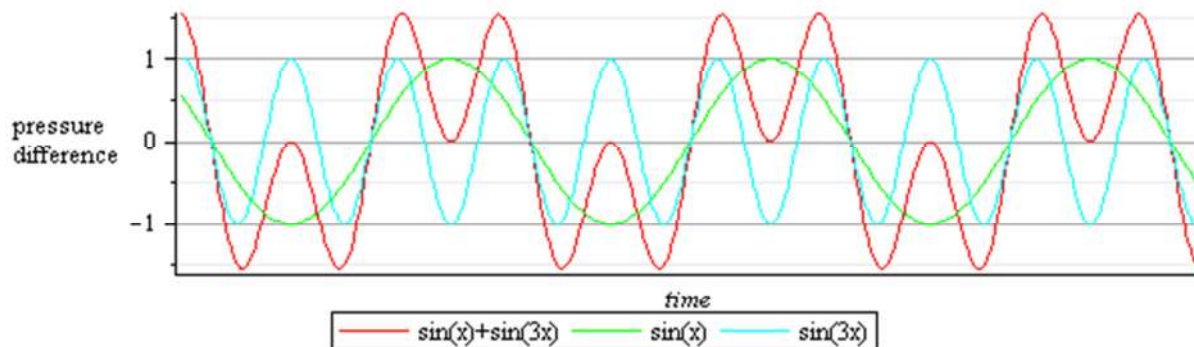


Figure 26: A qualitative graph showing two sine waves that are out of phase and their sum. The fundamental wave is displayed in green, the second-harmonic wave is displayed in cyan, and the sum is displayed in red. Note the resultant pattern of a high pressure peak followed by a lower peak, comparable to the alternating pattern of harmonic peaks exhibited in Figure 12.

While in reality many different waves will be reflecting and reverberating to interfere with the output of the reed, a full simulation of the recording booth is far too complicated to analyze without very sophisticated software and equipment. However, the basic theory alone can justify the presence of previously unexpected peak frequencies in the sound spectra.

One of the most interesting observations about the reeds' spectra may be that each reed maker appears to leave a distinct fingerprint on the reed, or a particular spectral shape defined by the number and relative sizes of its peaks. The sixth reed has sharp peaks where expected while the fifth has sharp "subharmonics" within the expected values, and the first differs from both in that some of its expected harmonics are dampened. Each spectrum is distinctly different, and yet all samples have the general sound of oboe reeds. The differences in sound quality are almost certainly a consequence of the fact that the sample reeds were made individually by hand. (A further experiment might pit hand-crafted reeds against mass-produced reeds—or mass-produced reeds against themselves—to determine what exactly causes the latter to often be considered "inferior" by professional oboists.)

The idea of a reed maker's fingerprint is further established by examining **Figures 12-14**. These spectra describe two entirely different reeds, both made by the same reed maker several weeks apart. While the reeds vary greatly in age, it is still possible to identify the underlying fingerprint in both of the reeds. The subharmonics present in the new reed are not as prominent in the old reed, but there is evidence of these subpeaks having been present earlier in the reed's life.

The comparison of old versus new reeds can also be conducted as it was in the hypothesis (**Figure 4**). By coincidence, the final reed actually ceased to work after testing was over, and so the recording depicted in **Figure 14** was its last. Thus, it is an excellent candidate for comparison against the new reed used in **Figure 12**.

For the sake of consistency with the format used in the hypothesis, the spectra are converted to the logarithmic format used previously. By overlaying one spectrum atop the other, we arrive at **Figure 18**.

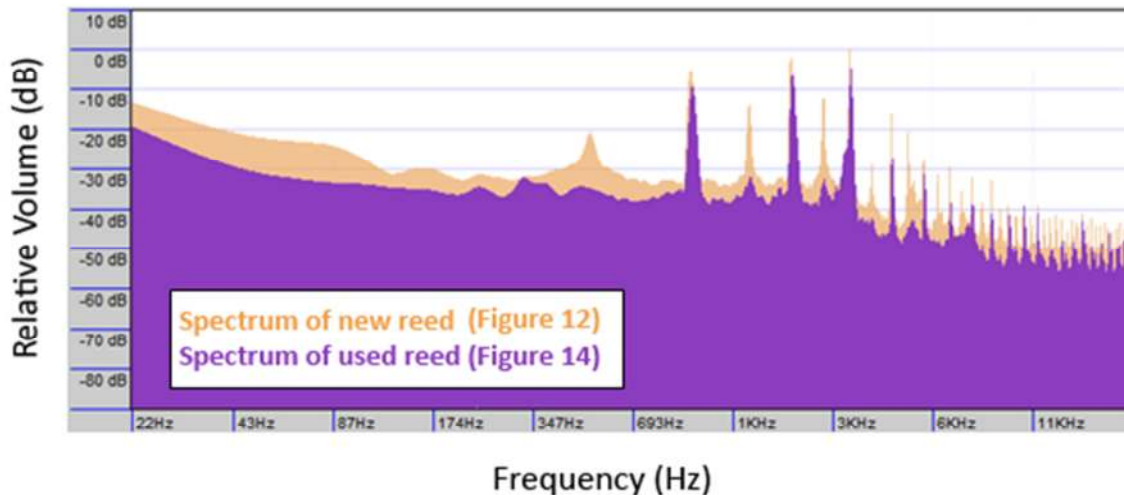


Figure 27: Figure 14 (purple) overlaid upon Figure 12 (orange). Note the overall decrease in magnitude, especially in the upper frequencies.

The comparison in **Figure 18** supports the claims made in the hypothesis regarding changes in reed spectra over time. Assuming that a professional reed maker’s technique is consistent, the two reeds can be expected to have had similar waveforms when newly made. Thus, the older reed can be treated as if it were once the newer reed. Of course, there are variations from reed to reed, but this assumption seems to hold because both the new and old reed demonstrate the reed maker’s characteristic spectral shape (as depicted in **Figures 12 through 14**). The reeds also both crowsed at nearly identical pitches under similar conditions, which is a good cursory indication that the techniques used to create both were sufficiently similar.

With the primary analysis of the spectra complete, the waveforms can now be analyzed. The fundamental pitch (a slightly-flattened C5) is evident at 513 Hz, which the first fundamental at 1037 Hz confirms. The first few peaks shared by both spectra are nearly equivalent in magnitude, although the older reed does show a slightly lower volume. The older reed also does not produce significant output at G6 (1550 Hz) or E7 (2600 Hz), although these two peaks are visible in the newer reed. While this discrepancy could indicate that the older reed is crowing an octave higher, it was confirmed at the time of recording that both reeds produced the same fundamental pitch. (These muffled frequencies may potentially be explained by the weakening of cane over time, which could dampen particular frequencies. However, a material analysis is not within the scope of this experiment and must be left for later research.)

Overall, the older reed can be described as having a lower volume than the newer reed. In addition, this relative difference grows more and more as the frequency increases, to the point that the older reed is nearly 10 dB quieter at frequencies above 11 kHz (that is, one-tenth of the newer reed’s volume). The dependence of volume decrease on frequency supports the hypothesis that upper harmonics will be more affected by age than lower ones.

Notably, the upper harmonics were not the only harmonics to fade from the spectrum. The older reed tended to lose many of its harmonics, which rendered its sound much drier and duller than that of the brighter new reed. Additional dampening was not expected, and may be attributable to a material failure due to wear of the cane. As mentioned previously, this experiment aims to analyze only the sound, but material analysis would be a worthwhile route for further research in the future. If a material were chosen that mimicked cane but did not fail in such a way that these harmonics were muffled, could it be used to make a longer-lasting bright reed? Alternatively, could a material be chosen that purposefully muffles these harmonics to produce a rounder, darker sound?

III. Conclusions

Despite the disadvantages of giant cane as a vibrating component, little analysis has been conducted to find a more suitable replacement. The aim of this work was to establish basic research in order to accelerate progress in this field. In order to accomplish this, an apparatus was designed to consistently measure the harmonic structure of the sound produced by a reed and to remove as much environmental variability as possible.

Through this experiment it was possible to collect a significant amount of data and use it to prove empirically many “axioms” of oboe playing. Most notably, it was possible to demonstrate acoustically what causes an oboe reed to change its timbre over the course of its lifespan. Furthermore, differing reed makers’ work was analyzed graphically rather than audibly, which made usually subtle nuances much more evident even to a musician whose ear is not finely tuned. The experiment also allowed for basic analysis of playing pressures, proving scientifically the simple fact that a stiffer reed takes more pressure to play.

It was found that while different oboe reeds vary greatly in their harmonic structures, a particular reed maker will tend to have a similar spectral shape in their reeds. Similarity of spectral shape is likely caused by consistency in technique. Furthermore, the timbres of reeds in different stages of their lifespans were confirmed to change, and these timbres were described qualitatively.

Being able to demonstrate these facts definitively instead of anecdotally is absolutely important to those conducting research in music, especially in fields pertaining to the double reed. By outlining here a simple device for analyzing the sound of the oboe reed, it is now possible for any motivated musician to duplicate these experiments with his or her own local reeds. A consistent test apparatus also allows the more scientifically-minded to examine alternate materials or techniques from a more familiar perspective. A change in tone or quality can now be described numerically instead of subjectively. Any reed can now be compared to one’s own “good” reeds objectively, and so it is possible to see whether a change in technique or material is a step toward or away from this desired goal.

This fundamental research points in many different directions. For example, one may consider the next step to be to alter one’s own reed-making technique to approach a more pleasing sound. Another musician may wish to try a different species from the *Arundo* genus to see if its sound is similar to that established using giant cane. Yet another may leave the reed alone entirely, and instead try to develop

a device to amplify or subdue particular harmonics in order to improve his or her sound. With a basic method of describing the reed's sound without anecdote, any of these routes are now possible.

IV. Acknowledgements

This work was conducted as part of a major requirement for the completion of the undergraduate program at WPI. I am deeply indebted to Professors Joe Halko (Humanities & Arts) and Satya Shivkumar (Mechanical Engineering) for their tireless help in developing, performing, and detailing this project. In addition, I am very appreciative to Professor Richard Falco (Humanities & Arts), who graciously offered the use of WPI's recording studio and equipment during the process of this research.

V. References

a. Literary

1. NORDMANN, Meagan. "Bobby Taylor: Sculpting His Voice on the Oboe." *Nashville Arts Magazine*. 8 June 2010. Last accessed 18 Nov 2010. Available from <<http://nashvillearts.com/2010/06/08/bobby-taylor-sculpting-his-voice-on-the-oboe>>.
2. BLAIS, Zachary. "An Overview of the Rise of *Arundo Donax* in Oboe Reeds." *The Double Reed*. Journal article ed. Dan Stolper, 2010.
3. STEWART, George W. Introductory Acoustics, 3rd ed. USA: D. van Nostrand Co. Inc., 1933. *Harmonics and Overtones*, pp. 182 Google Books. ISBN 140672016X.
4. BARNES, Charles L. Practical Acoustics, Vol. 3, Pt. 1. London: Macmillan and Co. Ltd., 1897.
5. MEHTA, Neeraj. Textbook of Engineering Physics, Pt. 1. New Delhi: PHI Learning Private, Ltd., 2008. ISBN 8120333616.

b. Audiography

6. University of Iowa. *Recording of Oboe at mf, C4 to B4*. Iowa City, Iowa: 23 July 1997. Last accessed 9 July 2010. Available from <<http://theremin.music.uiowa.edu/MIS.Oboe.html>>.
7. University of Iowa. *Recording of Tuba at mf, C3 to C4*. Iowa City, Iowa: Nov 2003. Last accessed 9 July 2010. Available from <<http://theremin.music.uiowa.edu/MIS.tuba.html>>.
8. BLAIS, Zachary. *Adapted Recordings of Oboe, Flute, and Tuba*. Available for download at <http://zacblais.com/research/audio_files_2.zip>.
9. University of Iowa. *Recording of Alto Flute at mf, C4 to B4*. Iowa City, Iowa: April 2000. Last accessed 10 July 2010. Available from <<http://theremin.music.uiowa.edu/MIS.altoflute.html>>.
10. University of Iowa. *Recording of Oboe at mf, C6 to Ab6*. . Iowa City, Iowa: 23 July 1997. Last accessed 10 July 2010. Available from <<http://theremin.music.uiowa.edu/MIS.Oboe.html>>.

Appendix I

Email correspondence with Mr. Stolper

Tue 1/26/2010 10:19 AM

Hello Mr. Stolper,

My name is Zac Blais, and I'm an undergraduate student of Chemistry and Music at the Worcester Polytechnic Institute in Worcester, MA. I'm about to start a major research project, along with Joe Halko (an IDRS member), on input and output conditions for traditional cane oboe reeds--hopefully as a basis for more advanced research on alternate reed materials later down the road. I'm very interested in publishing my findings in *The Double Reed*, likely toward July or August of this year, and Dr. Ishikawa referred me to you as oboe editor of the journal. Are there any particular requirements, or possibly any suggestions, you have for submissions for publication in the journal?

Thank you for your time,

Zachary Blais
Chemistry (Music)
WPI Undergraduate Class of 2012

[N.B.: A confirmation email was received but was no longer available on WPI mail servers for duplication.]

Wed 4/7/2010 1:14 PM

Hello Mr. Stolper,

I contacted you a couple of months ago about potential publication in the *Double Reed*. I'm starting to write some preliminary material, and would like to know what conventions (if any) I should keep in mind as I write. Specifically, right now I'm not sure how to include figures, images, etc. in my writing. Is it preferred to have them within the text, or include them as an appendix?

I'm hoping to receive my first physical copy of the *Double Reed* soon, so hopefully that will clear up my confusion. Until then, I'd be happy to hear any suggestions you might have on formatting, etc.

Thank you,

Zac Blais
Chemistry (Materials & Music)
WPI Undergraduate Class of 2012

Wed 4/7/2010 1:37 PM

Dear Zachary,

As I said before, various authors choose different formats for their work, and we try to honor their creativity. Footnotes at the end of the article can make for some additional clarity, I think. When you have the DR in hand, you'll have a better idea. I am eager to read your article!

Wed 4/7/2010 1:37 PM

Hi,

Thanks for the quick response. I wasn't sure if I had already asked you about this, and I lost a lot of old emails trying to configure Outlook a while back so I couldn't check for myself. I'm hoping to be able to pass the article on to you by roughly the first week of May, and I'm certainly eager as well!

Thanks,

Zac.

Mon 5/17/2010 8:44 PM

Hello (again) Mr. Stolper,

Attached is my review article on the history and use of giant cane in oboe reeds. Because the upcoming experimental portion will be so different from this historical portion, I present this to you as Part 1 of (at least) two installments. If you think that combining the two would be better once all the work is completed, I would be happy to wait (I certainly trust your judgment as editor much more than my own).

Please let me know if there are any technical issues with images, formatting, etc.—or any other issues for that matter. I'll do my best to fix anything that might come up.

I hope to hear back from you soon!

Thank you again,

Zachary Blais

Chemistry (Materials & Music)

WPI Undergraduate Class of 2012

Tuesday, May 18, 2010 9:48 AM

Dear Zachary,

Thanks for sending your article. I will forward it to our layout person who will advise us about any problems he might encounter. I look forward to staying in touch.

Best wishes,

Dan Stolper