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Instrument Construction: An Examination of the Effect of Lead Pipe Design Variability on Tuba Response

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INSTRUMENT CONSTRUCTION: AN EXAMINATION OF THE EFFECT OF LEAD PIPE DESIGN VARIABILITY ON TUBA RESPONSE

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Musical Arts

in

The College of Music and Dramatic Arts

by

Larry James Heard
B.M.E., Southeastern Louisiana University, 2011
M.M., Louisiana State University, 2013
May 2020
For Peanut,

I began this journey to inspire you,

and in your memory,

I complete it.
ACKNOWLEDGEMENTS

Many thanks go to Dr. Joseph Skillen for his help in guiding me through my tutelage as a player and scholar. My first interactions with him began many years before the inception of this written study, and he has been supremely influential in my growth as a musician, teacher, and as a life-long seeker of knowledge. He has given me the necessary tools and motivation to help me realize and manifest an appropriate topic for this document that would also be the most meaningful to my current interests, as well as my research goals for the future. Not only has he been impactful as an instructor and advisor, but—for me—he has been a model of leadership through optimism, kindness, and immense understanding. In addition, I must not forget other important individuals who served on my doctoral defense committee: Professor Carlos Riazuelo, Dr. Matthew Vangjel, and Dr. Chun Yang. I thank them for their support, as well as for being available and open to work with me throughout this process.

Finally, I owe my most sincere thanks to my family for always being there to build me up through years of challenges. There is no possible way to measure the amount of gratitude I have for them. They truly are the most important blessing in my life. To my sisters: You both are my daily inspiration, and you always have been. Thank you for encouraging me with your example and your respect. To my mother: You were right. You always are. Thank you for always believing in the part of me that I could never fabricate or toss aside. Through considerable pain and suffering, you showed me, from an early age, how to never give up, and how to smile through the tears. To my wife: You hold up my hands. You are strongest when I am at my weakest. Thank you for always cheering me on, and finding ways to remind me of my purpose. I am blessed that our steps have been guided to this point together. To my son: Don’t believe the obstacles. You can do anything. Thank you for being a gift, and an answer to many prayers.
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ABSTRACT

The document begins with a brief description of the main parts of the tuba: the mouthpiece, the valves, the body and the bell; in addition to a short explanation of the different types of material used to construct brass instruments. This study will function as the first installment of a bigger series exploring the variations in tuba sound when the different main parts are physically altered or swapped for other designs of the same part. This first installment of the series seeks to examine the section of the tuba known as the lead pipe in relation to the implications of varying the lead pipe and observing the effects of these changes. One of the goals of this research is to, through review of related literature, understand the acoustic processes that go into the creation of sound energy within a brass wind instrument. Another purpose of this writing is to discuss, through interviews of experts in the field, the lead pipe and how it is constructed, shaped, and designed, while gaining information as to how it could relate to the sound and response of the tuba. Finally, the primary objective of this study is to gather data through a series of performance tests in which the lead pipe design will be modified with results recorded.
INTRODUCTION

There is a certain level of understanding about each instrument manufacturer brand and how they are generally perceived. One performer may say this manufacturer typically features instruments that are overall rather nimble. Others may say another brand instruments are known to play with a great deal of color and complexity. These are somewhat blanket statements. My impression is that a general cohort of brasswind and woodwind musicians tends to apply their opinions to a whole brand of instruments as if the sound that comes from them is a tangible mark of the brand. When searching for tubas, this occurrence, and other certain characteristics are used to make surface-level decisions about any given tuba and its perceived value.

I have always been interested in the construction of brass instruments and the effect of this construction on the way the instrument plays or operates.¹ Hours have been spent casually observing the drastic as well as the minutest differences between instruments, all the while considering the implications of these variances in design.² It has occurred to me that there is a particular “template” of building brass instruments, from which different manufactures will pull ideas to bring about equipment with slight deviations. Sometimes these deviations can look attractive to certain individuals causing some to choose one brand and others to choose another. In my own experience, I have seen instruments with certain qualities carry a higher price than other instruments without the qualities. For the brass instruments, these variations will be most commonly found in the mouthpiece, the valve set, and the bell, with the greatest number of


alternatives coming from the mouthpiece. While observing the different designs of these parts, the question I often have is, “Can I measure the radiated sound of these variations?”

My interests have been centered on the largest of these instruments, the tuba. The tuba can be broken down into the following parts: mouthpiece, lead pipe, valve set, body, and the bell. This document will look closely at the implications for the variances in lead pipe. However, before examining this element in particular, it is important to provide a working discussion of the other parts. Because the focus of this paper is to examine the lead pipe, discussion on other parts of the instrument will feature cursory information only.

The Mouthpiece

The mouthpiece is the first part of the instrument that receives the vibrations from the air or breath produced by the individual. It takes the vibrations initiated by the breath and focuses it even further to be carried into the lead pipe and through the rest of the instrument. Mouthpieces are typically made with a funnel shaped cup or a bowl shaped cup. There are those with the opinion that the funnel cup mouthpiece, made popular by the tuba virtuoso, August C. Helleberg, is best suited for American style, or piston valve, tubas. On the other end of the spectrum, some advocate that the bowl shaped cups are more suited for German style, or rotary valve, instruments. This is of course a decision to be made by the individual performer.

Mouthpieces are generally made with additional material that surrounds the cup to help with stabilizing the vibrations. Mouthpieces vary in the amount of material used to surround the cup.
In addition to the type of cup, mouthpieces will also vary in the size of the cup depth, rim width, inner-diameter, rim edge, contour, throat, back-bore and shank. There are two different types of shank for tuba mouthpieces: American and European. American shank is normally smaller in size than the European shank, having a greater sized back-bore and, in many cases, throat.

Mouthpieces are typically made with brass, but are also made with other materials. These materials include plastic, titanium, stainless steel, and even wood. Metal-based mouthpieces made out of brass are normally coated with silver or gold to protect the user. Brass is known to be toxic when it comes in contact with skin. These different kinds of coating have notable differences for those who use them. Some believe the gold plated brass mouthpieces allow for greater mobility for players who move or shift their embouchure for better positioning during a performance on a given mouthpiece. Other materials like stainless steel or titanium are said to be popular for musicians who experience skin irritation or allergic reactions from the lead exposure of worn brass mouthpieces, as stainless steel and titanium are known to be hypoallergenic. Also it is maintained that the material used for these types of mouthpieces lessens the amount of vibration absorbed into the mouthpiece, or even lost because of it. Supposedly, more of these vibrations make their way into the instrument, allowing for a quicker and more projected response.

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The Body

The tuba has changed a great deal over the course of nearly 200 years. Older instruments did not have the general cosmetic elements of today, and today’s instruments vary significantly. My impression is that there are different ways to describe the body of the tuba, there is some disagreement on which way is the most accurate. From my observations it seems that the body can be broken down into two main parts: the branches and the bottom bow. Some instrument manufacturers will describe the body of the tuba in relation to a numbered branch system. The numbering of these branches can reach up to 5, but the distinction of what number goes to what branch may alter between different companies. A solution to this confusion is through the use of descriptive terms.

The first part of the body of the tuba after the bell is most commonly known as the bottom bow. There are manufacturers that may refer to this section of the tuba as the first branch of a tuba’s body. This portion of the tuba is generally considered the bottom of the tuba. It is what rests on the chair, tuba stand, or lap of the performer during periods of use. This part of the instrument will vary in size depending on the size classification and pitch type of tuba.

In most cases, the smallest size classification, 3/4, will feature tubas with the smallest or thinnest bottom bow tube. As larger sized tubas are built, it is typical that larger or thicker sized bottom bows will be needed for these tubas. For instance, the largest size classification, 6/4, will feature a tuba with considerably larger bottom bows than the smaller size classification. Also a key factor in the size of the bottom bow is the pitch type of tuba. Contrabass tubas are more likely to feature bigger bottom bow requirements than the higher pitched bass tubas.

---


The next part of the body of the tuba after the bottom bow is where some confusion may begin. This section is referred to by some as branch 2, referring to the bottom bow as branch 1. However there are others that refer to this portion of the instrument as branch 1, keeping the distinction of the bottom of the tuba a constant. For the purposes of this introduction, the descriptive term, top bow, will be used. The top bow is the highest point of the tubas body and can be found closest to the bell flare. In relation to size or thickness of tube, the top bow is smaller than the bottom bow. It functions much like the bottom bow, varying in size based on the size classification and pitch type of the tuba.

There are two parts that follow the top bow. I will refer to these parts as the bottom-inner bow and the top-inner bow. The bottom-inner bow is closest to the bottom bow and is smaller than the top bow. The top-inner bow can be found above the bottom-inner bow, closer to the top bow. It is smaller in thickness than the bottom-inner bow.

The top-inner bow then moves to a portion of the tuba that looks like a tube fashioned into the shape of the letter ‘S’. Chuck Nickels has referred to this part of the tuba as the “dog-leg” due to its bend forming the shape of a dog’s hind leg. The “dog-leg” is located mostly inside the inner bows and is smaller in thickness than the smallest inner bow. This small section connects the body of the tuba to the main tuning slide of the valve set.⁶

**The Valves**

Built within the body of the tuba are the valves. The purpose of the valves is to move the vibrations created within the lead pipe through the rest of the instrument. They also serve to, in a sense, lengthen the tubing of the instrument when the valves are pressed down, allowing for the instrument to sound notes that would otherwise not be possible or done with ease. There are two

---

The main types of valves that are used on the tuba. The first is based off of the original valve system created by Heinrich Stolzel in 1814. This invention was later improved upon by Francois Perinet in 1838. His upgrade was the precursor to the modern piston valve. The piston valve has since gone through significant changes, namely the invention of the compensating valve system, created by D. J. Blaikely in 1878, and later the automatic regulating piston valves, crafted by Victor Mahillon around 1886. During the early 1900s, companies like King, Conn, and J. W. York and Sons manufactured tubas that primarily used piston valves. Often times, the general public of tuba musicians will use the presence of piston valves to designate a tuba as “American-style”.

The second type of valve is the rotary valve. This valve was first created by Nathan Adams and patented later in 1835 by Joseph Riedl. The purpose of the rotary valve is to divert vibrations through lengthened tubing, much like the piston valve. The difference with the rotary valve is that it moves within the valve casing in a circular motion instead of vertically as with the piston valve. The valve creates a condition where the bore can remain consistent. This valve is thought to be the most popular option in Germany for use on tubas. For this reason, rotary valve tubas are often referred to as “German-style” tubas.

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9 John Ericson, Ibid.
The Bell

The next section up for discussion is a very important part of the tuba. The bell plays a significant role in the actual sound that is perceived by the player and listener. The bell is connected to the bottom bow. The lead pipe of a tuba is often fixed to the bell in some way. The bell can vary in diameter size, length, tube thickness, flare, and material.

The Diameter size of a tuba is one of the first specification people notice when shopping or observing tubas. A tuba’s bell can be anywhere between 12 inches in diameter to 22 inches in diameter, depending on what type of tuba and when it was created. As alluded to before, older German style tubas are thought to have a smaller bell diameter, whereas American style tubas are thought to be larger in this area.

Tuba bell lengths vary, but are typically long enough so that the end of the bell is at least as high as the top bow of the instrument. In most cases, the bell flare sits higher than the height of the top bow. German style, Kaiser tubas are known examples of tubas with a longer bell section length, whereas the American style, Martin tubas are known examples of tubas with a shorter overall bell length.

The thickness of the bell “tube” can vary tubas as well. The thickness of the bell section is often distinguished by the section just below the bell flare and referred to as the “throat” of the bell. These sizes vary often with relation to the size classification of the instrument. Typically, the smaller 3/4 sized instruments will feature smaller throats than the larger 5/4 or 6/4 instruments. The apparent “flare” will also affect the thickness of the bell section tube.

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The flare is a condition of two elements working together within the bell section. It can be described as the result of the relationship between the diameter of the bell and the size of the bell’s throat. Many American style tubas are made with a large 18-inch to 20 inch bell moving down to a throat of smaller diameter. This will give the impression of a large flare between the throat and the diameter of the bell. Many German style tubas are thought to have a considerably lessened flare due to the decreased difference between the diameter and the throat.

There is a sound difference in these two bell flares. German style tubas with a smaller bell flare are thought to have a sound that is more forward, or projecting. This phenomenon has been likened to the characteristics of a megaphone and its ability to project sound over large distances. American style tubas with the larger bell flare are said to have sound that is likened to the effects of surround-sound. Meaning, the sound may be warmer in presentation, but seemingly coming from everywhere.

The tuba’s bell can drastically affect the sound of the instrument because it takes up a greater percentage of the instrument in comparison to the lead pipe. For this reason, some musicians enjoy the results from changing or altering the material of the bell from the rest of the horn.\footnote{Robert W. Pyle, Jr., “The Effect of Wall Materials on the Timbre of Brass Instruments,” \textit{The Journal of the Acoustical Society of America} 103 (1998), 751.} There are tubas that feature a bell with a different gold brass material than the rest of the horn’s yellow brass or vice versa. Also, some musicians will strip the lacquer away from the bell only, leaving the rest of the instrument to have the lacquer still in place. These differences in the material will change the vibration of the bell, thus potentially creating a unique sound.
The Material

Tubas are brass instruments meaning, the metal used to construct them are made out of an alloy that consists of a combination of copper and zinc. There are different types of alloy that yield different sound results. Musicians have exploited these results to achieve a particular function or concept from their instruments.\(^\text{12}\)

Yellow brass instruments are considered to be the standard for brass instrument construction. It is thought to be quite resonant, made out of 70% copper. Instrumentalists and manufacturers maintain that this alloy produces a tone that projects a very direct sound. Instruments made with this kind of brass are known to stand out of the ensemble when needed.

Gold brass instruments are somewhat darker in color. This may be an effect of the higher amount of copper within its metallurgy. It is made with about 85% copper. Instruments made with this kind of brass are thought to feature a broad and thick tone while also maintaining the direct sound that the yellow brass can offer.

Rose brass is the alloy with the highest percentage of copper within its make-up. This alloy is made up of 90% copper. This allows instruments made with this material to feature a warm, rather mellow sound.\(^\text{13}\) Since the softer metal makes up most of the alloy, this type of brass may not project the same way as brass alloys with harder metal content.

Nickel silver is an alloy that features three different types of metal: Copper, Zinc, and Nickel. The make-up consists of 60% copper and 40% of a nickel and zinc composite. This particular alloy is known to be quite resistant to corrosion and is also a harder metal. An


industrial grade nickel silver can be found on a majority of marching brass instruments, as the harder metal allows for strong projection in sound, and protection against damage due to frequent use. This nickel silver can also be used to make the slides as well.\textsuperscript{14}

\textbf{Bracing}

The parts of the instrument that hold the instrument together are referred to as braces. These individual items are rather small in comparison to some other aspects of the tuba. Despite this, the way an instrument is braced can greatly affect the ways in which a horn plays. If braced correctly, a tuba will respond, as it should, freely with the proper amount of resonance. If braced incorrectly, the tone of a tuba could be deadened and dulled; or the instrument could resonate too freely such that intonation and quality of sound are adversely altered.

Because of the size of the instrument, tubas will generally feature more braces than other, smaller brass instrument. These braces are, more often than not, found throughout the valve set. There is also bracing connecting the valve set to the inner bows of the tuba. Many times, the inner bows of the tuba are braced to for support to the top and bottom bows of the tuba, as well as to the bell. The bell is often braced to the top bow. A tuba’s braces are put in specific spots to allow for the most desirable amount of resonance and fundamental in its sound. To add or remove any of these could drastically change the playing tendencies of the instrument.

There are many different variables that go into the creation of a tuba. My goal is to create a series in which I conduct an in depth examination of the whole horn and in some way measure different variables for each section of the horn. The first installment of this series will focus on the lead pipe. I seek to address different factors that may influence the response and even the audible sound of the instrument.

\textsuperscript{14} Chuck Nickles, interview by Larry J. Heard, Baton Rouge, LA, July 3, 2019.
I seek to present information regarding the construction, shaping, and design process of the lead pipe and how it relates to the nature of the sound radiated from the instrument. With this information, I can communicate to interested parties possible questions to ask during the tuba selection process. This may yield more informed decision-making when choosing a tuba, resulting in a greater satisfaction in the instrument as it pertains to the needs of the player. The data in this first installment is gathered through review of literature associated with the topic, interviews of knowledgeable individuals in the tuba design profession, and through sound and frequency (see Glossary) response experiments.
CHAPTER 1. METHODOLOGY

While shopping for tubas online, I realized there was no set way to construct the cosmetic presentation and look of the body and wrap of a tuba. Different companies used different schemes to organize the many tubes and pipes of the instrument. I began to wonder if there were some acoustical significance to how each tuba was constructed. One question found its way to the forefront of my thoughts on this subject: Does the lead pipe design affect the sound of a tuba? If so, will changing the design of a lead pipe for a tuba, or changing the lead pipe altogether yield a change in presentation with relation to what is heard from the tuba? From this question surfaced another: What is the most significant characteristic of a lead pipe to the efficiency of the tuba? I asked these questions because there seemed to be so much variety in the lead pipe bends. I was convinced there was something to be said of the bend.

What I’ve learned from interested parties is that the bend in particular doesn’t necessarily affect sound. This is much like the particular organization and formation of Sousaphones’ neck and bits as they don’t necessarily change the sound of the tuba, but it does create a more comfortable way to play the instrument, allowing the player’s face to meet with the mouthpiece without strain on the musician’s end. When a musician is unable to reach the mouthpiece comfortably, strain ensues. This could lead to a change in sound character emanating from the bell of the tuba. This is not to say that the pipe is causing this change. The design, however; what kind of impact can the design of the lead pipe provide? Is it possible to find at least two different lead pipe designs and put them on one tuba and measure that tuba on one pipe and then the other and determine whether or not there is a difference in the sound profile of the instrument? It is expected that the difference in design would provide, not a change in kind of sound, but the

presentation or behavior of the sound.

My goal for answering my questions is to find literature that presents ideas regarding the topic that I’ve chosen. This literature should help to answer the question by presenting other aspects of my topic, or by circulating around the idea of my topic, because that information is valuable as well. There is the possibility that this information may disapprove my topic or the assumptions that I have regarding the topic.

Before I present the information from the conversations with experts in the field, I want to present the assumptions or previous held theories that stemmed from my questions. It is my experience that assumptions are a good way to create direction; if one makes an inference, a step in a particular direction is taken. That direction tells you whether or not you are on the right path. For this reason I will have a section of the paper devoted to my thoughts before certain information was brought to my knowledge. It is important to present these reflections to show the progression of finding the more correct answers to my questions. This would be much like formulating and presenting a hypothesis, then testing that hypothesis, and recording the results.

Next, a portion of the document will be devoted to insights gathered from interviews of highly knowledgeable individuals on the topic. It would have been most helpful to interview at least four or five informed people on the subject. However, I’ve only had the opportunity to interview three participants: two individuals at length, and one person very briefly. Previous list of names to interview included Chris Bluemel, Alan Baer, Robert Carpenter, Chuck Nickles, Sam Gnagey, Tom Treece, Steve Koivisto, and Lee Stofer. I had opportunities to interview Robert Carpenter, Chuck Nickles, and very briefly, Sam Gnagey. It is possible that interviews with other individuals listed will be scheduled for studies of future research. Conversations with Robert and Chuck will be presented in a summary form as well as a full transcription. The
conversation with Sam Gnagey will be presented only in a short summary, as the official interview never actually happened, only a short, preliminary discussion.

In a section for Experiments, I would like to first present information regarding an experiment using two completely different tubas to show that two instruments that are the same instrument, in the same pitch, with similar overall build, and approximately the same size can have different qualities and will have a different sound. In this experiment, I will put, side-by-side, one tuba with another tuba. I will play them and record the excerpt performed. I will show the analytical data that presents the types of frequencies found in the sound of the excerpt performed. This will be used as evidence of the difference in sound and presentation.

I will also conduct an experiment in which I check the sound of both tubas using the spectrogram. Though this tool is typically used to measure the resonances of the human voice, I believe it can show us important information regarding the textures apparent in the open sounds of wind instruments. I will put, side-by-side, both tubas and play them and show the data from the sound spectrogram (see Glossary), referred to, henceforth, as spectrogram. This will serve as evidence of the difference in sound and presentation of both tubas. One tuba has different measurements then the other tuba. It would be interesting to see how these different measurements on different tubas can affect how the tubas’ sounds are realized on sound engineering devices. This is to make a connection for the reader that different models of instruments, though they are the same kind of instrument in the same pitch, will sound different and have different sound profiles,
so different designs or models of particular parts (tubes, pipes, valves) may do the same for one instrument.16

I will also do an experiment in which I switch lead pipes to determine the change in sound or response. In this experiment I will perform on a tuba with its original lead pipe. Then I will switch the lead pipe with a lead pipe of a different design, and perform on the tuba again. Before performing on the lead pipes, I will record the measurements of the lead pipes so the reader will understand the difference between the two. I will record the sounds performed using GarageBand. I will then take the recordings of these sounds and analyze them using GarageBand to see what frequencies are being utilized and if there is a difference between the two lead pipes. The images of the graphed analytics will be presented in the paper. I will also use a spectrogram to measure further what frequencies are creating the most concentrations in energy, with respect to the varying lead pipes. This information, along with information gathered from the GarageBand analysis will tell me what kind of difference I can hear, or not hear, and I will record these differences in the Results section for the reader.

I will also conduct an experiment based on individuals’ perception of possible difference in sound. I want to have a panel of at least 8 people. I want to play a series of short notes, and then a series of long notes. I want to do this twice, once with one lead pipe attached to the tuba used in the experiment, and once with a different lead pipe attached to the tuba. I want them to answer a short questionnaire about the sounds they heard. I would like to record the data and quantify it in a way that would indicate how well an audience can recognize changes in sound.

16 This statement, and subsequent experiment is inspired by the study done by Laetitia Placido, Adrien Mamou-Mani, and David Sharp, “Investigating Perceptual Differences Between Two Trumpets of the Same Model Type,” *Applied Acoustics* 72, 12 (2011): 907-914.
I believe that my method of answering this question is valid because other individuals who had questions regarding the sound of a brass instrument have used similar means, shown through research of what has been written on the topic, and through experimentation on the physical instruments themselves. I have not witnessed very many researchers using phone interviews to answer questions, but I would like to continue with the interviews because the individuals I spoke with have much more expertise in this field than I can boast. I have interviewed Sam Gnagy briefly, and I have interviewed Robert Carpenter, referred to as Bob, of Kanstul Musical Instruments. I’ve also interviewed Chuck Nickles, Chief Technical Designer for Wessex-Tubas. All of these individuals build tubas or have had an extensive amount of contribution toward the building of tubas. From the research that I’ve compiled, readers will notice that other individuals researching this kind of subject have used experiments on the physical instruments themselves to make a statement regarding the response of the instrument or its sound profile.

I am doing the same thing except I’m doing it for modern tuba. According to the research I’ve done, the closest that a researcher has come to doing an experiment on a tuba is the experiment done on the tubas mentioned in the article featuring the Wagner tubas. This article focuses on bore profile, but does not make a focus on variance due to changing the beginning pipe’s rate of change profile. There is an exception in the use of the Alexander Wagner Double tuba, in which the researcher measured the bore profile for both the B-flat side of the instrument and the F side of the instrument. Measuring the response of an instrument is nothing new. However, I am attempting to measure the response of an instrument with different parts back to back. I have yet to see research done on tuba with this method as the focus.

In discussing the shortcomings of my experiment, there are several issues that I would have like to make better. For instance, I would have much rather had the right tools and
mechanical instruments used for measuring sound and production, as well as for measuring waveform and determining the input impedance (see Glossary) curves.

It would have been very helpful if I were able to acquire the Brass Instrument Analysis System or BIAS from the Acoustic Rating Technology for Instrument Makers website. This device allows individuals to measure the potential radiated sound by assessing the acoustics and the inside of the horn. This system will be most helpful in future research analyzing sound production and its implications.\textsuperscript{17}

Currently, I don’t have this type of technology at my disposal. Because of this, I had to find information and formulate data from my available technology. These devices were enough to provide me with graphs and images that I can use to show the differences in sound for respective variables.

I would also have liked to have a way to artificially create sound from the tuba without having to perform on the tuba myself. It would better increase the validity of my findings if I eliminated the existence of human interaction, thus erasing the possibility of human variability. If I could create a system of artificial lips or use a setup that allowed me to utilize a loud sine wave to move through the tuba, and be recorded by a microphone at the bell end of the tuba, then I would have findings that were more devoid of human contact, thus eliminating to a greater degree the human variability.\textsuperscript{18} Because I lack the means to acquire or make this technology, I had to use the methods presented in the paper. So, my experiments are not perfect because of the above reasons, but the lack of proper technology provides an opportunity for further research.


CHAPTER 2. LITERATURE REVIEW

The literature I chose does not exhibit all that is available regarding the beginning processes of creating sound. The selected literature within the following review features the ten most helpful articles and papers for my topic. Altogether I read and gathered information from over 50 articles, papers, and studies. The following will feature research focused on subjects like the initiation of the waveform within a tube, bore profiles of low brass instruments, and useful methods for assessing the acoustical properties of sound.

2.1. The Physics of Brass Wind Instruments: J.M. Bowsher

There is an expansive bank of information regarding brass wind acoustics. A great deal of the information on brass wind acoustics is centered on the beginning mechanisms that initiate sound production. This process is known as input impedance. Many researchers have devoted a great deal of time and resources to explore this phenomenon. This occurrence refers to a frequency dependent quantity used to characterize the behavior of an instrument. It is calculated as the ratio of the pressure and volume velocity at the input or mouthpiece end. The input impedance provides an assessment of the amplitude (see Glossary) of sound pressure inside the mouthpiece as it is stimulated by a sinusoidal signal through the entry of the mouthpiece.

J.M. Bowsher published an article regarding this topic. In his paper, Bowsher expresses that brass musical instruments act similar to a tube that is closed at one point of the tube, and open at the other. It is important for the tube to be changed in order to achieve a greater level of frequency rates.

Specifically, the frequency rates that are typically achieved without the altered tube are the pitches found in the partials 1, 3, 5, and 7. When the tube has been modified accordingly, the frequency rates will move closer and pitches may be found on the partials 1, 2, 3, and 4. In order
for this to happen, the tube must be altered from completely cylindrical, to exhibiting a gradually conical, or flared out design.\textsuperscript{19}

In discussing the importance of design specifics, Bowsher’s research states that the way in which the mouth-pipe, otherwise known as the lead-pipe, is designed is crucial to the manner in which the instrument responds. Some tubes vary in diameter near the input point. This creates a “pronounced Venturi some 4 cm from the opening.” These deviations in the shape of the tube can be described as perturbations. When the perturbations in the mouth-pipe are controlled, the individual constructing the instrument has a greater chance of modifying the frequency of each impedance peak to meet any particular preference.

This article does well to provide information about what happens inside of the beginning stages of sound production around the area in which the frequencies are initiated. It notes that the occurrences that take place at the attack of a block of sound are of great salience. It also points to the notion that the design of the apparatus through which the sound travels is also of high importance. The conclusion presented in this work discusses the need for further research with regard to finding ways to excite oscillation with minimal variability.\textsuperscript{20}


“Input impedance is a more interesting and accurate acoustic measure because it is more immune to the effects of the measurement environment and because of the role it plays in the regeneration of sound at the lips.”\(^{21}\) In this study the pulse reflectometry practice has been used with different methods. One method used a single microphone technique. This method was done to measure the reflection functions of wind instruments.

The study notes that with each measurement technique and each measurement taken, it is necessary for the temperature in which the experiment is conducted to remain the same.\(^{22}\) This is due to the fact that large variations in speed of sound can have a significant impact on the measured results.

There is some difficulty in measuring input impedance because of the challenge in measuring volume velocity. The volume velocity needs to be the constant. Environmental conditions that fluctuate can affect the volume velocity.

The study lists several different methods for acquiring data for measurements of input impedance. One method discussed is the multi-microphone method. The writers of the study mention the technique of placing microphones inside the stimulating loudspeaker. In addition to that multi-microphone method, another method involves placing microphones near the high impedance capillary, speaker, and the test device.

There are also single-microphone methods. One method of this type uses a single pressure transducer. This method can directly measure the response of the instrument in real-time.


\(^{22}\) Alexander Buckiewicz-Smith, 6
In order to create the best results, it is wise to strive for the simplest kinds of signals. According to the study, the simplest type of signal is a maximum amplitude followed by zeros. However, the simple impulses are a challenge to acquire due to the low energy of the stimulus. Other problems may include the presence of too much background noise. Of course, the fact that the data in question is based off of one single pulse creates challenges as well.\textsuperscript{23}

The creators of the study used other types of signals to formulate data. The maximum length sequences were tests used to acquire a greater amount of data. This method has the lowest peak-to-signal ratio. It increases the amount of energy because of the high signal-to-peak ratio. Another method mentioned in this study is the Pulse Reflectometry Improvements method. Using short duration stimulus signals, there was evidence of band-limited chirps, and bursts of other types of brief sounds. The writers of this study also mention the possibility of lengthening the stimulus.\textsuperscript{24} According to the results of the impedance measurements done in this study, the researchers suggest that it is possible to use extremely long stimulus signals in a pulse reflectometry setup to measure reflection functions.

This study reveals the different methods for measuring the properties of sound production. The research done in this work is useful because it provides readers with an understanding of ways to measure the sound projected from musical wind instruments. It also outlines several formulas that can be useful in determining certain factors of the input impedance associated with short or long stimulus. This can help future researchers with identifying characteristics of sound production as they relate to different types of wind instruments, as well as different designs of particular instruments that are the same.

\textsuperscript{23} Alexander Buckiewicz-Smith, 17

\textsuperscript{24} Alexander Buckiewicz-Smith, 17
2.3. Brass Instrument Power Efficiency and the Relationship Between Input Impedance and Transfer Function: Wilfried Kausel

The desire to make improvements on established models of instruments is as old a human condition as the means of musical communication itself. Musicians never cease to find new and better ways to produce the sound concepts already heard in their minds. Not only have the instruments improved, but improvements have also been made through the methods by which we have enhanced our instruments. In many cases, the use of quantitative calculation has become a mainstay in the way manufacturers and their scientists are making more efficient instruments. This paper features several equations and formulas that can be used to measure the relationship between input impedance and transfer function. The use of simulation through formulas is one method, among many, in which the methods by which instruments are built have advanced.

\[ E = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{|p_{\text{out}}|^2 \text{Re}(Y_{\text{rad}})}{|p_{\text{in}}|^2 \text{Re}(Y_{\text{in}})}, \]

Figure 2.1. Formula for Power Efficiency

The formula shown in Figure 2.1 is used to determine the efficiency of an instrument. Power Efficiency is noted as \( E \). \( P_{\text{out}} \) and \( P_{\text{in}} \) are used to signify the output and the input powers, while the complex sound pressures located near the bell and occurring within the interior of the mouthpiece are noted by \( p_{\text{out}} \) and \( p_{\text{in}} \). \( \text{Re}(Y_{\text{rad}}) \) and \( \text{Re}(Y_{\text{in}}) \) are used to indicate the actual radiation from and input into the instrument. After presenting the above formula, Kausel,


\[ \text{Wilfried Kausel, 2—10.} \]

\[ \text{Wilfried Kausel, 3.} \]
Beauchamp, and Carral state the next step in which they modify the above formula:

\[
 E(\omega) = \frac{P_{\text{out}}}{P_{\text{in}}} = |T(\omega)|^2 \frac{\text{Re}(Y_{\text{rad}}(\omega))}{\text{Re}(Y_{\text{in}}(\omega))},
\]

Figure 2.2. Formula for Dependency on Frequency\(^{28}\)

The formula was altered to exhibit the dependence on frequency. This formula, in a sense, includes two formulas: \((T = p_{\text{out}}/p_{\text{in}})\), and \((Z_{\text{in}} = 1/Y_{\text{in}})\). The formulas help to find the pressure transfer function and the input impedance function, respectively. The research shown in this study exhibits a simulation in which the writers use a “standard one-dimensional transmission-line model for cylindrical and conical bore segments” (Kausel, 3). Throughout this work, several formulas like the one below were employed to factor the efficiency of brass instruments from a theoretical standpoint:

\[
 E(\omega) = \frac{4\pi r^2 T^0(\omega)}{D(\omega) Z_o \text{Re}(Y_{\text{in}}(\omega))}
\]

Figure 2.3. Formula for Theoretical Efficiency of Brass Instruments\(^{29}\)

From their work, the researchers found that their expectations of how the instrument would respond agreed with the results of their experiments. There were some variance between hypothesis and result, however they did not exhibit a wide discrepancy. The writers concluded that the agreements should be closer as the methods and systems used to create them advance.\(^{30}\)

This article is useful because it exhibits evidence of the practice of measuring the efficiency of an instrument using formulaic simulations. With these systems, instrument manufacturers can

\(^{28}\) Ibid.

\(^{29}\) Wilfried Kausel, 4

\(^{30}\) Wilfried Kausel, 8
create instruments that showcase vast improvements upon older designs of instruments.

2.4. Trombone Bore Optimization Based on Input Impedance Targets: Alistair C. P. Braden, Michael J. Newton, and D. Murray Campbell

In this article, researchers address the optimization of trombone bore profiles. The issue of “inharmonicity” was presented throughout the article. Inharmonicity has to do with the amount of harmonic alignment done to the resonator peaks to help with maintaining the oscillations of the lips.

The creators of this study did tests that suggest that when the inharmonicity of particular modes is smaller, a fixed phase relationship is created. A. H. Benade describes this as a “cooperative regime of oscillation”\(^{31}\). This study observes that a “perfectly-harmonic” number of resonances (see Glossary) would yield peaks that are among the tallest in the sum-function, therefore offering the most immediate response for the musician. During a series of perfectly-harmonic acoustical resonances, the strongest coupled oscillations will occur.

This can lead to the instrument responding in an inflexible manner. The instrument may create an observable “strong buzz” or oscillation. This means that a seemingly focused and pure tone may result. However, a musician may find that, when playing the instrument, there is difficulty in lipping or bending pitches. According to the creators of this study, when the musical instrument is constructed with a bore that exhibits a certain level of inharmonicity, lipping or bending pitches is found to be more manageable. Also, the research suggests that it may be a significant challenge to produce the best musical intonation when the harmonic series of resonances is perfect. Therefore, because of these difficulties, the study suggests that alterations

to the harmonic series of resonances are necessary in order to construct an instrument that more efficiently plays in tune.

The writers of the work conducted an experiment in which the input impedance was measured on three trombones. The first trombone used was a medium bore jazz trombone. The second trombone used was a large bore orchestral tenor trombone. The last trombone used was a bass trombone. In the experiment, the researchers took certain measurements of the input impedances of these select instruments using the BIAS input impedance measurement system. This tool measures the sound frequencies of brass instruments by using a setup that fully encompasses the mouthpiece while pumping air into and out of the mouthpiece and subsequently through the instrument.32 This device is typically used to assess elements of sound production like input impedance, pulse response, and harmonicity.

The results of the experiment featured Trombone A (medium bore jazz trombone) to have peaks that were more regularly taller than the peaks of the other trombones. The peak heights were significantly tall during the instruments production of the pitches that were within its upper range. This finding may be used to explain the instrument’s effectiveness in aiding performance in the high register. The instrument that had typically lower peaks than the other trombones was Trombone C (bass trombone).

The input impedance curve assessed with the BIAS system also created inharmonicity plots for each instrument. The researchers found that the instruments that were constructed with the larger bore had a tendency to produce pitches that were sharper in high playing, and became increasingly sharp as the instrument ascended. Their results also suggest that, throughout its range, the instrument that featured the smaller bore, showed a tendency to be more harmonic.

32 Alistair C. P. Braden, Michael J. Newton, and D. Murray Campbell, 2406
The writers of this study mention that these characteristics must be desirable attributes to the trademark sound of these trombones due to their “first-rate quality” status.

This paper presents the topic of bore optimization. According to the research, “optimization can be used for bore reconstruction (deducing an unknown bore from a known impedance) and for performance optimization (modifying an existing design to alter certain characteristics while maintaining others).” 33 In this experiment, a computer optimization simulation developed by A. H. Braden was administered. Braden’s technique used together the “n-mode impedance modeling” along with the Rosebrock optimization algorithm to locate a number of possibilities within the array of ways in which the instrument could be designed. This was done to correctly coordinate target criteria by distinguishing input impedance. 34

This article expresses the use of computer optimization algorithms to represent and potentially create an improved shape of a trombone instrument bell. The formula used for this simulation is: \( r(x) = b(-x)^{-y} \) where,

- \( r \) = bore radius
- \( x \) = distance along axis of instrument
- \( y \) = flare constant
- \( b \) = constant specified length and input/output radii

This experiment, through comparative analysis between tenor trombone and bass trombone, found that tuning the peak 2 has a noticeable effect on the lower playing register. In order to move peak 2 for a target frequency, peak 5 had to be moved slightly through a calculated target frequency. The optimization system met these targets, allowing peak 2 to be

33 Alistair C. P. Braden, Michael J. Newton, and D. Murray Campbell, 2407
34 Ibid.
closer to the desired realignment. Through the experiment certain modified characteristics were simulated and the results recorded.

Higher peaks were shifted between +5 cents and +20 cents, small alterations in comparison to peak 2’s approximately +41 cents. The impedance magnitude of peaks 3 through 6 are shortened to possibly produce fuller lows. The impedance magnitude of peaks 8 and 9 are taller, possibly producing clearer highs. The bore of the cylindrical section of the trombone is reduced from 6.95 mm radius to 6.63 mm radius. This simulated instrument is 26 mm shorter, with the bell contour subtly altered and the taper of the tuning slide modified.

Through these changes, there is a high possibility that the physical design of the “optimized” instrument also has a noticeable, different “look”. According to the experiment, the difference in the instrument’s physical traits began with the need to change certain aspects of the instrument’s acoustical properties.\(^{35}\) This study serves to provide evidence that an instrument’s physical design can be linked to its playability.

**2.5. Aeroacoustics of Musical Instruments: Benoit Fabre, Joel Gilbert, Avraham Hirschberg, and Xavier Pelorson**

When conducting experiments to comparatively measure sound production, it is necessary to create an environment in which there are a series of constants. The only differences that should occur are the respective results between two controls. The following study conducted by Joel Gilbert and Benoit Fabre discuss the measures taken to produce consistent factors within the mechanisms used to initiate sound through a musical wind instrument.

Lips are outward-striking reeds with a single mechanical degree of freedom coupled to the resonating air column in the pipe. The researchers used artificial lip excitation systems based on a pair of water-filled latex tubes. Using these systems, the researchers observed both inward-

\(^{35}\) Alistair C. P. Braden, Michael J. Newton, and D. Murray Campbell, 2409
striking and outward-striking behaviors of lips. Artificial blowing is an essential research and development tool in musical acoustics.

The non-linear acoustical response of the pipe, involving wave steepening and vortex shedding, is musically relevant. According to the study, a player’s control of the virtual wind instrument, allowing musical phrasing, is more important than the accuracy of the physical model used in sound synthesis. A brass player’s lips can commonly be described as outward-striking reeds, but they have more complex behaviors around the thresholds, and for the transitions between notes.36

This research goes on to express that simple models of flow in wind instruments are efficient in sound synthesis but do not clarify the input of geometric details on the playability of the instrument. Furthermore, the article states that detailed experimental measurements such as PIV, or direct numerical simulations are valuable only when confronted with simplified models.

It seems that this article is making a case for the use of lip reed models that are stripped of variability. If a musician was to create a sound through a tube, there will always be the chance of human variability. Even if the researchers made sure each task is achieved in the same manner for each test, this individual would still be unable to recreate every lip-excitation in a way that is exactly the same each and every time due to simple human error. This paper makes clear the importance of using some sort of mechanical system that can create sound through a tube in a way that is free from the variable of human contact.37


37 Benoit Fabre, Joel Gilbert, Avraham Hirschberg, and Xavier Pelorson, 18.

“The potential for nonlinear wave propagation to occur in a brass instrument at a given dynamic level (described as “brassiness potential”) depends on both the bore profile and the absolute bore diameter.”\(^3\) The article maintains that the brassiness potential is higher with long cylindrical sections of tubing as featured on trumpets and trombones. There is a lesser potential for brassiness (see Glossary) when there is a higher proportion of steadily expanding tubing, otherwise referred to as conical. This can be seen on instruments like flugelhorns and euphoniums. Due to this factor, the dependency between bore dimensions and brassiness potential can be exploited.

In this study, the researchers use a loudspeaker for sound initiation. It acts as a sort of artificial lips set. This speaker emits a sine wave input at the mouthpiece receiver eliminating both the mouthpiece and player variability.

In the beginning of the descriptions of the experiment, the paper makes distinctions between brassiness potential (B), and diameter of bore (D). In an effort to establish consistency, the creators of this study used one mouthpiece for five different instruments with different bore profiles. The researchers had a musician play these instruments on the same resonant mode and graphed the results. The graphs from comparisons of the B measurements suggested the greatest amount of brassiness from the tenor trombone, and the lowest amount of brassiness from the ophicleide. These graphs fit the predictions suggested in the brassiness potential parameter table that was used as a reference.

The article points out that, “musicians feel narrow, small bore instruments should yield a brassier timbre at a lower dynamic level than a wide bore instrument of similar relative bore profile. The reason for this is due to the fact that musicians’ judgment of dynamic level relates to the pressure in the radiated sound field rather than the pressure inside the instrument.” This is why it is important to have devices that can accurately measure the sound emanating from the tube. Human variability will take into account the effect of a room and other elements on the sound that is heard.

The paper also points out that measurements of nonlinear distortion suggest greater nonlinear distortion in instruments of 13.5 mm in diameter. The measurements suggest less nonlinear distortion for instruments of 6.4 mm in diameter. This may be why a trombone exhibits a greater tendency to be quite brassy in comparison to a trumpet.\(^{39}\)

Experiments and simulations done in this study using cylindrical tubes have confirmed that both the bore diameter, \((D)\), and the brassiness potential parameter are important in determining the spectral enrichment due to nonlinear sound propagation. Simulated spectral enrichment experiments within this research suggest greater spectral enrichment for narrower bore sizes. On the other hand, the tests suggest less spectral enrichment for wider bore sizes.

In their conclusion, the writers of this study maintain that spectral enrichment, also known as brassiness tone, is affected by bore diameter. An increase in the diameter of the bore allows musicians to generate a given dynamic level with lower input pressure and therefore less distortion. The reduced wall losses in the wider tubes increase the efficiency with which the higher frequencies are transmitted. So, the narrower the tube, the greater potential for measured

\(^{39}\) Arnold Myers, Robert W. Pyle, Joel Gilbert, D. Murray Campbell, John P. Chick, and Shona Logie, 685.
and perceived brassiness.

“One of the principal causes of spectral enrichment in brass instruments is the distributed nonlinear effect due to sound propagation in the bore. This results in a waveform leaving the mouthpiece becoming more and more distorted as it travels along the duct.”

2.7. Wagner Tubas and Related Instruments: An Acoustical Comparison: Lorna Norman, Arnold Myers, and Murray Campbell

It is widely understood that many low brass instruments are constructed using gradually expanding, or conical, tubing. In this study, the researchers sought to measure the brassiness of several low brass instruments. The study states several different models of Wagner tubas like Alexander, Mahillon, Morin’s and Schopper, were measured along with other low brass instruments like the trombone and the euphonium for comparison purposes. Other non-tuba instruments measured include the Mitsching-Alschausky trombone, the Besson cornophone, and the Cerveny euphonium.

The researchers conducted several experiments and tests to measure brassiness, and they found results that suggested the greatest increase in SC2, or radiated pressure for the Schopper tuba. This means that this instrument was found to exhibit more potential brassiness in its tone. The reason for this may be because the Schopper tubas tend to have a comparatively “rapid mouth-pipe expansion” that leads to a cylindrical section that is close to the length of about 700 mm. The diameter of the bore profile measures at approximately 12.5 mm.

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40 Arnold Myers, Robert W. Pyle, Joel Gilbert, D. Murray Campbell, John P. Chick, and Shona Logie, 678.

Figure 2.4. Graph for Length of Cylindrical Tubing
Norman et al, Wagner tubas: Bore profiles showing exclusively an estimate of the first half of the tubing for the Schopper Wagner tuba in F, and the Alexander Wagner tuba.42

Figure 2.5. Brassiness Curves
Norman et al, Wagner tubas: Brassiness curves showing $SC_2$ as a function of $P_1$ for instruments in 12-ft F and 13-ft E-flat, as well as for a double Alexander Wagner tuba with the F-side and B-flat side measured, and two single-pitched Alexander Wagner tubas in F and B-flat.43

43 Lisa Norman, Arnold Myers, and Murray Campbell, 154
The instrument that exhibited the least amount of potential for brassiness was the B-flat side of the Double Alexander Wagner tuba. The researchers found that this instrument was constructed with a beginning expansion of the lead-pipe that happens significantly quicker in comparison to the above instrument. This gradual expansion leads to a shorter cylindrical tubing of only about 200 mm, which also leads to more expansion, and then additional cylindrical tubing of approximately 500 mm. The bore diameter of this instrument was measured at 14 mm.

The researchers go on to suggest that the cylindrical, or near cylindrical tubing’s diameter proved to be the element that had the most influence on the instrument’s “non-linear behavior of the waveform in an air-column,” otherwise understood as its potential for brassiness in tone. The Schopper tuba is constructed with a narrower diameter that the Alexander tubas, making way for greater non-linear behavior. The researchers also reveal that there is something to be said about the length of the tube and its relationship to brassiness. According to the study, the longer tubes produced a more significant capacity for brassiness. On the other side of the spectrum, research done to measure the shorter instruments seem to suggest lower maximum values of SC2, or “brassiness potential.”

The researchers used a Double Wagner Tuba to measure the responses of longer instruments versus shorter instruments. The Double Wagner tuba features a 12-ft F side and a 9-ft B-flat side. Two measurements were taken for the two sides. So, the longer instruments may have a longer portion of cylindrical tubing, whereas the shorter instruments may exhibit a shorter portion of cylindrical tubing, thus creating the respective behaviors in brassiness.44

Also, based on measurements of the tubas, the B-flat side of the Alexander Wagner tuba has more conical, expanding tubing than narrow, cylindrical tubing. The F side of the Alexander

44 Lisa Norman, Arnold Myers, and Murray Campbell, 155
Wagner tuba features a greater proportion of narrow, cylindrical tubing than the B-flat side. The writers of this study imply that the B-flat side of the Alexander Wagner tubas has a lower level of brassiness potential, while the F side of the Alexander Wagner tubas has a higher level of brassiness potential.

2.8. A Simulation Tool For Brassiness Studies: Joel Gilbert and Ludovic Menguy

Brassiness is defined as the rate of spectral enrichment with increasing dynamic level. The article states that it is based on generalized Burger’s equations dedicated to weakly nonlinear wave propagation in uniform ducts. “At high dynamic levels, brass instruments generate sounds having strong high frequency components. The sounds are called brassy or “cuivres.” This is due to the essential nonlinearity of the wave propagation in the pipe.

Brassiness can be very different due to the variety of bore geometry. A conical bore implies a faster decay of the wave than a cylindrical bore. This faster decay reduces nonlinear wave steepening.

In this work, the researchers present a simulation tool that extends the work of Menguy and Gilbert in 2000. Brass instruments can be best described as longer-than-normal shock formation distances and are also referred to as non-uniform ducts. In their words, “the brassiness of the sound —in other words, its spectral enrichment—generated by brass instruments at high dynamic levels is mainly due to the essential nonlinearity of wave propagation in the pipe, resulting in wave steepening and generation of shock waves.”

The creators of this study then discuss the effects of an expansion of the pipe. They express that “conical” instruments are not as brassy as “cylindrical” instruments. That is, instruments

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with tubing that remains relatively cylindrical for longer just before expanding at the bell tend to exhibit a sound that is referred to as brassy. 46 Conversely, instruments with tubing that gradually expands throughout the entire length of the instrument all the way to the bell tend to exhibit a sound that is described as mellow or warm.


For a long time, the general community of musicians has felt that the material of an instrument had a significant impact on the playing qualities of the instrument. The material would affect the tone quality and overall characteristics of the musical vessel. Not only those who play musical instruments, but also those who build the instruments have long expressed this position. This is especially true for brass wind instruments.

This article gives a useful description of “formant peak.” This is a term within the disciplines of acoustical sciences that is characterized by the “spectrum of the steady tone of a brass instrument.”47 The spectrum’s most important and impactful attributes are considered to the harmonies that are found closest to the peak’s frequency. An instrument will exhibit increases in harmonics depending on how high or how low the measurements are of the formant peak. For instance, trombones exhibit a formant peak near 500 Hz. Because of this, if a player performs at an increased level, the higher end of the horn’s harmonies will increase quicker in comparison to the harmonies that are lower. So, at risen levels, the formant peak will also climb as well.48 The condition and strength of the material has some significance, according to past research.

46 Joel Gilbert, Ludovic Menguy, and D. Murray Campbell, 1856


48 Ibid.
This research suggests that the shifting of the spectral envelope along with a correlating playing level are linked with the measurable hardness of the material through which the sound vibrates. Through a modification of the compound metallic material, an experiment was conducted with subsequent results.

In the experiment, the researcher measured the responses of a S.E. Shires tenor trombone. The trombone was modified in such a way that made it possible to use interchangeable bells that screw on to the trombone body. The experiment required two bells for testing: a yellow brass (70% Cu, 30% Zn) bell an da red brass (90% Cu, 10% Zn). These bells were constructed in the same way, using one single mandrel for their formation.

The process of creating or simulating and recording sound involved the use of a “piezoresistive pressure transducer” fixed in the interior of the mouthpiece. This device is placed in the mouthpiece such that it is aligned with the interior. Additionally, a microphone was placed near the bell bout the distance of the radius of the bell. According to the information in the study, “this microphone placement gives a spectrum that is in good agreement with room-average spectra.”

The setup used to gather information created digitized data of a rate of 44100 Hz and resolution of 14 bits. The researchers used the SNDAN suite of programs. For their research, they employed a musician to create the tones used for analyzing sound production. The following notes were performed: Bb₁ (trombone pedal tone), Bb₂, F₃, Bb₃, F₄, and Bb₄. The performer was asked to play the above notes, all with a crescendo from pp to ff. To provide information regarding the attack of the notes, the performer played a brief period of repeated,

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49 Robert W. Pyle, Jr., 751
separated, short ff tones on B♭₃ and F₄.⁵⁰

The study expresses the claim of brass wind musicians that the use of different metallic mixtures gives different characteristics in tone as well as response tendencies. The paper goes on to reveal that reputations of the different kinds of brass instruments commonly used in performance. Yellow brass is known to provide more of a pure tone with crisp articulation. Red brass is thought to create a broader more mellow tome with softer articulation. In addition, the gold brass metal is known to yield a “warm sound with rounded articulation.”

The programs used for the experiment created some unforeseen variations. Peaks (see Glossary) were higher than anticipated, possibly due to the placement of the microphone. The experiment exhibited that the yellow and red brass bells “did produce noticeably different spectra for the lower played pitches, less different for higher pitches.”⁵¹ The research put forth by Pyle and others indicates the yellow brass is “brighter” in the lower ranges, but not at very soft or very loud dynamic levels. So, toward the higher pitches of the instrument, yellow brass and red brass exhibited similar brightness levels. Interestingly, though, the competing bells had different sound profiles, which suggests that the measurable brightness may not coincide with what the musician or audience member will hear.

“In general, the harmonies above the formant peak grew more slowly for the red brass bell than for the yellow brass.” This may refer to why many feel red brass has a softer tone profile than yellow brass, and why some feel that yellow brass has more ping to its presentation than red brass. The research suggests this maybe due to the steady rise in high frequencies, of the red bras, whereas in other brass alloys, these frequencies grow much more quickly.

⁵⁰ Ibid.

⁵¹ Robert W. Pyle, Jr., 751
The paper’s conclusion reveals that Pyle found measurable variances when switching the bells of different alloys. The writer goes on to say that an alteration in the bore taper would provide an even more drastic difference.\textsuperscript{52} Also, the study indicates that thought the differences are mostly noticeable to the player, this is salient because the musicians seek choices or options from which to choose, depending on how musicians choose to use the instrument.\textsuperscript{53}

\textbf{2.10. Influence of Wall Vibrations on the Sound of Brass Wind Instruments: Wilfried Kausel, Daniel W. Zietlow, Thomas R. Moore}

The researchers begin this study with an introduction that presents research previously conducted regarding the affect of wall vibrations on the sound produced from a brass instrument. First to be presented is information regarding Boner and Newman’s research on the material used for flue pipes. It moves on to a discussion about the Backus and Hundley research done in the 1960s. This research indicated that the pitches produced depended on the rate of oscillations of the walls. In their study, they found that if the walls were vibrating the pitch of the pipe would be lowered. This discussion is followed by a review of research done by Wogram on the wall oscillations of trombones. This researcher had musicians perform on the instruments and asked them to determine what kind of attributes were noticeable in the sound with the different wall materials he used. Wogram was able to record spectral differences of up to 3 dB. He later goes on to reveal Wogram’s claim that the changes in sound were almost unnoticeable. According to Wogram’s research, as interpreted by this study, the subjective observations regarding sound were confirmed the actual data taken through experiments. Kausel and his team suggest that this

\textsuperscript{52} Robert W. Pyle, Jr. 751

\textsuperscript{53} Robert W. Pyle, Jr., 752
Among other studies presented in the introduction is a work done by Richard Smith in 1978. In his research, he claims that the particular type, or condition, of metal or metallic mixture does not affect the sound or timbre of the instrument. The factor that influences the instrument’s sound the most is “wall thickness.” Smith observed significantly distinguishable contrasts in response between brass bells of .5 mm thick and .3 mm thick. This is due to the result that showed the amplitude of the vibration was inversely proportional to the wall thickness. The data implies that the sturdier the metal used in construction, the less helpful to high range playing the instrument is. Kausel, Zietlow, and Moore go on to discuss the level of criticism received by the above researchers because of the use of human performer. Critics felt that human performers should not have been used because their ability to intuitively create certain contrasts on tone and timbre.

Later in the introduction, the writers present information from research done by Moore involving the use of artificial lips and sandbags. The conclusions made from this research indicate that noticeable changes in tone profile occurred. An additional study included in the introduction exhibited the results of an experiment done by Ziegenhals in 2006. This work suggests that the wall oscillations of the musical “tube” also featured all the frequency integrants of the sound it provided. There is also the occurrence of “amplitudes approximately comparable to what is found in the sound field.”

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55 Wilfried Kausel, Daniel W. Zietlow, Thomas R. Moore, 3162

56 Ibid.
Through this section of exploring, once again, the various studies that were previously done, the researchers provide a strong thesis for the position that wall vibrations significantly affect the sound heard from the instrument. Kausel, Zietlow, and Moore follow the introduction with a brief description of the experiment exhibited in this current study. The researchers used a 40 W horn driver to stimulate the vibrations within the interior of a trumpet. The model of trumpet used was a 1970 King trumpet – Silver Flair model. The instrument was secured by fixing the valve cluster to a shelf made of aluminum. The researchers used a speaker to send a sine wave through the trumpet to be received by the driver, and subsequently recorded by the condenser microphone. This is all recorded using a microphone located by the bell. The response of the trumpet was measured by the ratio of the output to the input amplitude in relation to frequencies that started from up to 100 Hz to 2 KHz.

The results suggest that when the bell is damped, the vibrations of the material are greatly affected, thus significantly influencing the sound of the instrument. However, when the cylindrical tubing is damped, they recorded, there is no noticeable difference from when the cylindrical tubing was recorded without the sandbags to dampen it. This implies that changing the material of the tubing would not necessarily affect the vibrations of the wall in the tubing, thus not significantly affecting the response of sound of the instrument. However, changing the material of the bell alone to influence wall vibrations would indeed greatly impact these vibrations, thus altering, to a noticeable degree, the sound and response of the instrument.

In their conclusion, the writers again point out that, “there is no longer any doubt that the vibrations of the bells of brass wind instruments affect the sound produced during play.” 57 This information is useful, though it does not provide clear instruction on how to determine if

57 Wilfried Kausel, Daniel W. Zietlow, Thomas R. Moore, 3173
changing the lead pipe material would impact sound, it does raise questions that will lead to forth-coming inquiry into the influences of material on lead pipe wall vibrations. Though it is not within the focus of this study, this information regarding wall vibrations in the bell will be significant for future research when determining the effects of the bell on the sound and response of the tuba.
CHAPTER 3. THOUGHTS BEFORE RESEARCH

Before I sought to answer my questions about the lead pipe through concentrated study and acoustical analysis, I believed the lead pipe was very important mostly for tubas, but also carried some significance for trumpets, horns, trombones, and euphoniums. From my perspective, the significance for the other brass instruments was found in the kind of material used and the possible thickness of that material. As for tubas, the significance was in the lead pipe design: how it is bent and how long it is. These factors seemed to present themselves as salient with regard to the particular tubas that are in high demand. Tubas like the Hirsbrunner HP-50, Nirschl York, Yamaha York, Wessex Chicago York, and the Meinl Weston 6450 were, or currently are highly sought after, and are deemed as great sounding and responding instruments. Placement of valve slides may vary, position of valve set may be slightly different, and the specific wrap of the branches may alternate.

However, despite this, I saw that these instruments all have something in common: a very similar design in the lead pipe. Consider Figure (3.1), and examine the lead pipes. Most of these orchestral tubas seem to have the same lead pipe. Is this because the lead pipes provide a better response, or are these similar lead pipes used because their physical orientation cosmetically matches the lead pipe used on the J.W. York & Sons tuba from which these newer tubas originate? Note that this tuba exhibits this particular lead pipe bend.
Figure 3.1. Similar Lead Pipe Design
(From left to right): Restored CSO York held by Gene Pokorny, Hirsbrunner HB-50, Nirschl York, Yamaha York, Wessex Chicago York

Figure 3.1a. Similar Lead Pipe Design continued
Meinl Weston 6450 Baer

Chris Olka credits Chuck Nickles and how he was essential in the development of the Wessex York tubas, specifically with regard to the lead pipe. According to Olka, Nickles and his team assessed approximately five or six lead pipes before deciding on the one that is currently on both the 18-inch bell tuba and 20-inch bell tuba. The final decision was made due to the horn’s response with that particular lead pipe. In other words, it seems that the appropriate lead pipe is crucial for achieving optimal performance.  

measures were taken to create the best responding instrument they could create and it happened to look like the design of other York-style tubas. The lead pipes of the other tubas seem to come across below the bell throat horizontally, then with a sharp, but still even curve, move downward to the valve set.

Another observation I had is that not all tubas have lead pipes that do this. Contrary to what many may believe, tubas are a widely diverse instrument. There are many different designs for tubas all of which model after two or three original horns from the 1930s, 40s, and 50s. However, they are all still vastly distinctive. In my understanding, for a type of tuba to be so consistent with regard to something that—across the board for other tubas—is such a point of separation, then it must be significant. I believed that this bend design carried an incredible amount of importance for the playability of these horns.
CHAPTER 4. SUMMARY OF INTERVIEWS

Below is a list of the questions I provided to the individuals who sat down for an interview with me. I did not present the inquiries in any prescribed order. My goal was to allow the conversation to move toward the questions organically, as some questions were better transitions into others. I was not able to ask every question because the opportunity did not present itself for every question. Also, there were several of the questions that were discussed without my asking, but because the interviewee felt the need to move the conversation in that direction.

- What are your thoughts on the lead pipe bend and how it can contribute to the overall response of the horn?
- In your experience, would you say that the lead pipe bend could affect the intonation of the tuba overall, or at least on particular notes?
- In your understanding, how does lead pipe taper affect response?
- What are some of your experiences with lead pipe placement? Attached close to the bell? Attached off the bell?
- What are your experiences with lead pipe bending?
- What is the difference between lead pipe taper and bore size?
- In your experience, what have been the tendencies (response and sound quality) you’ve noticed with a tuba that has an American Shank lead pipe and also a tuba with a European Shank lead pipe?
- Does a lead pipe have to be a certain length all together with the end of the main tuning slide?
- Can the material of the lead pipe be different from the material of the rest of the horn?
Have you experienced different materials on a lead pipe, and did it make a difference to the response of the tuba?

In your opinion, does injury to the lead pipe affect tuba response?

Have you experimented with a raw brass lead pipe on a fully lacquered tuba, or vice versa? Did this create any note-worthy discoveries?

Does using a European-shank mouthpiece in an American receiver or an American-shank mouthpiece in a European receiver tamper with the tendencies of the lead pipe?

How many different lead pipe designs have you worked with?

I began Bob Carpenter’s interview by asking the first question on the list, regarding his thoughts on the bend of the lead pipe and how it could contribute to the response of the instrument. Bob started his answer with an account of how he and Tom Treece, an instrument designer for Kanstul Musical Instruments, Inc., bent a lead pipe “way out of whack” in order to test its influence on the tuba. According to Bob, it was very inconsistent in response and the ability of the horn to play in tune was adversely affected. Bob’s position on this topic was that the bend of the lead pipe could drastically impact the intonation of the instrument, if there was too much stress applied to the lead pipe while it was bent. He states that, because the lead pipe is at the beginning of the sound production system within the tuba, any stress located in the lead pipe would create very negative drawbacks. He then went further in relation to stress on the lead pipe. He describes the two types of stress that can occur when bending metal. First, Bob discusses residual stress. This is stress within the actual metal after it’s done being formed. This kind of stress is not always a bad thing. There is another type of stress that occurs during assembly of the metal parts. When a builder is forcing a part to go where the builder wants it to
go, it is likely causing harmful stress. When asked about the lead pipe bend and its effect on response Chuck took a different stance.

He felt that—because the tuba sans lead pipe is such a large percentage of the instrument, and the lead pipe itself, on a tuba, is such a small percentage of the instrument—the bend and any sensible variation in the bend would not make a huge impact. He goes on to say that on other instruments, like the trumpet, or the trombone, the lead pipe takes up a greater percentage of the horn. This can allow for greater impact when altering this part of the instrument. He notes that there are different crooks in certain slides of the instrument. Some of these crooks have sharp curves in them, however they are mostly there to for connecting purposes, not for a change in sound.

When I asked Bob about his opinions regarding the lead pipe taper and its influence on the response of the instrument, he gave another account of how Zig Kanstul, the founder of Kanstul Musical Instruments, Inc., fitted an F tuba with different lead pipes from a box of varied lead pipes. These lead pipes each had a different taper, and each created a different characteristic in the horn. He points out the need for the taper to be just right for proper transfer of vibrations. He also explains the actual definition of taper, which is the rate of change of the diameter. He speaks further about the topic in relation to the shank of a lead pipe receiver, and how the taper is the change of the initial shank measurement. An exciting moment in the interview was during our discussion of whether the placement of the lead pipe on the bell versus off the bell had any noticeable result either way. He stated that this is a topic that he has had many arguments with himself over. He reveals that his conclusion as of late is that it depends on the instrument. He mentions that there are great tubas where the lead pipe is attached wrapping around the bell. He’s also played tubas that were fantastic with the lead pipe attached in such a way where it is not
touching the bell as much. He states that the tubas he normally builds has the lead pipe fixed so that there is only one point of contact on the bell.

When I presented the topic to Chuck, he pointed out his experiences, and they were somewhat close to the same sentiment as what Bob expressed. Chuck states that he has noticed response changes of the tuba with each lead pipe placement. He feels that the bell makes the final sound, so if you change the bell, you could significantly alter the character of the instrument. He reveals that his goal is to apply as few things on the bell as possible. He wants to let the bell vibrate and do what it was meant to do. He also says that he feels there are certain cases where it depends on what the player wants the horn to do. If the musician wants to have a freer more soloistic presentation, then it would be necessary to take the lead pipe off the bell. If a musician wants to hear more fundamental in the core of the tuba’s sound, then placement of the lead pipe on the bell and wrapped around as much as possible would be ideal. He reveals that the more you solder to the bell, the harder you can push the volume while performing on the tuba. The tuba is less likely to break up as quickly. However, from his interview, I learned that this could lead to a loss of color in the sound. Also, the instrument may not respond as readily.

I was able to inquire to both Bob and Chuck about their individual experiences with lead pipe bending. Bob stated that he had done quite a bit of bending throughout his days working with tuba design. Aside from his account that included Tom Treece and bending a lead pipe all out of sorts, he did not really elaborate a great deal on his experiences with bending lead pipes. Chuck, on the other hand, had more to say. He expressed that he bends a lead pipe in relation to where the valves are going to be. The lead bend, for him, is mostly for ergonomic purposes. He also expressed how on many 6/4 C tubas, the lead pipe doesn’t go all the way around horn’s bell, and that is on purpose. In order for the horn to be in-tune, the lead pipe can’t be too long.
The next question that came up with Bob was the question regarding the difference between lead pipe taper and bore size. After I presented this question, Bob revealed that there were three different concepts in relation to the beginning of the instrument. There is the bore size, lead pipe taper, and shank. The bore size of the tuba is determined from the size of the aperture of the air going through the first or second valve. He expressed that the tuning slide, when pulled out, should have a measurement of .750; this is the bore. He also explained how the taper is the rate of change in the diameter. An American shank, or a European shank can have the same taper; they just start at different points with respect to the diameter.

When I asked Chuck about the type of taper and how the tuba responds, he explained that the receiver of many American style tubas is separate from the lead pipe. He stated that German ones tend to be constructed as one piece if it has a double taper. The front section of the lead pipe has an inward taper to secure the mouthpiece, and then it tapers out toward the end of the lead pipe. Chuck revealed that on American style tubas there is the possibility to change the taper beginning receiver because it’s separate from the lead pipe. He explains that it may not affect the instrument that much, but if there is frequent switching, it may affect the way the player approaches the instrument.

I presented the topic of the lead pipe length. Chuck mentioned that the lead pipe length is determined by the beginning of the lead pipe to the place where it meets the valve set. These can vary in size, so there doesn’t need to be one size. He expressed that many companies will construct a tuba with a lead pipe from a template used for all tubas. He said this could cause problems for some of the instruments. When I inquired about the use of different materials to Chuck, he pointed out that he often plays a tuba with a raw brass lead pipe. However, it is not because of sound difference. He again alluded to the fact that the raw brass lead pipe would not
impact much because of the percentage of the rest of the tuba versus the size percentage of the lead pipe. He said he uses raw brass lead pipes because he prefers to have something he can change and modify easily.

When discussing injury to lead pipes, Chuck was adamant that a small ding in the lead pipe, because it’s so small, would warrant a replacement of the whole lead pipe. If there is a dent in the lead pipe, he expressed that the lead pipe could go from .750 diameter to .5 and then back up again. This would definitely influence the way the horn responds during performance. When I mentioned the notion of an American shank mouthpiece in a European shank receiver, and vice versa, he plainly stated that there are too many variables from the whole tuba to say definitively that there is an impact in response. He told me his own experience with building the Wessex tubas. According to Chuck, the Wessex tubas are built between an American shank and Euro shank. He doesn’t find it to be true to that using different mouthpiece shanks in different receiver shanks causes changes in response.

I asked Chuck a question about the number of lead pipe designs he’s been able to work with toward the beginning of the interview. He frankly stated that he had worked with many lead pipes. He is now able to make his own lead pipes, and he’s probably constructed about 20. He mentioned that the lead pipes for tubas, unlike other higher voiced brass instruments, are not standardized. There is a great deal of variance because one thing isn’t going to work for every design of tuba.

I was able to get in touch with Mr. Sam Gnagey by way of a phone call. I did not intend for this phone call to be the interview. The purpose of this phone call was to setup a day and time where both Sam and myself would have a time slot in our schedules to speak with each other. In this planning phone call, we did, however, discuss briefly one or two topics in particular
regarding the tuba’s lead pipe. Unfortunately, this preliminary conversation was the only discussion he and I had.

In our short talk, I brought up to Sam the kinds of questions I was going to send to him through email. I mentioned he could read them over and maybe think about some answers that came to mind when he read them for our next conversation. I spouted off a couple of questions from the front of my mind like, “Do you create a lead pipe with a particular bend for a particular sound concept,” and “How does the bend affect the sound?” He answered that the main reason for the bends his lead pipes have is for ergonomic comfort for the player. He is mostly just trying to get the mouthpiece to the valves. Another discussion somehow made his way to conversation: he began to talk about the placement of the lead pipe on or off the bell. He expressed his preference for making sure that the lead pipe is soldered to the bell firmly. He said that that is the only way to place the lead pipe. He mentioned it helps center the sound of the instrument and prevents the bell from vibrating too freely.
CHAPTER 5. INSTRUMENT AND LEAD PIPE VARIABILITY TESTS

5.1. Hypotheses

I had my reservations about what to expect with varying lead pipes inserted into a tuba. From the research conducted in the study regarding trombone bore optimization, an experiment done in the study concludes with an optimized bore profile that was smaller than the original bore profile. It was suggested that the newer, simulated bore profile was more efficient and allowed the potential for improved sounds to be produced.\textsuperscript{59} In the study in which certain Wagner tubas and other low brass instruments are measured for their brassiness, it was found that the trombone had the greatest potential for brassiness.\textsuperscript{60} The trombone has a smaller bore profile than any tuba.

From these above cases, I formulated my hypotheses. In both of these studies, the smaller bore profile yielded more efficient sound, or more brassiness potential. Therefore, one of my hypothesis is the thinner, more cylindrical lead pipe will have the greater potential for brassiness as there will be more energy shown in its spectral readings.

My next hypothesis was formed with regard to the specifications of both lead pipes. The Holton 345 tuba came to me with a lead pipe that is about 16.5 inches long. For the remainder of this document, this lead pipe will be referred to as the “original” lead pipe. I measured the inside diameter of the pipes’ front and end with a General Carbon Fiber Digital Caliper. This is a tool specifically created for measuring the inside, outside, and depth of pipes. The opening of the lead pipe at the front, mouthpiece receiver end is .5940 inches in diameter. At the base of the lead pipe


pipe, the opening is .7430 inches in diameter. The gradual expansion from the diameter measurement of .5940 inches to an ending diameter measurement of .7430 inches is a rate of change of 25.08%. The diameter of the alternate lead pipe at the front, mouthpiece receiver end is .5815 inches. At its base, the opening is .7040 inches in diameter. The gradual expansion from the diameter measurement of .5815 inches to an ending diameter measurement of .7040 inches is a rate of change of 21.07%.

The Holton lead pipe (original) starts off slightly larger in diameter that the alternate lead pipe. In addition, the original lead pipe grows at a significantly faster rate. From these measurements I can say that, though both lead pipes are conical—in that they start at one measurement, and then gradually increase in diameter toward the base—the lead pipe that originally belonged to the Holton is more conical than the alternate lead pipe.

This information leads me to make a second hypothesis regarding the response of the tuba when experimenting with both of these lead pipes, but this second hypothesis also comes from other literature on this topic. According to the research presented in the literature review section of this document, when an instrument has a greater proportion of cylindrical tubing to conical tubing, that particular instrument typically exhibits a stronger, brassy tone, or at least it has the potential for greater level of brassiness. When an instrument is constructed with a greater proportion of conical tubing to cylindrical tubing, that instrument may feature a tone that is darker and possibly more mellow. Take, for example, the euphonium versus the baritone. The euphonium is commonly built with tubing that gradually expands from its starting point at the receiver. Of course, while the baritone section also does this, it was built to maintain longer sections of cylindrical—without significant expansion—kind of tubing before it begins the

61 Lisa Norman, Arnold Myers, and Murray Campbell, 153
conical expansion. These two contrasting designs have created impactful specific characteristics for both instruments.

Because of the above information, and the findings of the studies featured in the literature review, combined with the measurement profiles taken of the two lead pipes, I hypothesize that the alternate, more narrow pipe will yield spectral results that suggest the alternate lead pipe allows the Holton tuba the greater potential for brassiness. In addition, measurements from the spectrogram’s physical images will also indicate that the Holton tuba has an audibly brassier sound when using the alternate lead pipe.\textsuperscript{62} The lead pipe that originally belongs to the Holton 345 CC tuba may give readings that suggest it will impact the tuba in such a way to have the potential to produce a more mellow tone.

5.2. Experiment

For this experiment, I needed several tools, which were essential in recording the sample sounds and documenting the images that will serve as visual evidence of the results discussed in this chapter. For the purpose of recording the sounds used for comparison, I used a CAD Audio U37 USB Cardioid Condenser Studio Recording Microphone. This microphone was connected to a MacBook Pro computer running the Mac OS X, Version 10.6.4 system. The sound recording application running on this system was the GarageBand ’08, Version 4.1.2 (248.7). I used the Realtime Spectrogram and Spectrum Analysis application from OxfordWaveResearch. This is an application that runs on smart devices like an iPad or iPhone. I used this application on the iPad Pro, Version iOS 12.1.4. The spectrogram application needs access to a microphone in order to analyze sound. For this reason, I used the internal, or built-in, microphone on the iPad to record

sound for the application, as well as the above mentioned condenser microphone. To have visual
evidence of the sound recorded I used the iPad’s Snapshot feature to take quick photographs of
the spectral analysis rendered by the spectrogram. I also recorded video footage of the readings
of the spectrogram in real-time using a Canon Vixia HF R600 camcorder. This camcorder has
the ability to create snapshots of video footage. This was useful if there was an image that I did
not capture through the iPad’s snapshot feature; the camcorder recorded this image and it was
available after a simple review of the video. The GarageBand application on the MacBook has
the capability to show a graph of the amplitudes that correlate with the sound recorded. For the
purposes of this paper, I took several photographs of these graphs and edited them using iPhone
6s, Version iOS 12.0.1.

I played a concert $C_2$ on the Kanstul 5490 CC tuba using a Helleberg mouthpiece. I used
this mouthpiece for all experiments in order to maintain a control. I wanted the acoustical
properties of the mouthpiece consistently stay the same, so that there were as few variables as
possible affecting the lead pipes’ sound transfer qualities.63 I performed this note in four half
notes each with a half rest in between each half note. I then performed this same activity on the
Holton 345 CC tuba. I performed these notes first on the tuba’s original, thicker lead pipe with
the Helleberg mouthpiece inserted into the receiver. Next I repeated the activity on the same
tuba, but with the narrower, alternate lead pipe, and the same Helleberg mouthpiece. Four layers
of blue painter’s tape was wrapped around the base of the alternate lead pipe to provide a tighter
seal as the lead pipe was inserted into the valve set of the tuba. The spectrogram tool was placed
on a music stand 14 feet away from the chair where I sat during the performances of the half note

63 Jody C. Hall, “Analysis of the Resonance Patterns Obtained with Mouthpieces of
Varying Dimensions,” The Journal of the Acoustical Society of America 35
(1963), 1903.
The condenser microphone that was connected to the GarageBand recording system was placed on a stand 13 feet from the chair where I sat. I performed the half notes facing both the spectrogram and condenser microphone. Both the spectrogram and the microphone were facing in my direction. All together the setup formed an acute triangle organization:

![Figure 5.1. Spectrogram Analysis Experiment Set-up.](image)

This is a basic diagram of the set-up for performance experiments of which would be recorded and assessed through spectrogram analysis.

I also repeated the experiment on concert $G_2$ with the Kanstul tuba, then on the Holton using both lead pipes. Just as in the first Holton performances of the $C_2$, I first played using the tuba’s original lead pipe, then the alternate lead pipe.

After the performance of the open pitches, I performed mouthpiece pops on the Holton tuba using each lead pipe with the same mouthpiece. The setup for this portion of the experiment had to change, as I needed the bell of the tuba to be as close to the microphone of the spectrogram as possible. In the previous experiment, the spectrogram could pick up the sound of the tuba from 14 feet away, however, the mouthpiece pops did not read on the spectrogram from that distance. In order to ensure the mouthpiece pops would register on the spectrogram, I connected the condenser microphone to the iPad. The spectrogram application automatically switched over from use of the iPad’s internal microphone, to using the condenser microphone. I placed the bell directly under the condenser microphone.64

64 Alexander Buckiewicz-Smith, 9
The mouthpiece pops registered on the spectrogram, however, in order to acquire a useful reading that would yield informative images, I had to perform mouthpiece pops in quick, sixteenth note fashion, continuous for about 15 seconds. This task allowed me to see the overtones (see Glossary) forming over a longer horizontal axis, rather than one, thin vertical line for each singular pop. The pops were performed using the palm of my hand.

5.2.1. Audience Perspective Survey Experiment

I conducted an experiment in the form of a quick survey in which an audience of 19 knowledgeable musicians assessed and rated sounds produced from the Holton 345 CC tuba. The different lead pipes were used so that the musicians could rate the character of the tuba’s sound while switching the lead pipes.

The survey was divided into four descriptive terms: thick, brassy, light, and colorful. The audience panel was instructed to rate the sound of the tuba within a performance of an excerpt of the *Ode to Joy* melody. A rating of 1 to 5 was applied to each descriptive term. Therefore, the tuba could score a perfect score of 95 for each descriptive term. The excerpt was performed three times. The first two performances were done with the original lead pipe placed into the instrument. This was done in an attempt to get responses that were not influenced by the audience’s anticipation of a substituted lead pipe. I wanted to ensure that the responses recorded were from the panel’s perspective of what it heard in relation to the character of the tuba’s sound. The third performance of the excerpt was done using the alternate lead pipe. Also, I performed the excerpt from behind a sheet that completely blocked the panel from seeing the tuba or me. This was done so that the panel would not be able to see if I substituted a lead pipe, or what kind of lead pipe I was using when I did substitute. I believe that if they were to see when I substituted lead pipes, they would provide biased responses.
5.3. Results

When the sound from the tubas registered on the spectrogram, it was displayed as layers, or sections of concentrated acoustic energy that moved horizontally at certain frequency (Hz) levels. These concentrations are called formants (see Glossary), or natural resonances. They are also known as overtones. A deeper colored formant shows a higher volume of sound. The spectrogram will show red color on particular formants at certain frequency levels depending on what frequencies are activated the most in the sound. This red color shows the level of resonance. If the spectrogram exhibited a section with a lighter more yellow color, then this particular section had less concentrated energy, thus indicating less resonance for that frequency level.

As was referenced above, the amount of color shown in the readings of the spectrogram corresponds to the amount of spectral energy, or resonance, present in the overtones of that note. If a musician performs a note into the spectrogram, the lowest layer of concentrated energy is most likely the fundamental of the note. Each higher section of concentrated energy is an overtone of the fundamental. Some overtones will have more energy than others. It is possible for the lowest formant to have less concentration than higher formants. The stronger the energy of the higher formants, the richer the tone of the sound that is heard.

When vocalists perform, certain adjustments within their vocal tract occur to produce the appropriate sounds through certain vowels. The tongue’s placement in the oral cavity, otherwise referred to as the vocal tract shape, will impact the frequencies at which formants

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66 Loraine Sims, ibid.
happen.67 When I switch out lead pipes on a tuba, I am, in a sense, changing the shape of the vocal tract of that tuba. Because of this, the spectrogram will register the sounds to show formants, or overtones, that occur at different, albeit close, frequencies—depending on what lead pipe is being used. The change in the frequency at which formants occur is likely due to the fact that when the size of the pipe changed, it encouraged different overtones to excite by shifting energies from other overtones, much like the vocalist’s changing vocal tract shape. The readings in the spectrogram suggest the tuba’s modified response due to the different design of lead pipe attached to it.

While performing the experiment on $C_2$ using the original lead pipe, I noticed that the low overtone closest to the fundamental exhibited the most energy and was the thickest overtone in the reading. When I used the alternate lead pipe while performing the experiment on $C_2$, the higher overtones showed more concentrated energy. The lower overtones closer to the fundamental exhibit less concentrated energy than the higher overtones. This can also be seen through the peak amplitudes shown in Figures 5.2, 5.2a, 5.2b, and through the stacked comparison in Figure 5.2c. Different lead pipes will excite certain frequencies over others, creating higher peaks over one area of frequencies while staying comparatively low for others.

In the amplitude graphs, the height of the amplitude indicates the loudness of the waveform. The scale for the amplitude starts at the bottom of the y-axis at -96 dBFS. This signifies a very quite sound. At the top of the y-axis is 0, which implies a very loud sound. The graph features the range of frequencies from below 125 Hz to above 250 Hz on the x-axis. In a graph such as this one, emphasis is placed on the y-axis showing the level of loudness.

Figure 5.2. Peak Amplitudes for C₂ on Holton with Original Lead Pipe
Graph showing the peak amplitudes (dBFS shown on Y-axis) with respect to the frequencies (Hz shown on x-axis) while performing C₂ (2 seconds) on the Holton with its original lead pipe.
Figure 5.2a. Peak Amplitudes for C₂ on Holton with Alternate Lead Pipe

Graph showing the peak amplitudes (dBFS shown on Y-axis) with respect to the frequencies (Hz shown on x-axis) while performing C₂ (2 seconds) on the Holton with its alternate lead pipe.
Figure 5.2b. Peak Amplitudes for C₂ on Kanstul
Graph showing the peak amplitudes (dBFS shown on Y-axis) with respect to the frequencies (Hz shown on x-axis) while performing C₂ (2 seconds) on the Kanstul.
Graphs comparing the peak amplitudes with respect to frequencies while performing $C_2$ (2 seconds). The Holton with the original lead pipe is on the top, followed by the Holton with the alternate lead pipe and the Kanstul below it, respectively.

In the figures showing the spectrogram images, there are four columns of a series of formants, also referred to as overtones. Each column is featured in a light blue-green color and indicates the half note articulations of the performed note. Each half note articulation is followed by a period of silence also the length of a half note. The formants are exhibited in a varying hue
spectrum of yellow to red: yellow signifying the least amount of concentrated acoustical energy and bright, or dark, red signifying the most amount of concentrated acoustical energy.

When performing the experiment on $C_2$ while using the original lead pipe, the spectrogram showed the overtone centered on the frequency of 128 Hz to be thicker, possibly exhibiting a greater amount of spectral energy on that overtone. While this is the case for that particular section of concentrated energy, the overtone centered on 325 Hz was thinner, and less vibrant in color. When using the alternate lead pipe, the overtone centered on 320 Hz showed more spectral energy, whereas the overtone centered on 125 Hz was thinner. This reading suggests that, when using the alternate lead pipe, the higher overtone had more spectral enrichment, and the lower had less.

Though the performance on the Kanstul tuba occurred first in the experiment, I feel it is important to discuss it after the Holton with switching lead pipes due to an unexpected event, noticed only in hindsight. While performing the experiment on $C_2$ using the Kanstul tuba, the spectrogram registered images that were fascinating. It seemed that the Kanstul tuba performed in such a way that sort of resembled a combination, or an evening of the two sound profiles generated by the Holton with the original lead pipe, and the Holton with the alternate lead pipe. Like the Holton with the original lead pipe, the Kanstul’s spectral readings showed the strongest formant concentration on the overtone closest to the fundamental, or on the 130 Hz frequency. Interestingly, though the Kanstul also showed a more significant amount of concentrated energy centered on the 260 Hz, it also—much like the Holton with the alternate lead pipe—exhibited stronger frequency excitation on the overtone centered on 320 Hz, in comparison to the Holton with the original lead pipe.
Figure 5.3. Spectrogram Readings for C₂ on Holton with Original Lead Pipe
Spectrogram readings of the formant concentrations from the Holton tuba with its original lead pipe during the performance of C₂ (2 seconds). The Time (seconds) is shown on the x-axis, and the Frequency (Hz) is shown on the y-axis.
Figure 5.3a. Spectrogram Readings for $C_2$ on Holton with Alternate Lead Pipe
Spectrogram readings of the formant concentrations from the Holton tuba with the alternate lead pipe during the performance of $C_2$ (2 seconds). The Time (seconds) is shown on the x-axis, and the Frequency (Hz) is shown on the y-axis.
Figure 5.3b. Spectrogram Readings for C₂ on the Kanstul
Spectrogram readings of the formant concentrations from the Kanstul tuba during the performance of C₂ (2 seconds). The Time (seconds) is shown on the x-axis, and the Frequency (Hz) is shown on the y-axis.
Figure 5.3c. Spectrogram Readings for C₂ Comparison

Spectrogram readings of the formant concentrations from the (from left to right) Holton tuba (original lead pipe) tuba, Holton tuba (alternate lead pipe), and the Kanstul tuba performances of C₂ (2 seconds).

Also, it is important to note that the spectrogram images for the Kanstul when performing C₂ suggest that this instrument produces a sound with less noise than both the Holton with the original lead pipe, and the Holton with the alternate lead pipe. It should also be noted that the Kanstul’s spectrogram images revealed the instrument’s overtones to be wider, or thicker, but not always very brightly colored. On the other hand, The Holton, when utilizing the original lead pipe, had some overtones that were thinner in presentation, but also consistently bright and vibrant red, more so than the Kanstul. This may suggest that the Holton with the original lead pipe produces a sound that seems thick and dark to the ear, whereas the Kanstul may produce a sound that seems to the ear to be open and broad. Figure 5.3c provides a visual example of the acoustic profile of the Holton with the varying lead pipes and the Kanstul when producing the waveforms for C₂.

When performing the open G₂ within the four half-note experiment on the Kanstul tuba, the spectrogram revealed the strongest overtone to be centered on 198 Hz. The overtone centered on 395 Hz was also relatively significant, but did not exhibit as much resonance as the previously mentioned overtone. In the performance of the open G₂ on the Holton with the
original lead pipe, the spectrogram showed the most resonant overtone to be the one centered on 286 Hz. Though this overtone has the most concentration, the overtone that occurred at the 190 Hz level also indicated a very high amount of acoustical energy with similar width. With the alternate lead pipe, while performing the experiment on open $G_2$, the tuba produced a sound that created two bright red overtones at the frequencies 190 Hz and 285 Hz.

![Graph showing the peak amplitudes (dBFS shown on Y-axis) with respect to the frequencies (Hz shown on x-axis) while performing $G_2$ (2 seconds) on the Kanstul.](image)

**Figure 5.4. Peak Amplitudes for $G_2$ on Kanstul**

Graph showing the peak amplitudes (dBFS shown on Y-axis) with respect to the frequencies (Hz shown on x-axis) while performing $G_2$ (2 seconds) on the Kanstul.
Figure 5.4a. Peak Amplitudes for $G_2$ on Holton with Original Lead Pipe
Graph showing the peak amplitudes (dBFS shown on Y-axis) with respect to the frequencies (Hz shown on x-axis) while performing $G_2$ (2 seconds) on the Holton with its original lead pipe.
Figure 5.4b. Peak Amplitudes for G₂ on Holton with Alternate Lead Pipe
Graph showing the peak amplitudes (dBFS shown on Y-axis) with respect to the
frequencies (Hz shown on x-axis) while performing G₂ (2 seconds) on the Holton with the
alternate lead pipe.
Figure 5.4c. Peak Amplitudes Stacked Comparison

Graphs comparing the peak amplitudes with respect to frequencies while performing $G_2$ (2 seconds). The Kanstul is on the top, followed by the Holton with the original lead pipe and the Holton with the alternate lead pipe below it, respectively.

Figures 5.4, 5.4a, 5.4b, and the stacked comparison of peak amplitudes shown in Figure 5.4c reveal a different side of the modified response for the Holton tuba when swapping lead pipes. In these graphs, it can be seen that the Holton with the original lead pipe produces a sound that has higher peaks around 280 Hz. Then, when the alternate lead pipe is applied, the tuba
produces a sound that has higher peaks around 280 Hz, but they are not as high as the peaks from the Holton with the original lead pipe. The Kanstul, displayed on the top, seemed to exhibit the most even amplitudes.

When using the original lead pipe on the Holton, the tuba showed the widest overtone formants with high acoustical energy concentration. The spectral readings suggest that, for every overtone, the original lead pipe allowed the Holton tuba to produce the broadest sound with a substantial amount of thickness to the tone. When using the alternate lead pipe, the Holton revealed the brightest colors, though the width of the overtones were much thinner than the overtones in the spectrogram images of the Holton with the original lead pipe.

This may suggest that, with the alternate lead pipe, this Holton tuba may produce a largely thick and dark tone on open $G_2$, though not very open and broad. The Kanstul exhibited the smallest overtone widths and the least concentration of acoustical energy of all the experiments on open $G_2$, but still maintained the least amount of noise in its sound profile. Figures 5.5, 5.5a, and 5.5b show the readings within spectrogram images of each performance of $G_2$, while Figure 5.5c displays a side-by-side comparison to feature the different sizes of the formants contrasted next to each other.
Figure 5.5. Spectrogram Readings for G₂ on Kanstul
Spectrogram readings of the formant concentrations from the Kanstul tuba during the performance of G₂ (2 seconds). The Time (seconds) is shown on the x-axis, and the Frequency (Hz) is shown on the y-axis.
Figure 5.5a. Spectrogram Readings for $G_2$ on the Holton with Original Lead Pipe
Spectrogram readings of the formant concentrations from the Holton tuba with its original lead pipe during the performance of $G_2$ (2 seconds). The Time (seconds) is shown on the x-axis, and the Frequency (Hz) is shown on the y-axis.
Figure 5.5b. Spectrogram Readings for G₂ (2 seconds) on Holton with Alternate Lead Pipe

Spectrogram readings of the formant concentrations from the Holton tuba with the alternate lead pipe during the performance of G₂ (2 seconds). The Time (seconds) is shown on the x-axis, and the Frequency (Hz) is shown on the y-axis.
Figure 5.5c. Spectrogram Readings for G2 (2 seconds) Comparison
Spectrogram readings of the formant concentrations from the (from left to right) Kanstul tuba, Holton tuba (original lead pipe), and Holton tuba (alternate lead pipe) performances of G2.

Figure 5.6 shows the images of the mouthpiece pops performed on the Holton tuba with the alternate lead pipe and then the original lead pipe, respectively. As was stated previously, the mouthpiece pops were performed as continuous 16th note strikes onto the mouthpiece with the palm side of the hand at a tempo of approximately 60 beats per minute for 15 seconds. The resonant frequencies, or formants, are shown as stacked sections of acoustical energy in yellow with varying amounts of red color. The figure reveals that, when performing the mouthpiece pops on the narrower, alternate lead pipe, the spectrogram revealed sections of minimal concentrated energy with very little, if not none at all, amount of red color within the area surrounding the 100 Hz frequency. When using the original lead pipe to experiment using mouthpiece pops, the spectrogram showed a greater volume of darker, red color centered on the 100 Hz frequency, indicating some rise in excitation.
Figure 5.6. Mouthpiece Pops Comparison
A spectrogram reading of mouthpiece pops (15 seconds) showing the smattering of formants occurring for the alternate lead pipe (left) and the more concentrated formants when using the original lead pipe (right).
The following Figure 5.6a is the same spectral readings as in Figure 5.6. The color profile has been changed to greater show the contrast between the two images of lack or formant concentration and considerable formant concentration.

Figure 5.6a. Dramatic Mouthpiece Pop Comparison
The same mouthpiece pops, but in a more dramatic color grade.
This occurrence suggests that the original lead pipe on this Holton 345 CC tuba has more potential for a richer, possibly more complex tone, whereas the readings from the alternate lead pipe suggest that this pipe may yield a lighter, less thick tone.

From the Audience Perspective Survey, I found that when I first played the tuba with the original lead pipe, it scored a 72% for the “thick” descriptive term, and 35.8% for the “light” descriptive term. This suggests that when the original lead pipe is in the Holton 345 CC tuba, this tuba will produce a sound that is more likely to be perceived as “thick” or fundamental-rich (see Glossary), and less likely to be perceived as “light,” or lacking fundamental. However, during the second performance of the excerpt, when I used the original lead pipe again, it did not score in the same manner as the first performance in both the categories of “thick” and “light” for most of the members of the audience. This may be due to human variability on both my part, and also from the audience members themselves. I may have played the excerpt differently the second time.68 Or, it could be that the panel may have expected to hear something different, and so rated the performance differently though the sounds produced were much the same. I will also mention that, in an effort to ensure I would get scores that were not based on the anticipation of the panel, I took out the original lead pipe, and put it back in. This may have caused a slight difference in the lead pipe’s orientation into the valve set, which may have caused the tuba to respond, and thus, produce sounds that were different. However, with the alternate lead pipe inserted, the tuba rated at 52.6% in the “thick” category. This score was the lowest score of all performances for this category.

Table 5.1. Scores of the Holton tuba with original lead pipe during the first performance of the *Ode to Joy* excerpt.

![Holton with original](image)

Table 5.2. Scores of the Holton tuba with alternate lead pipe during the third performance of the *Ode to Joy* excerpt.

![Holton with alternate](image)
This score, and other scores in the survey activity, suggest that when the alternate lead pipe was used during the third performance of the excerpt, the members of the panel noticed a change in the sound in comparison to both previous performances. They rated the sound accordingly. The results imply that the audience felt that it did not have a significant enough amount of fundamental in the sound to rate higher in this particular category. See Figures 5.7 and 5.7a, as well as the close-up comparison of Figure 5.7b.

Figure 5.7. Spectrogram Reading of Excerpt Performance on Holton (Original) Spectrogram images from performance of *Ode to Joy* Arrangement Excerpt for Holton with the original lead pipe.
Figure 5.7a. Spectrogram Reading of Excerpt Performance on Holton (Alternate) Spectrogram images from performance of *Ode to Joy* Arrangement Excerpt for Holton with the alternate lead pipe.
Figure 5.7b. Spectrogram Reading of Excerpt Performance Comparison
A close-up of the above images to compare the most active formants, specifically the shifting of concentrated acoustical energy from one lead pipe to the other.

Though the third performance rated lowest on thickness, possibly due to the use of the alternate lead pipe, it rated the highest for the “brassy” descriptive term. The score for the third performance’s category of brassy was not very high, but the results imply that the audience heard tones from the alternate lead pipe that encourage a brassy profile, more so than the previous performances.69 Also, the performance of the excerpt using the alternate lead pipe scored much higher in the “light” category, to a significant degree, than the first performance of the excerpt. The audience members’ score in this category suggest that, with the alternate lead pipe, the tuba in the experiment responds in a way such that it produces a sound that is can be distinguished as less fundamental-rich.

With regard to color, the tuba scored nearly the same for each performance despite the changing of the lead pipes. The first performance earned a score of 54.7%, the second earned 55.8%, and the third performance, using the alternate lead pipe, earned a score of 54.7%. This may be due to a characteristic of the entire tuba itself—something that cannot be readily affected by the lead pipe alone.

The audience seemed to notice when there was a change in the character of the sound presented to them due to the swapping of the lead pipes. However, there is the reality that the audience could have been expecting a change in lead pipe, and they rated with the anticipation of what was to follow. Still, when there was a change, the panel scored in such a way that suggests they noticed something was different even from the sound profiles of the previous performances. This corresponds with the research that was previously done in this study, which seeks to communicate that changing the lead pipe on the tuba will create noticeable differences in how the tuba responds, and possibly how it sounds.

The responses of the panel in this survey do, in some way, correspond to the readings on the spectrogram. The spectrogram suggested that the Holton 345 CC tuba, when played using the original lead pipe, exhibited a more concentrated amount of energy within the overtones that were closer to the fundamental. The spectrogram also indicated that, when the tuba was played using the alternate lead pipe, the higher overtones further away from the fundamental had more concentrated energy.
CHAPTER 6. DISCUSSION

It was previously established that the stronger the energy in the higher overtones, the richer the sound. The term “richer” may need some clarification. In relation to musical sound characteristics, the term could be quite neutral, and can be used to refer to different sides of a spectrum. When spectral readings reveal a sound to have stronger, more concentrated energy in the higher overtones, the sound that corresponds to these readings may be considered “overtone-rich” (see Glossary), for someone may feel that more overtones can be heard in the sound. This term could also be connected to the common descriptive word known as “bright.” 70 In some cases, the term “brassy” can relate to these words as well.

When images from the spectrogram exhibit a sound to have a more concentrated amount of energy in the lower overtones that are closer to the fundamental, the sound associated with these readings is often considered “fundamental-rich,” for a listener may find that there is more core to the sound. Other words related to this description are “dark,” “thick,” or even “focused.” 71 So, when using the original lead pipe, the Holton tuba in this study may produce a sound that is more fundamental-rich. When using the alternate lead pipe, the tuba may have a greater potential to create a sound that is more overtone-rich. The former may be considered by some to be a darker tone, whereas the latter may be considered a brighter tone. Either way these are neutral descriptive terms that are appealing to many, dependent upon what the musician wants. It depends on the player or the conductor as to which sound is preferable. Often times, the situation can also determine what kind of tone is better suited to fit the style and character of the

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music and the composer’s intent. It is important that I describe these findings in a way that is neutral, because the idea that something is going to have this tone, or that, is quite subjective in nature and dependent upon what a musician wants according to the preconceived sound concept.

During the mouthpiece pops, the original lead pipe had more color to its spectral readings. There was more activity in the images shown on the spectrogram. This suggests that there is possibly more spectral enrichment for the original lead pipe, which may imply that it would yield a brassier tone. However, after conducting the panel perspective experiment, it has been revealed that most of the members of the panel did not find the sounds from the Holton tuba with the original lead pipe to be brassy, but just thick. Perhaps the spectral readings of the mouthpiece pops for the original lead pipe are indicative of the potential to present fundamental in the sound. The results from the survey would certainly agree with this. In addition, the mouthpiece pops may also present the lack of color, or concentrated activity, within the lower overtones shown in the spectral readings. This could be a sign for the lack of the fundamental, but stronger higher overtones. In other words, though it seems that the overtones closer to the fundamental, and even the fundamental itself, are discouraged, the higher overtones are being encouraged, or strengthened, in lieu of the harmonics closer to the fundamental. This was the case for the alternate lead pipe.

There are several different methods I would want to use to examine and measure the response of the tuba in relation to the use of varying lead pipes. As was mentioned before, I would like to have used an artificial lip system that would allow me to create a sound frequency through the tuba without having to play the instrument or manipulate the instrument in any way with my person. This would greatly increase the accuracy of the findings because it would be
devoid of the human variability and human error.\textsuperscript{72} Though I conducted the experiments through my own handling of the instruments, I believe the information gathered from this course of study is valuable to the field of brass wind instrument performance and pedagogy. It presents an idea that may currently be shared knowledge, and it provides this useful information in a written format that can be used for reference purposes, or for further research.

After the completion of this study, I realize that my hypotheses were not accurate. I felt that the alternate lead pipe, due to its narrower dimensions, would create a more efficient transfer of sound waves that would result in a more focused and compact tone. However, the original lead pipe consistently helped the tuba to produce the most focused and compact tones in comparison to the alternate lead pipe, and the other tuba used within the study. I also felt that a brassier tone might result from the use of the alternate lead pipe. Though the Holton tuba’s rating for brassiness was the highest in the audience perspective survey when using the alternate lead pipe, more research is needed to determine the amount of brassiness potential that can be measured from use of this lead pipe.

With regard to issues that need further research, the topic of audience perspective presents itself as an important area of study. There were certain variables that could have been controlled more. I would like to get to do an experiment like this again, partly to have another opportunity to setup the room and the materials used within the room setup to make sure the most accurate responses are recorded. For instance, instead of performing behind the audience and somewhat far from them, I would like to perform in front of them and closer to them. I believe that musicians hear differently sounds coming from in front versus coming from behind.

\textsuperscript{72} Wilfried Kausel, Daniel W. Zietlow, Thomas R. Moore, 3162.
I would also like to try the experiment multiple times with fewer people listening and responding each time. This is to make sure I can control the distance of the participants from the sound source. In the audience perspective experiment conducted in this study, listener participants sat at different distances from the sound source. I believe this may have altered how they heard the sound. One individual could have heard the excerpt differently than another due to the placement in the room. If everyone was sitting the same distance away from the sound source, hopefully it would ensure that each person would hear the sound in the same way. I would also need a thin curtain type of material that could cover my front and my sides so that no one can see my swapping of lead pipes. 73

When I did the audience perspective experiment, my procedure was to start with the original lead pipe, then perform on the alternate. If were to do audience perspective experiment again, I would probably start with the alternate lead pipe, and play that once just to see what people thought about it. I would then move to the original lead pipe, and play that once, just to see how people responded. I would then play a completely different tuba, and have people rate that as well, again, just to see how people felt about what they were hearing.

Another aspect of my experiment that I would like to modify through additional research is the testing of multiple lead pipes, each on multiple tubas. For this document, I only tested my theories on one instrument with only two different lead pipes. I was able to show a change in response, but this was the finding for one instrument. Would other instruments respond the same way? I’m interested to know what kinds of tubas will provide the most dramatic responses. Also, I would like to understand what lead pipe designs would have the tubas respond in the most

drastic ways. How many different formant occurrences could I find using a greater number of lead pipes? I would also like to test the possibility of similar readings on different lead pipes. I am interested in determining if it is possible to get a multiple of different behaviors at certain frequencies, or if tubas will generally behave according to a certain number of common acoustical characteristics.
CHAPTER 7. CONCLUSIONS

Throughout this document I sought to answer the question of whether or not a change in the lead pipe design would create noticeable differences in a tuba’s response and production of sound. I obtained useful information from the research of other individuals. This research leaned in the direction of confirming my expectations, however, I wanted to strive further in search of evidence that would answer the precise questions I posed in the beginning of my study regarding the design variability of the lead pipe. I spoke with experts in the field to get their take on the issues concerning my area of study. These individuals confirmed my thoughts, and disproved others. Their insight provided for me a number of ideas regarding ways to formulate procedures to test and measure my theories.

Through the experiments I conducted, I found that most of my beliefs were confirmed in relation to whether or not the tuba would exhibit a change in response with varying equipment. Because of this, I am confident in stating that changing the lead pipe design can directly affect the response of the tuba. There is a very high chance the remaining body of the tuba will respond to a different design in lead pipe much like a vocalist’s vocal tract responds to adjustments of the tongue. A variation in the lead pipe design can completely alter the character of the tuba’s sound.74 Spectrogram readings imply that a modifying the design of the lead pipe forces a tuba to resonate within a different set of frequencies. My research indicates that this occurrence can be immediate and noticeable to the ear.

This research also partly answers the question, “what would happen if I swapped equipment that was otherwise meant to permanently be fixed to the instrument?” I use the word “partly” because it only focuses on one section of the tuba, the lead pipe. This is a question that

many artists of smaller instruments can easily answer, for their instruments are often subjected to switching parts and modified build-setup (i.e. clarinets, flutes, etc.). For larger instruments, however, this is a harder question to answer because of the difficulty in creating opportunities for parts of the instrument’s body to be removable. This is not to say it cannot be done, only that it would possibly be a more inconvenient challenge. Valves, slides, and mouthpieces are commonly, and easily, removed and replaced, however sections of the body of the instrument are not often constructed with that intent.

This document will hopefully serve to provide useful information to interested parties on what any instrument can offer potentially just by understanding the section that begins the horn. The idea is that it will inform future buyers of tubas about what kind of used or even new instruments they may be considering. This information can be useful to influence questions about what kinds of sounds are desirable and what qualities are within a buyer’s personal sound concept.75 Hopefully this study will help interested individuals understand the usefulness of different kinds of sound qualities. There seems to be a growing tendency to label a particular horn good or bad because of certain aspects of what can be heard from the its bell. This is a dangerous way to categorize instruments. Any sound profile can be useful depending on certain situations that would benefit from utilizing the inherent qualities that make up that sound profile.76

These concepts were discussed briefly during the interview with Chuck Nickles. For instance, when the sound of a brass wind instrument is referred to as dark, some may think of


76 Robert W. Pyle, Jr., 752.
dull or dead. It may be best to consider other descriptive terms. Terms used in this study to correlate with a “dark” sound are thick, focused, or the most specific, fundamental-rich. If a sound is referred to as “bright”, some may also want to think of the sound as harsh or shrill. More useful terms may be brassy, warm, or overtone-rich. These more descriptive words can help to provide a musician with a more informed perspective of the best way to use an instrument with these qualities in its sound, and can also help guide a musician to an instrument, or certain interchangeable parts of an instrument that help to create the ideal sound.

7.1. Reflections for Future Research

The experiment to explore the audience’s perception of a radiated sound proved to be helpful. Though I gained useful information, I also found that there is a need for a more accurate collection of results. Also, there needs to be a way in which I can eliminate the amount of subjectivity in the use of descriptive terms as a means of describing sound.

I would like to try my audience perspective survey again in future research. At that time I would like to use a greater number of participants. I would also want to better educate the participants of the meaning of the sounds they hear. It will be helpful to devise a scale degree system by which participants can describe and rate a particular radiated sound. In the study about the Wagner tubas, the researchers used a numbering system to determine the amount of brassiness an instrument could potentially have. It may be in the best interests of my future work to incorporate this type of practice. I could do this method for each potential condition of brass sound in addition to brassiness.

77 Chuck Nickles

78 Ibid.

79 Lorna Norman, Arnold Myers, and Murray Campbell
In later studies, I will also be interested in examining other aspects of the lead pipe. In this study, I focused mostly on differing lead pipe taper designs and recorded results based on this criteria. Other features to study would be the material used on the lead pipe, and also the bend of the lead pipe. It was mentioned previously that these two conditions wouldn’t have a great deal of impact on a tuba’s overall sound due to the fact that the lead pipe makes up a small percentage of the instrument. It would still be helpful to understand the effects, if any, of using completely similar lead pipes with only the bend being a distinguishing variance, or the material being the only element that sets two lead pipes apart.

In addition to studying different elements of a lead pipe, I will be doing further research on the use of more lead pipes. In an effort to maintain the most accurate findings, it is important to use devices that can measure a radiated sound without the use of human interaction. For this reason, I will measure the effect of multiple lead pipes using the BIAS device for analyzing brass acoustics.\footnote{Klaus, Sabine K. “Measuring Sound: BIAS Aids Understanding of Brass Instruments.” Accessed on October 23, 2019 from http://collections.nmmusd.org/UtleyPages/Utleyfaq/BIAS/BIASArticle.html.} This will significantly increase the precision and validity of the results.
APPENDIX A. TRANSCRIPTION OF INTERVIEWS

Interview Transcription – Robert Carpenter

Bob Carpenter Interview:

Bob: A fellow named Tom Treece and I worked together on all the Kanstul tubas, and we actually one day did take an instrument that we were working on and Tom says, “Hey let’s do an experiment,” and he heated up the lead pipe and crammed his wooden stick in there and pushed the thing way out of whack. So that it would cool under tremendous stress and the horn was a mess. It was all over the road, the intonation was out. And that was great. Then we heated it up, and put it back in the normal place and went back to what it should be. But that was enough. It’s doing things to the extreme a little bit so that you can really actually state that there is some effect. So we found some tendencies; did we write them all down? No.

Larry: Is it alright with you if I start asking you questions and you let me know whatever your thoughts are on those questions?

Bob: Yes.

Larry: What are you thoughts on the lead pipe bend and how it can contribute to the overall response of the horn? I know you said something about that yesterday, but I wondered if you had anything else to say.

Bob: Well, we could go on for hours about this, as far as I’m concerned, the lead pipe and the (Bell), the entrance and the exit of the instrument are super critical. They are very important to the overall sound and response and general characteristics of the instrument. The lead pipe is as critical as the bell.

Larry: So in your experience would you say that the lead pipe bend could affect the intonation of the tuba overall or would it affect just on particular notes.
Bob: Both. We’ve done some experiments on lead pipes and putting them on with stress, meaning soldering them in a way that they not necessarily should be, so that the metal itself actually stressed. When you do that the 3rd partial, the 4th partial, the fifth of the chord can wind up high. The high C, top of the staff, can be flat. In general, the answer is yes, the lead pipe can affect intonation. And not just stress, also, but if the bore is not quite right, it can affect the rate of change and how well it responds.

Larry: When you say stress, do you mean how you bend it to meet the valves, or do you mean something else?

Bob: “Ok. When you bend metal, there are two types of stress: there is residual stress, stress within the actual metal after it’s done being formed, and that’s not necessarily a bad thing. Bells are spun in such a way that there is actually stress that’s lessened as a piece of metal. But, there is another type of stress that a tube or an instrument, where during the assembly one would really need to add the parts in a way where they want to be. And by that I mean you’re not shoving them in to place and bending something so that it goes where you want it to go. You need to bend it ahead of time, so that it lays nicely where it wants to go. Trying to think of something you can relate it to. IF you take a piece of metal and you bang on it, it’s going to make a noise, right? But if you hold one end of this piece of metal down and bang on it it’s going to make a really different noise. You know the whole thing about a saw, if you can play a saw, and you bend it, it will change pitch. IF you think of an entire tuba as a big piece of metal, if you bend it, while you are putting it together, it’s going to want to vibrate at a different pitch than it would if it were relaxed, or if you weren’t trying to bend it. And, actually, that makes a big difference. Many tubas are considered to be bad quality when their really just put together not quite right.

Larry: So, it’s not because it’s a bad tuba, it just wasn’t put together with enough attention to
particular stress levels of the metal? Bob: Right. So if things are under tension when you put them together, it’s not quite right. So it won’t vibrate right.

Larry: I heard this term called “lead pipe taper” and I have a question that’s kind of the same question. It’s two questions, but they’re almost kind of the same question, but one of the questions is, “In your understanding how does lead pipe taper affect response,” and I think I asked that because I don’t really know what lead pipe taper is.

Bob: So let’s talk about lead pipe taper for a second then. You know a tuba’s conical, right? It’s not cylindrical. The amount of change in the width of a tube determine how conical it is. So that change is the taper. So when you talk about a tapered lead pipe, all that means is that that lead pipe itself is conical, non-cylindrical. And the amount of change and where that change takes place is kind of the measure of the taper, and they’re not all the same. German tubas are different from the American tubas. And one of the things I got to do with Zig Kanstul, unfortunately I didn’t get to measure everything, not while I was doing it, was, one day I happened to be in the factory and he wanted to try different F tubas that he was developing. He was standing there with a torch and a box of lead pipes and a torch and he kept changing them out right as I was sitting there. They were all very different from one another. It was fascinating to me how different the taper of the lead pipe was affecting the way the tuba played.

Larry: WOW. So each one had a different taper.

Bob: Yes in real plain terms it got bigger or smaller from one end to the other at a different rate and in a different size.

Larry: So, then, the bore size. How is lead pipe different or the same. Because when I heard lead pipe taper, I immediately thought of bore size or the shank, whether it was an American shank or European shank.
Bob: So, those are three different concepts actually. Bore size, lead pipe taper, and shank are three different concepts with three different definitions. The bore size on the tuba is based on the size of the aperture of the air going through the first or second valve. You can pull the tuning slide out of the first valve and measure the inside of the tuning slide and it should come out as .750, three quarters of an inch diameter. And that’s the bore. When you see a tuba, and they say 750 bore or .75 bore, that means that three quarters of an inch is the diameter of the hole through which the air goes through the valves.

Larry: That makes sense.

Bob: Now the lead pipe is special. It’s that thing that’s going to translate the vibrations from your lips into that bore, and into that valve set. If you think of it that way; that’s pretty critical. I think of the bore like an antenna. The antenna’s really important, it has to be in tubes of the instruments so that it radiates. But now you’re talking about the input signal from your lips going in to the horn. And that’s where the lead pipe comes in and the taper needs to be just right for the waves inside there that you’re making so they can expand and be the right size at the right time. There’s a little bit of magic in there. Then you start talking about the shank, or the type of receiver: Euro shank mouthpieces and American shank mouthpiece and how they respond inside the tuba. It’s another fascinating thing, which I’ve played with a good deal.

Larry: So I know the European shank and the American shank, but if it’s an American shank, does that mean that it has to have a particular taper, Or can it have a varying taper as well? Because the American shank is the smaller one, so do some manufacturers or amateur tuba makers, do they even create a taper that decreases from the American shank as well? I guess it’s not a big difference, but could it decrease from something that is American shank at the receiver to something that is a little smaller when it gets to the valves?
**Bob:** There’s another topic that I think you just touched on. The taper is the rate of change of diameter, right? So the taper of a Euro shank and the taper of the American shank on the mouthpiece are actually the same taper, they change at the same rate. Because of that, both of them will become tight inside a standard receiver. They’re actually the same taper, but they’re different diameters. And because the Euro shank is a little larger diameter, they don’t go quite as far into the receiver. And then we would have to start talking physics, but I haven’t studied that physics. All I can talk about is the difference in the response in sound, and that for some reason, there is definitely a difference between the Euro shank and American shank. If you go and get a Laskey Euro shank mouthpiece versus a Laskey American shank mouthpiece, they actually respond a little bit differently in a tuba. They’re both the same taper, but one with a slightly larger diameter therefore it doesn’t go quite as far into the receiver. So you have a bigger distance from the end of the mouthpiece to the beginning of the lead pipe.

**Larry:** I find it very hard to find a Laskey Euro shank.

**Bob:** And you won’t. Sadly, Scott Laskey died about 6 months or a year ago, and they’re aren’t any more. Because of that, my dear friend Mike Roylance has been working with Dillon and with a company whose name I can’t remember to make some mouthpieces. So they have decent mouthpieces to give to students and stuff like that, and they’re really great. It’s not identical to Laskey, but it’s what I would recommend as far as mouthpieces go, to anybody.

**Larry:** This is an interesting question, because I feel like from what I’ve read and from the people I’ve talked to, there seems to be a divide. What do you think would be the best for a lead pipe? Should it be, in your opinion, mounted to the bell, or should it be basically off the bell a little bit to kind of allow the bell to resonate more?

**Bob:** I knew that was your question based on your preface to the question. That is one of my
favorite ones because I’ll wind up arguing with myself about it. I’m getting to a point where I thinking that it may just depend on the instrument. I’ve gone back and forth on that one. There’s just phenomenal tubas where the lead pipe is connected wrapping around the bell. And then I’ve played that one the same way. And I’ve played phenomenal tubas where the lead pipe is off of the bell. I’ve finally come to a place where I’d rather just watch other people argue about it. For most of my horns, by the time I’m done building the tubas I’ve built, there’s usually minimal contact. Usually there is just one contact place on the bell, and then a contact place on the lead pipe brace, and then contact at the entrance to the valve set. Honestly, that’s mostly because of my bending skills with the lead pipe. Unless you happen to bend a lead pipe that fits perfectly onto the bell, it’s going to be off of the bell.

**Larry:** What are the tendencies that you’ve notice on either side? Have you noticed anything, or any difference? Does one seem to blow freer around the bell, or does one seem to constrict more? Does it even matter?

**Bob:** There is that. I think there’s a third component. There’s this free blowing thing where things are vibrating, and there’s constriction where things aren’t vibrating the way you want it to. But then there’s this thing with York tubas sometimes, where you play it and the whole thing just resonates like mad. I don’t know you would describe that. The whole thing is just so resonant. I’ve experienced that with York tubas where the lead pipe is mounted on the bell. And the whole world is vibrating.

**Larry:** I’ve never played a York tuba. Bob: We’ll have to fix that. We’ll have to get you to Orlando.

**Larry:** I would love to get my hands on one just to see because I’ve read so much about them. The horn that I have is designed with that in mind. I’m so curious as to what it would feel like to
play that horn. Even if it’s not a big horn, even it’s a small horn that I just come across, but happens to be a York horn. I just want to know what it’s like. I don’t get it from what I’ve read, but at the same time I’m so curious.

Bob: I have on the order of 25 tubas. And my buddy Tom Treece has on the order of 40 to 50 tubas. I have a few York tubas that will make your teeth fall out. They’re crazy. And the thing is, you play these and you think, “Why?” And that’s what started the Kanstul thing. I think we’ve figured out much of what makes them great. Now some others have figured it out too. The alloy makes a huge difference. You’ve got these general things about building instruments, the design aspect, which is what you’re talking about where the lead pipe makes such a big difference. And it’s also where the braces go make a huge difference. The alloy of brass makes an enormous effect on the way these instruments reverberate. Mike Roylance insisted, and he was correct, that the thickness of metal makes a huge difference in how these instruments reverberate. It’s a combination of things that makes this stuff happen. York had it figured out. They built all these instruments from 1900 to 1940. They knew what they were doing. We’re just kind of refiguring out what it was they were doing.

Larry: You’ve already told me that you’ve done a good deal of lead pipe bending, and you’re pretty apt at that. Because my next question was, “What is your experience with lead pipe bending,” but I think you basically told me you’ve done it quite a bit.

Bob: Yes. I’ve done some lead pipe bending, Tom Treece does some lead pipe bending. We got that figured out, some.

Larry: Yesterday you told a story of how you bent this lead pipe, you bent it just to go in one direction and all the way in another direction, and the intonation was all out whack. When you bend a lead pipe, is it only to reach the valves, or is there also another motive to bending it. I
know that the beginning of the vibration, and whatever happens there is very important. Is there something that you’re trying to do, to affect that vibration in addition to making it get to the valves?

**Bob:** To be honest with you, not so much. I actually, when bending a lead pipe, it’s mostly to be ergonomic so that you can play the instrument and that it fits, and that the lead pipe fits into the valve set—not that complicated. The installation is important. But the bending of it is really more to get it to where it goes so that it’s comfortable enough to play.

**Larry:** I’ve done some online research. It’s hard to find articles on this. What I have read is mostly people talking about the lead pipe as a comfort thing. Whereas the put the lead pipe down a bit or bring it up a bit because it’s comfortable for them. It’s basically what you just said.

**Bob:** I can’t really argue with that so much. The key is that it is a taper that makes the instrument play ok and blow alright, and it fits so that you can play it. The most important thing is that, by the time you’re done, it’s not under stress, or tension once it’s installed.

**Larry:** I’m thinking about the Hirsbrunner 2p tuba, and its lead pipe is basically its tuning slide.

**Bob:** Is that the one with the tuning slide right off the lead pipe?

**Larry:** Yes. There is a guy who plays that horn. I had a tuba-euphonium quartet for the past year. He plays with me in that quartet. Every time I hear him play, I have to ask myself, “What is the effect of that design for lead pipe slash main tuning slide. It kind of comes off the bell, then it wraps down and over and into the valve set. And I’m left racking my brain asking, “Why did they do it like?” Because the horn always sounds great. People always jump off their horn and play the other horn. They’re just amazed with that horn. What is up with the lead pipe, though?

**Bob:** And you’re asking, “Why does that work, why did Hirsbrunner do that, why does it sound so great, and why did Conn do it back in the 20s. They did the same thing. It’s counterintuitive,
it’s slides in the face of everything that York did, or what I think. But it works. Like I said, there’s black magic involved in this too. The Hirsbrunner 2p and the Hirsbrunner 2, they’re great instruments, but they have a tuning slide stuck right in the lead pipe. The reality is, Peter knew his stuff, and Hirsbrunner knew his stuff. He built great horns. There’s other things to that instrument that are great and why that lead pipe worked so well, I don’t know. There are rules that I follow, but that doesn’t mean that the things that I know are the only truths. So I build a lead pipe that goes straight into the valve set every time I build a horn. They do a lead pipe that goes down, into the tuning slide curves back up and over itself into the valve set. It works.

**Larry**: I wonder if anyone else has tried to do something similar to Hirsbrunner. I would like to see what would happen if you tried to recreate the weird lead thing.

**Bob**: It goes back to the question of why does this work. I really think that in general the biggest things that destroys instruments and makes them sound bad is the tension that exists after the bad assembles. Assembly is critical, unless it’s done right, the tuba is going to sound bad. Hirsbrunner figured it out. Conn figured it out, but they couldn’t compete with York. But is that the lead pipe, probably not. Who knows?
Interview Transcription – Chuck Nickles

Larry: How many different lead pipe designs have you worked with?

Chuck: How many lead pipes? Many at this point. I know for that one particular tuba we went through seven pipes. Now I’m able to just make my own. The number is in the ballpark of over 20.

Larry: It’s crazy that the lead pipe can be so varied.

Chuck: Well, there are so many aspects that go into that. People think of it as, “Oh, it’s just a lead pipe,” because when you look at other instruments like trumpet or trombone, it’s pretty standardized. For tuba, we are not even close for being standardized for instruments. You could have a lead pipe for an E-flat tuba; the British style E-flat lead pipes are around 9 or 9 1/2 inches long. But then you could get to the German style B-flats and C’s and they could be close to 20 inches long. There’s a ton variance you could put into it. You can’t say, “I have this one lead pipe that’s going to work for everything,” because it’s not going to work.

Larry: Does there have to be a particular length from the receiver to the end of the main tuning slide for a lead pipe?

Chuck: No. It’s actually very different depending on the kind of style of tuba. For example, many of the American style tubas tend to have a short lead pipe, in the ballpark of about 12 inches, give or take. That depends on the manufacturer and the particular tuba. And then the valve section itself tends to be much shorter because pistons take up much less space physically than rotors do. While if you take a rotary valve tuba, the lead pipes tend to be longer on those, and the rotary valves themselves tend to be much longer. If you look at a four valve B-flat tuba for pistons versus a six valve rotary F tuba, it’s a huge difference there. I think much of what gives tubas their different styles—German styles versus American style—kind of comes
down to that, because that does drastically change the rate of taper for that first third of the instrument. I find that that’s really important for response, and it definitely affects intonation as well in that area.

Larry: I noticed that most of the rotary valve tubas have longer lead pipes and you get a tuba sound. And Most of the piston tubas have the lead pipe going into the valve. I’m wondering about the length before you get to the valves: is that basically what you’re talking about when you say “the length of the lead pipe”?

Chuck: When I think of length of lead pipe, I think from the very beginning of the lead pipe to where it plugs into the valves there. That can be drastically different, anywhere between 9 and 20 inches depending on the model of tuba. Sometimes it’s a preference for players in what they want for their instrument and sometimes it’s a mechanical thing. Sometimes you need the mouthpiece at this one point, and the valves are at this point, so it has to be at least this long to get there.

Larry: Does the particular bend and design of lead pipe affect the response, or even the sound of the tuba in your opinion?

Chuck: Sound: I would say not so much on tubas. Now, on other instruments I think it does make a big difference. I think much of it comes down to this. IF you think of each component of the instrument, say: Lead pipe, valve section, bows, bell. If we break down the instrument into those four parts. A lead pipe is, percentage wise of the entire instrument, pretty small on tuba. It may be 3 to 7 percent. While if you go to something like the trumpet; that’s more like 30 percent of the instrument. We get different responses from different makers, and I think it part of it comes down to, yes on the trumpet that can make a difference in the sound because it’s a third of the instrument that you’re talking about, while a tuba—because its such a small percentage—it
does make a big impact. People ask me about materials for a lead pipe as well. I think for things like trumpet and trombone it does make a bit of more impact than it does for tuba, because it’s such a larger percentage of the entire instrument. If you made a third of the tuba out of nickel silver or gold brass, you’re probably going to notice a little bit of change in the sound there. Same with a trumpet, if you change the lead pipe, that is almost a third of the instrument. While on tuba, it’s not really a big thing. Now the “design of it changes response,” Yes. I definitely think that’s makes a big difference. The bending of it, I’m not convinced it makes a huge difference there. Here’s a good example. If you play an open note on your tuba, and then you push down the second valve, it doesn’t really change how it plays. But that crook in the second valve is quite a sharp bend in there. If that type of bend doesn’t affect how the whole horn plays, then a little bit of a different bend on the lead pipe isn’t going to make a big difference. Now when you start adding things together then that’s when it makes more of an impact. That’s why I try to push up on the wrap of the fourth and fifth valve. I try to make them as open as possible, because when you’re using those valves you tend to be more valves at the same time. The one bend in the second valve when you play that doesn’t make a problem, but if you add now eight more bends or ten more bends from having extra valves in there, then it start to make more of an impact. The rate of taper is super important. There are three mathematical points that you have to look at: your starting diameter, your ending diameter, and your length. People will often times say that, “Well it has to start at this size or end at this size.” There are three parts of it. I could have two lead pipes that start and stop at the same diameters but have different lengths. Now they have a different rate of taper. Many people will say, “This is the one that works for everything.” The whole instrument works as a unit. You can’t say, “Ok, if you want really great response you’re going to use this lead pipe, and if you want the biggest sound, you use this lead
pipe for every instrument,” because what lead pipe works for a 6/4 B-flat probably isn’t going to work right on a rotary F tuba. There’s so much difference for the rest of the instrument too.

There are certain things that I can think of, like if I need it to be a little tighter playing, I can start it a little smaller and maybe mess with the rate of taper that way. Let’s say I put a lead pipe on a C tuba that tightens it up a bit, to where it isn’t so open playing to the point to where it’s hard to play. If I put that same lead pipe on an E-flat tuba, now it may be too stuffy. Many people like to think there’s this one component of the instrument that affects everything. There are sections of it that do make bigger impacts like the lead pipe. Pretty much, in my opinion, the first third of the instrument for tuba, makes the most impact on response, and much of the intonation issues there. Those tend to make much bigger progression as they taper through there, because they go through the valves section, there can be steps in the boar. That’s where response and intonation can really be affected in there. I’ve learned that making subtle changes to, let’s say, the bottom bow design or the top bow design doesn’t always have that big of an impact in there. However, if I change the tuning slide, or the dog-leg, right after the tuning slide, that can drastically change the intonation on the instrument.

**Larry:** Dog-leg?

**Chuck:** Yes, the dog leg is that S-curved piece that you see after most main tuning slides. That’s why I refer to it as the dog leg. Some people will use the numbering to name the branches. Different places do that differently. The US uses a little different numbering system than Germany does. Usually, I just try to use more Laymen’s terms when I talk to them so I don’t confuse people when I’m talking about bows. Some people will count the bottom bow as bow 1, while some people count the top bow after the bottom bow as bow 1. I try to use more descriptive names to name the bows that way. If I say the inner top bow, you know there are only
two top bows—the inner one—you know what I’m talking about. While if I say bow 5, you might scratch your head a little bit.

**Larry**: I don’t know what that would be, actually.

**Chuck**: You would have to count it, and on different instruments that could be different. I’ve seen German baritones, for example, some of the really fancy ones. From after the main tuning slide, all the way to the bell is one bow. While that could also be split up into three different bows, depending on how it’s manufactured and what they’re going for instruments wise.

**Larry**: About the different designs you went through: was that basically a difference or a change in rate of taper? Did each lead pipe you went through have a different taper?

**Chuck**: Yes. I went through rate of taper changes and I also went through wall thickness changes.

**Larry**: Wall thickness? Is that the thickness of the tube?

**Chuck**: Yes. Some I made heavier than others, which worked on certain instruments, and didn’t work at all on other instruments. When I’m trying to design an instrument, I think what I do is different than many other manufacturers. Many times people put out an instrument and they say, “This tuba is great at everything!” There is no tuba that’s great at everything. A jack of all trades is a master at none. When I make goals about designing an instrument, I try to figure out what am I going to use that instrument for. Then I build it to do that job really well. If I have a 6/4 B-flat, I’m not going to use it in quintet. I don’t need it to have a sound that can get really small and tiny to fit into a five-person ensemble. I need it to put out plenty of sound easily in an orchestra without it getting edgy or gross. My design for the entire instrument goes more in that direction. While if I making something for quintet, I would want to be really agile and easy to play that way. I don’t care about the volume when it’s a little lower. One of the big things I
shot for that 6/4 C was that, much of those 6/4 tubas tend to have kind of a crappy low end, and they get really harsh down low. So I gave up a little bit of color and ease in the very top register, because realistically you’re never going to play up there, Very, very rarely. And it’s not bad, it could have been a little easier, but I would have to sacrifice the low end on the tuba which is something I would actually use all the time on a big 6/4 C tuba.

**Larry**: That is very true. I use to play all of my high stuff on C tuba, because I didn’t know how to play F tuba. Then I learned how to play F to and realized, why am I playing high on C tuba.

**Chuck**: Yes. Why would I ever do this on C tuba? I don’t like to think of myself as an instrument maker. I think of myself as more of a tool maker. You as an artist have to do different jobs and want to do different things, and I just make the tools to help do those things for you. Many people will say this tuba is bad, and this tuba is great. Much of the time I disagree with that. Most instruments I’ve played aren’t bad. There are some that I wouldn’t recommend to anyone. For most instruments, I like to ask, “Does it do what you want it to do easily or not.” If it doesn’t do what you want it to do sound wise or playing style wise, then it’s going to seem like a bad instrument to you, because you’re trying to do these things, and it doesn’t want to do those things. While if you find an instrument that matches your sound concept and your playing style, then suddenly you’re saying, “This is a great instrument.” Many times, at these shows, when people play the instruments, I can tell if their going to like it or not. Usually within the first ten seconds, I can tell from their playing style and what sound is coming out of the bell, and if they like that or not. Many times I would use that to help guide them to the right instrument that matches their sound concept a little better.

**Larry**: This helps you sell them an instrument.

**Chuck**: Well, it’s more like I would sell them the right thing. What’s really nice for me is that I
don’t get paid commission, so I don’t care if I sell them a $5,000 tuba or a $10,000 tuba. So I would have them walk away with a tuba they’re going to keep for a while. So while my boss may like it if I sell them the expensive tubas all the time, if you sell it in six months, it doesn’t look that great for the company. You’re probably not going to come back and look at Wessex again. Get them the right thing the first time.

Larry: That’s a good point. Just being knowledgeable about what they want to do on the horn and using that to help them make a good decision. I think many people are looking for that “do it all horn”.

Chuck: I get that all the time at shows. They say, “I want it to have the biggest sound for orchestra, but I also want to be able to play the Vaughan Williams on it, and I want it to have perfect intonation, and I want it to make me a sandwich.” No instrumentalist has one instrument that they do all their work on. You’re never going to see a jazz trombone player playing his symphony horn for jazz gigs. He’s going to have his little horn for that, because it’s better for that. Then he’s going to have his large bore horn for orchestra because it does better at that. Can you make it work on one thing? Yes, but it’s not going to be perfect for any one particular job.

Larry: Does using a European shank in an American receiver or an American shank mouthpiece in a European receiver tamper with the tendencies of the lead pipe?

Chuck: The receiver of many American style tubas is separate from the lead pipe. German ones tend to be made as one piece it has a double taper in it. So the front part has an inward taper to hold your mouthpiece, and then it tapers out again, for the actual lead pipe. The American style instruments—and just American style lead pipes in general—have the lead pipe, and then the receiver’s separate piece on there. So many times, on those types of instruments, you can actually change the taper in the receiver without changing the lead pipe taper. It’s a very
small amount of difference: probably ten-thousandths of an inch, I think. It’s not a huge difference that way. Now when you switch back and forth from there, there is a little bit of response change. I don’t really think it changes the sound at all, by itself. I think how it affects the player and how it plays makes the musician change their playing, which in turn affects the sound. I feel many people think, “Oh this will just change my sound.” No, it’s going to change how the horn plays, which make you change how, you play, which affects the sound. It affects it, yes, but not in the way that people does. I think the best way to think of it is how far in or out does it go. This is the real frustrating thing for me is that no mouthpiece company is the same between each other when it comes to that taper. They’re all different. There’s no categorization at all in the industry. On my end it’s really hard to figure out what to build things for, because someone will say, “My mouthpiece fits perfectly but this other mouthpiece wobbles in the receiver.” I can’t make one taper that fits everything, because mouthpiece companies don’t do that. Most of the time I like to think of it more in terms of how far in or out does it go. People will say that this is an American receiver or European receiver, but that’s not always super accurate. It’s not a perfect world that way. I find that if the mouthpiece sticks out a little bit farther, you get a little bit more resistance and the slot are a little bit tighter. If the mouthpiece goes in deeper, it tends to open up the horn a little bit, but it also widens the slots a bit. That can really depend on the instrument and what the player wants. I find that really large tubas already have wide slots, so for me personally I would rather for my mouthpiece to come out a little bit further than go in further. The slots end up tightening up a little bit, which is not a bad thing on that kind of a tuba. While if I go the other way, it can end up being too wide. Then I have a hard time playing in tune because I can just put the notes wherever. However on smaller instruments it could go the other way, if I’m playing an instrument that has already really tight slots, and I
pull the mouthpiece out farther, suddenly it can get so tight that I’m chipping notes all the time, because the slot is so tight, it’s easy to miss the right spot. Those are very small changes that the player can make depending on what they want playing wise on that particular instrument and their set-up and what they’re trying to do with that. Some people have the thought of, “It has to be this far away from the gap.” I don’t really agree with that because it needs to be what the player needs for what they need to do.

**Larry:** I hear people always saying if you have a European shank tuba, then it’s going to be really open sounding like you’re blowing through a hallway. On the other side, if you have an American shank tuba it may be a little tighter. Where do you stand on that particular thought?

**Chuck:** I think there are way too many other variables in a tuba to say one way or the other. Here’s a good example. Because mouthpiece designs are so different, the receiver I actually built for Wessex is actually in between American and Euro. If that myth was true then all of our tubas would have certain playing to them and all that. I don’t find that to be true. Here’s another good example of that. All the old Besson Euphoniums had the in-between receiver: in between large shank and small shank. But when they became the more modern horns—they became the Bessons that we know today, they changed the taper inside the receiver itself so that it would accept a large shank mouthpiece. They didn’t change the lead pipe. They didn’t change anything else about it. The horns don’t really play any differently, because other than that one little thing there and a slightly larger outer shank diameter, there’s no difference between them. So I put that one more towards “myth” than “fact” that says it has to be a European shank. It also depends on what mouthpiece you play and what they designed it for.

**Larry:** You said something about this earlier. I want to make sure I ask it just to kind of hone in on this one idea of a lead pipe having a different material from the rest of the horn. I remember
you saying something like since the lead pipe is so small in relation to a tuba, it may not have that big of a difference.

**Chuck:** I find that on a tuba, it makes very little change. I’ve had times at the factory where I’ll have a gold brass one, and I switch it with nickel. Personally, I have to really listen to tell. Now, if you’re doing something like the bell of the horn, that I have noticed a difference in how it sounds, and how it responds, —but with the lead pipe—not on tuba. The smaller the instrument gets, the more impact I found that that makes, because it’s a larger percentage of the overall instrument. I like to use nickel silver whenever I can, because, A, it doesn’t rot. That is a big problem on tubas. That lead pipe is the first thing that the air-stream meets, so that’s where most of the “human matter” gets into the instrument. Those will rot, and that will make a big difference in how the instrument plays if there are holes in the lead pipe. Then I also like to use nickel silver really for structural reasons. Nickel silver is a much harder metal. If you bump your lead pipe a little bit, with nickel silver it’s less likely to dent than if it’s brass or gold brass. Especially if it’s gold brass. Gold brass is not really a metal per say. That’s just a marketing term that we use in the industry. But really it just means that there is a higher copper content. And with that, part of the reason why gold brass is more expensive—there are two reasons really—A. The copper itself is more expensive. When you have a higher coppers content, the material itself is just more expensive. That’s why they charge more for that. Also, though, copper is really soft, but it can work-harden pretty hard. I have personally found with gold brass that it’s hard to keep a consistency. If I make twenty lead pipes in gold brass, they’re not always going to be close to the same hardness. Copper when it’s annealed is supper soft. You could just bend it with your hand really easily. While it does work-harden pretty quickly, and gets to the point where you’re going to need hydraulics to bend it. So it can make a huge difference that way. I also like to use
nickel silver, because it’s just always hard. Your can anneal it and make it softer, but it tends to be hard all the time. That’s a reason why nickel silver is more expensive than (gold brass) because it’s just harder to work with. If you ever start hammering out sheet brass instruments, you’ll learn really quickly why people don’t do that in nickel silver. Whenever I can, I use nickel silver. If someone doesn’t want that I go with gold brass because red rot is a thing. That’s a deteriorating of brass. What happens is you get all these little red spots and the metal becomes super weak. You could just punch through it with a pen or a needle when it gets to that point.

Larry: That kind of goes into my next question. Have you experimented with a raw brass lead pipe on a fully lacquered tuba? Or vice versa?

Chuck: I’ve done that just because I’ve had a fully lacquered instrument where the lead pipe was trashed for one reason or another, and had to put on the same lead pipe that was unlacquered. You don’t really want to lacquer it before you put it on because you’re going to burn the lacquer when you solder it. And plus the solder isn’t slow on the top of the lacquer so you have to sand some it off anyway. I don’t find that it makes much of a difference. And it’s such a small percentage of the instrument. Now if you stripped the lacquer off half the instrument or the whole instrument, that’s a different story in my opinion. However, just the lead pipe, No. I wouldn’t say it makes a difference there.

Larry: Whenever you bend a lead pipe, are you bending the lead pipe to basically fit a template as to where the valves are going to be? Or do you bend the lead pipe to affect response? Is it more of an ergonomic thing, or sound thing?

Chuck: How we do it is we know where the valve sections is going to be on most of these horns, and we just do the bend to go around the bell to get the mouthpiece where we want that, so many times how we make the lead pipe is that it starts as a straight tube. We draw it, and that begins
with a taper, but it’s still straight at that point. Let’s say I use the same lead pipe on five different horns. I can make a ton of those pipes, and then I put them into different jigs to bend them to the right shape for each individual horn. If I use the same bend on a 6/4 tuba versus a 4/4 tuba, there’s going to be a big gap between the lead pipe and the bell. It’s not that hard to make a mold for that to be able to bend those correctly. That’s what many companies do. They’ll use a couple of lead pipes, if that, and they’ll just bend them to fit different horns. Larry: So it’s more of an ergonomic thing, I guess. It’s just to make sure everything is fitting as it should.

Chuck: That’s why you’ll see certain things different on different horns. Many of the 6/4 tubas, the lead pipe—especially on C’s—it doesn’t come all the way around the bell. And that’s because it’s not long enough to. However if I made it longer, to go around the bell, while it may be even more ergonomic, is going to change the response of the instrument. The other big thing too is if I make that longer, I have to take that distance out somewhere else. So suddenly I have to change either the tuning slide and make it even shorter than it already is, or I have to change another bow and make it shorter, and I have to change the taper of that bow too.

Larry: If you had a lead pipe and you had the valves at a particular spot so you had to bend the lead pipe to get it all to fit, do you start looking at intonation to make sure that the bends that you did affected intonation in the right way?

Chuck: I’ve notice that the bend has not really done anything negative to either response or intonation on the horn, unless you oval the pipe when you bent it. Sometimes you can run your fingers on the pipe and feel that it’s oval shaped. Either they didn’t put the pipe in the mold very well, or they didn’t build the proper supports for it, or it wasn’t filled properly. You have to fill the pipes with something to keep them from crimping when you bend them. Different companies
will use different things, I’ve seen anything, from using lead—which is the easiest thing to use—but also bad for you, health wise. Using molten lead is a bad thing. I’ve seen them using things like Cerrobend, which works really well, but you have to use it at certain temperatures, so it’s a little finicky that way. I’ve seen a tree sap kind of thing used before, which works well but melts at such a low point, that if you’re shop’s really hot during the summer, it will just melt off while it’s still in the pipe. And I’ve also seen things where people would fill them with liquid soap, and then froze them, and were able to bend it. That’s great in a certain way because it’s real easy to clean it out afterwards, and there are no health problems there, but you also have to work quickly. I personally haven’t found the bends to really affect things. I mean if you went really crazy with the bends, or added some kind of U into it, yes, that would probably do something bad there. Most lead pipe bends are done with as gentle of turns as possible, mostly because the tighter bends are harder to do. As long as you don’t mess it up in the process, I haven’t noticed any intonation and response changes from bends in the lead pipe. Many times when I test the horn, I’ll just put in the lead pipe while it’s straight. I don’t notice any difference between whether it’s just plugged in there or bent around. The only difference I notice is when it’s actually bent in there, it’s soldered onto the brace, or sometimes it’s soldered onto the bell. Those are the things I notice more than the actual bend of it.

Larry: About that: If the lead pipe is on the bell, or soldered to the bell, or it’s soldered to a brace that’s on the bell so it’s kind of off the bell a little bit. Have you notice any changes in response or how the tuba resonates.

Chuck: A little bit actually. My view of the instrument is that the bell makes the final sound. If you change the components before the bell, it will change things, but not huge drastic changes in the sound itself. If you change the bell, you could totally drastically change an instrument. My
personal view is I like to put the least amount of stuff on the bell as possible. To let the bell vibrate and do it’s thing. Now depending on what the goal of the instrument is though, that might change. I’ve found the more stuff you solder to the bell, the harder you can push it volume wise without it breaking up. However, it’s a trade off. I’ve noticed that when you start soldering more stuff to the bell, it doesn’t respond quite as quickly and you lose a little bit of the color in the sound. You get more of just the fundamental, and less overtones, and, depending on what someone wants, or the group they want, that could be a good thing or a bad thing.

If I’m trying to get a horn to be more of a soloistic horn, I personally like to take it off the bell. I like to put less things on the bell. On The 6/4 tuba, I did solder the lead pipe to the bell, but I also had almost no bracing on the bell. The only places where it’s soldered on is the lead pipe, the receiver brace, and where the bell attaches to the bottom bow, and there’s one spot where the top bow touches the bell, so that’s soldered on there. Others than that, there’s not bracing. I did that on purpose to liven it up because I want they kind of color in the sound of those instruments.

Larry: So you had the lead pipe on the bell, and it still resonates pretty freely?

Chuck: It still resonates pretty freely. Part of me felt I should take that off there, but because there was so little else soldered on there, I decided to actually keep that soldered on there. Plus there’s the whole structural-integrity-thing of the instrument. Yes, it might be more lively if I took everything off the bell, but then there is no support for the bell either, which means it’s more susceptible to damage. Everything is a trade-off and a balancing act.

Larry: If there is a little ding in the lead pipe, does that affect of the tuba or how it all plays altogether.

Chuck: Yes it does. I am a big proponent with lead pipes, that if you damage it, you should
replace it. Think of it this way. The start of your lead pipe is in the half inch range. .5, .55 to about .6 is as big as it gets. If you have a dent that pushes in .2, that’s a big part of the bore that you just shrank down right there. While if you had that same dent in the bottom bow, you won’t even notice it. Think of it in percentages. What percentage of the instrument did I just pinch down right there with that dent? That’s why the smaller the piping, the more dents affect the instrument. A bottom bow dent, unless it’s really extreme, or where the bottom connects to either the bell or the top bow, because many times those dents cause leaks, don’t really affect the playing of the horn that much. However, if you have one from the main tuning slide to the mouthpiece, even in that area can make a huge impact on how the instrument plays because if you measure it you can sometimes go from a 750 bore to a 500 bore for a spot and then back up again. That’s a big jump to have in this tiny little area. With certain parts o the tuba like the tuning slide crooks, you can take the dents out pretty easily. It’s not super hard, but lead pipes because of the length and the taper involved in all that is super challenging to remove those dents and get it back to where it was. Most of the time I’ve found that people who push out the dents, they end up expanding the lead pipe in that area too. You’ve changed the taper of the lead pipe, and you’ve made it bigger in some areas. I think if you put a big dent in your lead pipe, you should just replace it. It’s actually easier to get a new one on there.
APPENDIX B.
AUDIENCE PERSPECTIVE SURVEY MATERIALS

Instructions: Rate the excerpt you hear in relation to these four descriptive terms: Thick, Brassy, Light, Colorful.

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Figure B.1. Materials – Response Sheets
Audience members gave each performance a grade of 1—5 for each of the four descriptive terms: thick, brassy, light, and colorful.
Figure B.2. Materials – *Ode to Joy* Arrangement Excerpt
Figure B.2a. Materials—*Ode to Joy* Arrangement Excerpt Manuscript
This is the actual manuscript that was read during the performances for the audience participants.
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APPENDIX C. IRB APPROVAL

ACTION ON EXEMPTION APPROVAL REQUEST

TO: Larry Heard
    College of Music and Dramatic Arts
FROM: Dennis Landin
    Chair, Institutional Review Board
DATE: March 6, 2020
RE: IRB# E12161
TITLE: Instrument Construction: An Examination of the Effect of Lead Pipe Design Variability on Tuba Response


Review Date: 3/4/2020
Approved X Disapproved

Approval Date: 3/4/2020 Approval Expiration Date: 3/3/2023

Exemption Category/Paragraph: 2a,b

Signed Consent Waived?: No

Re-review frequency: (three years unless otherwise stated)

LSU Proposal Number (if applicable):

By: Dennis Landin, Chairman

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING – Continuing approval is CONDITIONAL on:
1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU’s Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
8. SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc. Approvals will automatically be closed by the IRB on the expiration date unless the PI requests a continuation.

* All investigators and support staff have access to copies of the Belmont Report, LSU’s Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb
APPENDIX D. GLOSSARY OF TERMS

Amplitude

1. Physics. the absolute value of the maximum displacement from a zero value during one period of an oscillation.

2. Music. how tall or large the acoustical vibrations are will indicate how loud the sound is.

Brassiness

1. a condition where brass instruments reach the extremes of sound production, exhibiting the potential to, or actually achieving a bold, loud, piercing, and sometimes harsh sound.

Formant(s)

1. Music. the range and number of partials present in a tone of a specific instrument, representing its timbre.

2. natural resonances

3. Acoustic Phonetics. one of the regions of concentration of energy, prominent on a sound spectrogram, that collectively constitute the frequency spectrum of a speech sound. The relative positioning of the first and second formants, whether periodic or

Most terms were found on dictionary.com. Others were conceptualized by Chuck Nickles and Larry J. Heard.
aperiodic, as of the *o* of *hope* is approximately 500 words and 900 cycles per second, is usually sufficient to distinguish a sound from all others.


**Figure D.2. Vocal Formants Example**

Frequency

4. Physics.

   b. the number of cycles or completed alternations per unit time of a wave or oscillation.

Fundamental-rich

1. a sound that has a substantial amount of the fundamental present in its acoustical properties, or exhibits more acoustical energy in the partials closest to the fundamental.

   a. also referred to as dark, thick, heavy, focused

Horn

1. Music. used commonly as an informal term for any musical wind instrument. For the purposes of this monograph, *horn* is primarily utilized to refer to the tuba.

Impedance

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1. Physics. the ratio of the force on a system undergoing simple harmonic motion to the velocity of the particles in the system.

Overtone
1. Music. an acoustical frequency that is higher in frequency than the fundamental.
2. an additional, usually subsidiary and implicit meaning or quality

Overtone-rich
1. a sound that has a substantial amount of the acoustical energy in the higher overtones.
   a. also referred to as bright, light, warm, colorful, sometimes brassy

Peak
1. the highest point of the amplitude of a sound waveform

Resonance
1. the state or quality of being resonant.
2. the prolongation of sound by reflection; reverberation.
3. amplification of the range of audibility of any source of speech sounds.

Sound spectrogram
1. a graphic representation, produced by a sound spectrograph, of the frequency, intensity, duration, and variation with time of the resonance of a sound or series of sounds.
REFERENCES


VITA

Larry Heard is currently pursuing the Doctor of Musical Arts degree from Louisiana State University. He will be graduating in May 2020. While in the doctoral program at LSU, Larry has enjoyed performing and working closely with the members of the LSU Tuba and Euphonium Studio. During his first and second year, Larry worked as an LSU teaching assistant for Kid’s Orchestra, instructing students on trombone.

Larry currently holds the Master of Music degree from LSU (2013) where he was privileged to receive instruction and pedagogical guidance from Dr. James Byo, an expert and dynamic mind-shaper within the Music Education department. In 2011, Larry graduated with his Bachelor of Music Education degree from Southeastern Louisiana University.

From 2013 to 2017, Larry taught at Fontainebleau High School as the Assistant Director of Bands. His responsibilities included instructing the Symphonic Band, teaching music and art appreciation courses, and working extensively with the Crimson Bulldog Marching Band. During his time there, his ensembles consistently scored superior and excellent ratings in competitions and were known as a strong and positive influence within the school and throughout the community. His students have gone on to find success performing in DCI ensembles, earn acceptance into and scholarships from top university music programs, graduate from college, and begin professional music and teaching careers.

Currently, Larry performs regularly with the Northshore Orchestra and the Northshore Brass. He also enjoys working as an active freelance musician on piano. Larry lives in Baton Rouge, LA with his beautiful wife and music-loving son.