Fall 12-2013

Evaluation of Alternate Mouthpiece Material Types to Minimize Vibrations and Heat Loss - The Research and Execution of Prototypes

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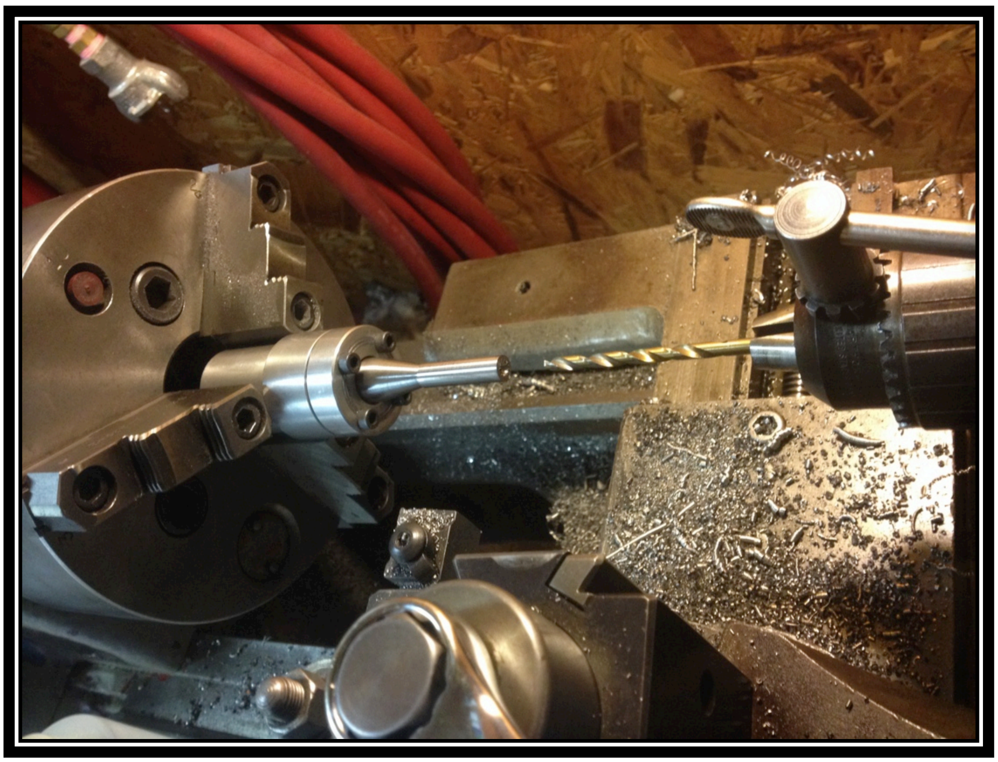

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MUS 499: BFA Performance Capstone

Marshall University

December 6, 2013

1pm DL 402

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By Kristen Bobuk

The elements of a mouthpiece contribute both individually and collectively to give the instrument its sound. There are ten main elements to a brass mouthpiece, including the inner rim diameter, rim width, rim contour, rim edge, cup, throat, backbore, shank, body material and plating material (as seen below). Every element of a mouthpiece contributes to the instrument's sound and each player chooses one mouthpiece that is available on the market that will complement his or her playing style. Shape and size are not the only contributors; the material used is also an important aspect. Traditionally, brass is the most common metal used and is typically plated in silver or gold, as many people are allergic to raw brass. Plastic is growing in popularity – particularly in marching bands – because it is less expensive and doesn't dent as easily as metal. It also has a much shorter warm up time. A drawback to plastic mouthpieces is that many musicians feel that the plastic produces a tone that is far inferior to that of metal. Through research and prototype construction, other options can be explored and can give the market a fresh, new look on mouthpiece material choice.

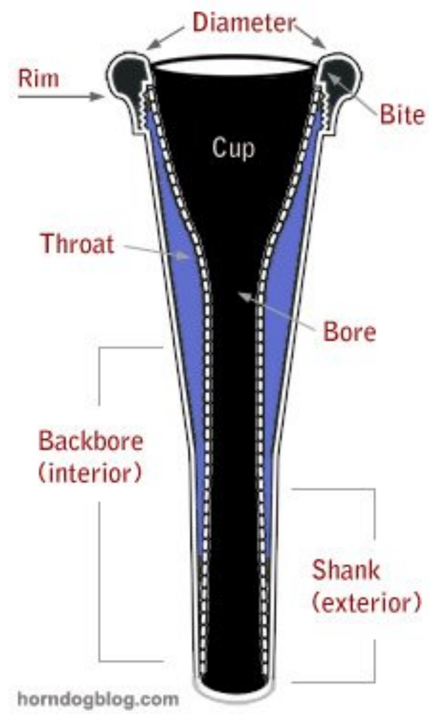

Figure 1 - Parts of a horn mouthpiece

Sound is a wave, specifically, travelling vibrations of some quantity or pressure. This begins with a mechanical motion in the medium through which it travels.[1] From here, pressure variations cause particles of the medium to vibrate and travel to an eardrum, where again, a mechanical motion vibrate the barrier as we hear sound. Density and hardness determine the speed of this pressure. Hardness is typically the dominating factor in propagating sound, so it will also be a dominating factor in determining the material for the new mouthpiece.

All instruments produce sound, yet they all do so in varying manners. These instruments are classified into four main groups: strings, woodwinds, brass, and percussion. From the primitive days, man found that if holes of a proper dimension and shape were cut in seashells, hollow animal horns, and other such objects, and these holes were blown with the lips in a certain manner, there would result a loud satisfying blast of sound.[2] From these humble beginnings there evolved modern instruments. The open cylindrical tube (i.e. open at both ends) became a flute. The cylindrical tube closed at one end became a clarinet. Conical tubes eventually evolved into what we know as the oboe and bassoon. Modern instruments are however, not as simple as a tube. These deviations turned out to be of significant musical importance.

Brass instruments, like the woodwinds, originated in primitive times. Acoustically, brass instruments could be classified along with the woodwinds as wind instruments, but they different in just enough important aspects that they merit separation; the most

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[1] John Carl Villanueva, "What Is Sound?," Universe Today, March 30, 2010, accessed November 10, 2013,http://www.universetoday.com/61166/what-is-sound/.

[2] Bate Philip, *Trumpet and Trombone* (New York: W. W. Norton and Company, Inc., 1980), 85.

important aspect being the origin of vibration.[3] In a woodwind, the vibrations are caused from an air stream or reed vibration, while a brass sound begins in the mouthpiece. Since human lips are significantly larger than a reed, they can more easily influence the air column vibrations. Second, the brass instrument uses the various resonance modes of the air column, but on a much larger scale. Finally, to obtain the pitches between these resonance modes, the brass instrument increases in length by means of adding additional tubing versus changing the tube by pressing buttons and covering holes.

Brass players place their lips on the ring of the mouthpiece and are placed under tension. By blowing air, they can be made to vibrate from the lungs, producing a buzzing sound. If the tension of the lips is increased, they will vibrate at a higher frequency, just as vibrating strings. If the ring is then placed against a tube, sound waves will begin to oscillate. The particular resonance frequency created in the air column closely mirrors that of the frequency of the lips.[4] This oscillation is known as the period or time in seconds required for one cycle. For our systems of sound, this number of cycles completed in one second is known as the frequency.

The mouthpiece consists of a small cup with a rim to accommodate the lips. The cup connects to a tapered tube of considerably smaller diameter than the rest of the instrument. This is where the biggest influence on the sound itself exists because of the change in oscillation influenced on the mouthpiece's shape and material. Once the sound wave exists the mouthpiece, it remains relatively steady.

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[3] John Backus, *The Acoustical Foundations of Music*, 2d ed. (New York: W. W. Norton & Company, 1977), 259.
[4] Ibid., 22-29

"The combination of a tuning fork and box illustrates a situation of great importance in physics. Whenever a system that can vibrate with a certain frequency is acted upon from the outside by a periodic disturbance that has the same frequency, vibrations of large amplitude can be produced in the system," this is known as resonance as defined by John Backus.[5] The frequency of the system is often referred to as the resonant frequency since it is the frequency for which excitement will produce the greatest response. This resonance will occur between the lips of the player and the mouthpiece.

Figure 2 - Tuning fork attached to a wooden box illustrating resonance

The mouthpiece of a brass instrument plays a significant role in the harmonics of the instrument. It actually brings the resonance into a harmonic sequence by bringing that resonance down with respect to the resonance of a closed tube.[6] Resonance is the

[5] Ibid., 76

[6] C.R. Nave, "The Mouthpiece Effect," HyperPhysics, November 9, 2013, accessed November 9, 2013, http://hyperphysics.phy-astr.gsu.edu/hbase/music/brassa.html.

tendency of a system to oscillate with greater amplitude at some frequencies than others. With respect to mouthpieces, these are sound waves. Resonance occurs when the system has accumulated enough energy to transfer between two storage modes - the player's lips and the mouthpiece. Acoustical resonance is the tendency of the specified acoustical system (the mouthpiece) to absorb more energy when it is forced to vibrate at a frequency that matches one of its own natural frequencies of vibration. This important phenomenon is an important consideration for the development of a mouthpiece as well as the rest of the instrument. Most acoustical instruments use an independent resonator such as the strings and body of a violin, the length of tube in a flute and the shape of a drumhead. As the mouthpiece brings this resonance down, it begins to act as a closed tube. This is the same as a "stopped pipe" in an organ; closed at one end. The tube has its own fundamental frequencies, but can also be overblown to produce other higher frequencies or notes.[7]

Hardness

In 1822, Frederich Mohs developed a scale for classifying mineral hardness. The scale is relative and classifies materials from 1 (softest) to 10 (hardest). Hardness depends on the crystallographic direction - meaning the strength of the bonds between the atoms in each crystal.[8] This also means that one material can have different classifications of hardness depending on the direction one measures this property. This explains any variance in given values. Mohs' hardness is a measure of the relative hardness and

[7] "Acoustic Resonance," Wikipedia, September 24, 2010, accessed November 7, 2013,http://en.wikipedia.org/wiki/Acoustic_resonance.

[8] "Mohs Scale of Hardness," Collector's Corner, November 10, 2013, accessed November 7, 2013,http://www.minsocam.org/msa/collectors_corner/article/mohs.htm.

resistance to scratching between mineral types. Mohs', as opposed to hardness tests performed by Rockwell, Vickers and Brinell rely on the ability to create an indentation into the tested material. Because sound waves perform on an atomic level, we must choose a hardness test that works on that same scale. Therefore, Mohs' hardness test will be used for the basis of hardness.

Material	**Hardness (unitless)**
Titanium	9.0
Steel	6.8
Stainless Steel	6.5
Cast iron	4.0
Brass	3.5
Bronze	3.0
Copper	2.8
Aluminum	2.7
Plastic	1.0

Figure 3 - Mohs hardness values

Recently, stainless steel (hardness value of 5 to 8.5) and titanium (hardness value of 9 to 9.5) mouthpieces have become available.[9] They are relatively rare but provide a more centered feel and sound by absorbing vibrations. This desired vibration absorption is because stainless steel and titanium are about twice as hard as brass (hardness value of 3 to 4), reducing unwanted vibrations because harder metal does not vibrate as easily. They are, however, much more expensive. We can see from the chart above the difference in hardness values and how they compare to each other.

When a player buzzes into a mouthpiece, the mouthpiece itself vibrates as well in all directions as your embouchure (facial muscles used to play a brass instrument)

[9] Ted Pella, "Hardness Tables Mohs Hardness Scale," Ted Pella, Inc, November 2, 2013, accessed November 2, 2013, http://www.tedpella.com/company_html/hardness.htm.

vibrates. The louder one plays, the more excess vibrations are created. The unwanted vibrations in brass mouthpieces can cause a crass tone and the pitches in the overtone series to be played unintentionally. This is caused by over blowing and the instrument produces an overtone instead of a fundamental tone, which is at a higher frequency and is unwanted. When the mouthpiece is vibrated at this higher frequency, it begins to produce the overtone pitches and boorish tone because of a separate sound wave. By using a harder material, it becomes much more difficult to produce this overtone, therefore, eliminating the crass tone. These vibrations cause a player to lose their intended sound and energy before the sound makes it into the horn. Joe Murphy, CEO of LOUD Mouthpieces and professional tuba player, gave the following testimonial.[10]

> Playing stainless steel, without a doubt, changed my life. As a professional tuba player, I feel like I have to "change the world" every time I perform, or somehow, nobody will ever like the tuba again. So, I put myself in the most extreme playing conditions possible. I write myself in the stratosphere constantly. I play at the highest dynamics I can possibly produce (depending on the job). I NEVER found a brass mouthpiece that did everything I thought a mouthpiece should do. As we all do, I searched and searched, looking for the "perfect" mouthpiece. I can tell you, I do things on stainless steel that I could not do on any brass mouthpiece. My range is a good fifth higher than it was on brass. I love stainless to such an extent that I started this company in 2005.

Thermal Conductivity

Thermal conductivity can tell us the ease upon which thermal energy (heat) can move through a material. Metals allow heat to travel through them quickly – meaning when a mouthpiece sits without being played, it can get cold quickly. This property is

[10] Joe Murphy, "Why Stainless Steel," LOUD Mouthpieces, November 7, 2013, accessed November 7, 2013,http://www.loudmouthpieces.com/whystainlesssteel_a/246.htm.

evaluated primarily in terms of Fourier's Law for heat conduction.[11] Heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity.

Stainless steel (thermal conductivity 16 W/m K) and Titanium (thermal conductivity 22 W/m K) are two very low conductive metals, meaning when room temperature is cold, more energy is needed for the player to warm up or keep the mouthpiece at a comfortable temperature; this is what makes plastic appealing as it has a thermal conductivity of 0.03 W/m K. Once that mouthpiece is warm, however, a low thermal conductivity will keep it warm for longer periods of time. The thermal conductivity of brass that is primarily used for base metal is 109.0 W/m K, a highly conductive metal. This means it will warm up quickly, but also cool off in just a small period of time; during a concert, for example, while not playing for a large number of measures. When the player reenters, they may not have the pitch accuracy they did before the break because of this. It is to the advantage of the player to have a mouthpiece made of a material of low thermal conductivity and have the mouthpiece stay warm for longer. The chart below compares metals of different thermal conductivity; both metals used and metals that are being considered.

[11] "Conductive Heat Transfer," The Engineering Toolbox, November 12, 2013, accessed November 12, 2013,http://www.engineeringtoolbox.com/conductive-heat-transfer-d_428.html#.Uo4kzGSgnyc.

Material	Thermal Conductivity (W/m K)
Plastic	0.03
Stainless Steel	16
Titanium	22
Steel	50.2
Cast iron	79.5
Brass	109
Bronze	110
Aluminum	205
Copper	401

Figure 4 - Thermal conductivity values[12]

There are a number of ways to find these values for thermal conductivity. Each method is only suitable for a limited range of materials - each depending on thermal properties and the median temperatures; the major difference being between steady-state and transient techniques. Steady-state trials are used when the temperature of the material does not change with time. Therefore, the signal analysis is relatively straightforward – steady-state implies constant signals. The downfall is that a well-engineered experimental setup is generally required. Transient techniques involve taking a measurement during the heating process and take temperature changes as a function of time. The advantage to this is that they can be performed more quickly, since there is no need to wait for the temperature to reach steady-state. The disadvantage to this method is the mathematical analysis is much more difficult. Thermal conductivity values today are generally

[12] "Thermal Conductivity of Some Common Materials and Gases," The Engineering Toolbox, November 21, 2013, accessed November 21, 2013, http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html.

measured by means of laser flash analysis.[13] An energy pulse heats one side of a plane-parallel sample, as the temperature rise on the backside rises due to the energy input is time-dependent detected.

In 1955, Fearn Ward filled a patent for a wooden mouthpiece for brass wind musical instruments. In 1959, he was granted this patent, 27 years after William Wolfe was granted the parent for a mouthpiece for horns. The patent gives the following justifications for using wood: configuration, material, durability, serviceability, playing qualities and ease and uniformity of manufacture at moderate cost.[14] Ward's explanation focuses on the thermal conductivity of wood and benefits over that of any metal; specifically, "less than one-half of 1%", or 0.5%. While Ward understood the benefits of using wood, with such a low thermal conductivity, his choice of material was poor. A few downfalls being that wood swells when it gets wet and any mouthpiece has substantial condensation and saliva on both sides, wood cannot prevent the unwanted vibrations causing a crass tone from overblowing, and wood can be very fragile.

Specific Heat

Specific heat tells us the amount of energy needed to heat the metal, while the rate of that heat transfer is the thermal conductivity. Both properties are important in understanding which material is optimal for a mouthpiece. Commonly, specific heat is defined as the ratio of the quantity of heat necessary to raise the temperature of a body one degree to that required to raise the temperature of an equivalent mass of water one

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[13] G Penco et al., "Thermal Properties Measurements Using Laser Flash Technique at Cryogenic Temperature," November 12, 2013, accessed November 12, 2013, http://accelconf.web.cern.ch/accelconf/p01/PAPERS/MPPH321.PDF.

[14] Fearn Ward, "Wooden Mouthpieces for Brass Wind Musical Instruments," Google, June 6, 1959, accessed November 9, 2013, http://www.google.com/patents/US2890614.

degree. By having a lower specific heat, less energy will be required to warm the mouthpiece. Aluminum has a specific heat of 0.9 KJ/Kg K, titanium is 0.523 KJ/Kg K, steel is 0.466 KJ/Kg K, cast iron is 0.450 KJ/Kg K, and brass is 0.380 KJ/Kg K. From these values in figure 5 below, we can see that brass is optimal from the available choices.

Material	**Specific Heat (KJ/Kg K)**
Brass	0.380
Copper	0.390
Bronze	0.435
Cast iron	0.450
Steel	0.466
Stainless Steel	0.500
Titanium	0.523
Aluminum	0.900
Plastic	1.670

Figure 5 - Specific heat values

Cost

The final and possibly most important property of these materials is the cost. To standardize the costs, they are based on current market prices for a 1-inch diameter solid round rod at 12 inches in length. While all mass-produced material changes with the market, these particular metals stay fairly constant relative to precious metals (i.e. gold, silver, platinum and palladium). These specific costs came from SpeedyMetals.com, the company where the metals for the prototypes were ordered. Of the options previously discussed, steel is the cheapest at only $7.60 with cast iron being nearly identical at $7.70. While stainless steel is known to be a very expensive metal, and is much more expensive than other metals, a 1-inch solid round rod is approximately $15.34.[15] The most

[15] "Metals Shopping for Orders of Every Size and Shape," Online Metals, October 7, 2013, Metals Shopping for Orders of Every Size and Shape.

expensive metal that has been evaluated is titanium at $134.36 for 12 inches, where raw material alone is more expensive than most brass mouthpieces' final cost. These costs are approximates, because each company sells their product for different prices based on machinability, chemical compositions, ductility, malleability, etc.

Material	Cost (per 1-inch diameter and 12-inches long)
Steel	$7.60
Cast iron	$7.70
Aluminum	$8.59
Stainless Steel	$15.34
Brass	$28.19
Plastic	$34.43
Bronze	$42.31
Copper	$43.66
Titanium	$134.36

Figure 6 - Cost of various materials

Plating

Different plating material can also have an impact on the overall quality of a mouthpiece. By experimenting with various materials, optimal combinations for different players with unique playing styles and preferences can be found. Plating, however, is less than one-thousandth of an inch thick. Its actual effect on the sound, comfort and properties of the material will be looked into through the blind study discussed in detail below. Though this study, players will evaluate playing comfort and sound from several different mouthpieces.

Plating choices, currently, are limited to gold and silver. Silver is by far the most common because it is cost effective and produces a good tone quality. Some believe it is not as comfortable as gold but it does have properties and qualities that some feel facilitate certain styles of playing. Silver can provide a clearer, dark tone, but requires more maintenance. Gold produces a fuller, rich tone and a darker timbre. Gold doesn't tarnish, and for those allergic to brass and/or silver, it is a better, but not economical plating alternative.

Chrome plating offers many substantial benefits. The technique of chromium plating is a technique of electroplating a thin later of chromium onto a metal object. The chrome layer can be decorative, provide corrosion resistance, ease cleaning procedure and increase surface hardness. The main benefit for using chrome plating is that chrome is the major difference between steel and stainless steel. Stainless steel is a steel alloy with a minimum of 10% weight percentage of chromium. This makes the steel "stain less", but not "stain proof".[16] Carbon steel rusts when exposed to air and moisture; this iron oxide film is active and accelerates corrosion by forming more iron oxide. Stainless steel has a sufficient amount of chromium present so that the passive film of chromium oxide forms which prevents further corrosion. By choosing a base material of carbon steel and plating in chrome, cost can be drastically reduced (by about 3 times) while maintaining the same benefits.

Also coated by electric current, copper plating will be tested. Because copper is so difficult to plate directly onto a passive surface, the mouthpiece must be nickel stricken first for the copper to adhere. As we learned earlier, copper is an excellent conductor of heat. However, due to the small amount of copper that will actually be present, we will need the blind testing to understand the true effects. The downside of copper plating is its reddish metal finish that will often clash with the color of most brass instruments. While

[16] Clarisse, "Difference between Steel and Stainless Steel," Difference Between.com, February 1, 2011, accessed November 7, 2013, http://www.differencebetween.com/difference-between-steel-and-stainless-steel/.

this is insignificant to the performance of the mouthpiece itself, for many players, it is noteworthy.

Another viable plating option is nickel. Nickel, as opposed to copper's reddish finish, is a silver-white metal. Nickel plating is mostly used for decorative finishes as it's smooth and offers a bright finish and advantages include high wear resistance, corrosion resistance, hardness, lubricity and magnetic properties.

Prototypes

At this time, the various dimensions of brass mouthpieces are already on the market. While there is a standard range for each dimension, nearly every plausible combination can be found. For the purpose of this project, it was decided to use a Giardinelli horn mouthpiece as the model. Giardinelli mouthpieces are known to be more comfortable than most other brands and are one of the classic, old standards of mouthpieces in the United States.[17] The model mouthpiece was dimensioned by use of digital calipers for the outside dimensions and a wax mold for the inside. A final drawing was drawn in MicroStation and can be seen below (values in inches). A larger drawing can be found in Appendix B.

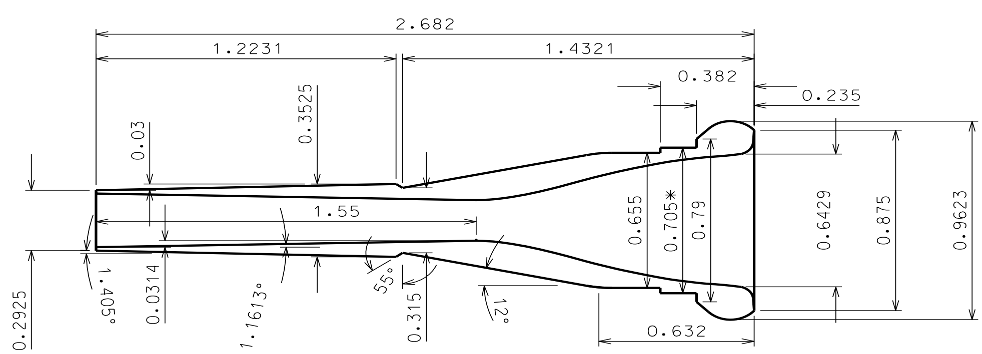

Figure 7 - Dimensions used for mouthpiece prototype fabrication in inches

[17] John Ericson, "Giardinelli Horn Mouthpieces through the Ages," Horn Matters, September 22, 2009, accessed November 12, 2013, http://hornmatters.com/2009/09/giardinelli-horn-mouthpieces-through-the-ages/.

Finding the optimal combination of base material and plating material comes down to finding the best of each property and deciding on it's importance. The three materials chosen for prototype creation were 1144 stress proof steel, grade 40 continuously extruded round bar cast iron (Durabar) and 6061-t6 aluminum. Steel was chosen because of its high hardness value, low thermal conductivity and low cost. Cast iron was chosen, primarily because it is the base element of steel. Steel is made up of 95-99% iron; the remaining elements can include manganese, phosphorus, sulfur, silicon and traces of oxygen, nitrogen and aluminum.[18] Adding a minimum of 10% chromium to the steel produces stainless steel. As can be seen in Figure 8 below, there is no noticeable difference between the commercially available mouthpieces (far left) and the fabricated mouthpieces (center and right).

Figure 8 - (left to right) Original, steel, cast iron

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[18] "Steel Composition," Key to Metals, November 7, 2013, accessed November 7, 2013,http://www.keytometals.com/page.aspx?ID=SteelComposition&LN=EN.

In the image above, the far left is the model (brass with silver plating), the middle is steel and right is cast iron. The steel and cast iron appear to be nearly identical to an observer. The third chosen material is aluminum because it adds an additional option for young players in marching bands as an enhanced alternative to plastic mouthpieces. It also adds an outlier for testing and aids in expanding results to the opposite end. Both steel and cast iron have relative high values of specific heat compared to the other materials in consideration, but aluminum is half of that of plastic, making it a much more suitable option. The two materials, plastic and aluminum, also differ significantly in thermal conductivity, however, for this, plastic has the advantage. Being on a scale of only 1 – 10, the difference between plastic's hardness value of 1.0 and aluminum's value of 2.7 is quite significant. The cost is also much less ($34.43 for plastic and only $8.59 for aluminum) making aluminum the better choice. A chart of all properties and values for materials discussed in this research can be found in Appendix D.

Prior to the early 1900's, natural horn (a horn with no valves) mouthpieces were formed from sheet metal. The dimensions were taken from the original via wax cast of the interior and calipers for the exterior. These dimensions are then used to make a steel mandrel on a lathe upon which the body of the mouthpiece was formed. From here, a pattern must be made to determine the shape of the sheet metal that will be used to cut the body. This pattern is cut out of the sheet metal (brass or silver) and formed into a cone and the seam is jointed with a high-temperature silver solder. Once formed, the cone fits loosely over the mandrel. The sheet metal is then formed to fit closely to the mandrel and a drawing process tentatively shapes the cone perfectly to the shape of the mandrel. The rim is turned on a lathe from a thick disk cut from the end of a 1 inch diameter brass rod.

The finished rim, body and shank are then soldered together with a lower-melting-point silver and given a final polishing.[19] This process was used until the early 1900's when the metal lathe became much safer and more popular. Machining from a single solid cylinder of metal rather than a sheet metal cone created a much smoother sounding mouthpiece and also produced much heavier product which aided in a better tone.

The newly created prototypes began by chunking the 1" diameter solid cylindrical rod with approximately 3 inch extending beyond the chunk jaws. The stock's raw end was smoothed and a 3/16 inch hole was drilled 1-1/4 inch deep, just beyond the future location of the bore. The throat and cup were then machined to a pattern developed from those of the original mouthpiece. This was the most time consuming and tedious part of the production process. The exterior shoulder, just behind the rim, was machined to the correct diameter and width, leaving a ring of material where the diameter and rim would be formed as seen in the image below. The diameter and rim were then machined to match the original as a pattern. The bite was hand-filed. The exterior of the mouthpiece was then machined, reducing it up to the shoulder previously formed. It was then tapered down to the shank created and roughed out, leaving it oversized for subsequent machining. All parts machined to this point were polished with an emery cloth, working up from 120 to 400 grit. The mouthpiece was then cut off the stock long and mounted in a fixture, which allowed for the shank and backbore to be machined. The shank was turned to its largest diameter and drilled 3/16 inch into the throat.

[19] Richard Seraphinoff, "How to Make a Classical Horn Mouthpiece," Natural Horns by Richard Seraphinoff, November 13, 2013, accessed November 13, 2013, http://www.seraphinoff.com/Content.aspx?fd6cd985-a1e0-4af7-9f5d-e1d2ad1dd3e3.

The overall length of the mouthpiece was then measured using a depth gauge and trimmed as necessary. A taper was then machined on the shank and a tapered reamer was used to create the backbore. Surfaces were again polished using the process previously detailed. The bore was then fine-tuned from each side with the tapered reamer until a 0.195-inch diameter gauge would just pass through. Final polishing was done on a cloth-polishing wheel with polishing compound. The mouthpieces were then cleaned with mineral spirits to remove and oil and polishing compound prior to wash with soap and water. Photographs from this process can be found in Appendix E.

Figure 9 – Prototype after turning the rim

Because six mouthpieces were created, the options for plating were near ideal. One steel and one cast iron were plated in chrome because of its significant advantages and also to make them near stainless steel without the cost. The remaining steel mouthpiece was plated in copper while the final cast iron was plated in nickel. Both aluminum mouthpieces were anodized, an electrolytic passivation process used to increase the thickness of the natural oxide layer on the surface of the metal.[20] This process increases corrosion resistance and changes the texture of the surface, changing the crystal structure of the metal near the surface. The aluminum mouthpieces were not plated as the others were for many major reasons. Aluminum corrodes instantly during the plating process, making it difficult to get a good bond with the metal plating being applied.

Evaluation

To evaluate the quality of the newly created mouthpieces, a blind study will be conducted with potential candidates including brass Marshall University faculty members and the horn studio. Participating evaluators being asked to play different mouthpieces and give their personal preference based on a set of questions listed in Appendix C. All evaluators will play the same mouthpieces and will respond to the same question set. Mouthpieces to be included in the blind test will include a silver plated brass mouthpiece, a gold plated brass mouthpiece, a plastic mouthpiece and the six prototypes created. These questions will begin with base questions about currently played mouthpiece(s). This information is significant because knowing the basis for comparison is always important. For example, if the player already plays a titanium mouthpiece, theoretically, everything else by comparison will rank low. However, if the player currently plays on a plastic mouthpiece, everything in comparison should rank high. The next group of questions ranks each mouthpiece played on a scale of one to five; one indicating they would definitely not play it on a regular basis, five indicating they definitely would.

[20] "Anodizing... the Finish of Choice," Aluminum Anodizers Council, November 7, 2013, accessed November 7, 2013, http://www.anodizing.org/Anodizing/what_is_anodizing.html.

Finally, a list of side-by-side comparison questions will be conducted, similar to an eye exam. The two highest ranked mouthpieces will be played back to back and the subject will chose their favorite. This will be followed by the chosen favorite compared to their third top ranked and so on until one mouthpiece is undoubtedly their favorite. In the case of an anomaly in their decision, more side-by-side comparisons will be done.

Mouthpieces made of a different material other than brass, stainless steel, and titanium can offer many appealing qualities to players at an affordable cost. Alternate materials can provide the hardness required for vibration mitigation and thermal properties for comfort, which will retain heat and prevent overblowing. With each different material option comes the opportunity for a player to find the "one" that fits their individual playing style and comfort. These alternate metals can limit the unwanted vibrations as stainless steel does but can also reduce the conductivity that makes a mouthpiece feel cold when not played.

Works Cited

"Acoustic Resonance." Wikipedia. September 24, 2010. Accessed November 13, 2013.http://en.wikipedia.org/wiki/Acoustic_resonance.

"Anodizing... the Finish of Choice." Aluminum Anodizers Council. November 7, 2013. Accessed November 7, 2013. http://www.anodizing.org/Anodizing/what_is_anodizing.html.

Backus, John. *The Acoustical Foundations of Music*. 2d ed. New York: W. W. Norton & Company, 1977.

"Conductive Heat Transfer." The Engineering Toolbox. November 12, 2013. Accessed November 12, 2013. http://www.engineeringtoolbox.com/conductive-heat-transfer-d_428.html#.Uo4kzGSgnyc.

Clarisse. "Difference between Steel and Stainless Steel." Difference Between.com. February 1, 2011. Accessed November 7, 2013. http://www.differencebetween.com/difference-between-steel-and-stainless-steel/.

"Metals Shopping for Orders of Every Size and Shape." Online Metals. October 7, 2013. Metals Shopping for Orders of Every Size and Shape.

"Mohs Scale of Hardness." Collector's Corner. November 10, 2013. Accessed November 10, 2013.http://www.minsocam.org/msa/collectors_corner/article/mohs.htm.

Murphy, Joe. "Why Stainless Steel." LOUD Mouthpieces. November 7, 2013. Accessed November 7, 2013. http://www.loudmouthpieces.com/whystainlesssteel_a/246.htm.

Nave, C.R. "The Mouthpiece Effect." HyperPhysics. November 9, 2013. Accessed November 9, 2013. http://hyperphysics.phy-astr.gsu.edu/hbase/music/brassa.html.

Pella, Ted. "Hardness Tables Mohs Hardness Scale." Ted Pella, Inc. November 2, 2013. Accessed November 2, 2013. http://www.tedpella.com/company_html/hardness.htm.

Philip, Bate. *Trumpet and Trombone*. New York: W. W. Norton and Company, Inc., 1980.

Seraphinoff, Richard. "How to Make a Classical Horn Mouthpiece." Natural Horns by Richard Seraphinoff. November 13, 2013. Accessed November 13, 2013.http://www.seraphinoff.com/Content.aspx?fd6cd985-a1e0-4af7-9f5d-e1d2ad1dd3e3.

"Steel Composition." Key to Metals. November 7, 2013. Accessed November 7, 2013.http://www.keytometals.com/page.aspx?ID=SteelComposition&LN=EN.

"Thermal Conductivity of Some Common Materials and Gases." The Engineering Toolbox. November 21, 2013. Accessed November 21, 2013.http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html.

Villanueva, John Carl. "What Is Sound?" Universe Today. March 30, 2010. Accessed November 10, 2013. http://www.universetoday.com/61166/what-is-sound/.

Ward, Fearn. "Wooden Mouthpieces for Brass Wind Musical Instruments." Google. June 6, 1959. Accessed November 9, 2013. http://www.google.com/patents/US2890614.

Appendix A

Capstone Proposal

Evaluation of Alternate Mouthpiece Material Types to Minimize Vibrations and Heat Loss – The Research and Execution of Prototypes

Senior Capstone Proposal for MUS 499

By Kristen Bobuk

Introduction

There are ten main elements to a brass mouthpiece. These include the inner rim diameter, rim width, rim contour, rim edge, cup, throat, backbore, shank, body material and plating material. Each of these elements contribute both individually and collectively to give the instrument its sound. Every element of a mouthpiece contributes to the instrument's sound and each player chooses one mouthpiece that is available on the market that will complement his or her playing style. Shape and size are not the only contributors; the material used is also an important aspect. Traditionally, brass is the most common metal and is typically plated in silver or gold, as many people are allergic to raw brass. Plastic is growing in popularity – particularly in marching bands – because they are less expensive and don't dent as easily as metal. They also have a much shorter "warm up time". A drawback to plastic mouthpieces is that many musicians feel that the plastic produces a tone that is far inferior to that of metal. Through research and prototype construction, other options can be explored and can give the market a fresh, new look on mouthpiece material choice.

Rationale

Recently, stainless steel (hardness value of 5 to 8.5) and titanium (hardness value of 9 to 9.5) mouthpieces have become available. They are relatively rare but provide a more centered feel and sound by absorbing vibrations. This desired vibration absorption is because stainless steel and titanium are about twice as hard as brass (hardness value of 3 to 4), reducing unwanted vibrations because harder metal does not vibrate as easily. They are, however, much more expensive.

Plating choices, currently, are limited to gold and silver. Silver is by far the most common because it is cost effective and produces a good tone quality. Some believe it is not as comfortable as gold but it does have properties and qualities that some feel facilitate certain styles of playing. Silver can provide a clearer, dark tone, but requires more maintenance. Gold produces a fuller, rich tone and a darker timbre. Gold doesn't tarnish, and for those allergic to brass and/or silver, it is a better, but not economical plating alternative.

Thermal conductivity can tell us the ease upon which thermal energy (heat) can move through a material. Metals allow heat to travel through them quickly – meaning when a mouthpiece sits without being played, it can get cold quickly.

Many more material choices can be explored beyond what is on the general market. With each different material option comes the opportunity for a player to find the "one" that fits their individual playing style and comfort. These alternate metals can limit the unwanted vibrations as stainless steel does but can also reduce the conductivity that makes a mouthpiece feel cold when not played. Stainless steel (thermal conductivity 16 W/m K) and Titanium (thermal conductivity 22 W/m K) are two very low conductive metals, meaning once the mouthpiece has been warmed up, it will stay warm longer. This is what makes plastic appealing as it has a thermal conductivity of 0.03 W/m K, meaning it retains heat much longer than the metals in question. The thermal conductivity of brass that is primarily used for base metal is 109.0 W/m K, a very conductive metal, so it will cool off much quicker than stainless steel or titanium. This capstone project will research other metals that can reduce the undesired vibrations but also have a low conductivity.

The specific heat tells us the amount of energy needed to heat the metal, while the rate of that heat transfer is the thermal conductivity. Both properties are important in understanding which material is optimal for a mouthpiece. By having a lower specific heat, less energy will be required to warm the mouthpiece. Aluminum has a specific heat of 0.9. J/gm K, titanium is 0.523 J/gm K, steel is 0.466 J/gm K, iron is 0.450 J/gm K, and brass is 0.380 J/gm K.

Different plating material can also have an impact on the overall quality of a mouthpiece. By experimenting with various materials, optimal combinations for different players with unique playing styles and preferences can be found. Plating, however, is less than one-thousandth of an inch thick. Its actual effect on the sound, comfort and properties of the material will be looked into through the blind study discussed below.

At this time, the various dimensions of brass mouthpieces are already on the market. While there is a standard range for each dimension, nearly every plausible combination can be found. For this capstone project, the most common dimensions will be used.

The unwanted vibrations in brass mouthpieces can cause a crass tone and the pitches in the overtone series to be played unintentionally. This is caused by over blowing and the instrument produces an overtone instead of a fundamental tone, which is at a higher frequency and is unwanted. When the mouthpiece is vibrated at this higher frequency, it begins to produce the overtone pitches and crass tone because of a separate sound wave. By using a harder material, it becomes much more difficult to produce this overtone, therefore, eliminating the crass sounds associate with it.

Hypothesis

Mouthpieces made of a different material other than brass, stainless steel and titanium can offer many appealing qualities to players at an affordable cost. Alternate materials can provide the hardness required for vibration mitigation, thermal properties for comfort which will retain heat and prevent overblowing. This capstone project will evaluate new base materials and plating material suitable for any horn player and create prototypes for testing.

Methodology

To find optimal combinations of materials for mouthpieces, three independent but concurrent research projects must be conducted – one for sizing of the mouthpiece dimensions, one for optimal vibrations and one for thermal issues. Once the optimal mouthpiece is proposed, a small but adequate sample size of aluminum, steel and cast mouthpieces will be created. Plans will be drawn up in Bentley MicroStation (CAD software) and prototypes of these mouthpieces will be fabricated by means of a lathe. Once these prototypes are created, final products will be plated in a variety of materials until one is chosen as the best option based on results from the blind study.

Evaluation

To evaluate the playability of the newly created mouthpieces, a blind study will be conducted with potential candidates including brass Marshall University faculty members and the horn studio. Participating evaluators being asked to play different mouthpieces and give their personal preference based on a set of questions listed in Appendix C. All participants will play the same mouthpieces and will respond to the same question set. Mouthpieces to be included in the blind test will include a silver plated brass mouthpiece, a gold plated brass mouthpiece, a plastic mouthpiece and all prototypes created. The sample size of market available mouthpieces is dependent on availability.

Summary

Current options in the market for brass mouthpieces are very small yet there are many other viable options that have not yet been explored therefore forcing musicians to choose one that may not fulfill their playing needs or enhance their style. Through research and prototype construction, other options can be explored and can give the market a fresh, new look on mouthpiece material choice.

Advisor Approval:

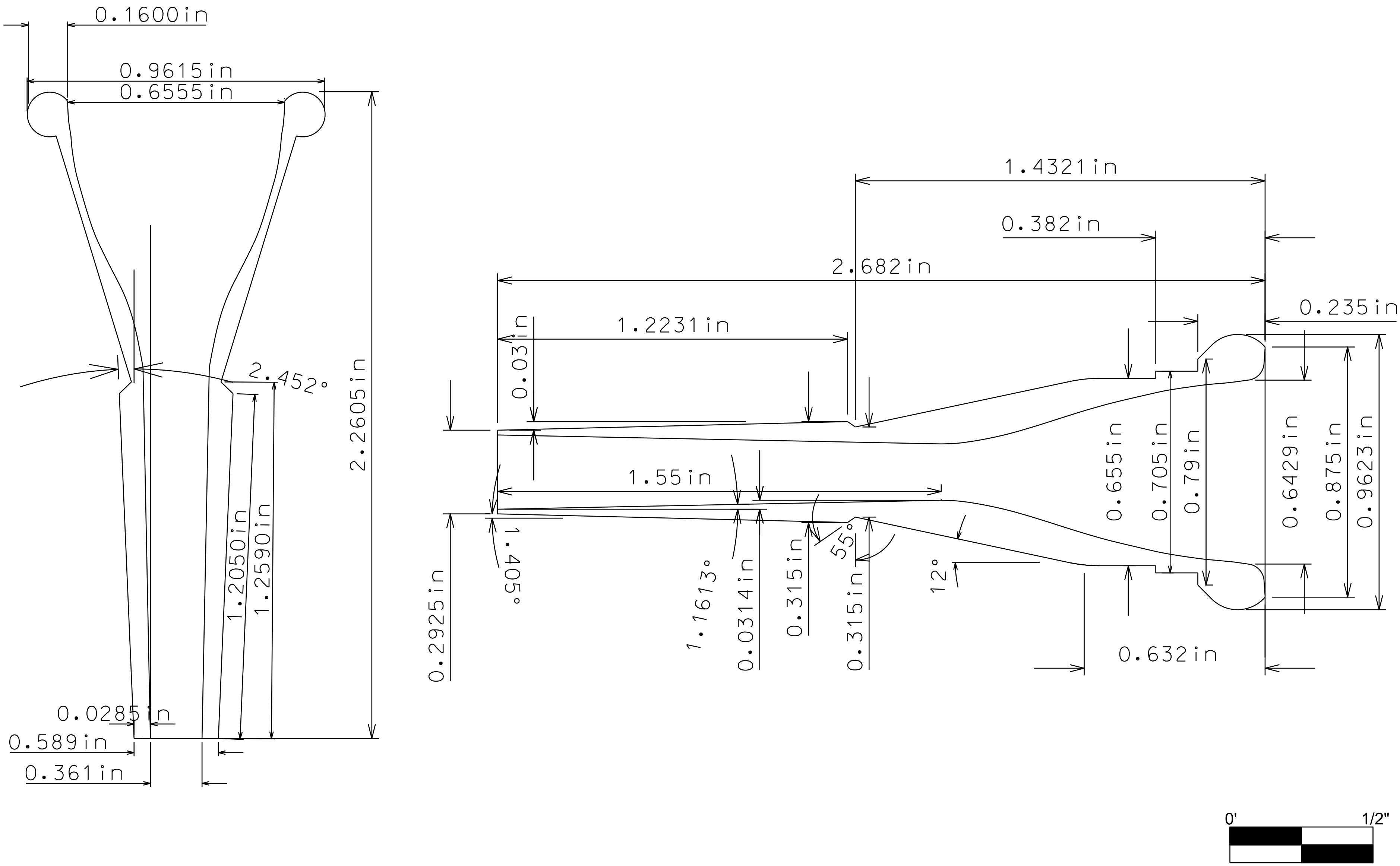
Dr. Stephen Lawson ____

Dr. Martin Saunders ____

Professor Jeffrey T. Huffman, M.S., P.E. _______________________________________

Appendix B

Original Mouthpiece Dimensions



Drawn By: Kristen Bobuk and Bryan Bledsoe	Designed By: Kristen Bobuk	Course: MUS 499	BFA Performance Capstone
Title: Original Mouthpiece Dimensions	Date: 12/6/2013	Scale: 1 inch = 1/2 inch	Sheet 1 of 1

Appendix C

Mouthpiece Evaluation Questions

Mouthpiece Evaluation

Participants Name: ____

Date: _______________________

How many years of horn experience do you have? __________

How many years of brass playing experience do you have? __________

Class Ranking: Fr So Jr Sr GS Faculty

Player Rating: 1 2 3 4 5 6 7 8 9 10

1 = Non music major, no horn experience

2 = Non music major, some horn experience

3 = Music major, some brass experience

4 = Music major, some horn experience

5 = Music major, brass major, lower level

6 = Music major, horn major, lower level

7 = Music major, brass major, upper level

8 = Music major, horn major, upper level

9 = Professional brass player

10 = Professional horn player

What mouthpiece do you currently play?

What material is it made out of?

What material is it plated with?

Brass, Silver plating, Stock

On a scale of 1 to 5, 1 being not at all and 5 being definitely yes, how likely would you be to use this mouthpiece on a regular basis?

1 2 3 4 5

Brass, Gold plating, Stock

On a scale of 1 to 5, 1 being not at all and 5 being definitely yes, how likely would you be to use this mouthpiece on a regular basis?

1 2 3 4 5

Steel, Prototype

On a scale of 1 to 5, 1 being not at all and 5 being definitely yes, how likely would you be to use this mouthpiece on a regular basis?

1 2 3 4 5

Aluminum, Prototype

On a scale of 1 to 5, 1 being not at all and 5 being definitely yes, how likely would you be to use this mouthpiece on a regular basis?

1 2 3 4 5

Cast Iron, Prototype

On a scale of 1 to 5, 1 being not at all and 5 being definitely yes, how likely would you be to use this mouthpiece on a regular basis?

1 2 3 4 5

Which do you prefer?

This section will vary by participant. The mouthpiece with the highest likelihood will be compared to the second. The chosen mouthpieces will then be compared to the third highest, down to the bottom until one mouthpiece is overwhelmingly chosen.

_______________________________________ or _______________________________________

_______________________________________ or _______________________________________

_______________________________________ or _______________________________________

_______________________________________ or _______________________________________

_______________________________________ or _______________________________________

_______________________________________ or _______________________________________

_______________________________________ or _______________________________________

Appendix D

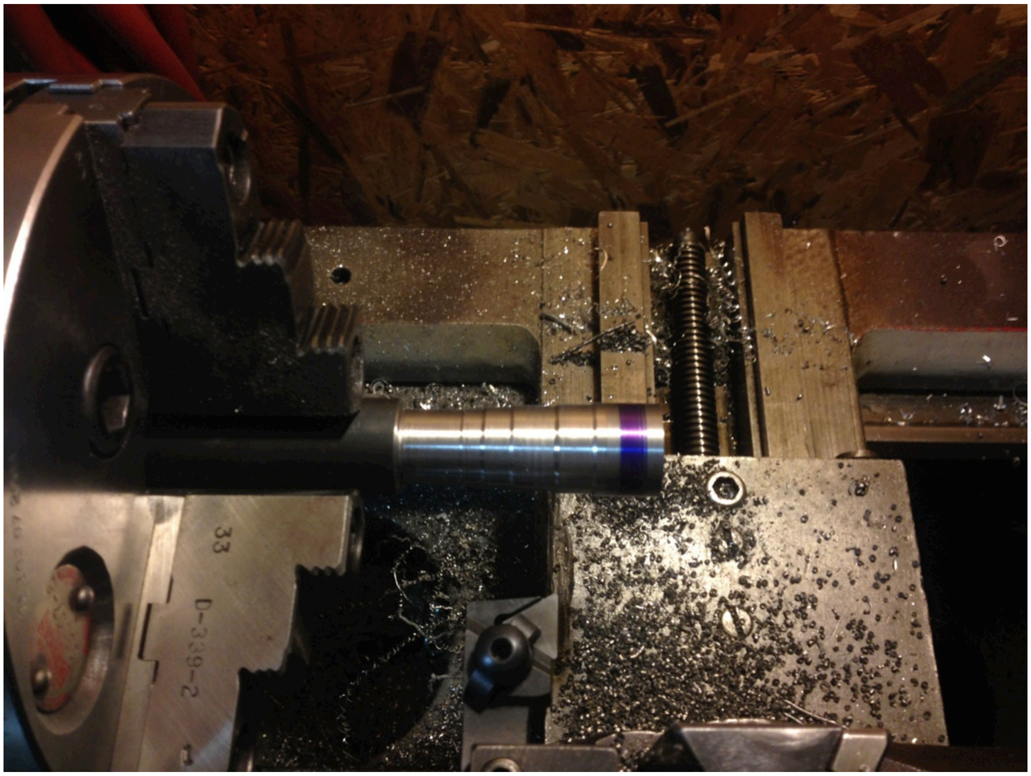
Material Properties and Values

Material	Density (kg/m3)	Hardness (unitless)	Thermal Conductivity (W/m K)	Specific Heat (KJ/Kg K)	Cost (1 inch round, 12 inch long)
Aluminum	2720	2.5-2.9	205	0.900	$8.59
Brass	8650	3-4.0	109	0.380	$28.19
Bronze	8400	3	110	0.435	$42.31
Cast iron	7300	4	79.5	0.450	$7.70
Copper	8940	2.5-3	401	0.390	$43.66
Plastic	1500*	1	0.03	1.670	$34.43
Stainless Steel	7740	6.5	16	0.500	$15.34
Steel	7850	5.5-8	50.2	0.466	$7.60
Titanium	4500	9	22	0.523	$134.36

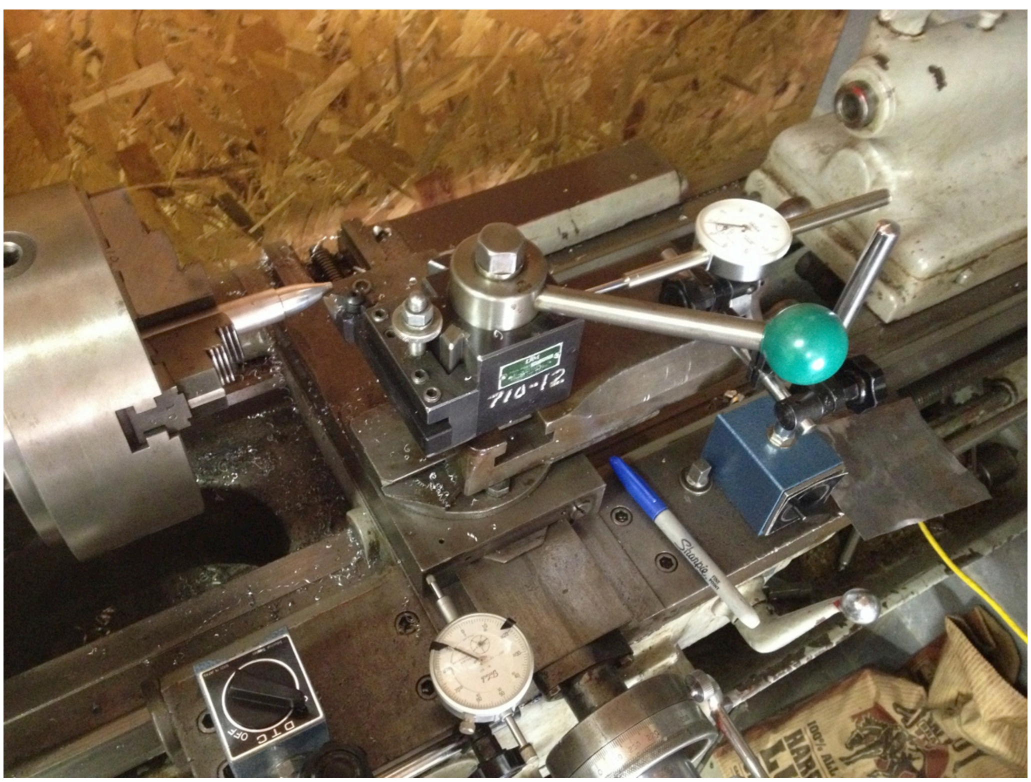
***Values vary greatly**

Appendix E

Prototype Creation Photographs

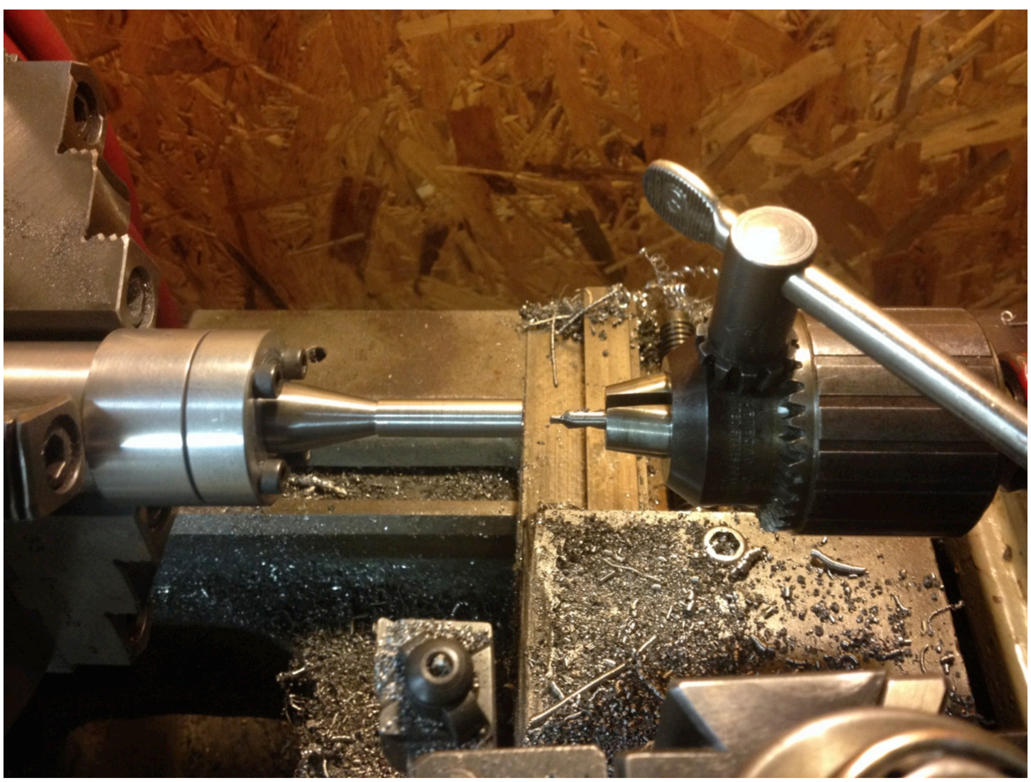


Machining of cup, throat and bore is finished; rough turning of outside features



Developing positive pattern of cup and throat to follow while machining mouthpieces

Finishing turning shoulder behind rim to final diameter



All except backbore and shank is complete and mouthpiece has been cut out of stock and mounted in fixture. Preparing to drill backbore and turn tapered shank

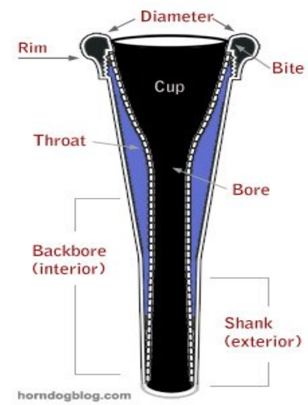
Appendix F

Presentation Slideshow

Evaluation of Alternate Mouthpiece Material Types to Minimize Vibrations and Heat Loss – The Research and Execution of Prototypes

By Kristen Bobuk

Parts of a Mouthpiece



How Sound is Produced

- Brass players place their lips on the ring of the mouthpiece and are placed under tension.
- By blowing air, they can be made to vibrate from the lungs, producing a buzzing sound.

How Sound is Produced

- If the tension of the lips is increased, they will vibrate at a higher frequency, just as vibrating strings.
- If the ring is then placed against a tube, sound waves will begin to oscillate.

Current Market

- Brass
  - Silver plating $35 - $75
  - Gold plating $85 - $135
    - Prices based on WWBW.com
- Stainless Steel No plating required
  - $120-$130
    - Kelly and Giddings and Webster brands
- Titanium No plating required
  - $285
    - Giddings and Webster

Important Properties

- Hardness
- Thermal Conductivity
- Specific Heat
- Cost

Breaking a Glass With Sound

Hardness

- When a player buzzes into a mouthpiece, the mouthpiece itself vibrates
- The louder one plays, the more excess vibrations are created
- The unwanted vibrations can cause a crass tone and the pitches in the overtone series to be played unintentionally
- Solution: A harder base material

Hardness

Material	Mohs' Hardness (1-10)
Titanium	9.0
Steel	6.8
Stainless Steel	6.5
Cast Iron	4.0
Brass	3.5
Bronze	3.0
Copper	2.8
Aluminum	2.7
Plastic	1.0

1 = Softest 10 = Hardest

Thermal Conductivity

- Thermal conductivity can tell us the ease upon which thermal energy (heat) can move through a material
- Metals allow heat to travel through them quickly – meaning when a mouthpiece sits without being played, it can get cold quickly.

Thermal Conductivity

- Heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity.

Thermal Conductivity

Material	Thermal Conductivity (W/mK)
Plastic	0.03
Stainless Steel	16
Titanium	22
Steel	50.2
Cast Iron	79.5
Brass	109
Bronze	110
Aluminum	205
Copper	401

Specific Heat vs. Thermal Conductivity

- Specific heat tells us the amount of energy needed to heat the metal, while the rate of that heat transfer is the thermal conductivity
- Both properties are important in understanding which material is optimal for a mouthpiece

Specific Heat

- Specific heat is defined as the ratio of the quantity of heat necessary to raise the temperature of a body one degree to that required to raise the temperature of an equivalent mass of water one degree
- By having a lower specific heat, less energy will be required to warm the mouthpiece

Specific Heat

Material	Specific Heat (KJ/Kg K)
Brass	0.380
Copper	0.390
Bronze	0.435
Cast Iron	0.450
Steel	0.466
Stainless Steel	0.500
Titanium	0.523
Aluminum	0.900
Plastic	1.670

Cost

- The final and possibly most important property of these materials is the cost
- To standardize the costs, they are based on current market prices for a 1" diameter solid round rod at 12" in length

Cost

- While all mass-produced material changes with the market, these particular metals stay fairly constant relative to precious metals (i.e. gold, silver and platinum)

Cost

Material	Cost $
Steel	$7.60
Cast Iron	$7.70
Aluminum	$8.59
Stainless Steel	$15.34
Brass	$28.19
Plastic	$34.43
Bronze	$42.31
Copper	$43.66
Titanium	$134.36

Plating

- Different plating material can also have an impact on the overall quality of a mouthpiece
- By experimenting with various materials, optimal combinations for different players with unique playing styles and preferences can be found

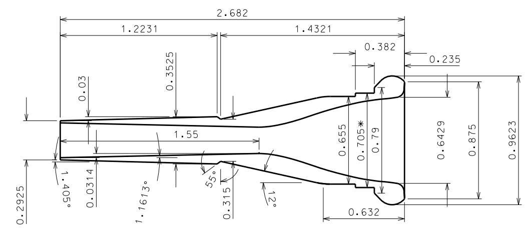
Plating

- Plating is less than 1/1000 of an inch thick
- Its actual effect on the sound, comfort and properties of the material will be looked into through the blind study
- Though this study, players will evaluate playing comfort and sound from several different mouthpieces.

Plating

- Chrome plating offers significant benefits
  - Corrosion resistance
  - Increase surface hardness
  - Stainless steel is carbon steel with <10% chrome
- Copper and Nickel were also used
  - Copper: Reddish metal finish
    - Excellent conductor of heat
  - Nickel: Silver-white metal finish
    - High wear and corrosion resistance
    - Increases hardness

Prototypes



- Values in inches

Prototypes

- 1144 stress proof steel
  - Only difference from stainless steel is 10% chrome
  - Very hard, low thermal conductivity
- Grade 40 continuously extruded round bar cast iron (Durabar)
  - Base material of steel/stainless steel
- 6061-t6 aluminum
  - Alternative to plastic

Prototypes

- Produced on a metal lathe
- Finished with emory cloth and polished
- Cleaned with mineral spirits and soap and water

Prototypes

Plating the Prototypes

- 6 prototypes
  - 2 steel
  - 2 cast iron
  - 2 aluminum
- Plating options:
  - Anodizing
  - Brass plating
  - Chrome plating
  - Copper plating
  - Heat treated
  - Nickel plating
  - Painting
  - Powder coating
  - Silver plating
  - Tin plating
  - Zinc plating

Plating the Prototypes

- Both aluminum mouthpieces were anodized and dyed

• Steel	-	Chrome plating
• Steel	-	Copper plating
• Cast iron	-	Chrome plating
• Cast iron	-	Nickel plating

Evaluation

- A blind study was developed
- Participating evaluators from Marshall University and the Huntington Symphony Orchestra were going to be asked to play the newly created mouthpieces and evaluate them.
- Unfortunately, the mouthpieces were not completed in time.

Evaluation

- Aluminum pieces could not be done alone and needed a larger batch to be anodized with
- Chrome solution took extra time to be shipped
  - Hexavalent chromium is toxic
  - Problem with new solution
- Problem with the new solution

Final Product

Conclusion

- Mouthpieces made of a different material other than brass, stainless steel, and titanium can offer many appealing qualities to players at an affordable cost
- Alternate materials can provide the hardness required for vibration mitigation and thermal properties for comfort, which will retain heat and prevent overblowing

Conclusion

- With each different material option comes the opportunity for a player to find the "one" that fits their individual playing style and comfort
- These alternate metals can limit the unwanted vibrations as stainless steel does but can also reduce the conductivity that makes a mouthpiece feel cold when not played