Acoustic Effects of Variables in Saxophone Accessories

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Abstract

The saxophone is a complicated instrument that has changed its tune multiple times throughout its history. Besides the player, the most important factors in determining the sound and response of the saxophone are its accessories - namely, reeds and mouthpieces. Against the backdrop of modern manufacturing advancements, this report provides saxophonists with a comprehensive exploration of variables in mouthpieces and reeds influencing their instrument's acoustics. The history and anatomy of each accessory is explored, as well as the benefits and deficits of choices of materials for each. The basic acoustic properties of the saxophone are covered to give readers an understanding of how variables can affect the response and tone of the instrument. By presenting and analyzing the measured effects of these variables, this report aims to empower professional players to make informed decisions, encouraging a departure from biases towards vintage gear. Additionally, it calls for increased transparency from manufacturers, advocating for clear specifications to guide players in their gear selection.

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I. Introduction

Since the invention of the saxophone in the late 1800s, the instrument and its various equipment have undergone numerous developments and changes. The early 1900s brought about a growing market for saxophones (and consequently, its accessories) with its popularization in marching and dance bands. Throughout the 1900s, player demands changed as new musical genres and styles of playing emerged. Jazz and swing bands in the 1930's led to bebop in the 1950's, and finally to pop in the 1970's. The saxophone went from being an instrument that was known for its soft, rounded timbre to a raucous screaming horn at the climax of every pop hit. Naturally, to accommodate these needs, saxophone accessories changed their tune at every step of development.

Today, developments in manufacturing techniques have made it possible to produce instruments and associated accessories that are customizable and interchangeable in a way that is simply overwhelming. Though having options as a player, competition in these markets, and the advancement in manufacturing techniques and efficiency are all ultimately good things for the saxophone world, there are some issues. First of all, most players are not experts on how the physics of their instrument work. This lack of knowledge means that advertisers have free reign on how they hook players into buying their new accessory. For example, Selmer, a historic company in saxophone production, released a mouthpiece called the "Jazz Flow" as of November 2023. How did they communicate its qualities to players? Did they list the specs? Show pictures of the important parts of the mouthpiece for tone production, such as the facing, baffle, and chamber? Explain how it might sound or respond? No. They have pictures of the external body of the mouthpiece, and say it's "inspired" by an older model (which means absolutely nothing). Saxophonists often have a bias towards older equipment due to this same lack of knowledge on how their instrument works. According to Mark Pipes, "...saxophonists will claim that contemporary materials and manufacturing techniques are inferior and cannot produce a product that compares to the heralded greats." (2018, pp. 4).

As a saxophone and woodwind player myself, I have been a victim of "gear-frenzy": That is, the chronic issue of never being able to settle on a single horn, mouthpiece, brand of reed, or even ligature for an extended amount of time. While experimentation is fine, lacking the awareness on how a given accessory might affect the actual response and resonance of your instrument can be frustrating. For this reason, I believe manufacturers can be more transparent with the specifications of the gear they are selling and why they are making it the way they are, and players can become more educated on what has been shown scientifically to produce a change in sound or response of an instrument.

I.I. Focus and Audience

The research and conclusions drawn in this report focus specifically on two accessories: reeds and mouthpieces. For this reason, the research here will be most applicable to woodwind instruments with those attributes, such as the clarinet and the saxophone. Furthermore, the saxophone has the broadest range in terms of its use in various musical styles, so more players gravitate to extreme setups than players of other woodwinds. As a result, this research is tailored to saxophonists. This is the instrument that manufacturers have experimented with the most in regards to the design of its mouthpieces. The other thing that makes the saxophone a desirable example for this report is the fact its base design (not including reeds and mouthpieces) has remained largely unchanged since its inception in the 19th century (Eugeni Doubrovski, Jouke Verlinden, Jo Geraedts, Imre Horvath, Vera Konietschke, 2012). For players trying to change their sound, the focus shifts from the base instrument to its accessories.

I.III Research Questions

To guide their research and provide a focus to this report, the author relied on four initial questions. Readers may also benefit from these guiding questions, provided below:

1. Historically, what is the standard, or, what is a traditional setup for reeds and mouthpieces?
2. What are the new developments in manufacturing these accessories, and how has this changed the materials that are now selected for the process for these today?
3. What are the advantages of accessories made with newer manufacturing processes? What are the disadvantages?
4. What effects do these new materials have on the overall acoustics/timbre of the instrument relative to the old ones?

II. Anatomy of Saxophone Mouthpieces and Reeds

Though most woodwind players understand that mouthpieces and reeds can create a difference in the response and resulting tone of their instrument, they don't understand the specifics of why. Mistakenly, it's here that a clear line gets drawn between vintage accessories and new ones in the minds of players. There are a lot of variables in how a mouthpiece is constructed, and the same is true of reeds. These variables can result in measurable differences in response and tone. To understand why, it's crucial to have a baseline knowledge of the anatomy of these accessories and how their manufacturing processes and characteristics have changed over time.

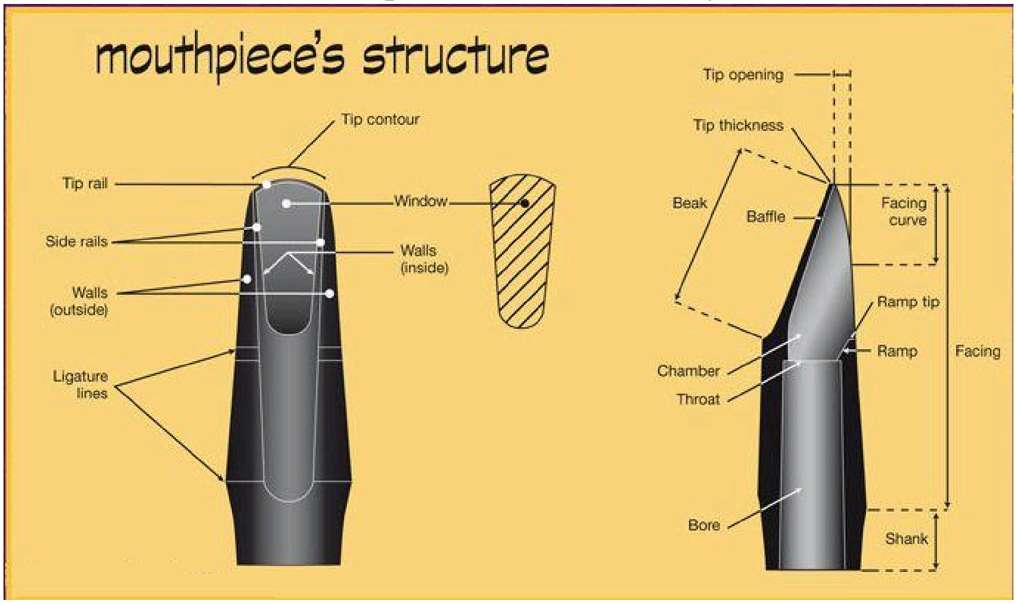
II.I Anatomy of Mouthpieces

Arguably the most important accessory, "...the mouthpiece of the saxophone strongly influences the sound quality and the experience of the player, such as ease of playing and the ability to modify the sound quality" (Doubrovski, Zjenja & Verlinden, Jouke & Geraedts, Jo & Horvath, Imre, Konietschke, 2012, p. 2). The key physical characteristics of a mouthpiece are described by the following:

External body: This includes the beak, the walls, the facing, and the shank. The beak is the top portion of the mouthpiece that a player's teeth or upper lip will rest on while blowing into the instrument. The facing is the part of the mouthpiece that is in contact with the reed. The beak and facing are bordered by the walls, and the shank is the bottom portion of the mouthpiece that thins out below the facing.

The facing: This is the part of the mouthpiece that is in contact with the reed, and includes the table, window, side rails, tip, and tip rail. The table is the section that is flat and solid. The window is where the opening of the mouthpiece starts. Bordering the window are the side rails, which curve upwards towards the tip and tip rail of the mouthpiece. The curve is called the facing curve of the mouthpiece. The opening between the reed when placed on the table and the tip of the mouthpiece is called its tip opening.

Figure 1 **Mouthpiece Structure Glossary**



Dansr/Vandoren, (2017). *The Key to Mouthpieces: An Explanation of Mouthpiece Anatomy*. https://banddirector.com/woodwinds/mouthpiece-reeds/the-key-to-mouthpieces-an-explanation-of-mouthpiece-anatomy/

Internal body: In order from the closest to the tip to the farthest away, the internal pieces of a mouthpiece include the baffle, side walls, ramp, chamber, throat, and finally the bore. The baffle is the inner part of the mouthpiece right next to the tip. The side walls describe the internal material that connects to the side rails on the facing of the mouthpiece, and the ramp is similar but for the material connecting to the beginning of the window closest to the table. The chamber describes the overall shape of the cavity closest to the window, which transitions into the throat. When assembled onto a saxophone, the throat is the farthest point the neck will go inside the mouthpiece. The bore is the rest of this cavity.

Within certain limits, almost all of the attributes listed here vary between mouthpiece models, and depending on the method used to create the mouthpiece, they can even vary between mouthpieces of the same model. The limits on these characteristics are crucial. After all, the mouthpiece needs to be compatible with the model of saxophone it is created for, which includes it being designed to fit on the neck cork, play in tune, and fit standard sized reeds and ligatures.

II.II History of Mouthpiece Characteristics and Manufacturing Techniques

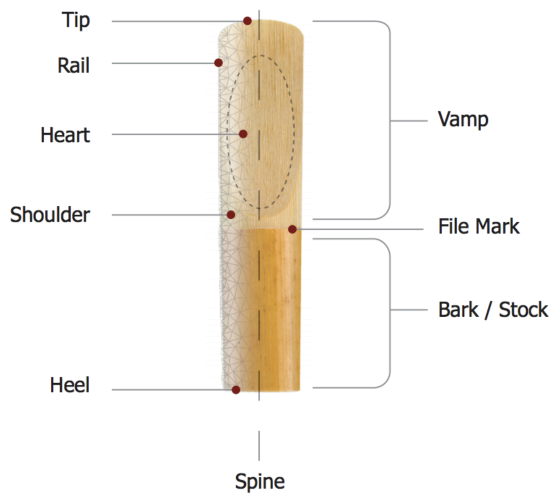
Originally handcrafted out of wood or ivory, saxophone mouthpieces underwent rapid changes in their manufacturing process throughout the 1890s and 1930s, with the latter half of that period introducing mouthpieces made out of glass, hard rubber, metal, and various combinations (Rose, 2020). During this time period, the mouthpieces produced generally followed Adolf Sax's original design, which consisted of a large, round chamber and a small tip opening. Over time mouthpieces moved from being primarily handcrafted to mass produced with machines. Usually this was a subtractive manufacturing process: a blank was fashioned from a mold, and then material was meticulously removed or machined away to arrive at the final product. Starting in the 1940s, saxophonists began to seek out different sounds and more projection. Tip opening and baffle shapes started to vary more. As the technology and science related to manufacturing developed, mouthpiece producers experimented with creating different internal shapes. For example, in the 1950's, Rico used a process called injection molding to create a plastic mouthpiece with a smaller, oval shaped chamber (Postma, 2018). These trends continued throughout the 1900's, and now mouthpieces with all kinds of internal shapes, tip openings, and baffles are available on the market.

Today, the new kid on the block is additive manufacturing. This is a technique that involves usage of 3D models to build products layer by layer. It typically involves some kind of 3D printing. According to Juan Rodríguez in their 2023 article, "The use of additive manufacturing techniques presents some advantages over traditional machining… it is possible to achieve very complex shapes that would be only achievable by experts, or sometimes even impossible to manufacture, with traditional machining." (pp. 1). The possibilities for customizing a mouthpiece using 3D printing are not to be ignored - in fact, there are already mouthpieces on the market created using these techniques. Additive manufacturing can be cheaper and produce less material waste than traditional methods as well. However, there are downsides. For one, 3D printers can't yet create mouthpieces made out of traditional materials that saxophonists know and love. Instead, they need to use plastics or dental resin - materials which have not yet proven their effectiveness or long term durability to saxophonists.

II.II Reeds

In comparison to mouthpieces, saxophone reeds have remained relatively the same since the late 1930's when mass production and distribution of reeds became the norm. In fact, Rico, a dominant reed manufacturer in the woodwind world, is still using machines created in the late 1930's to cut its reeds (Postma, 2018). Until recently, reeds have always been made out of cane. When dried, cut, shaved in the right manner, then moistened, cane will vibrate in a way suitable to produce a controlled sound for woodwind instruments. The reason for this is its long, woody cellulose fibers which grow straight in parallel lines across the plant. This allows it to absorb moisture and hold its shape even through the conditions of being played. Because cane is a natural material, there is often a lot of variation in its density and flexibility. Over time manufacturers have found ways of measuring these properties quickly, and as such reeds are classified by their strength when sold to consumers (usually between 2 and 5, in increments of .5). Cane reeds break down relatively quickly with use, often lasting a month or less.

Figure 2 **Reed Anatomy**



Ruff, Ryan, (2018). *The Ultimate Guide to Clarinet and Saxophone Reeds*. http://blog.kincaidsmusic.com/ultimate-guide-clarinet-reeds-saxophone-reeds/

Though reeds can be cut to different specifications to produce a wide range of timbres, cane's natural variability from day to day means that the specific effects of these changes are harder to measure. Moreover, drastic changes in their designs often have drastic effects on resistance due to the role of the reed in tone production, which can result in the instrument being much harder to play. Thus, for the purposes of this report, the object of focus will be on reed material - namely, the difference between synthetic (new) and cane reeds (traditional).

Popular synthetic reeds today are made of polymers that somewhat mimic the natural properties of cane. The main difference is these reeds don't absorb moisture or saturate with saliva like traditional reeds. "A group of synthetic materials, matching the stiffness and the density of the moist cane, are polypropylene, with unidirectional or bidirectional properties." (Bucur, 2019, pp. 1184). The ability of these reeds to vibrate without saturating with saliva means they last much longer and are more consistent across different humidity and temperature conditions. However, most saxophonists still prefer cane reeds.

III. Acoustical Analysis

To get a picture of how variables in the accessories covered in this report affect the sound of the saxophone, it's important to understand how researchers quantify acoustics. Some parts of sound are easy to describe. For instance, most people can tell the difference between when something is quiet or loud, or between one pitch and another. Others are not. Since the physics of sound are extremely complicated, the gritty details are left out of this report. The basics are this - a sound is made of various waves of oscillating pressure. For a single sound wave, the frequency will determine its pitch, and the amplitude its volume. A pitched sound is special in that it contains a series of harmonics, which are waves with clean mathematical ratios between their frequencies. The harmonic series starts at the fundamental, which is typically the pitch that humans hear when the sound reaches their inner ears. Any harmonic with a higher frequency than the fundamental is an overtone.

Figure 3 **The 1st 16 Harmonics of E Notated on a Musical Staff**

Total Guitarist (2008-2023). *What is the Harmonic Series?* http://totalguitarist.com/lessons/theory/harmonics/intro/

III.I Quantifying the Sound of the Saxophone

The sound of a saxophone can be described in terms of its timbre - that is, the character or quality of its sound independent of pitch or volume. Put simply, the timbre of a pitched sound is determined by the ratio of the amplitude of each harmonic relative to each other. It is common for saxophonists to classify timbres in a spectrum between “dark” or “bright”, but there is a lack of formality to this scale. One saxophonist’s dark could just as easily be someone else’s bright. Researchers have attempted to quantify these definitions for the sake of simplicity. In the context of research, a dark timbre for saxophone has been identified by a strong presence of the fundamental and progressively decreasing overtones in its sound spectrum (Pipes, 2018). Conversely, a bright timbre is identified by the presence of more high overtones in its spectrum.

III.II Data Collection Techniques

There are a number of methods for collecting the sound spectrum of a pitch in a research environment, and in the case of measuring and comparing saxophone timbre, multiple variables that need controlling. The studies referenced in this report all have different ways of collecting their data, so it’s important to keep in mind that they may not be easily compared directly to each other. That said, to get a general idea of how variables in the physical and material makeups of reeds and mouthpieces affect acoustics and response (as is the primary purpose of this report), they will be sufficient.

Before samples are collected, researchers will carefully construct a testing environment to control variables. Constraints are placed on what pitches are sampled, at what amplitude, and what duration. Though most of the papers referenced for this report used musicians to test gear, Ozdemir’s 2021 study on 3D printed mouthpieces used an artificial mouth equipped with pressure transducers to do so. They also only attached the mouthpieces to a saxophone neck, and used a single synthetic reed across all mouthpieces tested. This was done to control as many parameters as possible and record accurate and precise data. On the other hand, some studies referenced in this report used psychoacoustic analysis (human perceptions of sound) to gather their data. This isn’t completely invaluable, given the human element of music and sound.

Typically, researchers use a process called Fourier Transform to pick apart and digitally analyze sound:

> "To transform the sound amplitude envelope in time to the frequency domain, it is possible to apply a mathematical operation called Discrete Fourier Transform (DFT). Thanks to this function, the sound is digitized when stored in a computer by a sampling procedure, returning a vector that contains sound intensity values for each frequency…" (Bacciaglia, Antonio & Ceruti, Alessandro & Liverani, Alfredo, 2021, pp. 573-574)

Once all samples have been collected and transformed, spectral analysis and comparisons can be carried out. As mentioned previously, the amplitude ranges of harmonics in the spectrum can be used to determine qualities of the timbre.

IV. Measured Effects of Variables on Acoustics

As mentioned earlier, the data collection techniques of the studies referenced in this report are all slightly different. Nonetheless, there are solid conclusions that can be drawn from their data. The following section on reeds is more general, but the section after on mouthpieces will cover everything a player will need to know about how alterations may affect response and timbre.

IV.I Variables in Reeds

It is worth noting that discourse surrounding the acoustic properties of reeds is ongoing and controversial. The natural properties and variabilities in cane make it difficult to nail down which factors produce what results (not to mention that these can all change based on the player and mouthpiece combo), so their production has mostly been based upon getting them as consistent as possible.

Strength: In general, for cane reeds, harder reeds that are more resistant to bending produce a brighter sound, which is, they favor higher overtones (Petiot, 2017). Perhaps because of this favoring, anecdotally, saxophonists commonly find that it is easier to reach notes above the written range of the saxophone when using harder reeds. Due to their density, they can also withstand more air pressure without closing off against the mouthpiece, and thus have the potential to offer more volume. For most musicians, reeds of medium hardness produce a sound that is the most balanced and "rich". The overtones produced by reeds of medium strength are the most complex. Softer reeds have the easiest response, but this is at the expense of harmonic complexity of sound and volume producing abilities.

Material: According to Bucur's 2019 research article for the journal of Wood Science and Technology, "...there is considerable confusion in the properties of cane required for reproducing the tonal qualities of reeds" (p. 1184). As of the writing of this report, synthetic materials used for reed making have yet to completely mimic the longitudinal and transverse bending stiffness of a cane reed. However, in their 2022 study, Enis Ukshini measured the strain distribution on both cane and synthetic reeds, finding that "Vibration amplitude as well as strain values are a bit larger on the dry cane reed than on the synthetic reed, but the distribution is largely the same" (p. 4). From the literature, synthetic reeds seem to be a viable option for players since they *mostly* play the same as cane reeds. Since there is so much variability among cane reeds anyways, the difference isn't something that an audience would notice. The player might, however. Synthetics offer some advantages due to their consistency and longevity, but it is also clear that they aren't similar enough to cane to mimic its response. Perhaps with new materials or manufacturing techniques, these discrepancies can be resolved.

Figure 4 **Cane Vs. Synthetic Reed**

Pictured: On the left, a cane D'addario Royal 3.5 strength alto sax reed. On the right, a synthetic Legere 3.5 strength Signature alto sax reed. They are cut almost exactly the same, but respond quite differently.

IV.II Variables in Mouthpieces

Though the information in this section has been categorized neatly into the different parts of mouthpieces that affect sound and response, it's important to keep in mind that often changing one variable will have downstream effects on others. Each and every part of the mouthpiece works together to create the end result. Moreover, if one part is damaged or finished with subpar quality, everything can be out of balance and result in differences in tone and response. With all of this out of the way, the following is a solid guide for players who want to better understand how these parts come together.

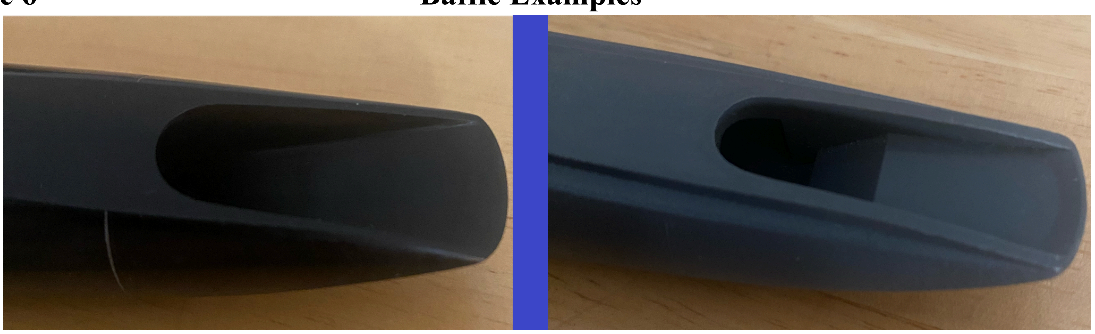
Chamber and throat: From the literature, it is clear that the cross-sectional area of the chamber and throat of a mouthpiece primarily affect external sound levels. There is an inverse relationship between chamber volume and loudness of the instrument (Ozdermir, 2021). As far as shape goes, this seems to be less important. The throat of the mouthpiece also has an effect on the brightness of the tone quality, with an inverse relationship between cross-sectional area and brightness. The chamber and throat also seem to modify the resistance of a mouthpiece, though not as much as the facing.

Figure 5 **Common Mouthpiece Chamber Shapes**

Pictured: From left to right, and top to bottom. On the top: round chambered mouthpieces. The left would be considered a small chamber, the middle a medium chamber, and the right a large chamber. On the bottom: popular departures from the traditional round chamber. On the left is a Selmer soloist with a horse-shoe shaped chamber and straight sidewalls. In the middle is a Brilhart with an oval shaped medium chamber and straight sidewalls.

Baffle: Combined with the chamber and throat volume, the height of a baffle on a mouthpiece can have effects on the flexibility of pitch. Ozdemir's study found that between baffle and chamber size, "…both parameters show a similar trend: a wider cavity (low [baffle] and high [chamber size]) results in a reduced possibility to adjust pitch" (2021, p. 9). In other words, the higher the baffle and smaller the chamber, the more flexibility. However, the baffle height is the most influential parameter in this category. The baffle also has a small role in the brightness and volume capacities of the mouthpiece, but not as much as other factors.

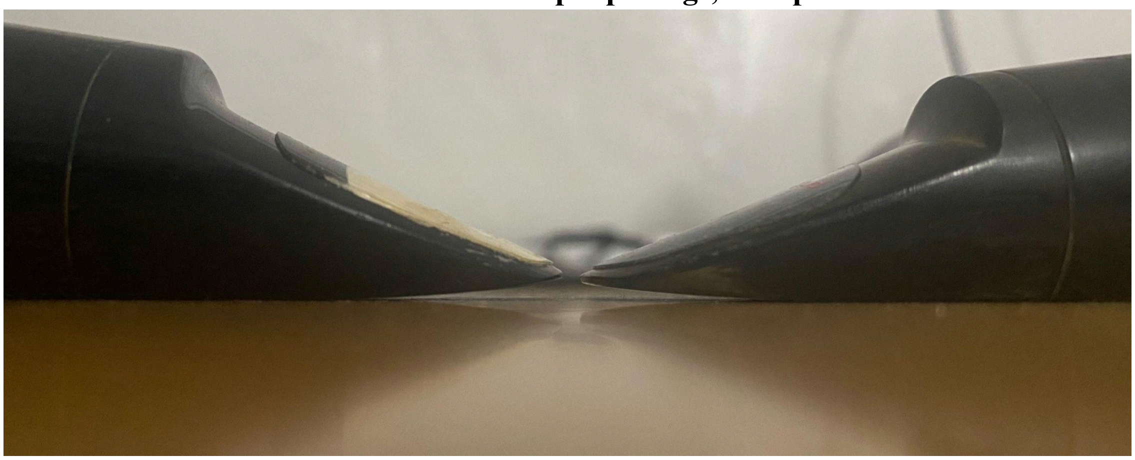
Figure 6 **Baffle Examples**



Pictured: On the left, a low baffle that rolls into the chamber. On the right, a high baffle with a step into the chamber.

Facing: The facing of a mouthpiece, combined with the tip opening, has the biggest effect on resistance. Changes in the length of the window and table in the facing don't seem to have any meaningful effect on measurements, but facing length along with tip opening are important factors. The facing length modifies the vibrating length of the reed. In general, a longer facing will play with less resistance than a shorter facing and respond quicker. The oscillation threshold, or the amount of air it takes to get a sound out of the saxophone, is also proportional to the tip opening. More air is required to get the reed to vibrate on a bigger tip, so it is more resistant. The tonal effects that tip opening can have aren't clear from the literature. According to his 2018 dissertation, Mark Pipes found "...if the facing and chamber stays consistent, the larger tip opening will create the potential for a darker timbre" (p. 110), but Ozdemir's 2021 study did not corroborate. The tip opening also has an important role in projection. "...with small [tip openings], when high blowing pressure is applied to the mouthpiece, the reed closes against the mouthpiece, blocking the airflow. On the other hand, with large [tip openings], playing the mouthpiece requires higher blowing pressure and hence it is more difficult to achieve louder sounds." (Ozdemir, 2021, p. 9). Therefore, the most effective tip opening for maximizing volume is an average tip size.

Figure 7 **Two Different Tip Openings, Compared**



Pictured: two mouthpieces with drastically different tip openings and facings. The difference is hardly noticeable. For this reason, hand finishing requires extreme precision and attention to detail.

Material: The overall effects that material can have on the timbre and response of a mouthpiece is still highly debated. For example, Ozdemir suggests that mouthpiece material having any effect on sound is a common false belief. On the other hand, Pipes finds that "...material affects the brightness of the timbre in a minor fashion" (2018, p. 111), and attributes it to "...thermal transfer from the air column to the bore or porosity of the material" (2018, pp. 111-112). A similar conclusion is drawn in a 2023 assessment of polymer mouthpieces for trombones where differences were found in the harmonic spectrums between brass mouthpieces and those made with PLA and Nylon. Their differences are attributed to differences in in-fill between materials (Rodriguez). Overall, it is clear that whatever effects materials have on the timbre and response, it is insignificant in comparison to the other factors that go into its design.

V. Discussion

As stated previously, the primary audience of this report are professional woodwind players who wish to grasp how different variables in their accessories will affect their playing. Armed with the secondary research contained in this report, saxophonists can cut down on a considerable amount of trial and error when picking out mouthpieces and reeds. Furthermore, it is my hope that manufacturers will start to be more transparent with the qualities they chose to create a piece of gear with instead of appealing to the vintage craze or spewing generalities to attract buyers.

V.I Primary Audience

For years, the saxophone community has put vintage gear on a pedestal. There is nothing wrong with using or collecting vintage gear, but proliferating that it is objectively better than modern gear is baseless. Instead of immediately dismissing the possibility, saxophonists should consider trying modern mouthpieces and reeds if they are unsatisfied with their sound. It is undeniable that additive manufacturing has the benefit of being extremely customizable, and since material has a minimal effect on sound and response, it doesn't have many drawbacks compared to mouthpieces made of traditional materials. Hopefully, armed with the knowledge in this report, professional players can also educate their students and help guide them towards gear that will assist them on their way to becoming better players.

In the end, trying gear before a purchase will always be the most ideal scenario. Due to differences in player physiology, sound concept, and choice of saxophone, no one can predict if they will like a certain piece of gear. Even armed with all of the knowledge in this report, players are just making an educated guess as to how gear will affect their sound. So, go forth with an open mind, and try things.

V.II Secondary Audience

In an era where manufacturing techniques afford an overwhelming array of customizable options, the lack of expertise among players becomes a harmonious note for advertisers, allowing them to sway choices based on superficial features rather than substantive qualities. Manufacturers should seize the opportunity to elevate their products by providing clear specifications, illustrating the intricacies of their creations, and demystifying the marketing jargon. An ideal relationship between manufacturers and players hinges on transparency and education.

VI. Conclusion

As the saxophone's evolution intersects with modern manufacturing techniques, players are now confronted with an overwhelming wealth of choices for selecting their accessories. Presented in this report, the intricate details of mouthpiece and reed anatomy, historical developments, and acoustical analysis provide woodwind players, particularly saxophonists, with a comprehensive understanding. The hope is that with this knowledge, players can free themselves of bias towards vintage gear and traditional materials to explore other options - namely, synthetic reeds and 3D-printed mouthpieces. Additionally, manufacturers will be encouraged to be transparent about an accessory's qualities. In the end, experimentation will still be part of the process for finding the optimal gear combination that aligns with a player's unique preferences and playing style. However, armed with this knowledge, saxophonists can now discern what factors will lead to what outcomes, ultimately contributing to the ongoing evolution of saxophone playing and the process of manufacturing gear.

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